American Journal of Emergency Medicine 31 (2013) 1352–1356

Contents lists available at ScienceDirect

American Journal of Emergency Medicine

journal homepage: www.elsevier.com/locate/ajem

Original Contribution

The accuracy of point-of-care ultrasound to diagnose long bone fractures in the ED☆

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ARTICLE INFO

Article history:
Received 30 April 2013
Received in revised form 21 June 2013
Accepted 22 June 2013

ABSTRACT

Objectives: To determine the diagnostic accuracy of emergency physician performed point-of care ultrasound (POCUS) for detecting long bone fractures compared to standard radiography.
Methods: This was a single-blinded, prospective observational study of patients presenting to two emergency departments (ED) with trauma to long bones. The study used a convenience sample of patients seen during the study investigators' scheduled clinical shifts. Patients presenting to the ED with complaints of long bone trauma were included in the study when a study investigator was available in the ED. POCUS examinations of injured long bones were performed using a standard protocol. The investigators documented their interpretation prior to radiographs being performed. After standard radiographs were performed, the final radiology reading by a radiology attending physician was obtained from the medical record.
Results: One-hundred six patients were enrolled into the study, and 147 long bone POCUS examinations were performed. Forty-two fractures were present by radiographs and the prevalence of fractures was 29%. The sensitivity was 90.2% (4/41, 95% CI: 76.9-97.3) and specificity was 96.1% (4/102, 95% CI: 90.3-98.9). The positive likelihood ratio was 23.0 (95% CI: 8.8-60.5), and the negative likelihood ratio was 0.102 (95% CI: 0.040, 0.258). The positive predictive value was 90.2% (4/41, 95% CI: 76.9-97.3) and the negative predictive value was 96.1% (4/102, 95% CI: 90.3-98.9).
Conclusions: Emergency physicians can accurately evaluate long bone fractures in the ED using POCUS. In particular, long bone fractures can be excluded with a high degree of confidence.

1. Introduction

Musculoskeletal injuries, including long bone fractures are very common and represent a large number of patients presenting to the Emergency Department (ED). According to the Centers for Disease Control and Prevention, fractures are in the top 20 discharge diagnoses from the ED. Taken together diagnostic codes that include fractures represent approximately 565,000 visits (3.5% overall) to the ED annually [1]. Radiographs are traditionally used to diagnose long bone fractures; however, radiography can be time-consuming, increase ED wait times and length of stay, as well as subject patients to ionizing radiation. This is of special concern in vulnerable populations such as children and pregnant women [2]. In austere environments such as resource poor settings or wilderness areas, radiographs may not even be available [3].

The use of point-of-care ultrasound (POCUS) to diagnose long bone fractures has several potential advantages compared to radiography, including avoiding ionizing radiation exposure in vulnerable populations. It may also expedite the diagnosis and treatment of long bone fractures associated with significant neurovascular injury. It could potentially decrease ED length of stay and increase patient satisfaction.

Prior studies have suggested that bedside ultrasound is highly sensitive and specific in the detection of long bone fractures [3-5]. Ultrasound has also been shown to be effective in identifying fractures missed by radiographs [6-11]. However, previous studies are small, focused on specific anatomical regions and/or limited patient populations such as children [3-24]. None of these studies explored the utility of POCUS in detecting intra-articular fractures. In addition, physicians with advanced ultrasound experience acquired and interpreted ultrasound images in some of these studies, making generalizability difficult.

This study attempted to address some of the limitations of previous studies by evaluating long bone fractures using POCUS. We enrolled patients of all ages presenting to the emergency department with suspected fractures and included suspected intra-articular fractures. Clinicians who performed the bedside ultrasound and interpretation had varying levels of training from novice to experienced, and included a medical student, emergency medicine (EM) residents, emergency/sports medicine fellows, and EM attending physicians. The purpose of this study was to determine the diagnostic accuracy of emergency physician performed POCUS for detecting long bone fractures compared to standard radiography.

☆ Meeting abstract presentations: Westerna SAEM; Keystone, Colorado February 2011. National SAEM; Boston, MA, June 2011.

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0735-6757/$ – see front matter
http://dx.doi.org/10.1016/j.ajem.2013.06.006

2. Materials and methods

2.1. Study design

This was a single-blinded, prospective observational study of patients presenting to two EDs with trauma to long bones. The study was approved by the Institutional Review Board and took place between November 2009 and October 2012. The study used a convenience sample of patients seen during the study investigators' scheduled clinical shifts.

2.2. Study setting and population

The study was conducted in two large urban academic ED's with separate EM residency programs. ED censuses were approximately 70,000 and 40,000 patient visits per year at each site. All patients presenting to the ED were evaluated by a board-certified EM staff physician. Both residencies have an active emergency ultrasound program. Hospital based credentialing in emergency ultrasound was available and was derived from American College of Emergency Physicians ultrasound guidelines.

All POCUS examinations were performed by one of nine study investigators which included two attending physicians, 3 sports-medicine fellows, 3 residents, and a fourth-year medical student assisting with the research study. The 2 attending physicians did not have specific training in musculoskeletal ultrasound prior to the start of the study. However, both had prior training in using POCUS to make bedside clinical decisions (eg, Focused Assessment with Sonography for Trauma, or FAST). The fellows, residents, and medical student each received a 15 minute in-service from the principal investigator on diagnosis of long bone fractures using ultrasound. The fellows and residents involved in this study were all trained in emergency medicine programs with an active POCUS training program. The fourth year medical student had minimal POCUS experience.

2.3. Study protocol

Patients presenting to the ED with complaints of long bone trauma were included in the study when a study investigator was available in the ED. Patients were eligible for study enrollment if they were medically stable, were not altered, had symptoms of a possible long bone fracture at any location along the bone in question, and required radiographic imaging as determined by the attending physician caring for the patient. Patients were excluded if they were medically unstable for any reason or had evidence of open fractures.

POCUS examinations were performed after clinical assessment and prior to obtaining radiographs. After obtaining informed, written consent, POCUS examinations of the injured bone were performed using Zonare (Zonare Medical Systems, Mountain View, CA), Ultrasonix (Ultrasonix Medical Corporation, Richmond, British Columbia, Canada), or Sonosite (SonoSite, Inc, Bothell, WA) machines with a high frequency (12–5 MHz) broadband linear array transducer. POCUS examinations were performed using a standard protocol. Ultrasound examination of the bone in question was performed with special attention on the area of maximal pain and/or deformity. Transverse and longitudinal views were obtained for all areas examined. If a patient had pain in 2 locations, such as an ankle injury, both the tibia and fibula were scanned for the presence of fractures. All ultrasound images were saved on the ultrasound system hard drive for future review. The determination of a fracture upon POCUS was defined as a break, step-off, or irregularity in the bony cortex (Figs. 1 and 2). Studies were labeled as indeterminate when the investigator was uncertain as to the presence or absence of a fracture. The investigators documented their interpretation prior to radiographs being performed. After standard radiographs were performed, the final radiology interpretation by a radiology attending physician

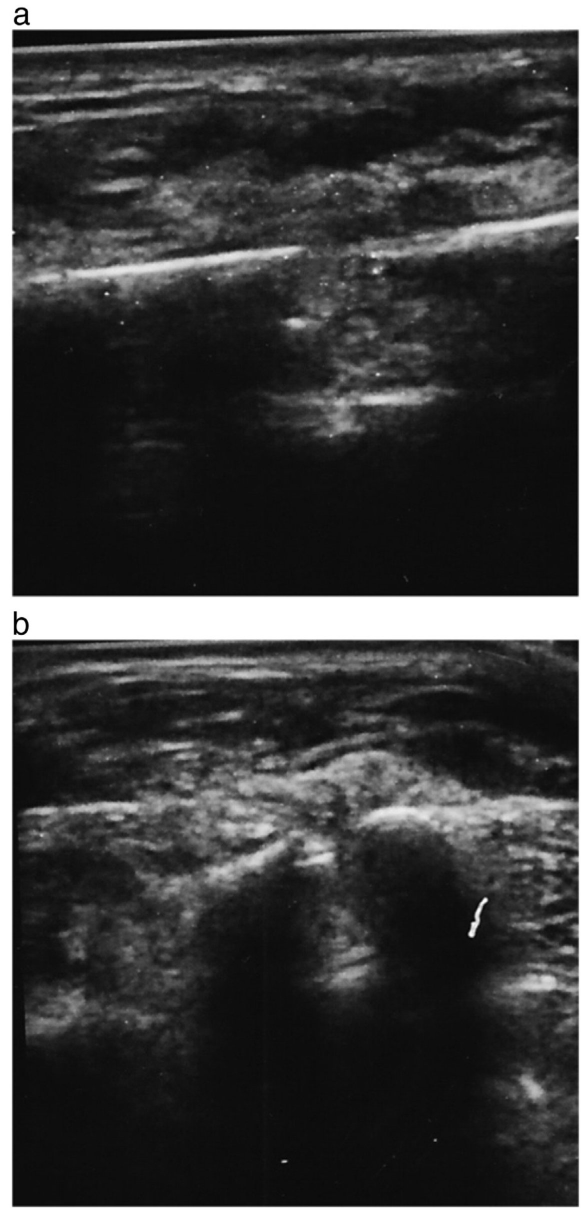

Fig. 1. Cortical irregularity in longitudinal (a) and transverse (b) plane indicating fracture.

was obtained from the medical record. The radiologists were not informed of the ultrasound findings or of the study in progress. All images saved on our Web-based image archival system were subsequently reviewed for accuracy by an ultrasound fellowship-trained attending physician who was blinded to initial ultrasound interpretations and radiography findings. He was the only investigator with formal ultrasound fellowship training and did not participate in enrolling patients or performing initial POCUS during the study.

3.4. Data analysis

All patient data were entered into a spreadsheet and data were analyzed using Stata (version 12.1, StataCorp, College Station, TX). Continuous data are presented as means (±SDs) or medians (with interquartile range), as appropriate. Categorical data are presented as frequencies or percentages. Sensitivity, specificity, and positive and negative likelihood ratios, as well as inter-rater reliability with 95% confidence intervals (95% CIs) were calculated. The 95% CIs for sensitivity and specificity were calculated using the exact method for binary data. We also included data for each examiner and analyzed

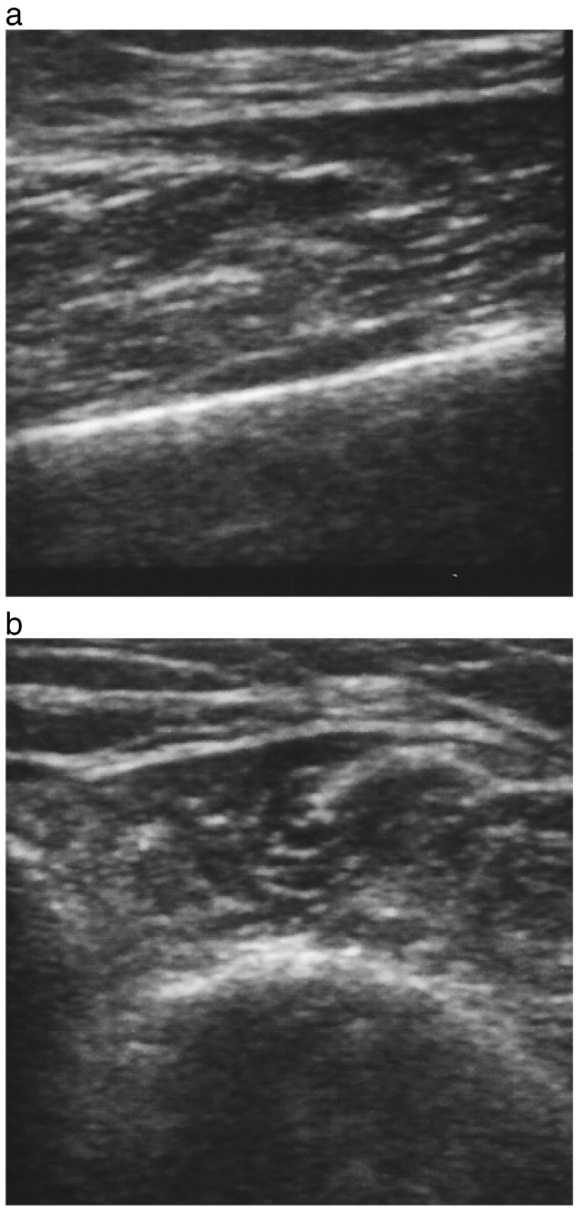

Fig. 2. Normal bone without cortical irregularity in longitudinal (a) and transverse (b) plane.

how individual and aggregate results changed over time during the study. We used Fisher's exact test for all comparisons of categorical data and the Kruskal-Wallis test for continuous data.

3.5. Sample size and power

Given previous work by Barata et al [19] and Marshburn et al [4], we estimated the true sensitivity of POCUS for detecting a fracture, using radiography as the gold standard, to be approximately 0.95. In addition, we expected the prevalence of actual fractures in patients enrolled in the study to be approximately 50%. Therefore, we estimated that we needed 146 diagnostic ultrasounds of suspected long bone fractures to have 80% power to detect a sensitivity and specificity of 0.95 with a 95% confidence interval of 0.90 to 1.00 [25].

3. Results

One-hundred six patients were enrolled into the study and 147 long bone POCUS examinations were performed. There were a total of 42 fractures present by radiographs, thus the prevalence of fractures in our study population was 29%. Four long bone exams were interpreted as indeterminate for the presence of fracture by investigators. Two of these were ultimately read as positive for fractures on the plain films by the radiologists, and two were negative for fractures. For the unequivocal studies included in the final data analysis (103 patients, 143 scans), mean age was 34 (SD ±20). We enrolled 25 children (24.8%) and 76 adults (75.2%). Fifty-two females (51.5%) and 51 males (49.5%) were enrolled. There were no statistically significant differences in age or gender of patients between scanned bones that did or did not have a fracture upon final radiology read. Table 1 shows the type and distribution of bones evaluated during this study.

The sensitivity was 90.2% (4/41, 95% CI: 76.9-97.3) and specificity was 96.1% (4/102, 95% CI: 90.3-98.9). The positive likelihood ratio was 23.0 (95% CI: 8.8-60.5), and the negative likelihood ratio was 0.102 (95% CI: 0.040-0.258). The positive predictive value was 90.2% (4/41, 95% CI: 76.9-97.3) and the negative predictive value was 96.1% (4/102, 95% CI: 90.3-98.9). The diagnostic odds ratio was 226.6 (95% CI: 53.9-953.2). The discriminatory ability of bedside ultrasound as estimated by the area under the receiver operating characteristics curve was 0.932 (95% CI: 0.882-0.981). The sensitivity and specificity did not significantly change over the course of the study period. The sensitivity of ultrasound to detect intra-articular fractures was 90.9% (10/11; CI 58.7-99.8). Table 2 shows the results stratified by bone.

There were 4 false-positive ultrasound exams by study investigators and all included the distal aspects of long bones: three distal radiuses and one medial malleolus. There were also four missed fractures on ultrasound exams by study investigators and included a distal radius buckle fracture, an intertrochanteric femur fracture, an avulsion fracture of the distal fibula and a lateral malleolus fracture.

For a random sample of 28 cases, the overall agreement between the bedside sonologist and blinded investigator was 96.4% with a κ of 0.921 (95% CI: 0.612-0.986).

Fig. 3 shows the distribution of POCUS examinations performed by each rater. Rater 9 performed 47.6 % (70/147) of all examinations. The sensitivity and specificity did not differ significantly between rater 9 and all other raters combined, suggesting relative homogeneity among raters.

4. Discussion

Ultrasound has previously been thought to be unreliable for fracture detection due to waves being reflected off the bony cortices [26,27]. However, it has recently been shown to actually facilitate visualization of cortical disruptions [26,27]. In fact, one cadaver study showed that ultrasound can be used to accurately detect cortical disruptions as small as one millimeter [26]. Several studies to date have documented the utility and advantages of ultrasound for fracture detection [6-11]. Ultrasound has been shown to accurately detect fractures of the clavicle, orbit, foot, ankle, rib, femur, and humerus. It has also been shown to accurately detect occult fractures not seen by traditional radiographs [6-11]. There is even some evidence that ultrasound may be more sensitive than plain films in the detection of

Table 1
Type and distribution of long bones

Bone	Frequency	Percent
Femur	2	1.4
Clavicle	7	4.8
Humerus	9	6.1
Ulna	26	17.7
Radius	33	22.5
Tibia	28	19.1
Fibula	42	28.6
Total	147	100

Table 2
Results stratified by bone

Bone	# Fractures present by radiographs (gold standard)	True positives by ultrasound	True negatives by ultrasound	False positives by ultrasound	False negatives by ultrasound	Equivocal ultrasound studies
Femur	1	0	1	0	1	0
Clavicle	4	4	3	0	0	0
Humerus	3	3	5	0	0	1
Ulna	3	3	23	0	0	0
Radius	14	13	16	3	1	0
Tibia	8	7	19	1	0	1
Fibula	9	7	31	0	2	2

some fractures [6-11]. False positives occur most often when interpreting cortical disruptions at places with reactive arthritis, tuberosities or other bends or surface irregularities in the cortex such as the distal ends of the radius, ulna, tibia and fibula [4]. This is one of the reasons it is crucial to confirm findings in 2 separate planes. Prior studies looking at diagnosis of long bone fractures by ultrasound have found sensitivities ranging from 73% to 100% [4,5,19] and specificities ranging from 83% to 92% [4,5,19].

This study found that POCUS had excellent specificity compared to radiography for detection of long-bone fractures (96.1%); however, the sensitivity was lower than expected (90.2%). Given a prevalence (pretest probability) of 29% in our study population, a negative POCUS exam (negative likelihood ratio = 0.102) would give a post-test probability of 4% and a positive POCUS exam (positive likelihood ratio = 23) would give a post-test probability of 90%. Our results are consistent with prior reports in the literature [4,5,19], although our findings suggest a higher specificity than previous studies. The prevalence of fractures in previous studies was similar to this study [3-5]. Our study suggests that ultrasound also may have a high specificity for detecting intra-articular fractures.

Prior studies documenting ultrasound's accuracy in detecting long bone fractures have only looked at specific populations such as children, specific body parts such as hands and clavicles, rural settings, or with radiologists rather than emergency physicians interpreting the images [3-24]. To our knowledge, this study is the most comprehensive study of its kind. It is the first to measure the sensitivity and specificity of ultrasound to diagnose long bone fractures in an urban setting with EM clinicians of varying ultrasound training levels and experience. This study included patients of all ages and all long bones, as well as intra-articular fractures. This is also the first study to our knowledge to evaluate inter-rater reliability of ultrasound images.

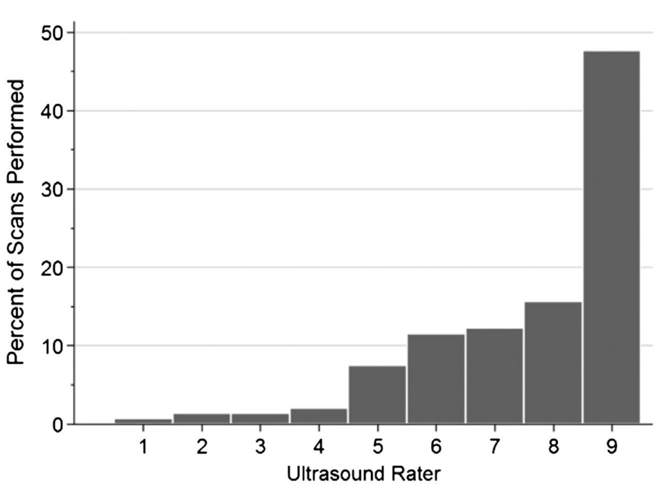

Fig. 3. Distribution of POCUS examinations performed by each rater.

Our findings suggest that the use of POCUS to evaluate long bone fractures has a high degree of accuracy. It was particularly useful at excluding long bone fractures in our study. For example, it would appear sensible to first perform POCUS on a suspected long bone fracture in the ED by an emergency physician and refer all positive cases for radiography, when possible. Based on our findings, this would result in ~10% of POCUS positive patients receiving unnecessary radiography. Currently, however, nearly all suspected fractures are automatically referred for radiographic imaging.

Our findings also suggest that an initial negative finding upon POCUS for a suspected fracture could be relatively safely discharged (with directions for follow up if symptoms persist or become worse) with an approximately 4% chance of actually having a fracture. While this may seem unacceptable, plain radiography may miss up to 10% to 15% of long bone fractures, particularly of the proximal femur [28]. Because there are serious medico-legal and cultural reasons why a negative POCUS ultrasound may never be used exclusively to justify discharge of a patient from the ED in the United States, our findings may apply more to other settings. Specifically, in resource poor countries, wilderness areas, or combat/conflict zones that may not have radiography immediately available, a negative POCUS exam might significantly improve a provider's ability to safely and sensibly triage patients to immediate versus delayed higher-level care.

A negative POCUS exam for a suspected fracture, along with a thorough physical exam, could allow a clinician to more accurately inform patients, especially those that are particularly vulnerable to the negative effects ionizing radiation exposure, of the risks and benefits of further radiographic imaging and allow patients to make more informed decisions regarding their care. Without POCUS, any individual patients in our study population would have an approximately 30% chance of a fracture based on prevalence. A positive exam increases that probability to 90%, while a negative examine decreases that probability to 4%. Thus, a POCUS exam may influence a patient's decision to wait for confirmatory testing (or make the wait more tolerable) and allow providers to sensibly prioritize the urgency for radiographic testing.

The ultrasound techniques developed for this study were easy to learn for clinicians with a wide range of both clinical and ultrasound experience. After a 15-minute training session, study investigators were able to apply these ultrasound skills at the patient's bedside. Although data regarding discomfort during performance of ultrasound was not formally recorded, the investigators of the study noted that no patient complained of discomfort and in fact anecdotally noted in a few cases that the ultrasound examination was more comfortable than the radiographic examination. Only minimal pressure on the patient's skin was needed to obtain adequate images.

There are several important advantages to using bedside ultrasound to diagnose long bone fractures. There is no radiation exposure, which is important in certain vulnerable populations such as pediatric and pregnant patients. It may also facilitate images when there is difficulty obtaining images due to patient positioning and/or patient transport. POCUS avoids the need to move patient from bed to table and back, avoids transport out of the patient's room, and allows the operator to manipulate the probe to the point of injury rather than asking the patient to move their injured body part. It allows evaluation of the site of pain and can also potentially look for other etiologies of patient's pain such as tendon/ligament injury, or other soft tissue injury. It may also increase patient satisfaction by more accurately giving patients the probability of a fracture and thus helping to justify waiting for radiographs or getting radiographs. Finally given portable ultrasound technology becoming increasingly available, fractures may be diagnosed in remote and resource poor settings such as war zones, ships, space and any other areas where a radiology suite is not immediately available, such as sporting events.

4.1. Limitations

The major limitation to this study is that the smaller than expected sample of patients with a fracture did not allow us to calculate the sensitivity of bedside ultrasound with the desired confidence interval (± 0.05). In addition, we only evaluated long bones and did not include bones of the hands and feet. Also, our study population was a convenience sample and thus could have resulted in a biased population. However, to the best of our knowledge, this is the most comprehensive study evaluating the diagnosis of long bone fractures in the ED by emergency physicians using POCUS compared to radiography.

4.2. Conclusions

Emergency physicians can accurately evaluate long bone fractures in the ED using POCUS. In particular, long bone fractures can be excluded with a high degree of confidence. Our study results also suggest that ultrasound can be useful in detecting intra-articular fractures.

Acknowledgments

Charlotte Shaughnessy, MD, Angela McKellar, MD for their help with initial study design and patient enrollment into the study. Heidi Forberg, MD, Lindsay Tanner, MD, Matthew Tennison, MD, Albert Fiorello, MD, and Jeffrey Stowell, MD for their help in enrolling patients into the study.

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