Ultrasonography of fractures in sports medicine

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ABSTRACT
High-resolution ultrasound is emerging as an important imaging modality in fracture assessment due to its availability, ease of use and multiplanar capabilities. Its usefulness includes injury assessment for the presence of a fracture when obtaining radiographs is not immediately available, detecting occult fractures not revealed on radiographs, and diagnosing bone stress injury before radiographic changes. Sonographic evaluation of bone, however, has limitations and should always be coupled with radiographs and possibly advanced imaging modalities such as CT and MR when clinically indicated.

INTRODUCTION
Acute fractures as well as stress fractures are common sports injuries. 1–4 Plain radiographs remain the mainstay for the evaluation of bone injury but can be limited by their availability and two-dimensional assessment of bone. For suspected acute bone injury, advanced imaging modalities such as CT and MR are often utilised when plain radiographs are normal or when a more detailed evaluation of the fracture pattern is required for optimal treatment planning. In cases where a stress fracture is suspected but radiographs are normal, MR can provide a definitive diagnosis. These advanced imaging modalities can also be limited by cost and availability; CT uses ionising radiation.

High-resolution ultrasound (US) has become a routine part of many sports medicine physicians' practices. US is commonly available in the sports medicine physician’s office as well as in the athletic training room. Thus, US is an option in the initial assessment of bone injury, particularly when plain radiography is not immediately available or is inconclusive.

While US has limitations on assessment of bone injury it does offer advantages in its accessibility and multiplanar imaging that can often reveal a fracture that standard radiographs may miss. These advantages have allowed utilisation of US in several ways: (1) sideline or immediate assessment of bone injury when radiography is not available; (2) evaluation for fractures that are often radiographically occult; (3) discovery of unsuspected fractures during the standard sonographic examination; (4) detection of signs of stress fractures before they become apparent on standard radiographs.

This narrative review introduces the reader to ultrasonography assessment of bone injury in the sports medicine setting.

Ultrasonography of normal bone and acute fractures
The cortex of bone is highly echogenic due to the high acoustic impedance mismatch between bone and the surrounding soft tissue. 5 Cortical bone appears as a bright hypechoic smooth line with posterior acoustic shadowing and reverberation artefact as seen in figure 1. 6 The brightness and detail of cortical bone is greatest when the US transducer is oriented perpendicular to bone. However, epiphyseal bone or bones with irregular contour often requires the US beam to be oblique to the bone cortex and this may result in loss of sonographic detail. Thus, these areas of bone may present a greater challenge when evaluating for a fracture (figure 1). Because of the high acoustic impedance of the cortex, structures deeper within bone are not assessable by US. MRI is needed to demonstrate intraosseous pathology such as bone oedema—characteristic of a stress reaction or bone contusion.

Ultrasonography is particularly suited for the evaluation of fractures in areas of bone that are linear, such as the diaphyseal and metaphyseal regions of long bones. Fractures in these regions appear as an interruption of the smooth cortical surface and are often accompanied by periosteal...
Figure 2  Acute mid-shaft ulna fracture. (A) Long-axis and (C) short-axis sonogram of an acute mid-shaft ulna fracture. The fracture is characterised by cortical interruption (white arrowhead) with periosteal thickening (black arrowheads). (B) Long-axis sonogram with Doppler imaging showing vascularity within the thickened periosteum as well as the surrounding soft tissue. (D) Corresponding anteroposterior radiograph.

Figure 3  Acute finger fracture. (A) Long-axis sonogram and (B) with Doppler imaging of a 3-day-old proximal phalanx fracture of the index finger. The fracture line is visualised as an interruption of the smooth bone cortex. A small fragment is present at the base of the proximal phalanx (arrow). Note the hypoechoic periosteal thickening associated with mild hyperaemia (arrowheads) as well as relative hyperechogenicity of surrounding soft-tissue due to oedema (asterisk). (C and D) Corresponding lateral and anteroposterior radiographs which provide a better panoramic view of the fracture pattern compared to the ultrasound images in this case.

Figure 4  Bone callus formation. (A) Long-axis sonogram with (B) corresponding radiograph of a 13-day-old fifth finger proximal phalanx fracture in a 12-year-old. Attempt at a closed reduction in the office setting was unsuccessful. Ultrasound shows early bridging callus formation (arrowheads) not visualised on radiographs. (C) Long-axis and (D) short-axis sonogram of a 6-week-old rib fracture undetected on initial radiographs showing callus formation (arrowheads).
thickening and hyperaemia and surrounding soft tissue oedema. In subacute fracture, US reveals early callus formation. In addition, ultrasonography can potentially assess the fracture alignment, although the panoramic view that radiographs offer provides a much better assessment of the fracture pattern (figures 2–4).

When utilising US to assess for bone injury it is important to be familiar with other types of bony irregularities that may mimic pathology (box 1). These changes in the cortical bone are distinguished from fractures by the history, absence of accompanying signs of injury and correlation with corresponding radiographs. In addition, the absence of significant pain with sonopalpation (ie, pressure of the site of examination with the US transducer) over a suspected location of injury also helps determine whether changes in the bone surface represent a bone injury (figure 5).

### Box 1 Cortical irregularities that may mimic a fracture line

- Nutrient vessels
- Physeal plates
- Cortical erosions
- Posterior acoustic shadowing from sesamoid bones, ossicles or calcifications
- Postsurgical changes
  - Hardware
  - Bone tunnels for suture anchors
  - Bone reshaping or partial excision

Long bone fractures

Ultrasoundography has a relatively high sensitivity and specificity to detect fractures, particularly when the fracture occurs along a flat area of bone, such as a long bone diaphysis or metaphysis (figure 6). Additionally, these regions of bone typically occur close to skin, further facilitating close scrutiny with sonographic examination. Table 1 summarises studies of fracture diagnosis by US. In particular, the study by Waterbrook et al evaluated 147 suspected long bone fractures with a sensitivity and specificity of 90% and 96%, respectively. The authors also concluded that US was most accurate when the fracture occurred within the diaphyseal or metaphyseal region with less accuracy when the fractures were located within the epiphyseal region.

Ultrasonography is particularly useful for the detection of rib fractures. Radiographs of rib fractures may not reveal non-displaced fractures because of the presence of other thoracic structures. CT scanning is a sensitive alternative but has the drawback of significant ionising radiation. US has the advantage that the transducer can be oriented along the long and short axis of the rib as it changes anatomic planes during its course along the chest wall. A fracture appears as a gap, step off or displacement of the rib cortex, and may be associated with a localised haematoma or soft tissue swelling.

**Figure 5** Normal bone surface irregularities. (A) long-axis sonogram with (B) Doppler imaging of the anterior mid-tibia showing a cortical interruption due to nutrient vessels. The lack of other signs of injury, the presence of a single artery and vein and no pain with transducer pressure distinguish nutrient vessels from a fracture. (C) Long-axis sonogram of a normal distal fibular physis (left is proximal, asterisk is epiphysis). Note the bony irregularity at the physeal region giving the appearance of bone fragmentation. Arrowhead is perichondral ring.

**Figure 6** Fourth metacarpal fracture. (A) Normal radiographs in a patient with post-traumatic pain at the fourth metacarpal phalangeal joint. (B) Long-axis sonogram with (C) Doppler imaging of the dorsal aspect of the distal fourth metacarpal showing a minimally displaced fracture (arrow). Note the periosteal thickening (black arrowheads) and vascularity within the periosteum (white arrowheads).
Beltrame et al.\textsuperscript{22} showed a 100% concordance between US and plain radiographs in 11 patients with rib fractures. Similarly, a study by Weinberg et al.\textsuperscript{12} revealed a sensitivity and specificity of 100 and 89%, respectively, for the diagnosis of rib fractures, a result superior to those obtained for most of the other types of fractures detected in their study. Thus, ultrasonography should be considered the test of choice when the clinical picture suggests the possibility of a rib fracture and radiographs are normal (figure 7).

Another advantage of US is its capability for dynamic examinations. This can be useful when assessing for the presence of a fracture non-union by demonstrating motion between the two fracture fragments with either passive or active motion at the fracture site (figure 8).

Paediatric fractures
Plain radiography remains the gold standard for the diagnosis and characterisation of physeal fractures. However, US may be particularly useful in situations in which there is a high suspicion of a physeal fracture but radiographs are normal, such as a non-displaced Salter-Harris type 1 or 2 fracture. Sonographic findings of a non-displaced physeal injury include thickening of the perichondral ring associated with oedema and hyperaemia, widening of the physis, cortical interruption and bony fragments at the physis. Often, comparison with the contralateral side can help distinguish a normal physis from that of a non-displaced fracture (figure 9).

Indirect signs of a fracture may help identify elbow fractures in the paediatric population. For example, in one study ultrasonographic identification of an elevated olecranon fat pad or lipohemarthrosis resulted a sensitivity of 98% whereas the absence of these signs resulted in a negative predictive value of 98%.\textsuperscript{14} Non-long bone fractures
Fractures in irregularly shaped bones, such as the wrist or foot, can be difficult to image, both by plain radiography and US. Of particular interest is fracture of the carpal scaphoid.\textsuperscript{13, 23, 24} When a scaphoid fracture is suspected clinically but radiographs are negative, CT or MR is often utilised to definitively diagnose the presence of a fracture.

US can be used to detect a scaphoid fracture after wrist trauma. In a study of acute wrist trauma that had negative radiographs the authors identified 12 of 13 scaphoid fractures.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Summary of studies utilising ultrasound in fracture diagnosis</th>
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<tr>
<td>Reference</td>
<td>Number of bones imaged</td>
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<tr>
<td>Barata et al\textsuperscript{7}</td>
<td>98</td>
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<tr>
<td>Waterbrook et al\textsuperscript{8}</td>
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<td>Eckert et al\textsuperscript{9}</td>
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<td>Bolandparvaz et al\textsuperscript{10}</td>
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<td>Neri et al\textsuperscript{11}</td>
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<td>Weinberg et al\textsuperscript{12}</td>
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<td>Yesilarslan et al\textsuperscript{13}</td>
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<td>Canagasabey et al\textsuperscript{19}</td>
<td>110</td>
</tr>
<tr>
<td>Chaar-Alvarez et al\textsuperscript{20}</td>
<td>101</td>
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Sens, sensitivity; spec, specificity.
(utilising CT as the gold standard) while also finding a 97% negative predictive value. Interestingly, this study also identified an occult fracture other than a scaphoid fracture in 11% of the patients studied. Thus, US is a useful imaging choice in assessing for scaphoid and other occult wrist fractures in the appropriate clinical setting when there are negative radiographs (figures 10 and 11). When a careful US examination of the wrist is performed in this situation it would be reasonable to following the patients clinically since several studies have found a very high negative predictive value. Conversely, when a fracture is suggested sonographically, a CT or MR is appropriate.

Ultrasonography has very good concordance with radiographs for detecting fractures after foot or ankle trauma (figure 12). Additionally, there have been numerous case reports describing the detection of non-long bone type fractures with US (figures 13 and 14). They suggest that ultrasonography is a useful adjunct to radiography when a non-long bone fracture is suspected.

As US machines become more commonplace in the athletic training room and/or the sidelines of a sporting event, US can be useful in identifying a fracture even before the player has access to plain radiography and thus determine playability (figure 15).

Figure 8 Second metatarsal non-union. (A and B) Long-axis sonogram of the proximal second metatarsal (proximal is right) while in foot dorsiflexion (A) and plantar flexion (B) showing cortical-type bone between the fracture ends (asterisk) and widening of the fracture space with plantar flexion as compared to dorsiflexion (dotted lines) consistent with a non-union. Corresponding radiograph (C) revealing chronic stress injury to the base of the second through fourth metatarsals, a healed fourth metatarsal stress fracture and screw fixation of a previous fifth metatarsal fracture.

Figure 9 Salter-Harris fracture of the distal fibula. (A) Long-axis sonogram of the distal fibula (proximal is left) with (B) normal contralateral side. There is bone fragmentation within the physis (arrow) and thickening of the perichondral ring consistent with a Salter Harris type 2 injury. Pain with sonopalpation over the physis also confirmed the presence of a physeal injury. (C) Corresponding radiograph. Asterisk is epiphysis.
**Figure 10** Fracture of the tubercle of the scaphoid. (A) Long-axis sonogram over the palmar aspect of the scaphoid (Sc) (right is proximal) and (B) short-axis sonogram shows a fracture (black arrowheads). Radiographs prior to the ultrasound were normal. White arrowhead is flexor carpi radialis tendon.

**Figure 11** Fracture of the base of the hook of the hamate. (A) Short-axis sonogram obtained over the medial aspect of the wrist at the level of the hamate shows a fracture (arrowhead) between the body of the hamate (large black arrow) and hook of the hamate (small black arrowhead). (B) Corresponding three-dimensional CT scan.

**Figure 12** Acute distal fibular fracture. (A) Long-axis sonogram with (C) Doppler imaging of a 14-year-old with a 4-day-old distal fibular fracture. Note the slightly widened fracture line with intervening fluid or haematoma (arrow), a thickened periosteum (white arrowheads), and surrounding oedema (black arrowheads). Doppler imaging (C) shows hyperaemia within the fracture line, periosteum, and surrounding soft tissue. (B and D) Corresponding radiographs.
Detection of an unsuspected fracture during the routine US examination

US examination of a joint or region is often performed for persistent undiagnosed pain after an injury. The physician/ultrasonographer should remain alert for the possibility of a fracture as reports have described the detection of an unsuspected fracture during the routine US examination of the wrist, ankle and foot (figure 16). Characteristic of these areas are multiple small bones and joints with complex shapes in which fractures may be difficult to detect by standard radiography. Thus, careful scrutiny of the bone surfaces should be a routine part of ultrasonographic examination of these areas particularly when a history of trauma is present (figure 17).

The shoulder region is another area in which fractures may go undetected with standard radiography. Fractures of the greater tuberosity, scapula, and coracoid process have been detected by routine sonographic examination in patients with persistent shoulder pain after a traumatic event. US imaging of stress fractures

Bone stress injuries are common in sports medicine and can be difficult to diagnose. Radiographs are the mainstay in the initial evaluation of a suspected bone stress injury. However, in the early phases of injury, radiographs are often normal. Some stress fractures, such as those of the mid-foot, may only show radiographic changes during the later part of the healing process, if at all. Typically, when a bone stress injury is suspected and initial radiographs are normal, MRI or bone scintigraphy is required for definitive diagnosis. However, there is increasing experience with ultrasonography in revealing changes associated with early bone stress injury. Furthermore, US has the advantage of immediate availability in some cases and ease of use when compared with other imaging modalities. It is important to emphasise that US should be used in conjunction with radiographs, and when indicated MR, in the evaluation of suspected bone stress injury.

The earliest sonographic findings of a stress reaction or fracture are hypoechogenic periosteal elevation and hypervascularity (figure 18). It is presumed that these changes correspond...
clinically to the onset of pain although there have been no studies to support this correlation. As the injury progresses there are a variety of sonographic findings that include: (1) a fracture line viewed sonographically as a disruption of the smooth bony cortex; (2) cortical irregularity or thickening; (3) hyperechogenicity of surrounding soft tissue due to oedema. Sonopalpation will also confirm localised tenderness at the location of bony pathology (Figure 19).

US may also visualise callus formation, often before standard radiographs. While follow-up US can confirm the presence of healing it does not predict the ability of an athlete to return to activity and the clinician must rely on the usual clinical parameters to determine return to sport or activity.

SUMMARY

High-resolution US is emerging as an important imaging modality in fracture assessment due to its sideline and office availability, ease of use, and multiplanar capabilities. Its usefulness includes injury assessment for the presence of a fracture when obtaining radiographs is not immediately available, detecting occult fractures not revealed on radiographs, and diagnosing bone stress injury before radiographic changes. Sonographic
evaluation of bone, however, has limitations and should always be coupled with radiographs and possibly advanced imaging modalities such as CT and MR when clinically indicated.

Summary points

- Ultrasoundography is useful for the immediate assessment of bone injury, particularly when radiographs are not available.
- For acute injuries, ultrasoundography may detect fractures that are radiographically occult.
- Ultrasoundography has been shown to detect unsuspected fractures during the standard examination of a joint or region of the body.
- Ultrasoundography is useful for the detection of stress fractures before radiographic changes are present.

Acknowledgements Figure 15 courtesy of Dr Robert Monaco.

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REFERENCES


