

Ultrasound in Emergency Medicine

ABILITY OF EMERGENCY ULTRASONOGRAPHY TO DETECT PEDIATRIC SKULL FRACTURES: A PROSPECTIVE, OBSERVATIONAL STUDY

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Abstract—Background: Blunt head trauma is a common reason for medical evaluation in the pediatric Emergency Department (ED). The diagnostic work-up for skull fracture, as well as for traumatic brain injury, often involves computed tomography (CT) scanning, which may require sedation and exposes children to often-unnecessary ionizing radiation. **Objectives:** Our objective was to determine if bedside ED ultrasound is an accurate diagnostic tool for identifying skull fractures when compared to head CT. **Methods:** We present a prospective study of bedside ultrasound for diagnosing skull fractures in head-injured pediatric patients. A consecutive series of children presenting with head trauma requiring CT scan was enrolled. Cranial bedside ultrasound imaging was performed by an emergency physician and compared to the results of the CT scan. The primary outcome was to identify the sensitivity, specificity, and predictive values of ultrasound for skull fractures when compared to head CT. **Results:** Bedside emergency ultrasound performs with 100% sensitivity (95% confidence interval [CI] 88.2–100%) and 95% specificity (95% CI 75.0–99.9%) when compared to CT scan for the diagnosis of skull fractures. Positive and negative predictive values were 97.2% (95% CI 84.6–99.9%) and 100% (95% CI 80.2–100%), respectively. **Conclusions:** Compared to CT scan, bedside ultrasound may accurately diagnose pediatric skull fractures. Considering the simplicity of this examination, the minimal experience needed for an Emergency Physician to provide an accurate diagnosis and the lack of

ionizing radiation, Emergency Physicians should consider this modality in the evaluation of pediatric head trauma. We believe this may be a useful tool to incorporate in minor head injury prediction rules, and warrants further investigation. © 2013 Elsevier Inc.

Keywords—ultrasound; computed tomography; Emergency Physician; skull fractures; pediatric head trauma

INTRODUCTION

Blunt head trauma is a common reason for medical evaluation in the Emergency Department (ED), resulting in approximately 7400 deaths, 60,000 hospitalizations, and more than 600,000 ED visits per year in the United States (1). Recently, the Health Department in Italy estimated that approximately 300,000 children per year require medical care due to traumatic brain injury (TBI), which is a leading cause of death and disability for children worldwide (2,3). The incidence of intracranial injury among young patients with head trauma is 4–12%, with several studies that subdivide by age and show a higher incidence among younger children (0–2 years) (4–7).

Due to the frequency and clinical importance of minor head trauma in pediatric patients, several studies have tried to develop reliable and practical prediction rules

aiming to identify patients who have sustained a TBI (1,4). The clinical evaluation of children younger than 2 years old with minor head trauma is a challenge for many clinicians (1,4,8). This results in great variation in practice when deciding whether to obtain a computed tomography (CT) scan, observe, or immediately discharge the patient because the majority of patients have few or subtle signs of TBI.

Depending upon the clinical setting, anywhere from 15% to 70% of children assessed in EDs in the United States and Canada for minor head trauma undergo head CT scanning. Moreover, the use of CT scanning more than doubled between 1990 and 1999 in the United States and between 1995 and 2005 in Canada (1,4,8). The increased use of CT scans adds to health care costs, the need for sedation, and exposes children to often-unnecessary ionizing radiation. Additionally, risks associated with transport to the CT scanner, frequently located away from the supervising physician, are added (6,9,10).

A primary challenge in caring for children with minor head injury is to identify those who are at very low risk for significant intracranial hemorrhage and safely discharge them without obtaining a CT scan. Clinical predictors of traumatic brain injury in children include: skull fractures, which, in general, have been found to be more predictive than scalp swelling or vomiting for TBI (1,4,7,10). In fact, the presence of skull fractures in children increases the likelihood of an intracranial injury four-fold to 20-fold (10–12). In studies of children with linear skull fractures, an associated TBI was present in 15–30%, and most intracranial injuries in asymptomatic infants are diagnosed because the infants have evidence of a skull fracture (10). Prior studies have reported the incidence of skull fractures in outpatients evaluated for minor head trauma as ranging from 2% to 20%, with higher risk noted in children younger than 2 years of age (5,7,10,12–14).

Skull fractures rarely present without local signs of head injury on physical examination. Younger age and scalp hematoma (particularly temporal, parietal, and occipital) are predictors for skull fracture (10,13,15,16).

CT scanning remains the gold standard for the diagnosis of skull fractures as well as for TBI. Plain radiographs are no longer considered a helpful screening tool for the diagnosis of skull fractures due to a relatively low sensitivity and because they are difficult to interpret and may miss as many as 25% of skull fractures (10,17–19).

Ultrasound has been shown to be an accurate instrument for the diagnosis of bony fractures. Recent studies show the utility of ultrasound in the diagnosis of nasal, zygomatic arch, sternal, rib, and clavicle trauma, as well as in radiographically occult ankle, wrist, and forearm fractures (20–27). Ultrasound of the skull has been used to assess the state of the dura in patients suffering

from a diastatic skull fracture, and more recently, transfontanelle ultrasound has been proposed as a reliable alternative to CT for minor head trauma in infants with skull fractures (28,29). Prior research to detect skull fractures with ultrasound consists of a case series and a single case report (30,31).

The aim of our study was to identify the sensitivity, specificity, and predictive values of ultrasound for identifying skull fractures when compared to head CT scanning in pediatric patients with minor head trauma, defined as a normal mental status and neurologic examination without hemotympanum, Battle's sign, or a palpable bone depression (32). Such patients are the majority of head-injured children presenting to the ED and well-studied with clinical prediction rules (1,4). To our knowledge, previous investigations on this subject are limited to a single case series (33).

MATERIALS AND METHODS

A prospective, observational study to calculate the ability of ultrasound to detect skull fractures compared to head CT was undertaken at the Anna Meyer Pediatric Emergency Department in Florence, Italy, with an annual total volume of approximately 45,000 patient visits per year and nearly 2000 patients with minor head trauma (MHT) per year. The hospital institutional review board approved the study before enrolling patients.

Children presenting to the ED with a history of head trauma requiring a CT scan of the head based on the request of their Emergency Physician were considered for enrollment into our study. Further inclusion criteria included: age < 18 years and localizing evidence of trauma such as hematoma, abrasion, or focal tenderness. Localizing signs of trauma were necessary to direct sonographers to areas most at risk for a fracture because entire head scanning was impractical. Patients with hemodynamic instability, neurologic deterioration, Glasgow Coma Scale score < 14, coma, open deformity, or a depressed fracture were excluded from our study. Additionally, patients who were not cooperative with the ultrasound examination were excluded.

Patients were enrolled into our study from July 9 to December 1, 2010, 24 h a day, 7 days a week. Once the treating Emergency Physician decided to obtain a cranial CT scan for a traumatized patient, a study investigator was contacted to perform an ultrasound study of the skull to evaluate for fractures. The research study protocol did not interfere with the clinical care of enrolled patients and the sonographers were blind to the clinical scenario. All efforts were made to perform the ultrasound before the CT of the head, and the results of the ultrasound were not used to manage the patient's care. At times, ultrasounds were performed soon after the CT scan, as long

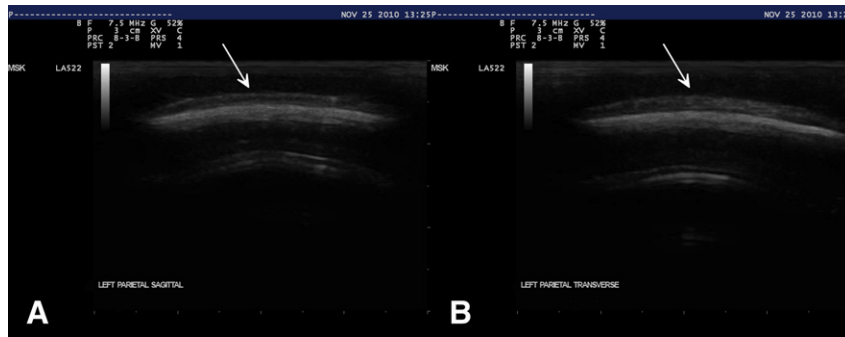


Figure 1. Normal cranial ultrasound in two orientations (A and B).

as the investigator was blinded to the results of the CT and the patient's management.

Informed consent was obtained from all parents or guardians and assent was obtained from all pediatric patients older than 5 years of age. After consent was obtained, a limited physical examination of the scalp was performed to localize signs of trauma and to delineate the area to be scanned. Investigators then attempted to familiarize patients to the ultrasound machine and probes. Patients also received non-pharmacologic sedation, including desensitization and distraction, in preparation for the scan. Ultrasound scans were subsequently performed using a 7.5-MHz, linear probe with a MyLab30® (Esaote Group, Genoa, Italy) ultrasound machine. Either an Emergency Medicine Ultrasound fellow or one of six different pediatric Emergency Physicians performed all scans. Each of these Emergency Physicians, who were previously inexperienced in ultrasound, participated in a 16-h ultrasound training curriculum focusing on principles and physics of ultrasound and the core emergency ultrasound applications as delineated by the American College of Emergency Physicians (34). Included in the curriculum was a 1-h didactic lecture on musculoskeletal applications, including cranial ultrasound. Additionally, each of these physicians performed cranial ultrasounds on volunteer models, then on healthy pediatric volunteers before being able to participate in the study protocol and enroll patients into the study by performing a bedside ultrasound scan.

Examinations studied the area of concern for a possible skull fracture evidenced by a cephalohematoma, abrasion, or focal tenderness. If an external hematoma was present, the examination typically progressed from one edge of the hematoma to the other, in perpendicular orientations (transverse and sagittal or coronal) to fully view the cranium below the hematoma. If the zone of the scan was near a cranial suture and a defect was noted, contralateral controls were performed to differentiate between fractures and anatomic sutures (31,35). Ultrasound visible fractures are defined as cortical defects seen in two orientations not correlating with anatomic, symmetric

sutures. Ultrasound findings were communicated to another member of the study team and recorded as negative (no fracture; see Figure 1) or positive (fracture; see Figure 2). In all positive ultrasound scans, the location of the fracture was described and a picture was recorded. Ultrasound findings were compared to the CT scan results obtained using a Philips Brilliance 40- or 64-slice (Eindhoven, The Netherlands) scanner. In cases of disagreement between the ultrasound and CT results, a single radiologist from the Anna Meyer Department of Emergency Radiology, blinded to the initial interpretation of both the ultrasound and the CT, as well as the clinical history of the patient, reviewed the case and provided the final CT scan interpretation.

Our study's primary outcome was to evaluate for cranial fractures on ultrasound. Fracture site was also recorded to assess correlation with CT scan location. This outcome was then used to calculate sensitivity, specificity, and predictive values of ultrasound in identifying skull fractures when compared with head CT.

Data were analyzed using STATA® V11 software (StataCorp, College Station, TX). All demographics were described using frequency and mean calculators within samples according to primary outcome. Descriptive statistics were calculated from a traditional 2×2 table to yield sensitivity, specificity, and predictive values. Student's *t*-test was used for sets of continuous data, χ^2 test was used for binary variables, and Fisher's exact test was used for comparisons with small cell sizes. A *p* value of < 0.05 was used to define statistical significance.

RESULTS

There were 767 patients seen at the Pediatric ED for head injury during the study period. Serial enrollment of all children meeting the above inclusion criteria yielded 58 patients. Three patients were excluded from our study (1 patient for hemodynamic and neurologic instability and 2 for poor cooperation with the ultrasound examination), resulting in 55 patients for analysis. Patient demographics are summarized in Table 1. Approximately half

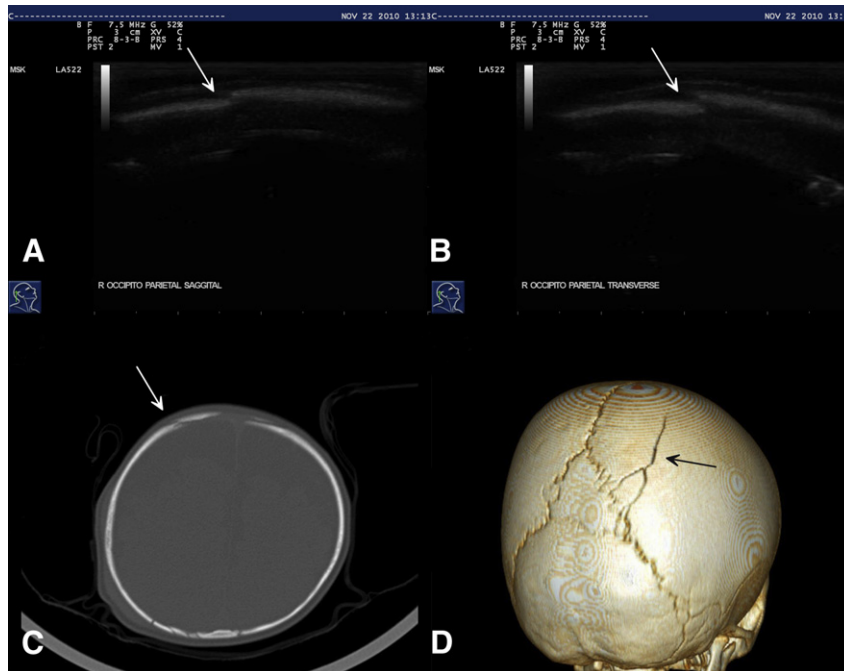


Figure 2. Ultrasound of cranial fracture in two dimensions (A and B) with comparative computed tomography axial (C) and three-dimensional (D) images.

of the ultrasound scans were performed by an Emergency Ultrasound fellow, and the other half were distributed evenly among six Emergency Physicians who completed an Emergency Ultrasound curriculum. Cranial fractures were seen on the CT scan in 35 (63.6%) of the 55 patients; 20 (36.4%) CT scans were interpreted as normal. Emergency ultrasound scans identified each fracture in the correct location with no false negatives, resulting in a sensitivity of 100% (95% confidence interval [CI] 88.2–100). One (1.8%) of the 55 ultrasound scans was interpreted as positive for a skull fracture, but the CT scan was read as normal. Nineteen (34.5%) of the ultrasound scans that were negative for fracture were subsequently validated by negative CT scans, yielding an overall specificity of emergency ultrasound for cranial fractures of 95.0% (95% CI 75.0–99.9) (Table 2). The positive predictive value of emergency ultrasound for cranial fractures in our study group was 97.2% (95% CI 84.6–99.9), with a negative predictive value of 100% (95% CI 80.2–100).

DISCUSSION

Our study shows that head ultrasound scans performed on pediatric patients with MHT may be accurate in diagnosing skull fractures. Ultrasonography is considered extremely safe and carries no risk of radiation (36,37). In our experience, ultrasound examinations of the skull were brief, painless, and relatively simple to perform. In fact, examinations performed by emergency

physicians with various levels of training were able to accurately identify or rule out cranial fractures. Another advantage to emergency ultrasound scanning is that none of our patients required pharmacological sedation for the ultrasound.

Our study demonstrated ultrasound's extremely accurate evaluation of cranial anatomy. In several cases, ultrasound detected fractures not initially identified by the staff radiologist on the CT scan that were later found on an over-read. Anatomic accuracy was so precise that we were able to identify structures such as vascular channels, sutures, and neuronal foramina, and distinguish in all cases except one these anatomic variants from fractures.

One patient out of the 55 in our study was identified as being a false positive when the ultrasound and CT scan interpretations were discordant. This 6-year-old boy fell from his parents' bed and came to the ED with a left parietal hematoma. Ultrasound showed a cortical irregularity in the area of the temporoparietal suture. Contralateral ultrasound imaging did not visualize a symmetric structure and the ultrasound was therefore interpreted as positive for fracture. On expert review and over-read of the CT scan, the radiologist noted asymmetry representing a non-calcified temporoparietal suture only ipsilateral to the trauma. Therefore, the asymmetry was correctly identified by ultrasound scanning and, in the context of trauma, incorrectly designated as a fracture. This shows how sensitive ultrasound scanning is in identifying anatomic cranial abnormalities.

Table 1. Demographics

	Patients with Cranial Fractures n (%)	Patients without Cranial Fracture n (%)	p-Value
Patients			
Total	37 (63.8)	21 (36.2)	
Included	35 (63.6)	20 (36.4)	1.0*
Excluded	2 (66.7)	1 (33.3)	
Age			
Mean (years)	3.7	6.3	0.038†
Range	2 m-14.9 y	4 m-14.3 y	
< 24 months	22 (40.0)	4 (7.2)	0.004*
> 24 months	13 (23.6)	16 (29.0)	
Gender			
Female	17 (48.6)	15 (75.0)	0.086*
Male	18 (51.4)	5 (25.0)	
Mechanism			
Alleged assault	0 (0.0)	1 (5.0)	0.363*
Bicycle crash	3 (8.6)	1 (5.0)	1.0*
Fall	28 (80.0)	11 (55.0)	0.050‡
MVC	2 (5.7)	2 (10.0)	0.616*
Pedestrian struck	1 (2.9)	3 (15.0)	0.131*
Sports injury	1 (2.9)	0 (0.0)	1.0*
Unknown	0 (0.0)	2 (10.0)	0.128*

MVC = motor vehicle crash.

* Fisher exact test.

† Student's *t*-test.

‡ χ^2 test.

Although future prospective research is necessary to delineate the potential role of ultrasound in clinical prediction rules, these findings may support the ability of ultrasound to reliably exclude fractures in pediatric patients. Bedside, limited ultrasound as practiced by Emergency Physicians must be interpreted, however, with caution when the ultrasound examination is equivocal or demonstrates any abnormality representing fracture. The 95% specificity in our study group may represent an acceptable amount of inaccuracy for this diagnostic modality because uncertainties on the ultrasound examination should prompt further diagnostic imaging to exclude cranial and intracranial pathology in the setting of trauma. Additionally, basilar skull fractures cannot reliably be identified and evaluated with cranial ultrasound.

Another advantage of incorporating ultrasound into clinical practice guidelines is that it assists those physicians who do not frequently evaluate children with MHT on a routine basis. Categorizing the extent and im-

Table 2. Statistics

	CT Positive for Fracture	CT Negative for Fracture
Ultrasound positive for fracture	35	1
Ultrasound negative for fracture	0	19

CT = computed tomography of the head.

portance of a cephalohematoma may be challenging, and definitive evidence of a skull fracture seen on ultrasound may guide the diagnostic work-up. Moreover, in hospitals where CT scanners are not always available or sedation for the scan is impossible, ultrasound may assist in transfer decisions. As Emergency Physician-performed ultrasound becomes a more widely used tool to aid clinical diagnosis and treatment, physicians must expand their use of ultrasound beyond what is currently being practiced. Our study demonstrates the ability of Emergency Physicians without previous echographic experience to learn and reliably apply musculoskeletal ultrasound to identify cranial fractures. Ultrasound, in general, has been shown to shorten the length of hospital stay and to lower the cost of inappropriate studies (26). It has also been shown that bedside imaging, where parents see the images, is well accepted and reassures families far beyond the modality's quantifiable diagnostic accuracy (26).

Due to the frequent use of observation for patients who are not at high risk for TBI, the overall rate of CT scanning for head trauma in our hospital and anecdotally noted in the Italian health system is lower than the United States national average. CT scans are the source of two-thirds of the collective radiation from diagnostic imaging; an estimated one million children every year in the United States are unnecessarily imaged with CT scans (1). Ultrasound may provide another avenue to reduce exposure to ionizing radiation in health care systems worldwide.

Limitations

Our findings must be considered in the context of several limitations. First, our study was conducted in a single center with one model of ultrasound machine on a small sample size by sonographers of varying experience. The small sample size resulted in a broad confidence interval, and it remains uncertain how our findings can be applied in other clinical settings. Second, all ultrasound scans performed in this sample were limited to a specific area on the scalp with focal signs of trauma and, at times, the contralateral region for comparison. Although this approach may limit the sensitivity of ultrasound for fractures, we felt that it represented the most practical and efficient method and correlated best with the fast pace of emergency medicine. Additionally, the goal of this study was to measure the ability of ultrasound to detect skull fractures when compared to CT scans of the head. How these results can be implemented into the evaluation of head trauma in the future remains unknown and will require further research. Finally, comparisons to head CT of cost, time to diagnosis, procedural sedation rates, length of stay in the ED, and discomfort associated with the imaging, were not evaluated.

CONCLUSION

Bedside emergency ultrasound of the skull may accurately diagnose cranial fractures in head-injured children with visible scalp injuries when compared to CT scanning. Considering the simplicity of this examination, the minimal experience needed for an Emergency Physician to provide an accurate diagnosis and the lack of ionizing radiation, future studies performed in different countries should be conducted to confirm our findings from Tuscany. Toward this end, we are conducting such a study in the United States. In the meantime, Emergency Physicians may wish to consider ultrasound to help diagnose skull fractures in head trauma.

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ARTICLE SUMMARY

1. Why is this topic important?

Head trauma is a common reason for medical evaluation in pediatric Emergency Departments (EDs), often requiring computed tomography (CT) scanning of the brain to diagnose skull fractures and intracranial pathology.

2. What does this study attempt to show?

The study attempts to lay a foundation for future studies geared at utilizing skull fracture in prediction rules for intracranial injury. The present study evaluates whether bedside ED ultrasound is an accurate diagnostic tool for identifying skull fractures when compared to head CT.

3. What are the key findings?

In a sample of 55 patients enrolled over a 5-month period, bedside emergency ultrasound demonstrated 100% sensitivity and 95% specificity when compared to CT scan for the diagnosis of skull fractures. Positive and negative predictive values were 97.2% and 100%, respectively.

4. How is patient care impacted?

Because this is a foundation study, it is uncertain what impact ultrasound's ability to accurately diagnose skull fractures may have on patient care. Further studies must evaluate the utility of incorporating echographically diagnosed skull fractures into prediction rules and risk stratification tools for intracranial injury.