Goal-Directed Ultrasound in the Detection of Long-Bone Fractures

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Background: New portable ultrasound (US) systems are capable of detecting fractures in the remote setting. However, the accuracy of ultrasound by physicians with minimal ultrasound training is unknown.

Methods: After one hour of standardized training, physicians with minimal US experience clinically evaluated patients presenting with pain and trauma to the upper arm or leg. The investigators then performed a long-bone US evaluation, recording their impression of fracture presence or absence. Results of the examination were compared with routine plain or computer aided radiography (CT).

Results: 58 patients were examined. The sensitivity and specificity of US were 92.9% and 83.3%, and of the physical examination were 78.6% and 90.0%, respectively. US provided improved sensitivity with less specificity compared with physical examination in the detection of fractures in long bones.

Conclusion: Ultrasound scans by minimally trained clinicians may be used to rule out a long-bone fracture in patients with a medium to low probability of fracture.

Keywords: Ultrasound, Fractures, Humerus, Femur.

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Trauma is the leading cause of significant morbidity among personnel deployed to remote areas such as Antarctica, submarines, and Naval surface vessels, and is the primary cause of evacuations to definitive care facilities.[1–3] Traditional diagnostic imaging capabilities are limited or non-existent in these settings; excessive size and weight prevents inclusion of x-ray capability in the battlefield, submarines, and spacecraft. The advent of small, portable ultrasound systems may provide an alternate diagnostic imaging capability applicable to medical care in remote areas.

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Ultrasound is of proven accuracy in focused examinations, such as the Focused Abdominal Sonography for Trauma (FAST) examination. Recent clinical investigations are defining a wider range of conditions in which rapid ultrasound examinations performed by non-radiologist physicians can influence treatment decisions. For example, the ability of emergency physician sonographers to perform compression Duplex ultrasound scanning in the emergency department has been prospectively investigated.[4,5] Fractures of long-bones are of particular interest, since associated bleeding and neurovascular compromise can cause substantial morbidity.[8] Early identification is therefore likely to effect immediate treatment or evacuation decisions, and ultrasound may provide a rapid, reliable diagnostic imaging capability for these injuries. However, when compared with a clinician's initial history and physical examination, ultrasound's accuracy for fracture detection is unknown. This study prospectively compares the accuracy of ultrasound versus the physical examination for the identification of fractures of the humerus and femur. To increase the validity of the results for the remote care setting, only clinicians with minimal formal ultrasound training participated in this study.

MATERIALS AND METHODS

This prospective observational study was conducted in the emergency department of three teaching hospitals in the twelve-month period from November 2000 to November 2001, after approval from the Human Subject Committees of each institution, and adhered to established guidelines on the treatment of human subjects. The study population was derived from a convenience sample of patients who met inclusion criteria and provided informed consent. Inclusion criteria were the following: patients had to be 18 years or older, be able to understand and sign informed consent, have had humerus or femur trauma, and have a radiograph or computerized tomography (CT) scan ordered to evaluate for the possibility of a fracture in either of these bones. Patients who were unstable, who had open fractures, who had humeral or femur deformity itself diagnostic for fracture (e.g. angulation), or who had orthopedic hardware in the traumatized bone were excluded from the study.

The study investigators consisted of five emergency physicians (three attendings and two residents) and one surgery resident. None of the investigators were ultrasonographers, although the emergency physicians had performed the FAST examination as part of their practice. The investigators received standardized formal training in humeral and femoral fracture detection using a Sonosite 180 portable ultrasound device (Sonosite, Inc., Bothell, WA) with a 5 MHz transducer head. The formal training consisted of a twenty minute video presentation on a scanning technique specific to fracture detection devised by two of the authors (AS, SM), followed by a forty-minute practice session on a live normal model.

The ultrasound technique consisted of a scan of the femur or humerus in several steps. For the femur examination, the transducer was placed on the lateral thigh just superior to the patella, with the probe transverse to the longitudinal axis of the thigh, revealing an easily identifiable cross sectional view of the femoral cortex for immediate orientation. The transducer was then rotated to a longitudinal position and moved proximally to obtain a view of the normally smooth femoral shaft. At the femoral neck, the transducer was angled slightly for alignment, and scanning was continued to the midpoint of the inguinal ligament to visualize the femoral neck, head, and pelvic acetabulum. During this portion of scanning, slight rotation of the femur permitted demonstration of the articulation of the head with the acetabulum.

A similar technique was used for evaluation of the humerus. The transducer was placed at the anterior distal humerus, and a cross section of humeral cortex was identified for orientation. By rotating the transducer longitudinally and scanning along the humerus to its greater tuberosity, the normally smooth humeral shaft was visualized. Finally, scanning just distal to the acromial process of the scapula allowed visualization of the humeral head.

Emergency department patients who had x-rays ordered for trauma to the shoulder, humerus, hip, or femur were initially eligible for the trial. Initial treatment (e.g. ice, analgesia, sling) was not delayed pending ultrasound evaluation.

After all eligibility criteria were confirmed and patient consent obtained by a study investigator, the investigator recorded their level of fracture suspicion (high, medium, or low) based on the physical examination alone, before performance of ultrasonography. For the purpose of the comparison with the ultrasound interpretation, high clinical suspicion was recorded as a positive clinical examination, and a medium or low clinical suspicion was recorded as a negative clinical examination. Investigators then performed the ultrasound examination detailed above. This examination was interpreted as positive for fracture if the investigator detected a clear disruption of cortical bone, shown either as a step-off or as an interruption in an otherwise continuous cortical line.

All study investigators recorded the results of their clinical examination and their ultrasound interpretation without knowledge of the patient's radiograph results. Radiology attendings interpreted all radiographs, and if plain film results were equivocal, a computer-aided tomography (CT) scan was performed. In all cases, a definitive diagnosis was made by radiologist attending review of plain film or CT results. In concert with routine practice, radiographs formally read as normal by attending radiologists were deemed to have no fractures, and further follow up was not pursued.

RESULTS

58 patients were enrolled over the study period, most presenting with femoral trauma (45/58, 78%) (Table 1). Half the patients had fractures (28/58, 48%) (Table 2). Ultrasound images of a normal mid-shaft femur (Fig. 1), and a closed, non-comminuted humeral mid-shaft fracture (Fig. 2) are shown below. Figure 1 also demonstrates the reverberation artifact that occurs at the acoustically reflective interface between soft tissue and bone.

The study results are summarized in Table 3. Three physical examinations were falsely positive and six were falsely negative. Two of the false negative physical examinations were in patients with fractures at the intertrochanteric line, one in the femoral neck, two in the distal femur, and one in the distal humerus. All false negative physical examinations occurred in patients over the age of 60.

Five ultrasounds were falsely positive (patient ages 28 to 87), and two were falsely negative (ages 70 and 85). All false ultrasound readings occurred in patients with fractures near the hip (acetabulum, obturator, though hip fractures were also the most common type of fracture in the study's population. Both false negative ultrasound readings occurred in patients with intertrochanteric fractures, one of whom also had re-

Table 1 Characteristics of Patient Population

Characteristic	*N*	Percent
Age (yr)		
Median	79	
Range	28–97	
Injured extremity		
Upper arm	13	22
Thigh/hip	45	78

Table 2 Percent of Injured Extremities with Fractures

Bone	*N*	Fractures	%
Humerus	13	5	39
Femur	45	23	51

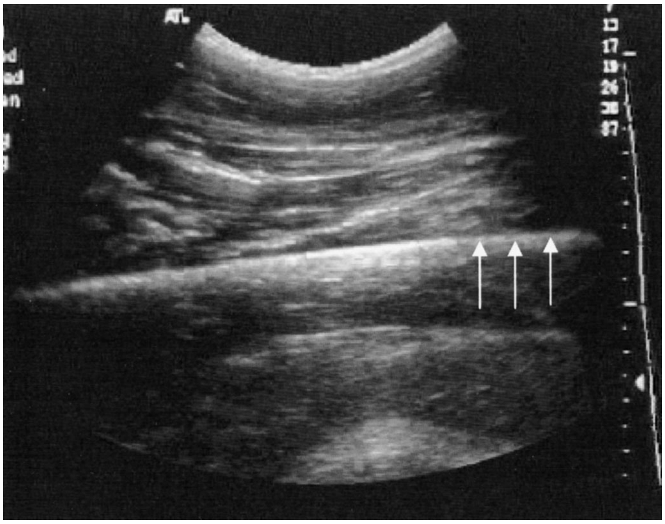

Fig. 1. *Longitudinal ultrasound scan of a normal femur at mid-shaft. White arrows point o a portion of the smooth, linear cortical line.*

ferred knee pain. Three of the false positive ultrasounds occurred in patients with pelvis fractures at the acetabulum, pubic ramus, and obturator ring. No inaccurate ultrasound readings occurred in patients with humerus fractures. Six of the seven inaccurate ultrasound interpretations were by attendings, who performed the majority of study examinations (49 of 58).

Ultrasound evaluators commented that mid-shaft fractures were readily apparent, and no ultrasound false positives or negatives occurred in patients with femur fractures below the intertrochanteric line or with any humerus fractures. No patients gave an indication of, or reported, any discomfort from the ultrasound examination.

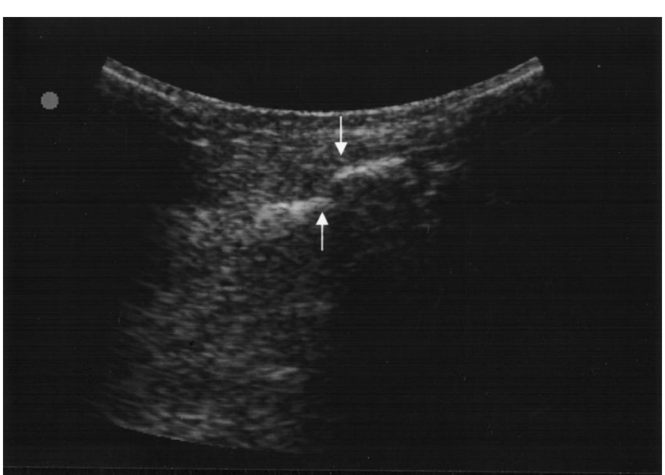

Fig. 2. *Longitudinal ultrasound scan of a simple, closed femoral fracture at mid-shaft. White arrows indicate the disruption of the cortical line and the step-off associated with the fracture.*

Table 3 Sensitivity, Specificity, and Accuracy of the Ultrasound and Physical Exam

Ultrasound Interpretation	Fracture	No Fracture	Total
Positive	26	5	31
Negative	2	25	27

Sensitivity 93% (95% CI 77% to 99%), specificity 83% (95% CI 65% to 94%).

Physical Exam Interpretation	Fracture	No Fracture	Total
Positive	22	3	25
Negative	6	27	33

Sensitivity 79% (95% CI 59% to 92%), specificity 90% (95% CI 74% to 98%).

DISCUSSION

Ultrasound shows promise as a diagnostic imaging tool in fracture detection. Although ultrasound was previously assumed to be limited by ultrasound wave reflection at bony cortices, subsequent investigations found that this acoustic characteristic of bone actually improves visualization of cortical disruptions.[9,10] Grechenig and colleagues were able to image cortical disruptions as small as 1 mm in cadavers.[10] In live patients, other investigators reported ultrasound images of long-bone fractures to be “striking and not difficult to interpret.”[11]

Previous investigations have demonstrated the ability of ultrasound to image fractures of the clavicle,[13] orbit,[14,15] foot, ankle,[16,17]rib,[18] femur, and humerus[7,19–21] and to image occult fractures not identifiable by traditional radiography.[13,17,18] Others have reported ultrasound’s capability to image hematoma formation and soft-tissue interposition in fracture sites, to assess interosseus membrane integrity, and to document fracture healing.[22,23]

The development of hand-held ultrasound systems may therefore enable a means of more quickly identifying clinically significant fractures, through more rapid image acquisition and simultaneous interpretation at the bedside. Furthermore, the small size of these systems enables their use in locations where traditional radiography and experienced physicians are not available. To be incorporated into the initial assessment of the trauma patient, the image produced by these systems must be interpretable by the minimally trained operator, and the accuracy of the interpretation must be comparable to the conclusions of the initial physical examination as performed by a clinician.

We found the ultrasound techniques developed for this study easy to teach to non-radiologists with minimal prior ultrasound experience. Following an hour-long standardized formal training session, the ultrasound skills were simple to perform at the patient’s bedside, and were easily retained during the length of the trial.

While objective data regarding discomfort was not formally recorded as part of this study, the operators were impressed that no patient complained of discomfort with the

US examination, even when specifically asked. In fact, very light contact of the probe with the patient's skin produced images of sufficient quality for interpretation.

We also found that ultrasound had high sensitivity and specificity for fracture detection using traditional radiography or CT, interpreted by radiology attendings, as the gold standard. This high sensitivity and specificity compared favorably to the physical examination as performed by the experienced clinician, and was upheld despite limited training in ultrasound techniques.

Ultrasound was, however, limited in detection of fractures near the hip. All inaccurate ultrasound interpretations occurred with femur fractures at or above the intertrochanteric line. This is most likely due to the surface irregularities of the normal greater trochanter and femoral neck, which can scatter the impinging acoustic wave resulting in a less distinct reflected signal, and may be interpreted as a cortical discontinuity. While not prospectively recorded, all investigators upon discussion stated that the femur proximal to the intertrochanteric line was difficult to assess for fracture. Our results indicate, therefore, that ultrasound in fracture detection may be of most use in detecting and ruling out femoral shaft and humerus fractures only, where it was 100% sensitive in detecting humerus and femoral mid-shaft fractures.

The median age of our study population is older than in the typical trauma population, which may have effected US accuracy in this study. The presence of irregularities in the bony cortex, such as from degenerative joint disease, scatters the acoustic signal, making the US image more difficult to interpret. The higher incidence of degenerative joint disease expected in our study population may have reduced the accuracy of the US examination, and suggests that US would demonstrate greater accuracy in the typical trauma demographic.

Thus, in the setting of fracture assessment, ultrasound accuracy is promising, but may be appropriate for clinical decision-making in shaft fractures only. Above the intertrochanteric line, where a missed fracture can result in substantial patient morbidity, US does not appear to reliably rule out a fracture.

For appropriate indications, however, US appears to be capable of providing a rapid screen at the point of care in a trauma resuscitation room, for the patient going directly to the operating theater for exploratory celiotomy, or in remote deployments (battlefields, field research teams, spaceflight crews) for rapid fracture identification where immediate x-ray imaging is not available.

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