

Resuscitative Long-Bone Sonography for the Clinician: Usefulness and Pitfalls of Focused Clinical Ultrasound to Detect Long-Bone Fractures During Trauma Resuscitation

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Abstract

Bone has one of the highest acoustic densities (AD) in the human body. Traditionally, bone has been considered to be a hindrance to the use of ultrasound (US), as US waves are reflected by the dense matrix and obscure underlying structures. The intense wave reflection, however, can clearly illustrate the cortical bony anatomy of long bones, making cortical disruption obvious. Ultrasound can be used at the bedside concurrently with the overall trauma resuscitation, and may potentially limit the patient's and treating team's exposure to ionizing radiation, corroborate clinical findings, and augment procedural success. The extended focused assessment with sonography for trauma (EFAST) is an essential tool in the resuscitation of severe torso trauma, frequently demonstrating intra-pericardial and intra-peritoneal fluid, inferring hemo/pneumothoraces, and demonstrating cardiac function. Although it is typically considered as a diagnosis of exclusion, multiple long-bone fractures may be a source of shock and can be quickly confirmed at the bedside with EFAST. Further, the early detection of long-bone fractures can also aid in the early sta-

bilization of severely injured patients. Sonographic evaluation for long-bone fractures may be particularly useful in austere environments where other imaging modalities are limited, such as in the battlefield, developing world, and space. While prospective study has been limited, selected series have demonstrated high accuracy among both physician and para-medical clinicians in detecting long-bone fractures. Pitfalls in this technique include reduced accuracy with the small bones of the hands and feet, as well as great reliance on user experience.

Key Words

Resuscitation · Ultrasound · Fracture · Critical care · Bone

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Introduction

Ultrasound (US) is one of the most widely used diagnostic imaging modalities throughout the world. It is

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also a technology that lies in the spectrum between physical examination and medical imaging. While clinical users typically do not have the comprehensive experience of dedicated technicians, they bring an overall appreciation and responsibility for the patient's immediate condition to the bedside. As a result of this point-of-care use, US allows the real-time confirmation and documentation of critical pathophysiology. Furthermore, US is a safe, painless, repeatable modality whose scope encompasses a near-limitless array of medical and surgical conditions. In trauma, numerous investigators have highlighted the accuracy of US in detecting thoracoabdominal injuries, to the point where US is considered as an essential clinical tool in trauma resuscitation guidelines [1–4]. In addition to traditional cart-based US systems, reliable and more versatile hand-held units are also becoming increasingly available to aid the clinician in a variety of challenging settings [5]. Ultrasound can, thus, be brought to the bedside to immediately confirm or refute clinical diagnoses, as well as to aid in the safer performance of invasive procedures [6].

A focused examination of the pericardium and dependant intra-peritoneal sites constitutes the focused assessment with sonography for trauma (FAST) [7]. Along with others who have suggested nomenclature to describe more ambitious yet standardized resuscitative algorithms, we introduced the extended FAST (EFAST), which is an additional thoracic examination to quickly provide information regarding the presence of hemo/pneumothoraces [8–10]. Dulchavsky et al. [11] have subsequently described the FASTER examination as the further addition of extremity US to this approach, aimed at improving overall trauma diagnosis in challenging environments.

This approach appears to be justified from the standpoint that US shows great promise as a diagnostic imaging tool in fracture detection. The use of this portable device facilitates expeditious orthopedic investigations, especially in unstable individuals who cannot be transported to the radiography suite. It also avoids exposing both the team and the patient to radiation [11]. The non-invasive nature of this technique, the ability to view the fracture from multiple planes, and to assess the fracture in the context of other life-threatening pathophysiology all justify the increased attention to this modality. Ultrasound can be utilized in locations where the ability to obtain a traditional radiograph may not be available or in situations where remote care is performed, such as military encounters, rural medicine, and aerospace applications [11–13]. The medical needs of operational medicine

such as in space and military conflict, have, in particular, stimulated the investigation and discussion of bone US [11, 14–16]. The placement of a cast or other immobilization device and the subsequent long-term incapacitation in the field or during space-flight microgravity poses additional technical demands, as well as having a significant impact on the ability to continue duties or missions [11, 17, 18].

Physical Principles

Historically, the high acoustic densities (AD) of bone has been considered to be a liability. The bone–soft tissue interface has very large acoustic impedance, causing almost total reflectance of the acoustic waves, and a dorsal acoustic shadow typically precluding meaningful imaging deep to bone [11, 15, 19]. By understanding these basic physical principles, a clinician can use US to diagnose and manage long-bone fractures, as well as minimize the interference of bone in interrogating the viscera. In the past, the reflection of US waves by the highly calcified cortex of the long bones was considered as one of the limitations of pursuing US study. However, this high wave reflection is now considered as the key point for diagnosing fractures (Figures 1, 2). This reflection can be used to simply and quickly visualize contour imperfections such as steps and breaks in the bony cortex associated with fractures, as well as discontinuities in muscles or tendons associated with rupture. Additionally, US can aid procedural guidance, such as the location of anechoic fluid collections for the proper placement of

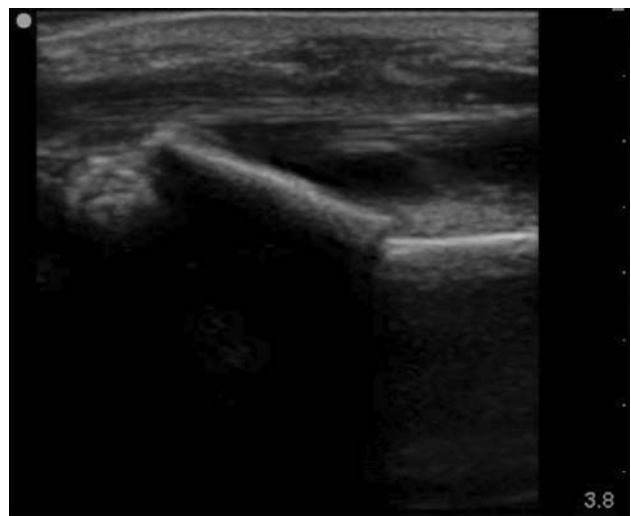


Figure 1. Ultrasound (US) imaging of fractured mid-shaft radius with dislocation.

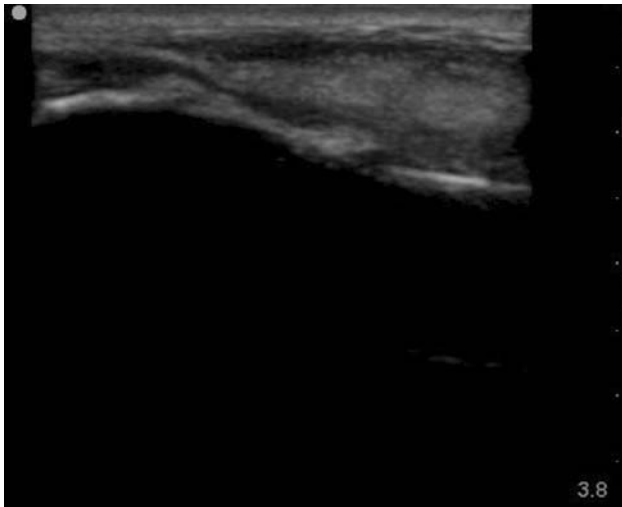


Figure 2. Same patient after fracture reduction.

anesthesia for a hematoma block and dynamic movement of the wave reflection in real-time fracture reduction [15, 20, 21]. The bony anatomy of long bones is easily visualized with a high-frequency linear array probe of at least 7.5 MHz or higher, as long as the overlying soft tissue is not excessive. Linear transducers have an appropriate footprint to produce a reliable demonstration of cortical discontinuities. In an experimental cadaveric bone study, Grechenig et al. were able to detect cortical discontinuities of 1 mm and larger [19]. They also described the direct US signs of fracture as being cortical discontinuities, step-offs in the cortex, and kinking of the bony axis, along with indirect signs such as distal bands of echo in the region of the fracture [19]. In detecting occult pediatric fractures, Simanovsky et al. [22] sought obvious breaks in the echogenic cortical line, cortical depressions, echogenic fragments adjacent to the cortex, periosteal elevations, and subtle periosteal fluid collections.

Scanning Technique

The US examination can be initially conducted with the transducer placed longitudinally to evaluate cortical integrity. At least two longitudinal planes should be scanned, although an original description by Hübner et al. reported scanning in four longitudinal planes with transverse scans obtained as appropriate [23–25]. The cortex of the bone is seen as a homogenous, bright reflection of echoes with dorsal acoustic shadowing. False-positive results can be produced by scanning the fracture parallel to its line; therefore, a transverse scan by turning the probe 90° to the area of probable injury

should be performed to confirm the diagnosis. Finally, when time permits, the contra-lateral extremity should be carefully examined to both to detect injuries as well as to provide a normal control when uninjured. The clinician should attempt to detect an obvious cortical disruption, as this is the most reliable sign confirming a bony fracture, but other abnormalities should also be noted, including steps, axial deviations, periosteal lesions, hematomas, fluid collections, or any other soft-tissue changes [23]. The reported experience claims that there is no added distress or pain to the victim if care is taken by the examiner and US coupling gel is liberally applied [16, 23].

Reported Experience

While there is sparse reported experience with resuscitative bone US, clinicians are appreciating the utility of this approach in many areas of emergency care. A number of studies have described high overall accuracy rates in diagnosing pediatric long-bone fractures. Further, Hübner et al. [23] note that the cartilaginous nature of the pediatric joint and musculoskeletal system may actually make US a superior imaging modality compared to radiography. They examined 163 children with 224 suspected fractures and found that US delivered the highest (> 89%) accuracy for femoral and humeral diaphyseal fractures, as well as for the forearm injuries [23]. Fractures of the small bones of the hands and feet were less dependably identified however [23]. Patel et al. [26] reported on the usefulness of bedside US in detecting fractures, the need for reduction, and the adequacy of reduction in children, which was comparable to the results of conventional radiography. Williamson et al. [27] reported using modestly high frequency (6–10 MHz) probes to detect pediatric forearm fractures, while Chen et al. reported 97% sensitivity and 100% specificity for similar pediatric fractures [25]. Finally, Katz et al. [28] reported that there is no significant difference between the detection of newborn pediatric fractures with either US or radiography.

Although this technique is very promising, there has been less published experience in adults. Wang et al. [24] reported a series of foot fractures in which 9% of patients with radiographs interpreted as normal had fractures of the foot and ankle demonstrated by US. Marshburn et al. [16] used a relatively low frequency 5-MHz non-linear transducer and a first-generation hand-carried US machine to examine suspected humerus and femur injuries. They noted a higher sensitivity but lower specificity compared to

physical examination for fractures at these locations, with an overall 93% accuracy and a 100% accuracy for humeral fractures. The sensitivity of US in fracture detection can vary based on the anatomical area examined. Upper extremity fractures are easier to diagnose because of the favorable anatomic location of the bony structures in relation to the subcutaneous tissues [11]. Unfortunately, none of these reports focused on evaluating US during the setting of actual trauma resuscitation for the multiply injured patient.

After diagnosing long-bone fractures, reduction is required to stabilize the patient and prevent further ongoing bleeding. Adequate pain control for reduction has always been a challenging task for clinicians, where generous sedation and intravenous analgesia are often required. The hematoma block however, is an effective alternative and safe means to provide analgesia for the reduction of fractures [29]. Crystal et al. [30] reported their experience on using US-guided hematoma block for successful closed reduction. This has been well tolerated by patients, without the need for sedation or intravenous analgesia. In adults and children, hematoma can be identified as a hypoechoic fluid collection anterior to the fracture site. This area serves as a landmark for dynamic hematoma block. A needle containing anesthetic can be tracked using US to the area of the fracture, and then injected into the fracture to provide adequate anesthesia in a hematoma block. Additionally, US can be used in real time to observe dynamic reduction of the bony fracture. Observation of the hyperechoic cortical line into a normal anatomic position during a reduction procedure may assist in fracture reduction.

The portable and non-ionizing nature of US makes it an ideal tool to guide bony reductions in real time. This allows the reductions to be performed at the bedside, often with children being restrained by parents, avoiding the need to transport sedated or distraught children to a fluoroscopy suite [25]. A number of groups have subsequently noted greater than 90% success rates with US-guided anatomic reduction of forearm fractures [25, 31]. This practice has gained wider acceptance among pediatric practitioners, but it need not be a practice limited to children. Besides confirming anatomic reduction, US may also be able to infer cases where difficulties may be anticipated. Soft-tissue interposition can prevent successful closed reduction and impedes or delays the union of fractures. US has been used for the early diagnosis of soft-tissue interposition in fracture lines [32]. The sensitivity and specificity for the detection of soft-tissue interposition impeding reduction was reported as being 96.9 and

86.3%, respectively [33]. US can, therefore, inform the clinician as to whether failure of the closed reduction is secondary to soft-tissue interposition, in which surgical intervention is mandatory, or other causes, in which nonsurgical methods can be applied [33].

Suggested Integration with the Overall Resuscitation Sequence

The Advanced Trauma Life Support Course remains the most important series of guidelines for the management of critically injured patients worldwide. It emphasizes treating the greatest threat to life first, but further acknowledges that musculoskeletal injuries occur in at least 85% of bluntly injured patients [34]. The elegance of resuscitative bone US, thus, relates to the fact that the US tool can be used for the preceding focused examination of airway, respiratory, circulatory, and neurological systems, before being used to assess for major bony injury [4]. Critical steps in assessing these systems often involve bony pathology. Although US has been trialled in the laboratory in the process of surface matching for pelvic surgery, we are unaware of its current use in acute pelvic fracture detection [35]. Nonetheless, pelvic fracture-related bleeding has recently been proposed as the leading cause of preventable hemorrhagic trauma death following blunt trauma [36]. Although a controversial concept [37], we believe that a truly determinate (not indeterminate) FAST examination directs the search away from the peritoneal cavity and justifies earlier angiographic intervention with known serious pelvic fractures [38]. Fractures of long bones can easily be the cause for ongoing hemorrhagic shock, usually due to the associated bleeding and neurovascular compromise, which can cause substantial morbidity for trauma patients. Therefore, early identification is likely to effect immediate treatment to stabilize the patient. This early examination would logically consist of screening limbs suspected to harbor bony fractures based on physical examination. Such early identification of long-bone fractures may hasten the identification of compartment syndromes, avoiding consequent rhabdomyolysis and renal failure, and early stabilization, which may help to decrease the incidence of fat emboli and consequent respiratory failure, and, finally, recognizing that the missed injury often becomes the most important injury after life-threatening events are corrected and forgotten. The portability of US helps facilitate a detailed head-to-toe imaging after cardiorespiratory stability has been assured, no matter where the patient is physically located and concurrently to other ongoing care. This phase of the sec-

ondary survey would be much more detailed than the early phase, focusing on subtle findings.

Pitfalls

Like all US techniques, the performance of the examination is operator-dependant. As a result, obtaining useful information relies on generating a meaningful image, as well as correctly interpreting the image in the clinical context. Even obvious fractures with diastases may not be apparent when the transducer is parallel to the fracture line, mandating that multiple views be obtained [19]. Overall, the technique has been less dependable for fractures adjacent to joints and the small bones of the wrists, hands, and feet [23]. Marshburn et al. [16] noted that all diagnostic errors in their study were related to fractures near the hip and above the intertrochanteric line, as well as the fact that all false-negative examinations (the most common diagnostic error) occurred in patients older than 60 years of age. Further, they advised that, based on their experience with an elderly trauma population (mean age 79 years), that the presence of bony cortical irregularities (e.g., degenerative joint disease) scatters the US signal, interfering with correct interpretation. Grechenig et al. described numerous artifacts that can be generated by pathologic bone, including reverberation artifacts, ring down, curved, acoustic shadow, or pseudo-lesions, all of which may interfere with correct interpretation [19].

Future Directions

While diagnosing diaphyseal fractures of the appendicular skeleton is not a particularly difficult exami-

nation for experienced sonographers, training is still required. This education, along with constant practice and critique, is the ideal manner for clinicians to gain confidence [39]. In settings where less experienced clinicians are required to make diagnoses and triage decisions, work is continuing on both tele-robotic US systems to remove the human element [40] and/or tele-mentoring techniques to enhance the human element



Figure 3. Visual inspection and gentle palpation reveal uncertainty regarding the bony status of the bilateral patella after a motor vehicle crash.

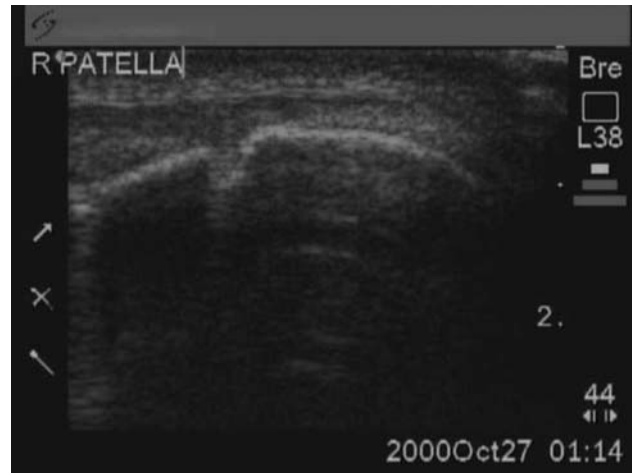


Figure 4. Bedside hand-carried US image demonstrating cortical disruption of the right patella.



Figure 5. Subsequent radiographs of the right patella confirming fractured right patella.

[41]. Given the dramatic differences in acoustic impedance illustrated by cortical bone, it is also conceivable that auto-detection informatics might soon be able to autonomously diagnose fractures in extreme operational settings.

Returning to basic principles of good clinical care, it has long been noted that missed injuries after trauma are most frequently musculoskeletal (50–75%), with the extremities being the most common site of fractures [42, 43]. These missed injuries become more common in the more seriously injured and unconscious victim [43]. Such alarming frequencies of missed injuries may be reduced through a methodical and thorough tertiary examination [44, 45] (Figures 3, 4, 5). As a result, we plan to investigate the utility of enhancing the tertiary survey through the liberal addition of bedside bone US in the near future.

Conclusions

In addition to its numerous other uses, ultrasound (US) provides a convenient bedside screening tool to confirm and document long-bone fractures as a potential cause of ongoing shock and future morbidity. With wider appreciation, US may play a major role in guiding care providers in the detection and early reduction of fractures causing hemodynamic instability, thus, having a major impact on the overall outcomes in the severely injured. As bone US becomes a practical tool, we can only note that generations of orthopedic surgeons, previously ridiculed by their more cerebral colleagues, have now been vindicated. The stethoscope of the 21st century actually CAN hear bone.

Conflict of interest statement

The authors declare that there is no actual or potential conflict of interest in relation to this article.

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