Comparison of Ultrasound and Plain Radiography for the Detection of Long-bone Fractures

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Objective: To compare emergency medicine (EM) resident physicians’ ability to identify long-bone fractures using ultrasound (US) versus plain radiography (X-ray).

Methods: This was an IRB-approved, randomized prospective study. Study participants included 40 EM residents at a single site. Fractures were mechanically induced in five chicken legs, and five legs were left unfractured. Chicken legs were imaged by both modalities. Participants were given 2 min to view each of the images. Participants were randomized to either US or X-ray interpretation first and randomized to viewing order within each arm. Participants documented the presence or absence of fracture and location and type of fracture when pertinent. Mean proportions and standard deviations (SDs) were analyzed using paired t-test and linear models.

Results: Forty residents (15 postgraduate years (PGY)-1, 12 PGY-2, 13 PGY-3) participated in the study. Thirty-one participants were male, and 19 were randomized to US first. Residents completed a mean of 185 (SD 95.8) US scans before the study in a variety of applications. Accurate fracture identification had a higher mean proportion in the US arm than the X-ray arm, 0.89 (SD 0.11) versus 0.75 (SD 0.11), respectively (P < 0.001). There was no statistically significant difference in US arm and X-ray arm for endpoints of fracture location and type.

Conclusion: EM residents were better able to identify fractures using US compared to X-ray, especially as level of US and ED experience increased. These results encourage the use of US for the assessment of isolated extremity injury, particularly when the injury is diaphyseal.

Keywords: Diagnostics, fracture, ultrasound, X-ray

INTRODUCTION

Ultrasound (US) is a frequently used imaging modality in the emergency department (ED). It has advantages of being a rapid, cost-effective, noninvasive technique that does not use ionizing radiation. US has many applications in the ED setting, including intra-abdominal, cardiopulmonary, various soft-tissue applications and as a procedural adjunct (e.g., vascular access, incision, and drainage). In spite of literature describing US as a diagnostic modality used for the assessment of bony injuries for over two decades, point-of-care US is still variably employed in the evaluation of extremity trauma.[1]

Extremity trauma is a common complaint in the ED, and long-bone fractures account for 3.5%–3.9% of ED visits nationwide annually.[3] Long-bone fractures can have significant complications including neurovascular compromise, potentially causing significant morbidity or mortality. Current industry practice for patients presenting to the ED with extremity trauma is assessment by plain radiography (X-ray), which has disadvantages of wait time, reliance on departmental resources and other staff, patient exposure to ionizing radiation, increased patient discomfort, and cost. Conversely, ED physicians can use US to rapidly assess extremity trauma to mitigate these drawbacks.

Studies have shown that US is a reliable imaging modality in the evaluation of bony injuries. Prospective studies have demonstrated US as high as 100% sensitive and 94% specific in the diagnosis of long-bone fractures, while a prospective urban ED study found a diagnostic accuracy of 94% and no false positives.[3,4] Similarly, bone/site-specific studies have shown sensitivities and specificities ranging from 85% to 100% for the hand, scaphoid, nasal and zygomatic, knee, and tibia.[3,4]
and sternal fractures.\textsuperscript{[5-9]} In the pediatric population, studies have shown similar results in the evaluation of extremities, clavicle, elbow, and forearm.\textsuperscript{[2,10-13]} Moreover, some studies have shown equivalent or superior sensitivity and specificity when compared to X-ray.\textsuperscript{[8,9,14,15]}

The goal of this study is to compare emergency medicine (EM) resident physician diagnostic accuracy when comparing US and X-ray for long-bone fracture.

**Methods**

This was an IRB-approved, randomized prospective study conducted in 2015. Study participants included 40 EM residents at a single site. The study involved participants examining ten store-bought chicken legs.

Five types of fracture (transverse, comminuted, avulsion, oblique, and buckle) were mechanically induced into five store-bought chicken legs, with an additional five legs left as unfractured controls.

The fractures were induced using a kitchen knife, needle nose pliers, a hammer, and blunt force. For the more subtle fractures with only partial cortical defects (buckle, avulsion), the chicken legs were first warmed in sub-boiling hot water for 10 min in an attempt to make the bone more pliable. This aided in the induction of these partial cortical defects without disrupting the entire cortex.

Each of these ten legs was then gently placed individually, on a bed of cloth towels in a medical basin, and submerged in water to a level of one inch deep above the leg. This provided stability while the legs were carefully manipulated and transported for imaging.

Next, all ten legs were imaged through both US and X-ray. US image clips were obtained first, using a SonoSite M-Turbo machine, 5 MHz standard linear probe. Two video clips were made: a short and long axis, 15 s per clip. All clips were made by one emergency US fellowship-trained EM physician. Video clips were saved in ten individual folders as MP4 files and playable in Windows Media Player.

Then, X-ray images were obtained using a C-arm (GE Medical Systems, OEC MiniView 6800). Anteroposterior (AP) and lateral films were obtained by gently rotating the legs underwater while leaving the bucket stationary. Films produced were 13.5 cm diameter-negative images, printed by a Sony Video Graphic Printer, Model UP-980.

Participants were randomized to either US or X-ray first and additionally randomized to viewing order within each arm. Participants received a 10-minute tutorial on identification of fractures by US and X-ray and then were given 2 min to view each set of US clips and X-ray images. Participants decided the presence or absence of any fracture. If a fracture was observed, participants identified the location and type of fracture. Gold standard for positive fracture was identification by gross dissection.

Mean proportions and standard deviations (SDs) were analyzed using paired \( t \)-test and linear models (SAS Institute Inc. 2011. Base SAS 9.3 Procedures Guide, Cary, NC: SAS Institute Inc). \( P = 0.05 \) was considered significant.

**Results**

Forty residents (15 postgraduate years (PGY)-1, 12 PGY-2, 13 PGY-3) participated in the study. Table 1 illustrates study participant characteristics. Thirty-one participants were male, and 19 were randomized to US first. Residents completed a mean of 185 (SD 95.8) US scans before the study.

Accurate identification of a fracture had a higher mean proportion in the US arm than the X-ray arm, 0.89 (SD 0.11) versus 0.75 (SD 0.11), respectively \((P < 0.001)\). The secondary endpoint of fracture location was slightly higher in the US than X-ray arm, with a mean proportion of 1.00 (SD 0.03) versus 0.97 (SD 0.09), respectively \((P = 0.1173)\). The secondary endpoint of fracture type was, however, slightly higher in the X-ray than US arm, with a mean proportion of 0.52 (SD 0.12) versus 0.51 (SD 0.13), respectively \((P = 0.5903)\).

While these secondary endpoints were not statistically significant, further analysis demonstrated that subtle cortical defects (buckle and avulsion fractures) were more commonly identified by US than X-ray (mean proportion 0.78 vs. 0.51 for buckle fracture, and 0.92 vs. 0.55 for avulsion fracture). Other fracture types were similar between US and X-ray (0.91 vs. 0.95 for transverse; 0.80 vs. 0.76 for oblique; and 0.93 vs. 0.92 for comminuted). Figure 1 demonstrates an avulsion fracture and a buckle fracture using X-ray, US, and gross dissection.

A linear model using the difference in proportions of correct answers was performed using PGY level, number of prior scans (surrogate for experience), and to which arm subjects were randomized, as covariates. PGY level \((P < 0.0001)\) and number of previously completed scans \((P = 0.0146)\) were statistically significant, but not to which arm subjects were randomized \((P = 0.5775)\).

**Discussion**

This study shows that participants were better able to identify fractures using US compared to X-ray, especially as experience with US and ED experience increased. This study should encourage the use of US in the assessment of isolated extremity injury. This and other studies suggest ED physicians using US

**Table 1: Study participant characteristics**

| PGY level | #Participants (31 males, 9 females) | Mean #previous scans (SD) |
|-----------|-----------------------------------|--------------------------|
| 1         | 15                                | 98 (70)                  |
| 2         | 12                                | 205 (76)                 |
| 3         | 13                                | 268 (42)                 |

PGY: Postgraduate year, SD: Standard deviation, EM: Emergency medicine.
can assess long bones for fracture with at least equal accuracy compared to interpreting their own X-rays. This is an important consideration; a 2004 study sampling 97 hospitals concluded that ED physicians primarily read their own radiographs about 60% of the time, with variation depending on the type of radiograph, daytime versus nighttime, and the ED clinician’s confidence in the primary read. During the nighttime, however, 55% of EDs had no radiology reading for radiographs at all.\[16\] Consequently, US may be an alternative imaging modality to X-ray for long-bone fracture assessment.

US may be the modality of choice for subtle fractures. These fractures are less likely to need manipulation or closed reductions, so the role of X-ray is further minimized. Analysis of our data demonstrated when a fracture was large and “obvious,” i.e., comminuted or transversely fractured; participants were able to identify the fracture and location with relative ease, regardless of imaging modality. However, for the subtle avulsion and buckle fractures, participants were better able to see these small cortical defects through US than X-ray. This is particularly important in the pediatric population, where buckle fractures are common and often involve the diaphysis. Moreover, the fact that US may identify a subtle diaphyseal fracture may improve clinical management, leading to prompt splint application and close orthopedic follow-up. In the circumstance of subtle cortical defects that may have been missed on X-ray, whether pediatric or adult, US may actually lead to improved clinical outcomes and reduced potential morbidity.

Participants were able to accurately diagnose fracture on US using minimal training. Participants had received 10 min of training before the study (5 min for each modality), and an emphasis was placed on looking for a continuous versus discontinuous cortex, the latter representing an abnormal finding suggesting fracture. Participants were better at detecting these subtle “step-offs” in the hyperechoic bony cortex on US than in the AP and lateral films. A caveat to any US evaluation is the sonographer’s ability to reliably perform and interpret the scan. Our study demonstrates that with a short tutorial, residents were able to accurately diagnose fractures on US. This has implications for the generalizability of our findings and adoption in the community, especially in environments that require EM physicians to independently read plain radiographs.

Training to achieve technical competency was not assessed with this study. Standardized video clips were used to maximize fracture identification by visualization alone and eliminate the potential variability of the images had the participants performed the US scans. On the one hand, the standardized US clips may be a limiting factor because US requires the clinician to operate the US machine and perform the scan correctly, i.e., proper probe selection, proper depth and gain, imaging the appropriate anatomy/location of potential bony injury, etc. On the other hand, the use of premade US clips may actually impede identification of a diaphyseal fracture because participants are “blindly” viewing the entire diaphysis without an area of clinical suspicion. Real-time US has the added benefit of the patient providing feedback as to the exact location of maximal tenderness. This means that the US clinician should have a well-defined anatomical location to focus their scanning, whereas in this study, the use of standardized clips meant that participants did not have this bedside aide.
Regardless of who performs the US examination, the results are promising. In previous studies investigating US for the evaluation of fractures, there has been variability in the performer of the US scans. Specifically, scans were completed by ED physicians, certified sonologists, or nonphysician US technicians and sometimes followed by interpretation from a radiologist. In addition, resolution (high versus regular) and probe selection varied between studies. Of note, though, even in previous studies with variable imager and technique, sensitivities and specificities for long-bone fractures ranged from 90% to 100%.\textsuperscript{[3,4,11]}

**Limitations**

This study has limitations. The quality of the X-ray images may not be comparable to that in a typical ED. Unlike electronic imaging systems that are available at many EDs, this study used negative images that participants held up to background light. Although participants were able to manipulate these negatives in any way they wanted during their 2-min allotment, participants were unable to utilize any of the tools available in most electronic radiographic imaging systems. For example, electronic imaging systems allow the user to “zoom in,” change image phase, change contrast, etc. These tools may increase a participant’s proportion of correctly identifying bony injuries through X-ray.

Another limitation of this study is anatomical; only diaphyseal fractures were examined. However, long-bone fractures often involve the metaphysis and/or epiphysis and may have intra-articular extension. These fractures carry potential increased morbidity such as nonhealing nature and subsequent osteoarthritis. These fractures are also of particular importance in the pediatric population when Salter–Harris fractures are of clinical concern. As this study only evaluated diaphyseal injury, it suggests that US may be most appropriate when the suspected injury location/point of maximal tenderness is diaphyseal and does not involve an articular surface.

The study used a chicken bone model rather than human subjects. Although the model seemed to be a good representation of human bone, there may be radiographic and sonographic differences from human bones. Use of an animal model, however, allowed for a controlled setting to create fracture types. The gold standard was gross dissection, which may be challenging to replicate in human models. Future studies will need to evaluate US for long-bone fractures in the clinical setting as many of the patient-centered outcome measures such as length of stay, patient satisfaction, and timeliness of diagnosis could not be assessed with our study design.

**Conclusions**

US has a promising role in diagnostic evaluation of long-bone fractures, particularly in cases with subtle cortical defects. With a short tutorial, physicians were able to accurately identify fractures on US using a chicken bone model. Prospective human studies will be needed to validate these findings.

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**Conflicts of interest**

There are no conflicts of interest.

**REFERENCES**

1. Steiner GM, Sprigg A. The value of ultrasound in the assessment of bone. Br J Radiol 1992;65:589-93.
2. Barata I, Spencer R, Suppiah A, Raio C, Ward MF, Sama A, et al. Emergency ultrasound in the detection of pediatric long-bone fractures. Pediatr Emerg Care 2012;28:1154-7.
3. McNeil CR, McManus J, Mehta S. The accuracy of portable ultrasonography to diagnose fractures in an austere environment. Prehosp Emerg Care 2009;13:50-2.
4. Dulchavsky SA, Henry SE, Moed BR, Diebel LN, Marshburn T, Hamilton DR, et al. Advanced ultrasonic diagnosis of extremity trauma: The FASTER examination. J Trauma 2002;53:29-32.
5. Tayal VS, Antoniazzi J, Pariyadath M, Norton HJ. Prospective use of ultrasound imaging to detect bony hand injuries in adults. J Ultrasound Med 2007;26:1143-8.
6. Platon A, Poletti PA, Van Aaken J, Fussetti C, Della Santa D, Beaulieu JY, et al. Occult fractures of the scaphoid: The role of ultrasonography in the emergency department. Skeletal Radiol 2011;40:869-75.
7. Adeyemo WL, Akadir OA. A systematic review of the diagnostic role of ultrasonography in maxillofacial fractures. Int J Oral Maxillofac Surg 2011;40:655-61.
8. Bonnefoy O, Diris B, Moind M, Aunoble S, Diard F, Hauger O, et al. Acute knee trauma: Role of ultrasound. Eur Radiol 2006;16:2542-8.
9. You JS, Chung YE, Kim D, Park S, Chung SP. Role of sonography in the emergency room to diagnose sternal fractures. J Clin Ultrasound 2010;38:135-7.
10. Patel DD, Blumberg SM, Crain EF. The utility of bedside ultrasonography in identifying fractures and guiding fracture reduction in children. Pediatr Emerg Care 2009;25:221-25.
11. Chien M, Bulloch B, Garcia-Filion P, Yousuff M, Shrader MW, Segal LS, et al. Bedside ultrasound in the diagnosis of pediatric clavicle fractures. Pediatr Emerg Care 2011;27:1038-41.
12. Rabiner JE, Khine H, Avner JR, Friedman LM, Tsung JW. Accuracy of point-of-care ultrasonography for diagnosis of elbow fractures in children. Ann Emerg Med 2013;61:9-17.
13. Chaar-Alvarez FM, Warkentine F, Cross K, Herr S, Paul RI. Bedside ultrasound diagnosis of nonangulated distal forearm fractures in the pediatric emergency department. Pediatr Emerg Care 2011;27:1027-32.
14. Güirkov R, Clevert D, Krause E. Sonography versus plainxrays in diagnosis of nasal fractures. Am J Rhinol 2008;22:613-6.
15. Turk F, Kurt AB, Saglam S. Evaluation by ultrasound of traumatic rib fractures missed by radiography. Emerg Radiol 2010;17:473-7.
16. Saketkhou DD, Bhargavan M, Sunshine JH, Forman HP. Emergency department image interpretation services at private community hospitals. Radiology 2004;231:190-7.