Advanced Ultrasonic Diagnosis of Extremity Trauma: The FASTER Examination

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Background: Ultrasound is of proven accuracy in abdominal and thoracic trauma and may be useful for diagnosing extremity injury in situations where radiography is not available such as military and space applications. We prospectively evaluated the utility of extremity ultrasound performed by trained, nonphysician personnel in patients with extremity trauma to simulate remote aerospace or military applications.

Methods: Patients with extremity trauma were identified by history, physical examination, and radiographic studies. Ultrasound examination was performed bilaterally by nonphysician personnel, blinded to radiographic results, with a portable ultrasound device using a 10- to 5-MHz linear probe. Images were videorecorded for later analysis against radiography by Fisher's exact test.

Results: There were 158 examinations performed in 95 patients. The average time of examination was 4 minutes. Ultrasound accurately diagnosed extremity injury in 94% of patients with no false-positive examinations; accuracy was greater in midshaft locations and least in the metacarpal/metatarsals. Soft tissue/tendon injury was readily visualized.

Conclusion: Extremity ultrasound can be performed quickly and accurately by nonphysician personnel with excellent accuracy. Pulmonary ultrasound appears promising; blinded verification of the utility of ultrasound in patients with extremity injury should be performed to determine whether *e*xtremity and *r*espiratory evaluation should be added to the FAST examination (the FASTER examination) and to verify the technique in remote locations such as military and aerospace applications.

Key Words: Fracture, Ultrasound, Space medicine, Soft tissue injury.

J Trauma. 2002;53:28–32.

Extremity fractures are common in victims of blunt trauma; the diagnosis is suggested by history and physical examination findings and typically confirmed with radiography.[1] Fractures can occur in remote areas where radiographic evaluation is delayed or impossible such as in field military conflicts, rural medicine, or potentially during space exploration.[2] Power, weight, and space requirements make radiography impractical in these applications; therefore, sound clinical diagnosis is paramount.[3] Unfortunately, environmental effects such as noise and limitations in training of health care providers in these situations further obscure the diagnosis of orthopedic injury.

Advances in ultrasound technology and capabilities have expanded the clinical use of ultrasound to the trauma setting.[4] Isolated case reports have suggested that ultrasound may provide an additional modality for diagnosing orthopedic injury. However, there is little information regarding the utility of newer, portable ultrasound devices that may facilitate expansion of this technique (A.W. Kirkpatrick, unpublished data).[5–11] Furthermore, the ability of nonphysician personnel to obtain high-quality ultrasound images for diagnosing orthopedic injury is not known. We report the use of a high-fidelity, portable ultrasound device by nonphysician personnel after a short introductory course, to acutely diagnose orthopedic injuries in an urban, Level I trauma center.

Submitted for publication October 12, 2001.

Accepted for publication February 1, 2002.

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This work was scheduled for presentation at the 61st Annual Meeting of the American Association for the Surgery of Trauma, which was canceled because of the terrorist attacks of September 11, 2001.

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MATERIALS AND METHODS

The study protocol was approved by the university human investigation committee. During a 3-month study period, stable patients with a clinical history and physical examination suggestive of extremity orthopedic injury presenting to the emergency room at Detroit Receiving Hospital, a Level I urban trauma center, were assessed for study inclusion. The patients were identified by emergency medicine personnel or the trauma team, which consisted of surgical attendings with surgical and emergency medical residents.

Inclusion criteria included the following: ability to give informed consent, stable vital signs, age range 18 to 80 years, and no preexisting orthopedic conditions such as history of fracture or extremity deformity. Exclusion criteria included the inability to give informed consent, unstable vital signs, preexisting orthopedic disease, and extremity injury or skin loss/open fracture precluding adequate ultrasound evaluation.

Ultrasound Training and Technique

All of the ultrasound examinations were performed by cast technicians (associate or bachelor of science level education) who received 2 hours of didactic and practical instruction in the use of portable ultrasound to evaluate extremity injury. The technicians were instructed in the principles of extremity ultrasound, which included hands-on demonstration of the normal ultrasound findings in models with normal extremity anatomy and in patients with various orthopedic injuries. The technicians also viewed prerecorded ultrasound examinations of patients with extremity orthopedic injuries, which clearly demonstrated the diagnostic cortical discontinuity and soft tissue swelling.

Informed consent was obtained from patients who met inclusion criteria. The ultrasonic examinations were performed before radiographic evaluation when possible or while the radiographs were being developed, allowing the ultrasonographer to remain blinded during the examination. Patients with a confirmed diagnosis of fracture or injury before ultrasound were excluded from analysis. All examinations were completed within 6 hours of admission to the hospital.

The ultrasonic examination was performed initially in the unaffected extremity to determine a baseline and to affirm the normal ultrasound findings in patients without injury. The examination was done with a Sonosite 180, hand-held, portable ultrasound machine (Sonosite, Inc., Bothell, WA) using a 10- to 5-MHz linear probe (Model L38, Sonosite). A standardized technique was used that initially included scanning in a longitudinal plane of the extremity with the focal depth of the window to maximize visualization of the cortical interface, which is readily discernible as an unbroken, strongly echoic line. The ultrasound probe was then moved longitudinally to evaluate the cortex for irregularities, breaks, or fluid accumulation. A transverse examination of the bone was performed to provide additional confirmation of fracture (Fig. 1). The scan was then repeated in the contralateral extremity. The ultrasonic examinations were videorecorded on a Sony Digital Video Cassette (Model GV-900, Sony Corporation, Tokyo, Japan) for later analysis by one of the authors (S.A.D.). The technician's initial diagnostic interpretation, patient demographics, duration of the examination, and findings were recorded on a data sheet for later evaluation by blinded physician experts.

Initial diagnostic impression and patient demographic data including age, mechanism of injury, ultrasound examination results, and radiographic findings were collated to determine the sensitivity and specificity of orthopedic ultrasound in the diagnosis of extremity injury. Statistical analysis was performed with Fisher's exact test.

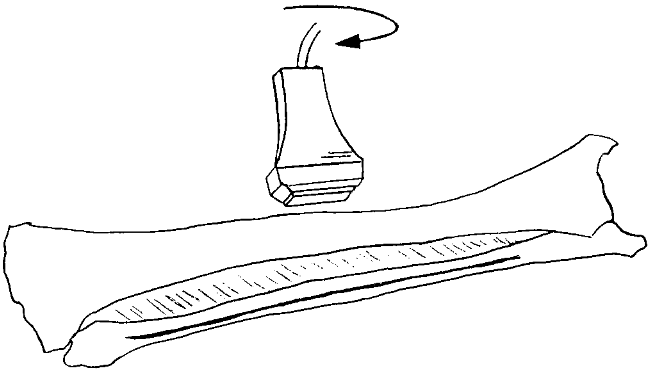

Fig. 1. *The ultrasound examination was initially conducted with the transducer placed longitudinally to evaluate cortical integrity. Areas of probable injury were then confirmed by turning the probe head 90 degrees to obtain a transverse scan through the bone.*

RESULTS

Patients were actively enrolled in the study over the period December 1, 2000, to February 1, 2001. Although it is impossible to determine how many patients were potentially enrollable during the study period, the most common reasons for nonenrollment were instability of medical status, inability to obtain consent, technician unavailability, and previously confirmed diagnosis of extremity fracture.

There were 95 patients who fulfilled inclusion criteria during the enrollment period and had ultrasound of the extremity performed. The majority of patients were men (82%) and the injury demographics of the patient population reflect an urban Level I trauma center. The predominant mechanism of injury was motor vehicle crash, assault, fall, or gunshot wound. The average total time required to complete the ultrasound examination was 4 minutes.

The distribution of ultrasound examinations is shown in Table 1. Examinations in the leg and forearm were easy to interpret (Figs. 2 and 3) and had a low false-negative rate. There were no false-positive examinations in this series in any fracture location.

Ultrasound examinations of the hand and foot were more challenging to image and subsequently diagnose. Although

Table 1 **Location of Injury versus Accuracy**

Location	True (Positive)	True (Negative)	False (Positive)	False (Negative)	*p* Value	Relative Risk
Forearm/arm	12	22	0	1	1.00	1.06
Femur	5	20	0	1	1.00	1.2
Tibia/fibula	15	18	0	3	0.79	0.91
Hand/foot	4	25	0	4	0.11	Inf.
Tendon	9	18	0	1	1.00	1.08

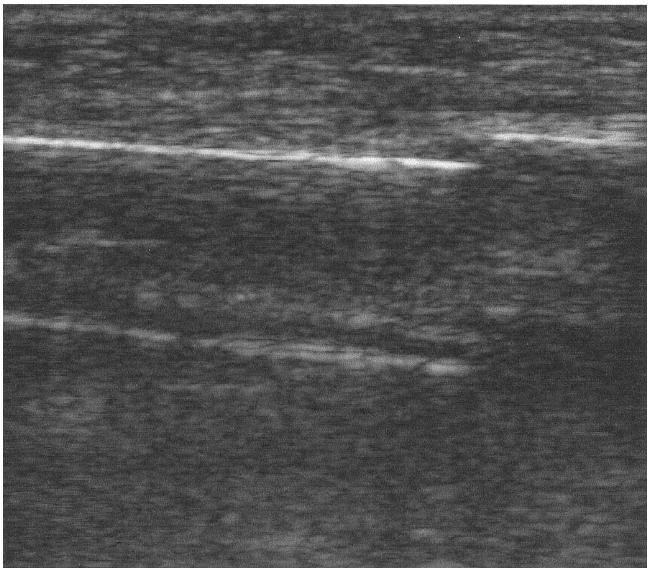

Fig. 2. *Representative static ultrasound image of a midshaft ulnar fracture demonstrating a well-demarcated cortical break. There is evidence of fluid accumulation in the soft tissues superior to the fracture site consistent with fracture hematoma.*

image quality was compromised in some patients, a number of the ultrasound examinations were adequate to be later interpreted by a physician expert as consistent with fracture (Table 2). Mechanism of injury did not alter the accuracy of the examination.

Physician Overreads of Technician Interpretations and Missed Injuries

The accuracy of the orthopedic ultrasound examinations was dependent on the location of the injury. There were no missed injuries in patients who had midshaft fractures of the radius/ulna, humerus, femur, or tibia/fibula. Physician overreads were greatest in areas where anatomy was challenging (hand/foot, tendon, femur).

DISCUSSION

The triage and definitive care of patients with extremity injury requires prompt and accurate diagnosis to guide management decisions.[12,13] Although radiography is routinely used to confirm the diagnosis and extent of orthopedic injuries, contraindications to ionizing radiation (e.g., pregnancy) are occasionally present. Furthermore, the ability to obtain a radiograph may not be present in situations where remote care is performed, such as military encounters, rural medicine, and aerospace applications. The placement of a cast or other immobilization device, and subsequent long-term incapacitation in the field or during microgravity, poses additional technical demands as well as having significant impact on the ability to continue duties or mission.[14,15] These considerations underscore the need for exploring the efficacy of alternative diagnostic methods to confirm the presence of an orthopedic injury before definitive care. Furthermore, evacuation decisions must be made on the basis of accurate assessment of sprains or strains, which can be managed conservatively on site, versus fracture, where transfer is required.

Fig. 3. *Radiologic confirmation of the ulnar fracture demonstrates a bicortical fracture with minimal displacement of the bony elements.*

Table 2 **Sensitivity versus Specificity of Orthopedic Ultrasound**[a]

Location	Sensitivity (%)	Specificity (%)	Physician Overreads
Forearm/arm	92	100	0
Femur	83	100	1
Tibia/fibula	83	100	0
Hand/foot	50	100	2
Tendon	90	100	1

[a] Physician overreads of technician interpretations and missed injuries. The accuracy of the orthopedic ultrasound examinations was dependent on the location of the injury. There were no missed injuries in patients who had midshaft fractures of the radius/ulna, humerus, femur, or tibia/fibula. Physician overreads were greatest in areas where anatomy was challenging (hand/foot, tendon, femur).

The Crew Health Care System aboard the International Space Station will be equipped to provide immediate emergency care for the purpose of patient stabilization and emergency return to Earth using an escape vehicle.[16] The power requirements and weight associated with radiologic capability prevent this modality from being flown on the International Space Station. The Human Research Facility is a payload in the International Space Station laboratory module, which will have ultrasound capabilities for research, and possibly operational use by the crew medical officer during medical contingencies. The risk of orthopedic injury as the result of kinetic impacts from large structures and payloads during the construction phase of the space station make diagnostic imaging highly desirable. The clinical presentation of orthopedic injury in space to a nonphysician crew medical officer in an environment with significant background distractions may prevent the proper diagnosis of soft tissue injury.

There is a paucity of information regarding the use of ultrasound in the diagnosis of soft tissue and orthopedic injuries.[4] Detailed anatomic information of the extremities can be obtained with ultrasound and correlated to pathologic conditions including orthopedic injuries. Swelling and hematoma formation are often present that aid the diagnosis (R. Claybrooks, unpublished data). The bone–soft tissue interface has a very large acoustic impedance, causing almost total reflectance of the acoustic waves.[10] This high reflectance can be used to visualize contour imperfections such as steps and breaks in the bony cortex associated with fractures and discontinuities in muscles or tendons associated with rupture.[17,18]

The use of ultrasound with high-frequency probes (6–10 MHz) to detect orthopedic injuries appears to be a reliable technique. Katz et al. described a series of clavicular fractures in newborn babies, and found no substantial differences in the detection rates between ultrasound and radiographic examinations.[6] A similar technique was used by Wang et al. to detect radiographically occult fractures in patients with foot and ankle injuries whose initial radiographs had been deemed normal by clinicians or radiologists.[7]

This prospective, blinded evaluation demonstrates that orthopedic injury can be reliably diagnosed on-site by nonphysician personnel after a brief training period. Extremity ultrasound had an overall accuracy of 94% in all patients; however, there were anatomic differences in sensitivity noted. Upper extremity fractures were readily diagnosed because of the favorable anatomic location of the bony structures in relation to the subcutaneous tissues. There was one false-negative examination in a patient with a distal ulnar styloid fracture that was not appreciated by the ultrasonographer. In retrospect, reviews of the ultrasound recordings by the principal investigator (S.A.D.) demonstrate the fracture site in the distal ulna at the limit of the scan. Diagnosis of tibia and fibular fractures was similarly accurate, with the exception of fractures that involved the joint space and could be confused with normal anatomic structures such as the joint plate or articular cartilage. Proximal hip or femoral fractures were challenging to visualize because of the large amount of soft tissue coverage in this area and lack of simple ultrasonic windows in this location. Quadriceps tendon injuries, including incomplete rupture, were readily visualized by ultrasound and correlated with the operative findings. Edema was often apparent in the injured extremity and did not affect diagnostic accuracy; rather, the presence of tissue swelling served as a marker of more severe injury. Fortunately, we did not encounter air in the tissue planes in any of the study patients. Subcutaneous air has been shown to significantly reduce the diagnostic accuracy of ultrasound in abdominal and thoracic applications and would limit the utility of the examination.[19]

Fractures that involved the joint space or small avulsion injuries were difficult to visualize. The ultrasonic images of the foot and hand were not optimal because of the size and configuration of the linear probe, which was difficult to oppose to the irregular surface of the tissues. Finally, the maximal ultrasonic field depth was 7 cm with the high-frequency probe used in these trials. Diagnostic images of the proximal femur were challenging to obtain because of the thickness of the soft tissues overlying the fracture site in some patients.

The use of this portable device facilitates expeditious orthopedic investigations, especially in unstable individuals who cannot be transported to the radiography suite, and avoids exposure of the team and patient to radiation. This technique can be expanded to locations where radiography is unavailable such as military conflicts, rural medicine, and space medical applications. There is a risk of orthopedic injury during the construction phase of the International Space Station because of potential kinetic impacts from large equipment or the spacecraft bulkhead.[14,15] Use of a small, robust ultrasound device such as this may allow on-orbit verification of an orthopedic injury to guide treatment decisions.[20]

There are key technical points of orthopedic ultrasound that deserve mention. First, there is general consensus that high-frequency transducers are required for optimal images. Dynamic scanning is optimal for evaluating cortical integrity at the point of maximal tenderness and for gauging soft tissue swelling. These findings are often not apparent on static imaging. Scanning should begin in the contralateral, uninjured extremity to familiarize the operator with normal bony landmarks. Probe placement and ultrasound settings are maximized by visualizing the echogenic line of the bone cortex longitudinally and confirming the cross-section of the bone in transverse section. After the depth of field and sensitivity of the transducer are adjusted, the injured extremity is evaluated for soft tissue changes or breaks in the continuity of the cortex consistent with fracture.

Orthopedic ultrasound for the detection of fractures or tendon disruption is a clinically attractive modality that can be readily learned. The bony anatomy is easily visualized with a high-frequency probe and can be rapidly verified in the normal contralateral extremity. The scan can be concomitantly accomplished as other therapeutic maneuvers are performed and has a sensitivity that approaches radiography in midshaft locations. The ultrasound diagnosis of fractures in close proximity to joint spaces or in distal locations requires additional interpretive experience. We recently reported that ultrasound of the lung was an effective method for evaluating the respiratory system to exclude pneumothorax.[19] The further expansion of ultrasound, mandated by requirements of the space program, suggest that trauma ultrasonographic evaluation could be added to the abdominal FAST examination (the FASTER examination: focused abdominal sonography trauma extremity respiratory). The verification of orthopedic ultrasound, coupled to newer, portable ultrasound equipment, may allow expanded application of ultrasound in clinical situations where radiography is difficult or impossible.

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EDITORIAL COMMENT

Surgeons continue to use ultrasound as a diagnostic modality to successfully evaluate patients with acute surgical problems. In this study, ultrasound detected fractures in the extremities of injured patients, which may be particularly useful in situations where radiographic resources are unavailable. Although the authors proved their hypothesis, the most valuable part of this investigation is the education of surgeons in the use of specific ultrasound physics principles. For example, the authors used a high-frequency linear transducer to detect the disruption in the cortical reflex, that is, the fracture. The transducer is different from the lower frequency (3.5 MHz) curvilinear transducer that surgeons are accustomed to using for the detection of hemoperitoneum, hemopericardium, and hemothorax. Furthermore, the authors highlight the principle of tissue acoustic impedance (defined as the density of tissue times the speed of sound through that tissue). Bone has a widely different tissue acoustic impedance than soft tissue, thereby allowing visualization of the fracture.

Investigations such as this one continue to underscore not only how important it is for surgeons to use ultrasound in the evaluation of the injured patient, but also emphasize the importance of the principles of ultrasound imaging. The more we learn these principles and appropriately apply them to imaging our patients, the more we will enhance our credibility in the field of ultrasound imaging.

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