The Utility of Bedside Ultrasonography in Identifying Fractures and Guiding Fracture Reduction in Children

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Objective: To compare bedside ultrasonography (BUS) to radiography for identifying long bone fractures, the need for reduction, and the adequacy of reduction.

Methods: Children aged 2 to 17 years presenting to a pediatric emergency department with long bone injuries were prospectively enrolled. Bedside ultrasonography was performed before ordering initial radiographs. If a fracture was identified, measurements of angulation and displacement were made based on BUS images. Radiographs were used to guide management. Patients who had a fracture identified on radiograph underwent standard care. Later, agreement between BUS and radiography for fracture identification, the need for reduction, and the adequacy of reduction were determined.

Results: Thirty-three patients were enrolled, the mean age was 9.1 years (±3.1 years). Sixty six bones were studied; 56 (84.8%) involved the upper extremity. Fractures were identified in 59.1% of all bones; 13 (33.3%) required reduction.

The agreement between BUS and radiography for fracture identification was 95.5%, for the need for reduction 92.3%, and for the adequacy of reduction 92.3%. The sensitivity and specificity of BUS for fracture identification, need for reduction and reduction adequacy was 0.97 (95% confidence interval [CI], 0.85–1.00), 0.93 (95% CI, 0.74–0.99), and 1.00 (95% CI 0.79–1.00), and 0.85 (95% CI, 0.61–0.96), 1.00 (95% CI, 0.59–1.00) and 0.80 (95% CI, 0.30–0.99), respectively.

Conclusions: These data suggest that BUS evaluation of upper extremity injuries not involving joints maybe comparable to radiography for identifying fractures, the need for reduction, and the adequacy of reduction in children. If further investigations which include a larger number of lower extremity, growth plate, and joint injuries support our findings, BUS may gain a more prominent role in managing children with all long bone injuries.

Key Words: ultrasonography, fracture, reduction

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Orthopedists have traditionally relied on radiography and fluoroscopy for the evaluation of injured children. Such modalities are time consuming, expose the patient to radiation, and may require long periods of procedural sedation. Moreover, if a fracture requires reduction, patients must often be casted before obtaining radiographs and recasted if the reduction was not adequate.

Bedside ultrasound (BUS), which is ultrasound performed outside the radiology suite by nonradiologists, has several attributes that make it potentially useful for the evaluation of orthopedic injuries in children. Cortical disruption is easily identified because the bony cortex appears brightly echogenic on ultrasound. New high-resolution transducers permit the detection of cortical discontinuities as small as 1 mm.[1]

Although the usefulness of BUS for fracture evaluation and management has been described, few studies have evaluated its use in pediatric patients.[2–7] The purpose of this study was to compare BUS to radiography for identifying long bone fractures, the need for reduction, and the adequacy of reduction in children.

METHODS

Before the initiation of the study, 3 pediatric emergency medicine (PEM) physicians, none of whom had formal training in ultrasonography, completed a 2-hour didactic and practical session and performed 2 practice BUS examinations supervised by the lead investigator. Children ages 2 through 17 with suspected radius, ulna, tibia, or fibula fractures were prospectively enrolled. The study was performed from March 2006 through January 2007 in the pediatric emergency department (PED) of an urban public hospital when one of the participating physicians was available. Exclusion criteria were open fractures, neurovascular compromise, hemodynamic instability, and suspected fractures likely involving joints. Informed consent was obtained before enrollment. The study was approved by the Committee on Clinical Investigations of the Albert Einstein College of Medicine and Jacobi Medical Center.

Before radiographic examination of each suspected fracture site, the PEM physician performed a sonogram of the suspected fracture site using a Sonoline G40 portable ultrasound machine (Siemans Medical Solutions USA, Inc. Mountain View, CA) with a 7.5-MHz linear small parts probe. Bedside ultrasound images were taken in a longitudinal plane on the dorsal and lateral aspects of the forearm or leg at each injury site. The longitudinal BUS dorsal and lateral images correspond to the lateral and anteroposterior (AP) plain film radiograph images respectively (Figs. 1–4).

Based upon BUS evaluation, the PED physician recorded whether a fracture was present in either or both of the 2 bones at

FIGURE 1. Anteroposterior radiograph of the forearm of a 6-year-old child with a displaced and angulated radius fracture and a buckle fracture of the ulna.

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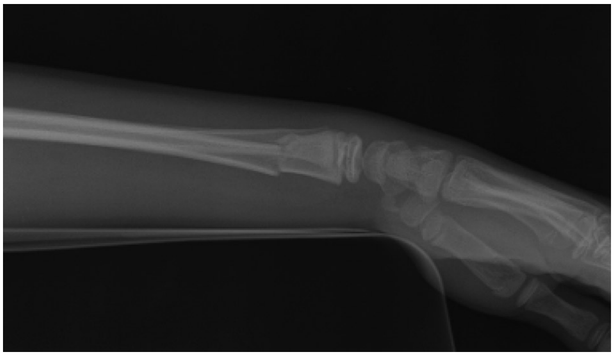

FIGURE 2. Lateral radiograph of the same patient in Figure 1.

each site. If the PED physician identified a displaced fracture, the degree of angulation and the distance of displacement were determined using the standard caliper software available on the ultrasound machine. Bedside ultrasound angulation measurements were determined by drawing 2 intersecting lines along the edge of the cortex, generating an angle (Fig. 5). Displacement measurements were made by calculating the distance from the normal cortex to the fractured edge of cortex (Fig. 5). Because buckle fractures do not require reduction, they were labeled as such, and no measurements were recorded (Fig. 6).

Following BUS evaluation, all patients underwent standard radiographic examination. Plain film radiographs were used for all patient management decisions. The attending pediatric radiologists' final interpretations of all radiographs were considered the gold standard for determining the presence or absence of fracture. The decision to cast or reduce and cast a fracture was at the discretion of the treating orthopedic physician who was blinded to all BUS results. If the patient required fracture reduction, a repeat BUS was performed by the PED physician after the reduction was complete but before casting and repeat radiography. The treating orthopedic physician was blinded to these results as well.

At a later date, a senior orthopedic resident, blinded to the BUS results, reviewed all radiographs. For radiographs containing a displaced or angulated fracture, the resident recorded

FIGURE 3. Bedside ultrasound image obtained in the longitudinal and lateral plane illustrates the cortical disruption of the fractured radius. This image corresponds to the AP radiograph in Figure 1.

FIGURE 4. Bedside ultrasound image of the fractured radius obtained in the longitudinal and dorsal plane. This image corresponds to the lateral radiograph in Figure 2.

measurements of angulation and displacement distance using calipers available on the Impax Web1000 PACS system (Agfa, Ridgefield Park, NJ). Because the physicians performing BUS were not expert in evaluating how much angulation or displacement required reduction, to compare BUS to radiography regarding the need for reduction we used a 2-step process. First, we compared the PED physician's determination of the presence or absence of fracture by BUS to the radiologist's interpretation of the plain film radiograph. Second, to determine how BUS compared with radiography for determining the need for reduction or the adequacy of reduction, we compared the measurements of angulation and displacement made from the BUS image of each fracture to standard published orthopedic criteria for fracture reduction.[8] For example, according to Wheeless' Textbook of Orthopaedics, a child younger than 6 years should have a radius fracture reduced if angulation is greater than 15 degrees, children between 6 and 10 years are allowed up to 10 degrees of angulation, and in patients above 12 years, no angulation is acceptable. If the BUS measurements met published criteria, the BUS was coded as indicating the need for reduction. The same procedure was used to evaluate BUS regarding the adequacy of reduction. The determination made

FIGURE 5. Bedside ultrasound image of a fractured radius with measurements of displacement and angulation.

FIGURE 6. Bedside ultrasound image of the ulna, obtained in the longitudinal and dorsal plane, demonstrating a buckle fracture. This image corresponds to the lateral radiograph in Figure 2.

from comparing BUS measurements to standard orthopedic criteria were then compared with the orthopedists' interpretation of the initial and any postreduction radiographs.

Data were analyzed using SPSS v.12.0 (SPSS, Inc., Chicago, IL). Test performance characteristics of BUS for detecting fractures, the need for reduction, and the adequacy of reduction were determined. Agreement between BUS and radiography was assessed using simple agreement and the kappa statistic. We estimated that for the ultrasound to be clinically useful, it should agree with x-ray readings of fracture or no fracture at least 95% of the time with a narrow confidence interval (CI). A sample size of 66 bones would be sufficient to show a 95% agreement with the lower bound of the 95% CI above 87%.

RESULTS

Thirty-three patients were enrolled. The mean age was 9.1 (±3.1) years, and 67% (22) were male. Sixty-six bones were studied including 56 (85%) from the upper extremity and 10 (15%) from the lower extremity; overall, 59% had a fracture. Fractures of the upper extremity accounted for 87% of all fractures. Twenty-eight percent (11) were buckle fractures, and 71.8% (28) were angulated and/or displaced. Among the latter group, 46.4% (13) met criteria for reduction based on published orthopedic guidelines.

Agreement between BUS and radiography for fracture identification, the need for reduction, and reduction adequacy is reported in Table 1. The test performance characteristics of BUS compared with radiography for detecting fracture, the need for reduction, and the adequacy of reduction are shown in Table 2. Because of the limited number of lower extremity injuries, a subanalysis of the test performance characteristics of BUS for upper extremity injuries is provided in Table 3.

In 3 of the 66 bones studied (4.5%), BUS and radiography did not agree on the presence of fracture. Two patients had both distal radius and ulna buckle fractures identified by BUS. The radius fractures were identified on radiography; however, the ulna fractures were not mentioned by the attending radiologist. Therefore, it was assumed that the ulnas were not fractured. On review of these 2 cases, both patients had follow-up radiographs obtained weeks later that revealed callus formation on the ulna as well as the radius. In the third case, the BUS was interpreted as normal but a fracture of the tibia was identified by radiography.

In 2 cases, buckle fractures of the distal radius were identified on BUS, but not on the preliminary report by the radiology resident. In the final reading by the pediatric attending radiologist, the fractures were noted.

In 3 (7.7%) of 39 cases, BUS and radiography did not agree on the need for reduction. Case 1 was a 5-year, 9-month-old child with a distal radius fracture; the BUS and radiograph measurements were 12.6 and 17 degrees, respectively. Case 2 was a 9-year 6-month-old patient with a distal radius fracture. The BUS and radiography measurements were 11 and 9 degrees, respectively. In case 3, angulation on the volar side of the radius met criteria for reduction, but it was not identified on the standard longitudinal dorsal and lateral BUS views. There was 1 case of a radius fracture in which BUS identified the fracture and the need for reduction but did not identify the reduction as adequate.

DISCUSSION

Our results indicate that BUS performed by PED physicians with minimal training may be equivalent to radiography for detecting fractures of long bones not involving joints. Williamson et al[6] demonstrated that ultrasound imaging performed by a consultant radiologist was as good as radiography for the detection of isolated, uncomplicated forearm fractures in children. In a recent study by Chen et al,[3] the accuracy of BUS in identifying forearm fractures performed by a pediatric emergency medicine physician on children with upper extremity injuries was similar to the accuracy of BUS in our study. Hubner et al[4] also found good correlation between BUS and radiography for fractures of the long bones of the upper and lower limbs in pediatric patients; however, the sonograms were performed by pediatric surgeons who each had performed at least 1500 sonograms and had attended a training course on evaluating bony surfaces.

Marshburn et al[9] demonstrated that ultrasound examinations performed by clinicians who had undergone 1 hour of standardized training could be used to rule out long bone fractures in patients older than 18 years with a medium to low probability of fracture. Using BUS to assess the shaft of the radius, ulna, tibia, and fibula for fracture may require less training than other applications because the examination is relatively limited and focused, and the long bones are superficial and easy to evaluate.

In our study, BUS may be more accurate than radiography for identifying buckle fractures. There were 2 patients in which BUS seemed not to agree with the initial radiograph in identifying buckle fractures of the ulna accompanying radius buckle fractures. These cases were therefore coded as false

TABLE 1. Agreement Between BUS and Radiography

Measurement	Fracture Identification, N = 66	Need for Reduction, N = 39	Reduction Adequacy, N = 11
Agreement n (%, 95% C.I.)	63 (95.5, 87.3–99.1)	36 (92.3, 79.1–98.4)	10 (90.9, 58.7–99.8)
Kappa κ (±SE)	0.91 (±0.05)	0.85 (±0.08)	0.74 (±0.24)

TABLE 2. Test Performance Characteristics of BUS

Outcome	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Fracture identification (n = 66)	0.97 (0.85–1.00)	0.93 (0.74–0.99)	0.95 (0.82–0.99)	0.96 (0.78–1.00)
Need for reduction (n = 39)	1.00 (0.79–1.00)	0.85 (0.61–0.96)	0.86 (0.64–0.96)	1.00 (0.77–1.00)
Reduction adequacy (n = 11)	1.00 (0.60–1.00)	0.80 (0.30–0.99)	0.89 (0.51–0.99)	1.00 (0.40–1.00)

positives. However, further radiographic follow-up of these patients revealed that there was callus formation of the ulna indicating previous undiagnosed fractures in both patients. There were also 2 different cases of buckle fractures of the radius which were identified by BUS, although the preliminary reading by a radiology resident was negative for fracture. Upon review of both of these cases, the attending pediatric radiologist reported that there were buckle fractures present on the initial radiographs. Hernandez et al[10] noted that angulated buckle fractures often are isolated, subtle, and easily overlooked on plain radiography. It may be easier to identify buckle fractures using BUS.

Few fractures in our series involved the lower extremity, so we were not able to evaluate BUS separately for lower extremity injuries. The tibia and fibula are technically more difficult to scan than the radius and ulna. These fractures tend to occur longitudinally and in multiple planes rather than transverse and in 1 plane as in upper extremity fractures. One case of a tibia fracture was not identified by BUS. On review, the displacement was equal to 1 mm. Cadaver studies, as well as the study by Hubner et al,[4] have shown that sonography is less dependable in detecting differences in cortical disruption of less than 1 mm.[1] It may be that when imaging the lower extremity, the entire bone must be scanned in multiple planes for proper evaluation.

Bedside ultrasound agreed with radiography regarding the need for reduction in all but 3 cases. In case 1, the BUS angle measurements would have met published criteria for reduction if the child had been 3 months older. In case 2, the angle measurements obtained by BUS and radiography were very close and, in fact, were separated only by the cutoff angle measurement requiring reduction. On review of the third case, BUS correctly identified the fracture. However, only the longitudinal dorsal and lateral views were obtained as per the BUS scanning protocol. The volar angulation, which met published orthopedic criteria for reduction, was not appreciated by BUS. To enhance the ability to determine the need for reduction, 3 planes, including the volar aspect, should be imaged.

Overall, BUS was highly consistent with radiography for determining reduction adequacy. In only 1 case, a fractured distal radius that required reduction, BUS and radiography did not agree. Although this case clinically did not appear to involve the joint, the radiograph revealed that the fracture was close to the joint. Bedside ultrasound correctly identified the fracture and determined that it needed reduction, but the angle measurements were difficult to obtain. Hubner et al[4] have demonstrated that sonography is less dependable for injuries near joints. Evaluating the usefulness of BUS in these less common injuries or injuries involving the growth plate was beyond the scope of this study.

Presently, after a reduction attempt, the child must be transported to the radiology department, reimaged, and resedated if the reduction is not adequate; a process that may have to be repeated multiple times. With BUS, repeated examinations can be performed in real time to assess reduction adequacy. Although we did not have a large number of cases that required reduction, our results support the findings of Chen et al[3] and Durston and Swartzentruber[11] that BUS performed by emergency medicine physicians is useful in assessing the adequacy of fracture reduction. In the study by Chen et al,[3] BUS was used to assist the treating orthopedist in reducing the fractured bones, and success was determined by the orthopedist's decision to repeat the reduction after radiographs were obtained. In our study, we measured degrees of angulation and distance of displacement, we blinded the orthopedists to our BUS findings, and we used the published orthopedic literature to determine if a fracture required reduction or repeat reduction. In addition, this study differed from the other recent studies that examined the performance of BUS in fracture reduction in that we had 3 PEM physicians, all of whom had no formal training in BUS, perform all studies. We believe, our study, therefore, provides further evidence that BUS can be used as an alternative and accurate tool during reduction attempts, minimizing radiation exposure and possibly even repeated procedural sedation.

Our study did not explore some areas that may be important to physicians. We chose to exclude injuries involving joints. Therefore, the applicability of our findings toward these, and accompanying growth plate, injuries may be limited. However, few patients were excluded, and most patients with fractures requiring reduction had diaphyseal fractures that did not involve the joint. Our sample size was calculated to include all long bones; however, analysis revealed that most of the bones studied were of the upper extremity. Although there were fewer lower extremity injuries studied than expected, test performance characteristics were similar to that of the upper extremity. Although our study did not formally evaluate pain during the BUS examination, it was our observation that the BUS examination did not exacerbate pain. Although not essential, a gel stepoff pad can be used to provide both an acoustic window and to help minimize pain by providing a cushion. In addition, we also did not explicitly record time requirements for each BUS. It was also our observation that the time required to set up the machine and perform the scans was minimal, usually less than 5 minutes.

TABLE 3. Test Performance Characteristics of BUS for Upper Extremity Injuries

Outcome	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Fracture identification (n = 56)	1.00 (0.87–1.00)	0.91 (0.69–0.98)	0.94 (0.80–0.99)	1.0 (0.80–1.00)
Need for reduction (n = 35)	1.00 (0.7–1.00)	0.82 (0.55–0.95)	0.86 (0.63–0.96)	1.00 (0.73–1.00)
Reduction adequacy (n = 11)	1.00 (0.60–1.00)	0.80 (0.30–0.99)	0.89 (0.51–0.99)	1.00 (0.40–1.00)

CONCLUSIONS

Our data suggest that BUS of the upper extremity may be equivalent to radiography for identifying fractures not involving the joint and for determining the need for fracture reduction. Although few children had fractures requiring reduction, BUS may also be equivalent to radiography for evaluating the success of reduction. Further investigation should address issues in training PED staff in BUS, time for the completion of care, avoidance of radiation exposure, and confirmation of lack of exacerbation of pain. In addition, larger prospective blinded studies of injuries to the lower extremity, joints, and growth plates would increase the generalizabilty of BUS to all long bones. If our findings are supported, BUS may continue to gain a more prominent role in managing children with orthopedic injuries.

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