Ultrasonography of fractures in sports medicine

Douglas F Hoffman,[1] Erik Adams,[2] Stefano Bianchi[3]

[1]Department of Orthopedics and Radiology, Essentia Health, Duluth, Minnesota, USA
[2]Midwest Sports Medicine Institute, Middleton, Wisconsin, USA
[3]CIM SA, Cabinet Imagerie Médicale, Genève, Switzerland

Correspondence to
Dr Douglas F Hoffman, Department of Orthopedics and Radiology, Essentia Health, 400 E. Third Street, Duluth, MN 55805, USA; douglas.hoffman@essentiahealth.org

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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 hyperechoic 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

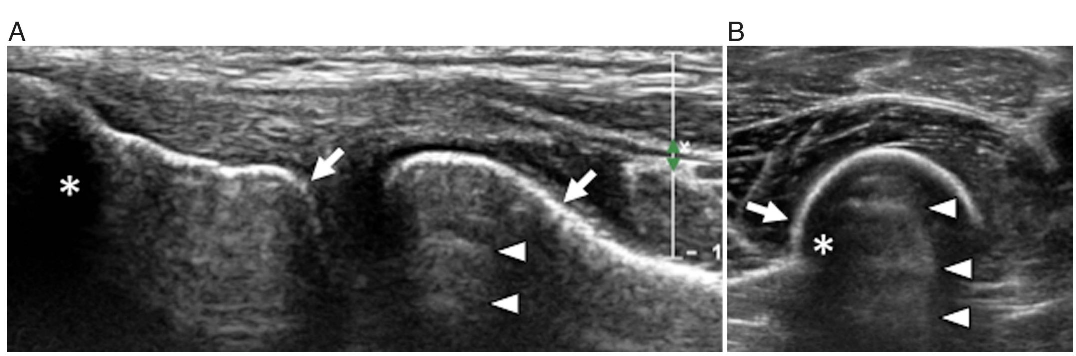

Figure 1 Normal bone. (A) Long-axis sonogram of the lateral elbow over the radiocapitellar joint and (B) short-axis sonogram of the femur at the mid-thigh demonstrating sonographic features of normal bone. Note the smooth hyperechoic cortex of bone that becomes less sharp when not perpendicular to the transducer (white arrows). Both shadowing artefact (asterisk) and reverberation artefact (arrowheads) are also demonstrated.

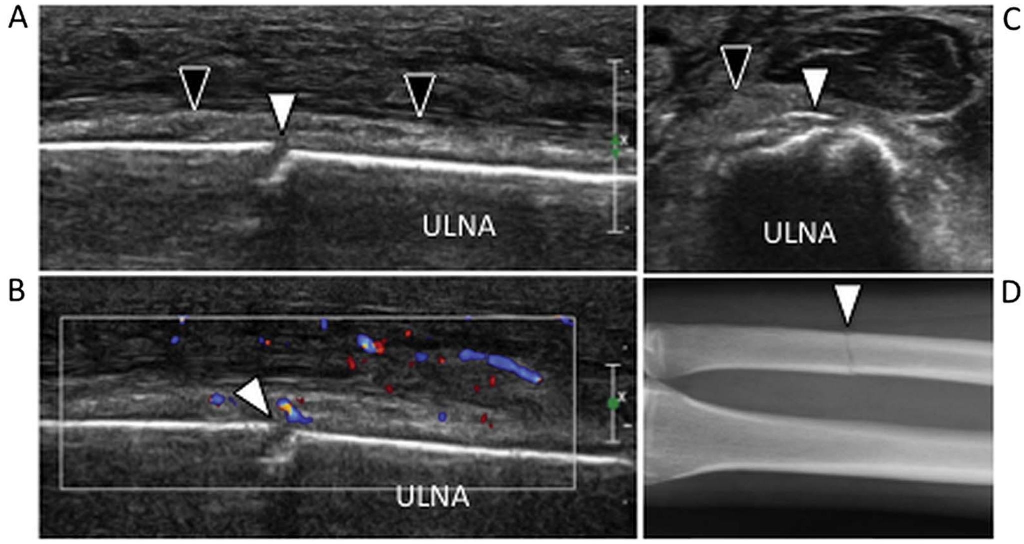

Figure 2 Acute mid-shaft ulna fracture. (A) Long-axis and (C) short-axis sonogram of an acute mid-shaft ulna fracture. The fracture is characterised by cortical interruption (white arrowhead) with periosteal thickening (black arrowheads). (B) Long-axis sonogram with Doppler imaging showing vascularity within the thickened periosteum as well as the surrounding soft tissue. (D) Corresponding anteroposterior radiograph.

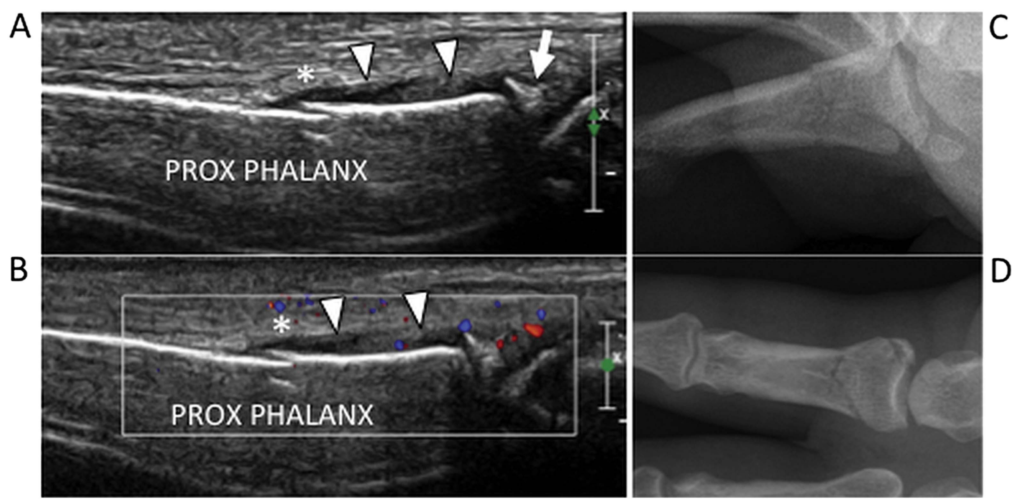

Figure 3 Acute finger fracture. (A) Long-axis sonogram and (B) with Doppler imaging of a 3-day-old proximal phalanx fracture of the index finger. The fracture line is visualised as an interruption of the smooth bone cortex. A small fragment is present at the base of the proximal phalanx (arrow). Note 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.

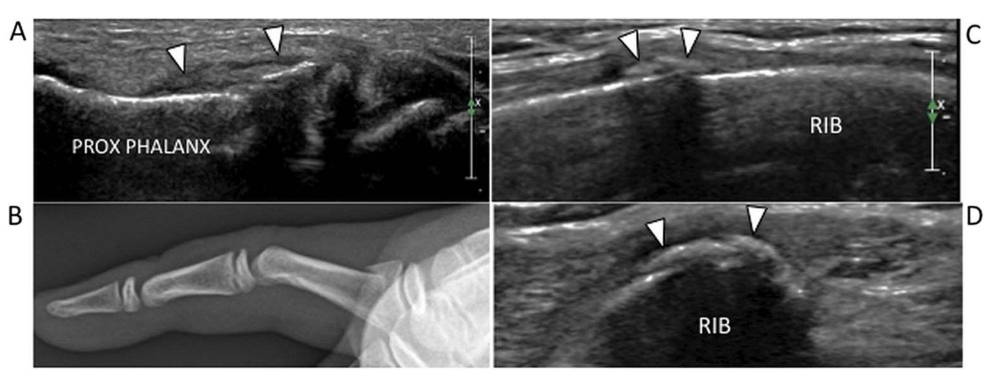

Figure 4 Bone callus formation. (A) Long-axis sonogram with (B) corresponding radiograph of a 13-day-old fifth finger proximal phalanx fracture in a 12-year-old. Attempt at a closed reduction in the office setting was unsuccessful. Ultrasound shows early bridging callus formation (arrowheads) not visualised 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).

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

thickening and hyperaemia and surrounding soft tissue oedema. In subacute fracture, US reveals early callus formation.[6] 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.[6] 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).

Long bone fractures

Ultrasonography 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).[7–11] 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.[7–20] In particular, the study by Waterbrook *et al*[8] 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.[12 21 22] 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.

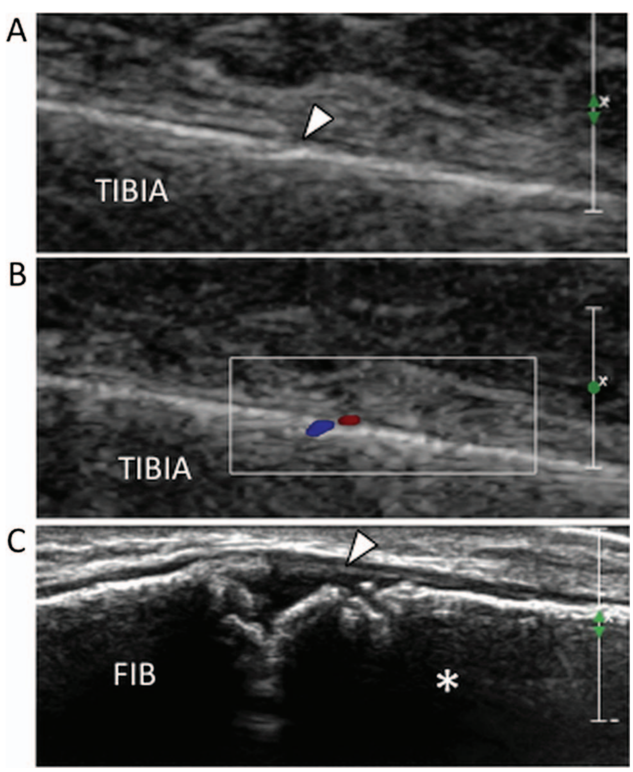

Figure 5 Normal bone surface irregularities. (A) long-axis sonogram with (B) Doppler imaging of the anterior mid-tibia showing a cortical interruption due to nutrient vessels. The lack of other signs of injury, the presence of a single artery and vein and no pain with transducer pressure distinguish 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.

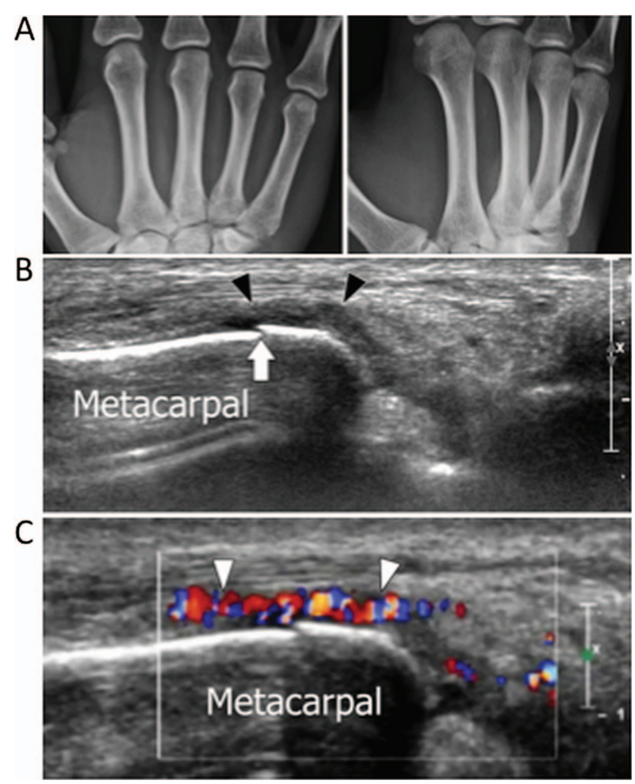

Figure 6 Fourth metacarpal fracture. (A) Normal radiographs in a patient with post-traumatic pain at the fourth metacarpal phalangeal joint. (B) Long-axis sonogram with (C) Doppler imaging of the dorsal aspect of the distal fourth metacarpal showing a minimally displaced fracture (arrow). Note the periosteal thickening (black arrowheads) and vascularity within the periosteum (white arrowheads).

Table 1 Summary of studies utilising ultrasound in fracture diagnosis

Reference	Number of bones imaged	Types of fractures	Gold standard	Number of fractures	US sens/spec (%)	Comments
Barata *et al*[7]	98	Paediatric long bones	X-ray	43	95/86	Sens/spec for determining need for reduction were 100/97
Waterbrook *et al*[8]	147	Long bones	X-ray	42	90/96	Best accuracy for middle of long bones
Eckert *et al*[9]	76	Paediatric forearm	X-ray	52	96/97	One torus fracture seen by US was not visible on radiographs
Bolandparvaz *et al*[10]	80	Long bones	X-ray	9	55–75/62–84	Multisystem trauma patients; sens/spec varied by fracture site
Neri *et al*[11]	204	Paediatric metacarpal	X-ray	79	91/98	Most errors occurred near the ends of bones
Weinberg *et al*[12]	348	Multiple	X-ray	84	73/92	86% of ultrasound errors occurred at the ends of long bones
Yesilaras *et al*[13]	84	Fifth metatarsal	X-ray	33	97/100	Positive predictive value 95% CI 97% to 100%
Rabiner *et al*[14]	130	Paediatric elbow	X-ray	33	93/76 for elevated olecranon fat pad	98% negative predictive value if no fat pad elevation nor lipohemarthrosis
Platon *et al*[15]	62	Scaphoid	CT	13	92/71	Sens/spec for high-risk scaphoid fracture 100%/67%
Yildirim *et al*[16]	63	Scaphoid	MRI	14	86/100	Negative predictive value 100%
Hedelin *et al*[17]	122	Ankle malleoli	X-ray	23	100/87	US superior to Ottawa ankle rules for deciding which patients do not need X-ray
Ekinci *et al*[18]	131	Ankle malleoli and metatarsals	X-ray	20	100/99	High rate of patient satisfaction versus radiographs
Canagasabey *et al*[19]	110	Ankle malleoli	X-ray	11	91/91	One fracture missed due to scanning technique
Chaar-Alvarez *et al*[20]	101	Paediatric forearm	X-ray	46	96/93	US less painful for paediatric patients than radiography

Sens, sensitivity; spec, specificity.

Beltrame *et al*[22] showed a 100% concordance between US and plain radiographs in 11 patients with rib fractures. Similarly, a study by Weinberg *et al*[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%.[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.[15 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

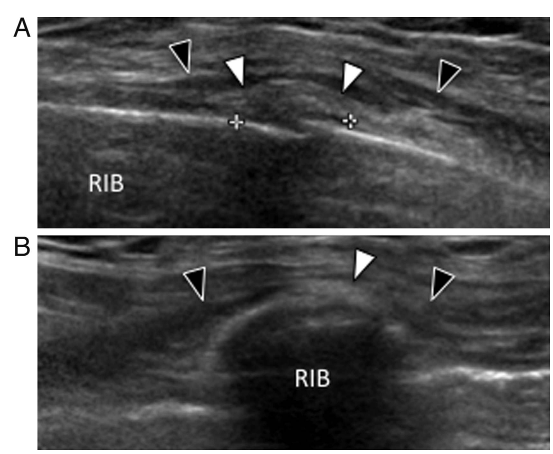

Figure 7 Rib fracture. (A) Long-axis and (B), short-axis sonogram of a rib fracture in a patient with normal radiographs. The fracture appears as an interruption of normally smooth bone cortex (between calipers) with elevation and thickening of the periosteum (white arrowheads) and adjacent soft tissue oedema (black arrowheads).

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.

(utilising CT as the gold standard) while also finding a 97% negative predictive value.[15] 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).[17–19 25] Additionally, there have been numerous case reports describing the detection of non-long bone type fractures with US (figures 13 and 14).[26–35] 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).

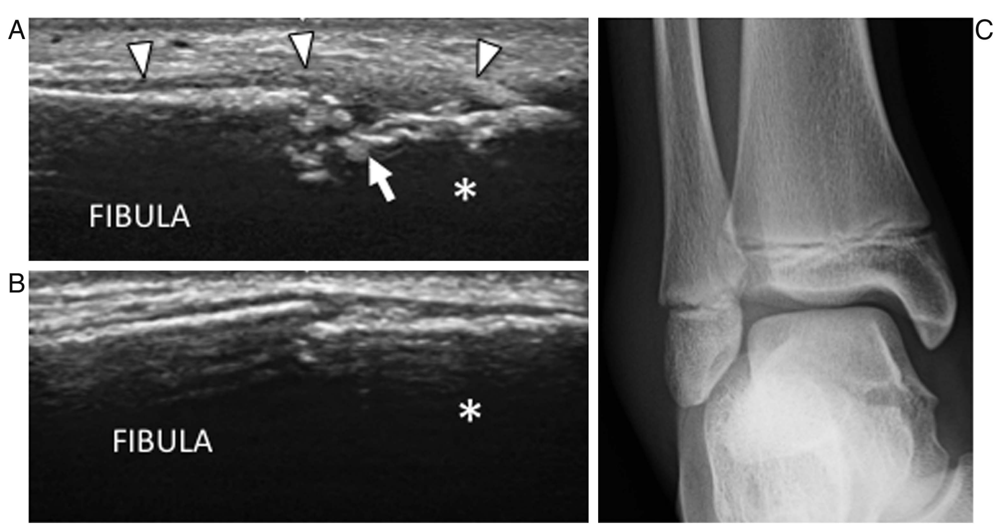

Figure 9 Salter-Harris fracture of the distal fibula. (A) Long-axis sonogram of the distal fibula (proximal is left) with (B) normal contralateral side. There is bone fragmentation within the physis (arrow) and thickening of the perichondral ring consistent with a Salter Harris type 2 injury. Pain with sonopalpation over the physis also confirmed the presence of a physeal injury. (C) Corresponding radiograph. Asterisk is epiphysis.

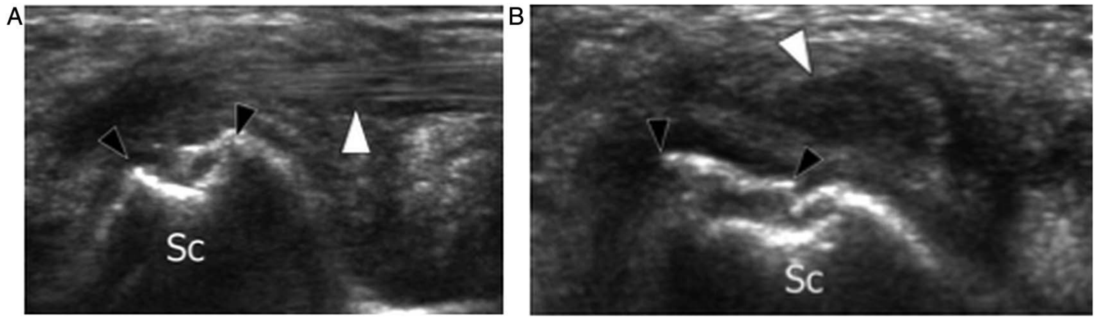

Figure 10 Fracture of the tubercle of the scaphoid. (A) Long-axis sonogram over the palmar aspect of the scaphoid (Sc) (right is proximal) and (B) short-axis sonogram shows a fracture of the tubercle (black arrowheads). Radiographs prior to the ultrasound were normal. White arrowhead is flexor carpi radialis tendon.

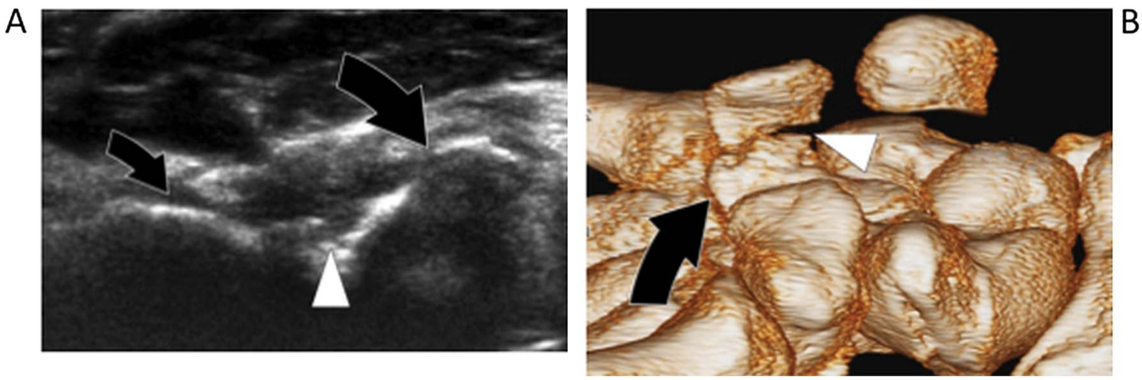

Figure 11 Fracture of the base of the hook of the hamate. (A) Short-axis sonogram obtained over the medial aspect of the wrist at the level of the hamate shows a fracture (arrowhead) between the body of the hamate (large black arrow) and hook of the hamate (small black arrowhead). (B) Corresponding three-dimensional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

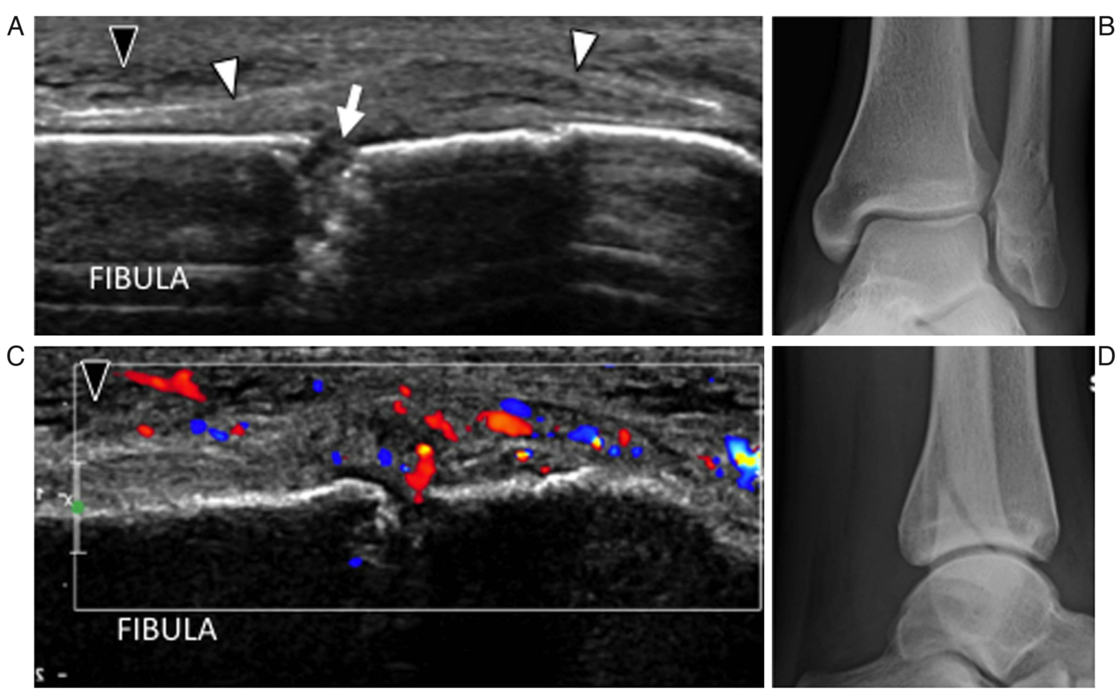

Figure 12 Acute distal fibular fracture. (A) Long-axis sonogram with (C) Doppler imaging of a 14-year-old with a 4-day-old distal fibular fracture. Note the slightly widened fracture line with intervening fluid or haematoma (arrow), a thickened periosteum (white arrowheads), and surrounding oedema (black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

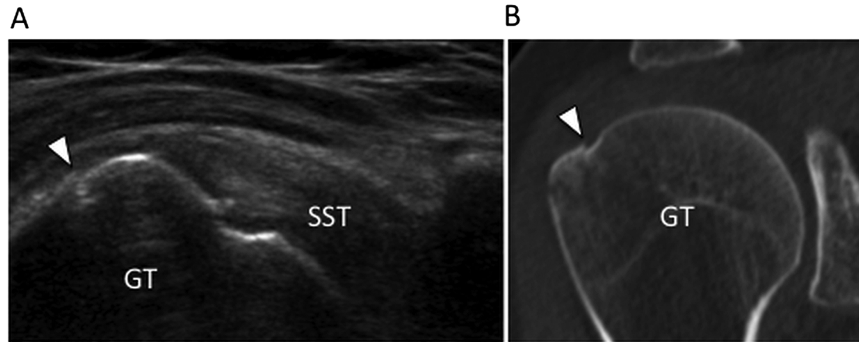

Figure 13 Fracture of the greater tuberosity of the humerus. (A) Long-axis sonogram of the greater tuberosity (GT) of the humerus revealing a non-displaced fracture (arrowhead) not visualised on prior radiographs. (B) Corresponding CT scan. SST is supraspinatus tendon.

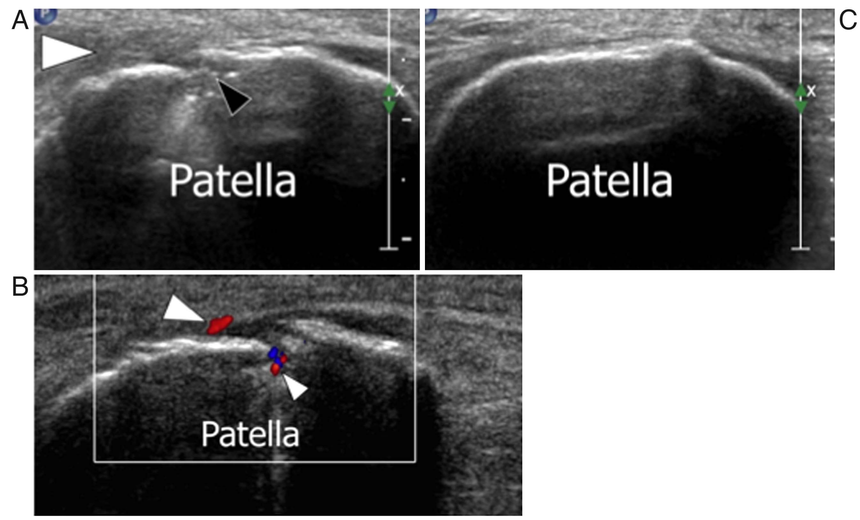

Figure 14 Acute patellar fracture. (A) Long-axis sonogram of the patella shows a fracture (black arrowhead) with surrounding soft tissue oedema (white arrowhead). Prior radiographs were reported as normal. (B) Long-axis sonogram of the patella with Doppler imaging shows hypervascular changes inside the fracture (small arrowhead) and within the periosteum (large arrowhead). (C) Long-axis sonogram of the contralateral normal patella.

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).[25 30 34 35] 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.[27–29]

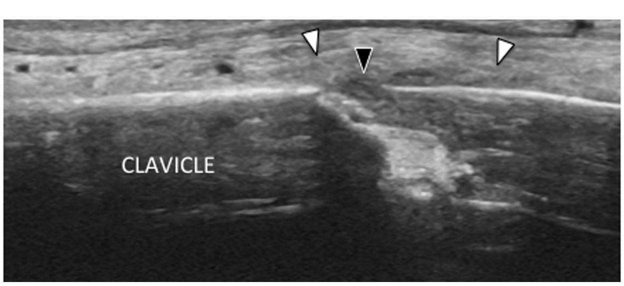

Figure 15 Acute clavicle fracture. Long-axis sonogram of a collegiate football wide receiver who experienced acute shoulder pain after a fall directly on the lateral aspect of his shoulder. Sonogram was initially performed since X-ray capability was not immediately available and revealed a fracture. Black arrowhead is oedema within the fracture. White arrowheads are periosteal thickening.

US imaging of stress fractures

Bone stress injuries are common in sports medicine and can be difficult to diagnose.[3 4] 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.[36 37] 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.[37–43] 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 hypoechoic periosteal elevation and hypervascularity (figure 18). It is presumed that these changes correspond

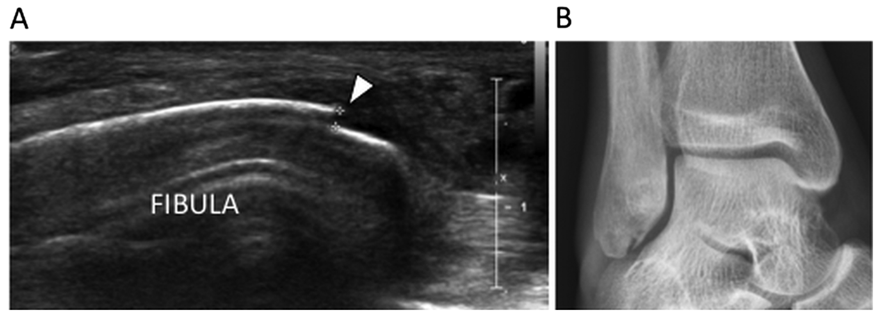

Figure 16 Unsuspected distal fibular fracture. (A) Long-axis sonogram of the distal fibula 1 month after ankle trauma shows a non-displaced distal fibular fracture (arrowhead). Initial radiographs were negative and the unsuspected fracture was revealed during evaluation of the calcaneofibular ligament. (B) Corresponding anteroposterior radiograph taken after the sonographic evaluation.

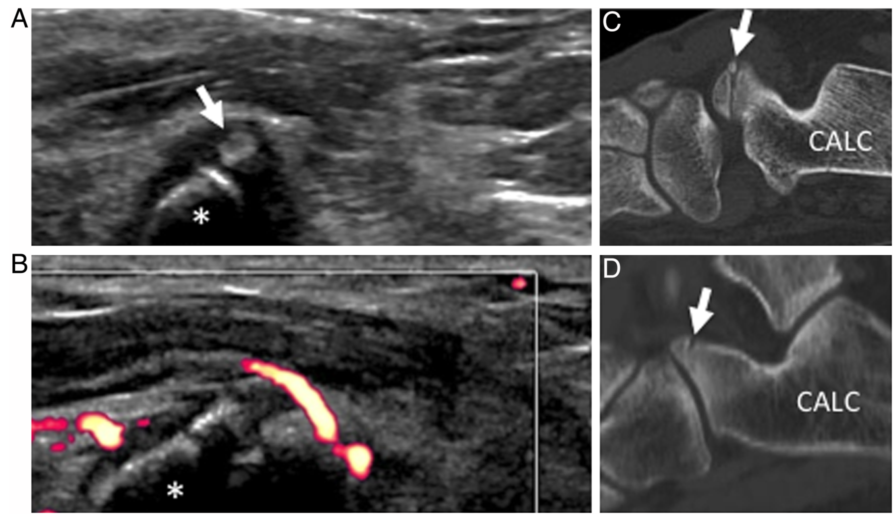

Figure 17 Anterior process of the calcaneus fracture. (A) Long-axis sonogram in a patient with persistent lateral ankle pain 4 months after an inversion ankle injury which shows an anterior process of the calcaneus fracture (arrow). (B) Long-axis sonogram with Doppler imaging showing hypervascularity around the anterior process of the calcaneus fracture. (C) Corresponding coronal and (D) sagittal CT scan showing the fracture (arrows). Asterisk is anterior process of the calcaneus.

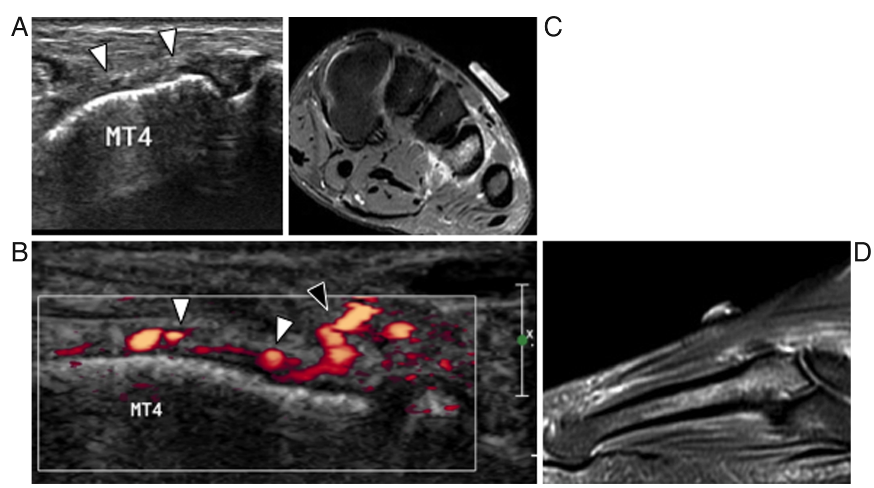

Figure 18 Fourth metatarsal stress reaction. (A) Short-axis sonogram of the proximal fourth metatarsal showing periosteal thickening (white arrowheads). (B) Long-axis sonogram with Doppler imaging of the proximal fourth metatarsal showing hypervascularity both within the periosteum (white arrowheads) and surrounding soft tissue (black arrowhead). (C) Corresponding axial and (D) sagittal T2 MR.

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

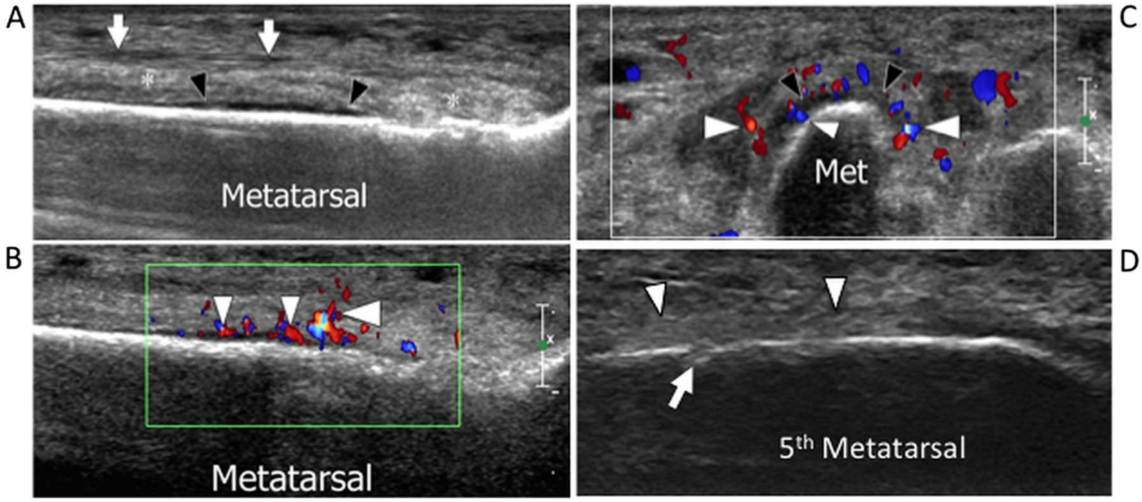

Figure 19 Third and fifth metatarsal stress fractures. (A), Long-axis sonogram obtained over the dorsal aspect of the third metatarsal (proximal is left) shows periosteal thickening (black arrowheads), and surrounding soft tissue oedema (asterisk). Corresponding radiographs were normal. Arrow is extensor tendon. (B and C) Corresponding long-axis (B) and short-axis (C) sonograms with Doppler imaging of the third metatarsal showing vascularity within the thicken periosteum (small white arrowheads) as well as the surrounding soft tissue (large white arrowhead). (D) Long-axis sonogram of the proximal fifth metatarsal (proximal is right) shows a fracture (arrow) and periosteal thickening (arrowheads) consistent with a zone 3 stress fracture. Corresponding radiographs were normal.

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

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

Acknowledgements Figure 15 courtesy of Dr Robert Monaco.

Competing interests None.

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REFERENCES

1 Bijur PE, Trumble A, Harel Y, *et al*. Sports and recreational injuries in US children and adolescents. *Arch Pediatr Adolesc Med* 1995;149:1009–16.
2 Watkins J, Peabody P. Sports injuries in children and adolescents treated at a sports injury clinic. *J Sports Med Phys Fitness* 1996;36:43–8.
3 Kiuru MJ, Niva M, Reponen A, *et al*. Bone stress injuries in asymptomatic elite recruits: a clinical and magnetic resonance imaging study. *Am J Sports Med* 2005;33:272–6.
4 Spitz DJ, Newberg AH. Imaging of stress fractures in the athlete. *Radiol Clin North Am* 2002;40:313–31.
5 Erickson SJ. High-resolution imaging of the musculoskeletal system. *Radiology* 1997;205:593–618.
6 Zamorani MP, Valle M. Bone and joint. In: Bianchi S, Martinoli C, eds. *Ultrasound of the musculoskeletal system*. Berlin, Germany: Springer-Verlag, 2007:137–85.
7 Barata I, Spencer R, Suppiah A, *et al*. Emergency ultrasound in the detection of pediatric long bone fractures. *Ped Emerg Care* 2011;28:1154–7.
8 Waterbrook AL, Adhikari S, Stolz U, *et al*. The accuracy of point-of-care ultrasound to diagnose long bone fractures in the ED. *Am J Emerg Med* 2013;31:1352–6.
9 Eckert K, Ackermann O, Schweiger B, *et al*. Sonographic diagnosis of metaphyseal forearm fractures in children. *Ped Emerg Care* 2012;28:851–4.
10 Bolandparvaz S, Moharamzadeh P, Jamali K, *et al*. Comparing diagnostic accuracy of bedside ultrasound and radiography for bone fracture screening in multiple trauma patients at the ED. *Am J Emerg Med* 2013;31:1583–5.
11 Neri E, Barbi E, Rabach I, *et al*. Diagnostic accuracy of ultrasound for hand fractures in paediatric patients. *Arch Dis Child* 2014;99:1087–90.
12 Weinberg ER, Tunik MG, Tsung JW. Accuracy of clinician-performed point-of-care ultrasound for the diagnosis of fractures in children and young adults. *Injury* 2010;41:862–8.
13 Yesilaras M, Askay E, Atilla OD, *et al*. The accuracy of bedside ultrasonography as a diagnostic tool for the fifth metatarsal fractures. *Am J Emerg Med* 2014;32:171–4.
14 Rabiner JE, Khine H, Avner JR, *et al*. Accuracy in point-of-care ultrasound for diagnosis of elbow fractures in children. *Ann Emerg Med* 2013;61:9–17.
15 Platon A, Poletti P-A, Aaken JV, *et al*. Occult fractures of the scaphoid: the role of ultrasonography in the emergency department. *Skeletal Radiol* 2011;40:869–75.
16 Yildirim A, Ünlüer EE, Vandenberk N, *et al*. The role of bedside ultrasonography for beside ultrasound in the emergency department. *Turk J Traum Emerg Surg* 2013;19:241–5.
17 Hedelin H, Goksör L-Å, Karlsson J, *et al*. Ultrasound-assisted triage of ankle trauma can decrease the need for radiographic imaging. *Am J Emerg Med* 2013;31:1686–9.
18 Ekinci S, Polat O, Günalp M, *et al*. The accuracy of ultrasound in foot and ankle trauma. *Am J Emerg Med* 2013;31:1551–5.
19 Canagasabey MD, Callaghan MJ, Carley S. The sonographic Ottawa foot and ankle rules study (the SOFAR study). *Emerg Med J* 2011;28:838–40.
20 Chaar-Alvarez FM, Warkentine F, Cross K, *et al*. Bedside ultrasound diagnosis in nonangulated distal forearm fractures in the pediatric emergency department. *Ped Emerg Care* 2011;27:1027–32.
21 Léland E, Wylie K. Towards evidence-based emergency medicine: best BETs from the Manchester Royal Infirmary. BET 1: ultrasound in the diagnosis of rib fractures. *Emerg Med J* 2014;31:169–70.
22 Beltrame V, Stramare R, Rebellato N, *et al*. Sonographic evaluation of bone fractures: a reliable alternative in clinical practice? *Clin Imaging* 2012;36:203–8.
23 Davis TR. Prediction of outcome of non-operative treatment of acute scaphoid waist fracture. *Proc R Coll Surg Engl* 2013;95:171–6.
24 Reigstad O, Grimsgaard C, Thorkildsen R, *et al*. Scaphoid non-unions, where do they come from? The epidemiology and initial presentation of 270 scaphoid non-unions. *Hand Surg* 2012;17:331–5.
25 Atilla OD, Yesilaras M, Kilic TY, *et al*. The accuracy of bedside ultrasonography as a diagnostic tool for fractures in the ankle and foot. *Acad Emerg Med* 2014;21:1058–61.
26 Botchu R, Bianchi S. Sonography of trapezial ridge fractures. *J Clin Ultrasound* 2014;42:241–4.
27 Botchu R, Lee KJ, Bianchi S. Radiographically undetected coracoid fractures diagnosed by sonography. Report of seven cases. *Skeletal Radiol* 2012;41:693–8.
28 McCrady BM, Schaefer MP. Sonographic visualization of a scapular body fracture: a case report. *J Clin Ultrasound* 2011;39:466–8.

29 Randall MP, Laurence AM, Keith YW, *et al*. Nondisplaced fractures of the greater tuberosity of the humerus: sonographic detection. *Radiology* 1992;182:201–4.
30 Enns P, Pavlidis T, Stahl JP, *et al*. Sonographic detection of an isolated cuboid bone fracture not visualized on plain radiographs. *J Clin Ultrasound* 2004;32:154–7.
31 Celi J, Gautard G, Della Santa JD, *et al*. Sonographic diagnosis of a radiographically undiagnosed hook of the hamate fracture. *J Ultrasound Med* 2008;27:1235–9.
32 Copercini M, Florent B, Martinoli C, *et al*. Sonographic diagnosis of talar lateral process fracture. *J Ultrasound Med* 2003;22:635–40.
33 Lukac D, Milenovic N, Drapsin M, *et al*. Ultrasonographic diagnostics and evaluation of calcaneal fracture: case report. *Srp Arh Celok Lek* 2013;141:532–5.
34 Boutry N, Vanderhofstadt A, Peetrons P. Ultrasonography of anterosuperior calcaneal process fracture: report of 2 cases. *J Ultrasound Med* 2006;25:381–5.
35 Wang CL, Shieh JY, Wang TG, *et al*. Sonographic detection of occult fractures in the foot and ankle. *J Clin Ultrasound* 1999;75:421–5.
36 Khan KM, Brukner PD, Kearney C, *et al*. Tarsal navicular stress fracture in athletes. *Sports Med* 1994;17:65–76.
37 Bodner G, Stockl B, Fierlinger A, *et al*. Sonographic findings in stress fractures of the lower limb: preliminary findings. *Eur Radiol* 2005;15:356–9.
38 Battaglia PJ, Kaeser MA, Kettner NW. Diagnosis and serial sonography of a proximal fifth metatarsal stress fracture. *J Chiropr Med* 2013;12:196–200.
39 Drakonake EE, Barbi A. Metatarsal stress fracture diagnosed with high-resolution sonography. *J Ultrasound Med* 2010;29:473–6.
40 Khy V, Wyssa B, Bianchi S. Bilateral stress fracture of the tibia diagnosed by ultrasound. A case report. *J Ultrasound* 2012;15:130–4.
41 Banal F, Gandjbakhch F, Foltz V, *et al*. Sensitivity and specificity of ultrasonography in early diagnosis of metatarsal bone stress fractures: a pilot study of 37 patients. *J Rheumatol* 2009;36:1715–19.
42 Etchepare FB, Rouhier B, Rosenberg C, *et al*. Ultrasound ability in early diagnosis of stress fracture of the metatarsal bone. *Ann Rheum Dis* 2006;65:977–8.
43 Papalada A, Malliaropoulos N, Tsitas K, *et al*. Ultrasound as a primary evaluation tool of bone stress injuries in elite track and field athletes. *AJSM* 2012;40:915–19.

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Douglas F Hoffman, Erik Adams and Stefano Bianchi

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