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US findings in traumatic wrist and hand injuries

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ABSTRACT
Traumatic injuries of the wrist and hand are common. Ultrasonography (US) is a cost-effective, noninvasive, and effective imaging method for diagnosing traumatic lesions affecting the tendons, annular pulleys, ligaments, vessels, and nerves, and for detecting foreign bodies in the wrist and hand. The objective of this article was to review the main US findings of traumatic lesions in the wrist and hand.

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The wrist and hand are the most important functional parts of the body in daily life activities and are prone to traumatic injuries. These injuries constitute 6.6% to 28.6% of all injuries and 28.0% of all musculoskeletal injuries (1, 2). According to Schoffl et al. (3), wrist and hand injuries account for 14.0% to 30.0% of all treated patients in emergency care. Although these injuries are not life-threatening, the accepted treatment strategy for traumatic injuries is immediate reconstruction of all injured tissue structures. Hence, early diagnosis of the injured tissue is important for clinical management.

Current ultrasonography (US) systems equipped with linear-array transducers have improved the capability of US to examine superficial organs and tissues. As an easily accessible, rapid, noninvasive imaging technique that also provides dynamic examination, US is a good imaging modality for examining the musculoskeletal system (4, 5).

The purpose of this article was to review the main US findings and discuss the potential value of this technique in the evaluation of traumatic injuries of the wrist and hand.

US techniques

Using proper US examination techniques based on a thorough knowledge of the relevant anatomy and artifacts is essential for accurate diagnosis. High-frequency linear-array transducers (7–15 MHz) are mandatory for the ultrasonographic evaluation of superficial structures. The wrist and hand are best examined with the patient seated in front of the examiner with the wrist and hand placed on a table. The transducer is held with the first three fingers, and the other fingers rest on the table to reduce contact pressure. The longitudinal axis is the principal axis and is essential for diagnosis, while the transverse images are used for support. A large amount of transmission jelly is required for good contact and near field resolution.

US findings of the injured tendons, annular pulleys, nerves, vessels, bones, small joints, and foreign bodies are briefly summarized below.

Tendons

Tendon injuries are the second most common injuries in the hand after fractures (3). Most injuries are direct injuries to the tendons, but less frequent indirect traumas may cause damage to the tendon, tendon sheath, and pulley system (6). The recognition of a tendon rupture is usually based on the physical examination and history. An acute loss of motion, a patient's report of hearing a popping sound during the injury and the final position of the finger generally demonstrates a tendon rupture. However, imaging is necessary for diagnosis, especially in complicated cases.

US has been used as a diagnostic tool for tendon injuries since the 1990s. Hoglund et al. (7) detected the rupture of recently repaired ten-

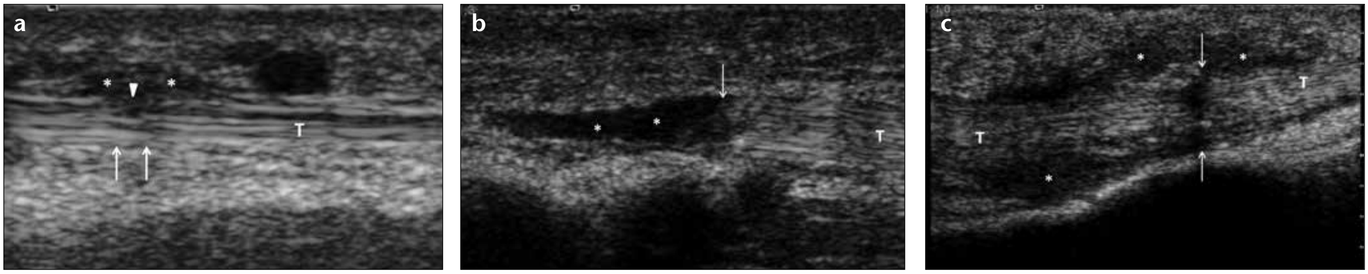

Figure 1. a–c. Tendon injuries. In partial extensor tendon rupture **(a)**, a hypoehoic area (*arrowhead*) within the dorsal aspect of the tendon and effusion (*asterisks*) around the tendon are seen on a longitudinal US image; *arrows* indicate intact tendon fibers at the palmar aspect. T, extensor tendon. In complete flexor tendon rupture **(b)**, longitudinal US image shows complete flexor tendon rupture with retraction and effusion (*asterisks*) in the tendon sheath; *arrow* indicates the rupture site. T, flexor tendon. A thickened adherent tendon surrounded by mixed echogenic fibrotic tissue (**c**, *asterisks*) is seen in the postoperative period. Suture materials are seen within the rupture site as hyperechoic foci; *arrows* indicate rupture site. T, tendon.

dons using US in 1991. In addition, Corduff et al. (8) used US imaging to assess the state of healing of zone 1 flexor tendon repairs in 1994. US can examine the whole length of a tendon, from the forearm to the distal insertion site. Tendons have a typical fibrillar echotexture, which reflects their histological structure of longitudinally oriented bundles of collagen fibers; normal tendons are more echogenic than muscle. The operator should be careful when evaluating a tendon with US, as a slight oblique angle of the US beam in the longitudinal or transverse planes causes a false reduction in the echogenicity, known as anisotropy, which is more likely to occur when the tendon is curved or when a nonlinear array transducer is used. This may lead to misdiagnosis (9).

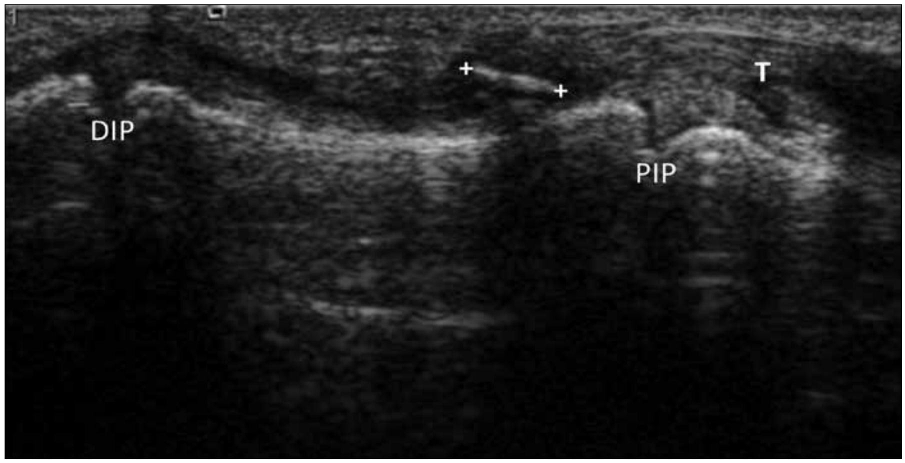

Figure 2. Flexor tendon rupture with avulsed bone fragment. *Calipers* indicate avulsed bone fragment. DIP, distal interphalangeal joint; PIP, proximal interphalangeal joint; T, flexor tendon

Diagnostic findings of a partial tendon rupture include a hypoehoic/anechoic foci within the tendon, tendon swelling, and effusion in the tendon sheath (Fig. 1a). Nonvisualization of a tendon at the site of injury, the loss of its fibrillar pattern and discontinuity of the tendon with the gap at the rupture site are the signs of complete rupture (Fig. 1b) (10, 11). The gap between the two ends of the tendon that fills with fluid is helpful for making the diagnosis, especially in the case of a recent injury. Occasionally, these gaps become filled with mixed echogenic material in relatively late presentations, which is interpreted as fibrinous tissue. This appearance may lead to the misdiagnosis of an intact tendon in these cases (10, 12).

As a result of an inactive flexor system and injuries to other soft tissues of the digits, the tendons can sometimes adhere to the surrounding scar tissue. An adhered flexor tendon appears to be continuous at the repair site, with no evidence of a gap, but the tendon is thickened and enclosed by mixed echogenic tissue, which is interpreted as fibrosis in these cases. There is some disorganization in the fibrillar pattern of a tendon (Fig. 1c). After trauma, some tendons retain their integrity with minimal impairment of the fibrillar pattern, and they becomes thinner than normal. These tendons show little or no gliding during active-passive finger motion on US. An increase in the length of the tendon or tendon stretching may explain these ultrasonographic findings. Because these tendons become nonfunctional, they should be seen and managed as a ruptured tendon. Dynamic US is recommended for the diagnosis of these nonfunctional tendons (12, 13).

Avulsion fractures mostly affect the insertion of the deep flexor tendon at the distal phalanx, which occurs commonly in young people when there is forced extension of the digit during maximum contraction of the flexor muscle (5). Tendon rupture with an avulsion fracture is diagnosed on US when the normal tendon cannot be identified in its expected location, and a bony fragment is seen at the end of the ruptured tendon (Fig. 2).

US can also be used to detect iatrogenic tendon lesions in the postoperative period (14). Extensor tendon injuries are commonly encountered after fixation of distal radius fractures with palmar locking plates. Tenosynovitis and partial-complete tendon rupture in the extensor compartment are commonly encountered complications after an operation (Fig. 3). Tenosynovitis can be diagnosed easily with the presence of an effusion or thickening of the synovium around the tendons (15).

Annular pulleys

In an annular pulley rupture, the diagnosis is usually made by the presenting history and physical exam findings. US has also been proposed as a useful tool for evaluating possible annular pulley ruptures (16). Demonstration of subluxation of the flexor tendon, instead of a course along the concavity of the phalanges, and an increase in the tendon-phalanx distance are diagnostic (Fig. 4). Klauser et al. (17) showed that patients with a tendon-phalanx distance of 0.3 cm at rest or 0.5 cm on dynamic images can be validly diagnosed with a pulley rupture. Diagnosis of the rupture is more easily made when the US is performed with forced flexion of the finger, i.e., active pressure of the finger towards the transducer (18, 19).

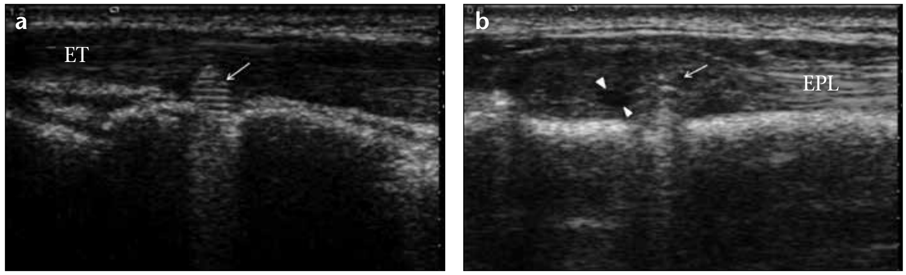

Figure 3. a, b. Ultrasonographic appearance of extensor tendon impingement with screw tip. Longitudinal US images of the distal radius reveal that the screw tip (**a, b,** *arrows*) is protruding into the extensor tendon (ET) and partial rupture (**b,** *arrowheads*) of extensor pollicis longus (EPL) tendon.

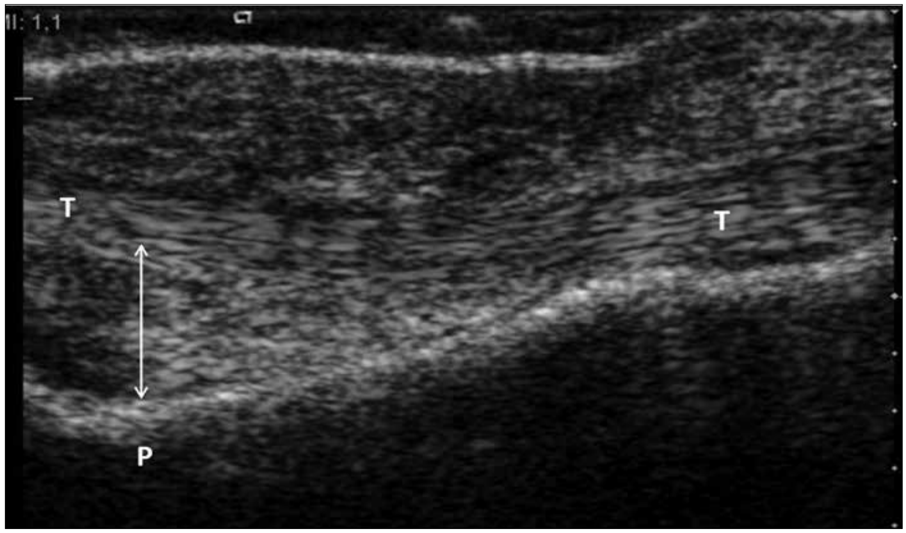

Figure 4. Ruptured annular pulley. Longitudinal US image of the middle finger demonstrates abnormally increased flexor tendon (T)–phalanx (P) distance due to flexor tendon subluxation.

Nerves

As a consequence of their relatively superficial location in the wrist, peripheral nerves may be damaged by trauma (20). The nerve most commonly injured in the upper extremity is the radial nerve, followed by the ulnar and median nerves (20, 21).

The diagnosis of peripheral nerve lesions is commonly based on clinical and electrophysiological examination. This clinical and diagnostic information provides some objective data, such as the possible location and chronicity of the peripheral nerve lesion, but leaves many unanswered questions about the type and severity of the lesion. For example, such examinations cannot differentiate a neuropraxic lesion from a nerve transection in the acute stage and cannot localize a very focal neuropraxic lesion on a lengthy segment of nerve. Moreover, this information gained from electrophysiological examination can be obtained only with the beginning of the reinnervation, which occurs approximately 6–8 weeks after the injury. As we know, the nerve injuries that require surgical repair have better results if the nerve is repaired immediately after injury. For this reason, an early and correct diagnosis of the injured nerve is important to determine the appropriate treatment strategy (22, 23).

Because of the superficial course of the peripheral nerves in the wrist, high-frequency US seems to be an optimal imaging method. Although US of the peripheral nerves may be considered a new topic in medicine, US has been used as a diagnostic tool for three decades. Solbiati et al. (24) studied the ultrasonographic appearance of the recurrent laryngeal nerve in 1985, and in 1988, Fornage (25) used US to evaluate peripheral nerves in healthy subjects and in 11 patients with a mass that developed from a peripheral nerve.

The normal nerve is seen as a hypoechoic neuronal fascicle with hyperechogenicity surrounding the connective tissue on US. The normal echogenicity of the nerves is between the relatively low echogenicity of muscle and the higher echogenicity of the tendon (23, 26).

The ultrasonographic findings for injured nerves include disruption or total loss of the normal fascicular pattern of the nerve (Fig. 5a), local swelling or thickening and decreased echogenicity of the nerve (Fig. 5b), loss of integrity of the nerve bundle (Fig. 5c), and neuroma formation at the transected nerve end (Fig. 5d) (23, 26).

US can be used to facilitate the preoperative diagnosis and planning of the optimal treatment strategy. However, US has some limitations in evaluating the nerves. First, US examinations are operator dependent and require an experience in superficial soft tissue structures, which have a relatively long learning curve. Second, postoperative and/or posttraumatic subcutaneous air, suture materials, and deteriorating soft tissue planes may prevent visualization of the nerves (23, 26).

Vessels

The vascular structures of the wrist and hand are predisposed to injuries due to their superficial location, lack of protection, and close proximity to the bone (27). Upper extremity injuries constitute approximately 40.0% of all peripheral vascular injuries, and radial and ulnar arterial injuries make up 4.0%–36.0% of upper extremity arterial injuries; more than 67.0% result from penetrating trauma (28, 29). The most common cause of upper extremity vascular injury is penetrating trauma secondary to lacerations from broken glass, gunshot wounds, and stab wounds (29).

The prognosis of patients with vascular injury is typically good, but depends on early diagnosis and timely repair of the injured vessels (2). Catheter arteriography is the gold standard imaging method for traumatic artery injuries. However, it is both invasive and costly. Nevertheless, US can provide valuable information about the vessel lumen and vessel wall. Arterial and venous thrombosis, dissection and pseudoaneurysm are the most common vascular injuries that occur after acute and repeated chronic traumas (30, 31).

Thrombosis of the distal upper extremity arteries is uncommon and occurs most often on the ulnar side (32). Traumatic (penetrating, blunt, or iatrogenic) and occupational (e.g., hypothenar hammer syndrome or the use of vibratory tools) factors may cause thrombosis in the ulnar and radial arteries (30, 32). Thrombosis of a vessel is seen as an iso-hyperechoic structure filling the lumen on gray-scale US. Color Doppler US that shows absent flow in the artery or vein lumen is diagnostic (Fig. 6).

Pseudoaneurysm is a rare vascular complication and caused by a partial laceration of the arterial wall that results in a cyst-like structure connected to the arterial lumen. Trauma is a more common reason for pseudoaneurysm formation. Vascular access attempts for arteriovenous fistulas in hemodialysis patients, catheterization of arteries, and sampling for arterial blood gas analysis are other rare reasons for pseudoaneurysm formation. The ultrasonographic features of pseudoaneurysms include a nonspecific anechoic cyst-like mass on gray-scale US. However, Doppler US findings are typical with vascular color-coding and include a characteristic “yin-yang” phenomenon and spectral findings (Fig. 7). US is also used in the treatment of pseudoaneurysms. Specifically, US-guided compression or thrombin injection has been shown to be effective in the treatment of peripheral pseudoaneurysms (33–35).

Traumatic arterial dissection rarely involves arteries of the extremities. Direct or forceful repeated trauma can lead to arterial dissection. The visualization of the intimal flap, thrombus in the false-lumen and/or reduced flow distally are diagnostic for dissection (Fig. 8).

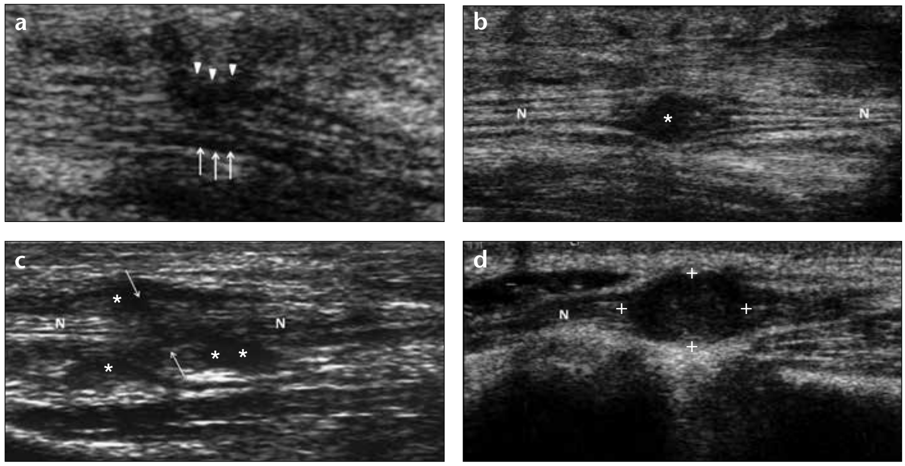

Figure 5. a–d. Nerve injuries. Longitudinal US **(a)** shows fascicular discontinuity (*arrowheads*) at the palmar aspect of the ulnar nerve compatible with partial transection; *arrows* indicate intact fascicules. Longitudinal US **(b)** reveals swelling and hypoechogenity (*asterisk*) in the median nerve in a different patient. Longitudinal US image **(c)** shows loss of continuity of the nerve, the injured nerve ends, and effusion (*asterisks*) in the nerve sheath; *arrows* indicate transection site. Longitudinal US image **(d)** demonstrates neuroma formation (*calipers*) at the end of the nerve in the chronic stage of complete nerve transection. N, nerve.

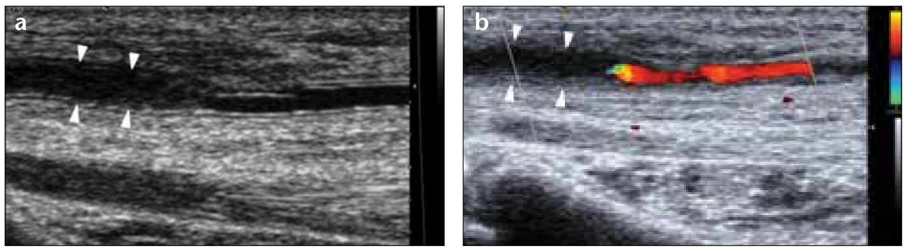

Figure 6. a, b. Thrombosis of the median artery after direct trauma to the wrist. Gray-scale longitudinal US **(a)** demonstrates the widening of the artery diameter and the presence of endoluminal thrombus. Color Doppler US image **(b)** shows absence of blood flow in the lumen at same level. *Arrowheads* indicate thrombosed segment.

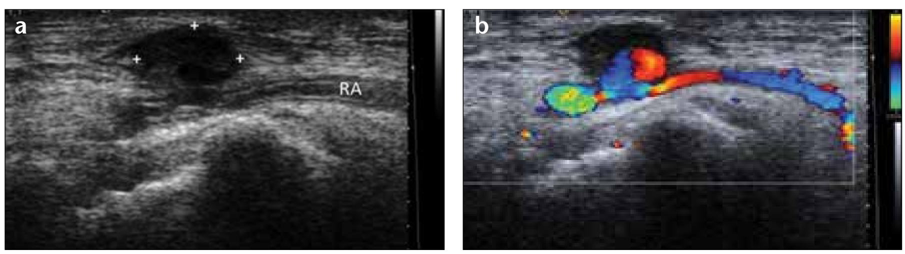

Figure 7. a, b. Pseudoaneurysm. A cyst-like lesion connected with radial artery is seen on gray-scale US **(a)**; *calipers* indicate pseudoaneurysm sac. RA, radial artery. Color Doppler US image **(b)** shows the classic “yin-yang” pattern of turbulent blood flow of a pseudoaneurysm with a small amount of peripheral thrombosis.

Arteriovenous fistulas are pathologic connections between arterial and venous vessels and are commonly the result of a direct trauma, especially after a penetrating injury. On Doppler US examination, turbulent and pulsatile flow on the venous side of the fistula and low resistance flow on the arterial side of the fistula are diagnostic for arteriovenous fistulas (36).

Foreign bodies

Foreign bodies are commonly encountered after penetrating wounds and could lead to pain, soft tissue infection, and abscesses (27). US can be used effectively to locate foreign bodies and to demonstrate their relationship with tendons, nerves, and vessels. Plain radiographic examination can detect only radiopaque fragments (earth and metal), whereas radiolucent material (vegetable, wood, and glass) may remain undetected even at surgery (37, 38). US may be the best imaging modality to identify and locate both opaque and radiolucent foreign bodies in the soft tissues. Foreign bodies appear as hyperechoic structures with acoustic shadowing; a comet tail artifact can be seen if metallic fragments exist. The reflectivity of a foreign body depends on its acoustic impedance on US. Therefore, metal and glass are significantly more reflective than glass and wood, respectively. As a result of reactive inflammation or granuloma formation, a hypoechoic area surrounding the foreign body can be demonstrated in subacute and chronic lesions (Fig. 9). The only way to detect small foreign bodies is to recognize the posterior shadowing artifacts and the surrounding hypoechoic area. Complications of foreign bodies, such as tenosynovitis or abscesses, can be diagnosed with US. The early detection and accurate location of the foreign body by US is important for successful surgical removal. Preoperatively, US-guided positioning of a cutaneous marker can help the surgeon to localize the fragment, which can help avoid long intraoperative searches and minimize damage to the soft tissue (39). The limitations of US in detecting foreign bodies include false positives (soft tissue calcification, sesamoid bones, etc.), and in the early stage of trauma, gas in the soft tissue can obscure the visualization of a foreign body.

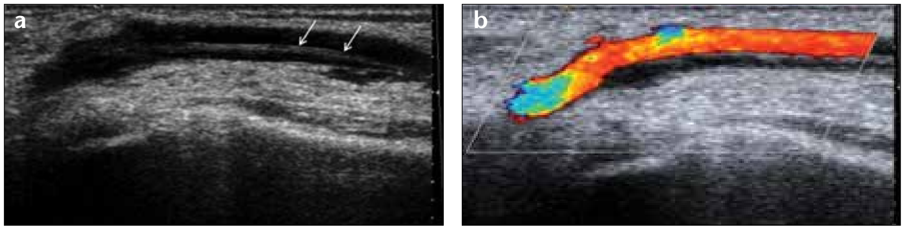

Figure 8. a, b. Traumatic radial artery dissection. Gray-scale **(a)** and color Doppler US **(b)** images reveal an intimal flap (**a**, *arrows*) and thrombosed false-lumen.

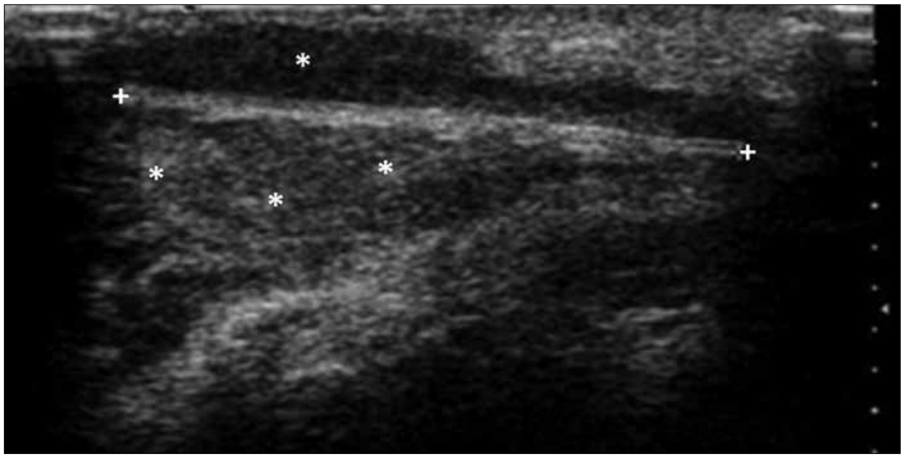

Figure 9. Foreign body (glass) in the subcutaneous soft tissue. Foreign body (*calipers*) appears as a linear hyperechoic structure surrounded by reactive inflammatory tissue (*asterisks*) in the subcutaneous soft tissue.

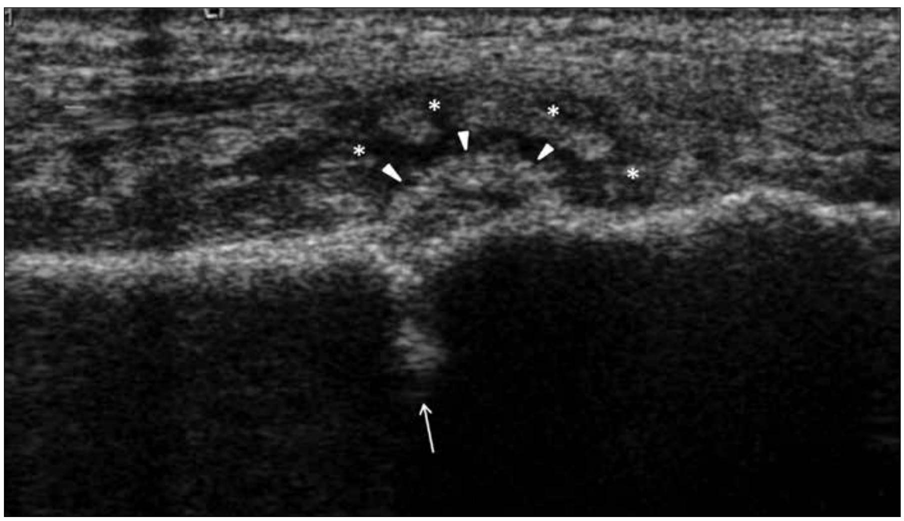

Figure 10. Radius fracture. A longitudinal US image through the radius shows cortical discontinuity (*arrow*) with clear evidence of callus (*arrowheads*), which was diagnosed incidentally. Soft tissue edema is seen at the fracture site (*asterisks*).

Bones and joints

The diagnosis of traumatic bone lesions and fractures relies mainly on radiography, computed tomography, and magnetic resonance imaging. Nevertheless, radiologist should pay attention to cortical bones and joints during an US examination and prompt further investigation in the case of an irregularity of the bone surface (Fig. 10). The value of US in diagnosing scaphoid fractures has been discussed in the literature (40–42). These studies revealed that US can diagnose a scaphoid fracture if the periosteal and/or cortical changes are evaluated. They also concluded that US can detect scaphoid fractures in patients presenting with negative initial radiography results and may eliminate the need for a more invasive or expensive diagnostic test. Similarly, some studies found that US can accurately identify fractures of superficial bone (e.g., proximal tibia, distal radius, and ribs) and reveal more fractures than radiography (43–45). In the event of normal findings on conventional radiographs, US should be considered as an alternative imaging method for bone and joint injuries if computed tomography or magnetic resonance imaging are not available (40).

The superficial and small joints of the wrist and hand are accessible with US, which can easily reveal evidence of traumatic synovitis and effusion in these joints (46).

The most important limitation of US is the dependence on the skill of the operator. Nofsinger et al. (47) concluded that most errors were a failure to recognize both normal and abnormal anatomy and errors caused by technical limitations. In addition, clinicians are still not aware of the usefulness of US in resolving clinical questions about wrist and hand pathologies.

Conclusion

Traumatic injuries of the wrist and hand are common. The consequences of inadequate diagnosis are profound, not only in terms of cost but also in terms of permanent disability. US is cost-effective, non-invasive and is a capable imaging method for the visualization of the injured tissue and may shorten the delay between the onset of injury and treatment.

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Conflict of interest disclosure

The authors declared no conflicts of interest.

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