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REVIEW ARTICLE

Stefano Bianchi
Carlo Martinoli
Ibrahim Fikry Abdelwahab

High-frequency ultrasound examination of the wrist and hand

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S. Bianchi M.D.
Servizio di Radiodiagnostica,
E.O. Ospedale Galliera, Genoa, Italy

C. Martinoli M.D.
Istituto di Radiologia, Università di Genova,
Genoa, Italy

I.F. Abdelwahab, M.D.
Department of Radiology,
Mount Sinai Medical Center, New York,
NY, USA

S. Bianchi M.D. (✉)
Corso Paganini 1\5, I-16125, Genoa, Italy

Abstract High-frequency ultrasound (US) is an efficient, rapid and inexpensive altenative to magnetic resonance imaging (MRI) for investigation of diseases in the soft tissues of the wrist and hand. US allows detection of foreign bodies and the reliable identification of a variety of traumatic lesions affecting tendons, annular pulleys, ligaments, vessels and nerves. Inflammatory diseases of tendons, including acute and chronic tenosynovitis and some degenerative conditions in the wrist and hand, can also be diagnosed. In entrapment neuropathies, US is able to identify nerve shape changes and possible extrinsic space-occupying lesions that may cause nerve compression within the tunnels. In patients with localized swelling of the hand or wrist, US is able to assess the presence of an expansile lesion and to characterize its nature in most cases. The objective of this article is to review the main findings and the primary indications of US in the investigation of disorders of the hand and wrist.

Key words US · Hand · Wrist · Tenosynovitis · Carpal tunnel syndrome · Ganglia · Neoplasms

Introduction

The development and refinement of ultrasound (US) transducers with frequencies higher than 10 MHz has improved the capability of US to examine superficial organs and tissues, and US is accepted as a primary means of examining the musculoskeletal system. Its low cost, availability, noninvasive nature and the possibility of a dynamic examination make US an excellent imaging technique to investigate a wide range of conditions affecting the hand and wrist [1–7].

The purpose of this review article is to describe the main US findings and discuss the potential value of this technique in the investigation of diseases of the hand and wrist.

Traumatic lesions

US can be used effectively both to locate foreign bodies and to identify injured ligaments, annular pulleys, tendons, nerves and vessels.

Foreign bodies are commonly encountered in penetrating wounds of the hand [8]. If undetected, they can lead to persistent pain, soft tissue infection and abscesses. Early detection and accurate location of the foreign body by means of imaging is critical for successful surgical removal. X-ray examination is able to detect radiopaque fragments (metals), whereas radiolucent material (vegetable, wood) may remain undetected even at surgery [8]. US has proven to be an accurate means to identify and locate both opaque and radiolucent foreign bodies [9–14], which appear as hyperechoic structures with acoustic shadowing, comet tail artifact (metallic fragments) or both (Fig. 1). In subacute and chronic lesions, a hypoechoic area surrounding the foreign body can be demonstrated as a result of reactive inflammation, abscess or granuloma for-

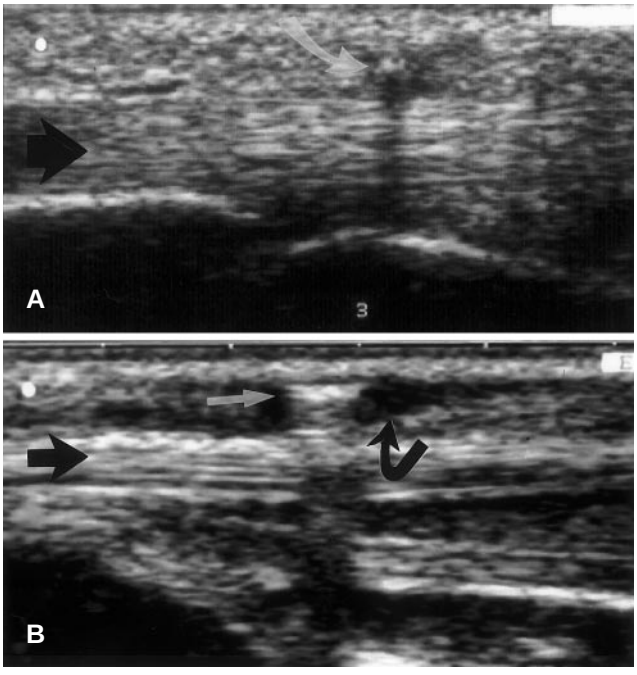


Fig. 1A, B Foreign bodies. Longitudinal 10–13 MHz US scans in two patients presenting with wood (**A**) and glass (**B**) foreign bodies located in the ventral aspect of the finger and the palm respectively. Both foreign bodies appear as small hyperechoic structures (*white arrows*) located in close relationship with the flexor tendons (*black straight arrows*). The first exhibits a sharp acoustic shadowing, the second a comet tail artifact. In **B**, a hypoechoic rim (*black curved arrow*) due to reactive inflammation surrounds the fragment

mation (Fig. 1B). The posterior artifacts and surrounding hypoechoic area are often helpful in detecting small foreign bodies that could otherwise be unnoticed. Standard radiographs show the size and shape of radiopaque foreign bodies better than US, since US can visualize only the superficial aspect of the fragment [14]. US shows the relationships with surrounding structures more precisely, and preoperatively US-guided positioning of a cutaneous marker can help the surgeon to localize the fragment [14], while the depth below the skin can be reliably measured with electronic calipers [14]. This can avoid long intraoperative searches, minimizes damage to soft tissues and avoids irradiation. Complications of foreign bodies, such as tenosynovitis, can be assessed with US [11] (Fig. 2). Limitations of this technique are: false positives, usually due to soft tissue calcification and sesamoids located in unexpected sites, and false negatives, mainly occurring in the acute phases of trauma when open wounds and intervening soft tissue gas can obscure the pathology [9].

A common injury of ligaments in the hand involves the ulnar collateral ligament (UCL) of the thumb, often referred to as gamekeeper thumb or ski pole [15–19]. Displaced tears of UCL require surgery to prevent instability of the metacarpophalangeal joint and functional impairment of the hand. US findings of disruption have been described and compared with MRI findings [15], cadaveric specimens [16] and surgical data [17]. US is able to identify a tear of the UCL in approximately 90% of surgically proven cases [17, 18]. Differentiation between displaced and nondisplaced ligament can readily be obtained, and this can help to establish the need for surgery [17].

The digital annular pulleys, which retain the flexor tendons against the bones during flexion of the finger [20], can be damaged by both chronic microtrauma and acute injuries. Repetitive movements of the finger may lead to both thickening of the annular pulleys and swelling of the tendons with subsequent impingement of the involved tendon in the narrowed digital tunnel. Clinically, the condition is known as “trigger finger”, where transient locking of the flexed finger is followed by a painful snapping during extension. US findings include diffuse thickening of the synovial sheath and increased size and irregular echotexture of the involved tendons [21]. Dynamic changes in the shape of peritendinous envelopes are commonly observed. Although the diagnosis of trigger finger is clinical, US can guide therapeutic decisions (sectioning of the thickened annular pulleys versus local injections of steroids). Acute injuries of annular pulleys, due to maximal resisted flexion of the fingers, are observed in rock climbers who are accustomed to hold the body weight with one hand. If they are not treated early and appropriately these ruptures can cause chronic pain and flexion contractures. Although annular pulleys cannot be visualized by conventional imaging, the diagnosis of tears can be made by demonstrating subluxation of the flexor tendons: instead of coursing along the concavity of the phalanges, they lie at variable distances from the volar cortex of the phalanges. Dynamic US scans obtained during resisted flexion of the affected finger may increase the subluxation of tendons (Fig. 3A,B). A peritendinous fluid collection due to tenosynovitis is commonly observed in patients with pain. US findings of annular pulley tears correlate well with the MRI findings (Fig. 3C,D), and although MRI and CT are able to diagnose such tears, US can be considered an effective and less expensive alternative.

High-frequency US probes can be used to examine all tendons of the hand and wrist from their myotendinous origin through to the bone insertion. Careful scanning technique performed with either passive or active movements of the fingers, and the depiction of the fibrillar echotexture with the knowledge of anatomic landmarks, are all crucial in identifying tendons and differentiating them from adjacent structures [22]. Partial tendon tears usually present with tendon swelling, echotextural abnormalities and signs of tendon discontinuity. In complete tears, the ruptured tendon is not visualized at the site of injury and its retracted end can be seen proximally (Fig. 4). In acute lesions, an effusion in the tendon sheath is usually observed. US has proven to be an effective means of re-

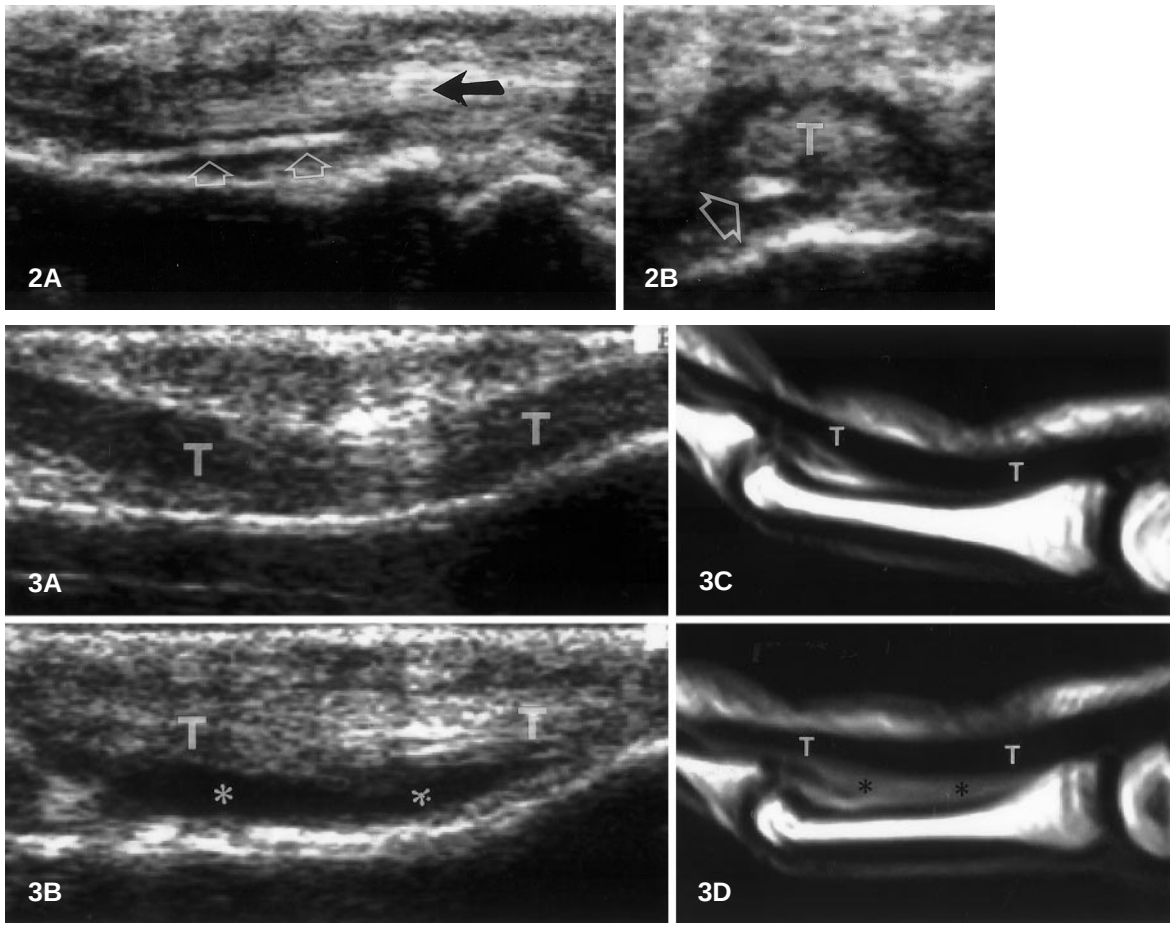


Fig. 2A, B Tenosynovitis caused by a foreign body. Longitudinal (**A**) and transverse (**B**) 10–13 MHz US scans in the middle finger over the proximal phalanx show an elongated wood fragment (*open arrows*) penetrating the synovial sheath of the flexor tendons (*T, black arrow*). A thin hypoechoic effusion in the tendon sheath permits the precise localization of the fragment in the synovial space

Fig. 3A–D Ruptured annular pulley of the ring finger. Longitudinal 10–13 MHz US sonograms of the middle (**A**) and ring (**B**) fingers over the proximal phalanx during mild flexion, with T1-weighted MR correlation (**C,D**). In **A** and **C**, normal flexor tendons (*T*) lie against the bone. In **B** and **D**, flexor tendon subluxation leads to an increased distance of the tendons (*T*) from the bone. An effusion in the synovial space (*asterisks*) is demonstrated

viewing the integrity of surgical repair of flexor tendons [23].

The value of US in post-traumatic nerve tears is twofold: confirmation of the clinical and electromyographic diagnosis and assessment of the level of injury. In complete tears, the nerve body is interrupted by an irregular hypoechoic area interposed between the nerve ends due to inflammatory changes. Local pressure obtained with the probe during scanning can lead to acute pain (sonographic Tinel sign).

Because of their superficial location and close proximity to the bone, vessels of the hand and wrist are predisposed to injuries. Microtrauma to the vessel wall may cause intimal thickening with fibrin deposits, thrombosis and pseudoaneurysms. The ulnar artery and its branches are most commonly affected, especially in Guyon's canal, where this vessel can be damaged against the hook of the hamate [24, 25]. Repeated local trauma can result in arterial thrombosis and, possibly, in ulnar nerve damage. US shows lack of pulsation of the artery and the clot, as a hypoechoic structure filling the lumen. Color Doppler can increase the diagnostic confidence by showing absent flow in the artery. Retrograde flow in the arterial palmar arches can be encountered in cases of occlusion of one of the feeding arteries (radial or ulnar) and in arterial steals caused by hemodialysis fistulas. When arteriovenous fistulas are created between the radial artery and the cephalic vein in the distal forearm, blood flow from the ulnar artery can contribute to fistula flow via the palmar arches and retrograde flow in the distal radial artery.

Although the value of US in diagnosing scaphoid fractures has been discussed [26], the diagnosis of bone abnormalities and fractures relies mainly on radiography or high-resolution CT. However, bone surfaces should be examined during a routine US study of the hand and wrist, and even minor irregularity of the bone surface should precipitate further imaging studies.

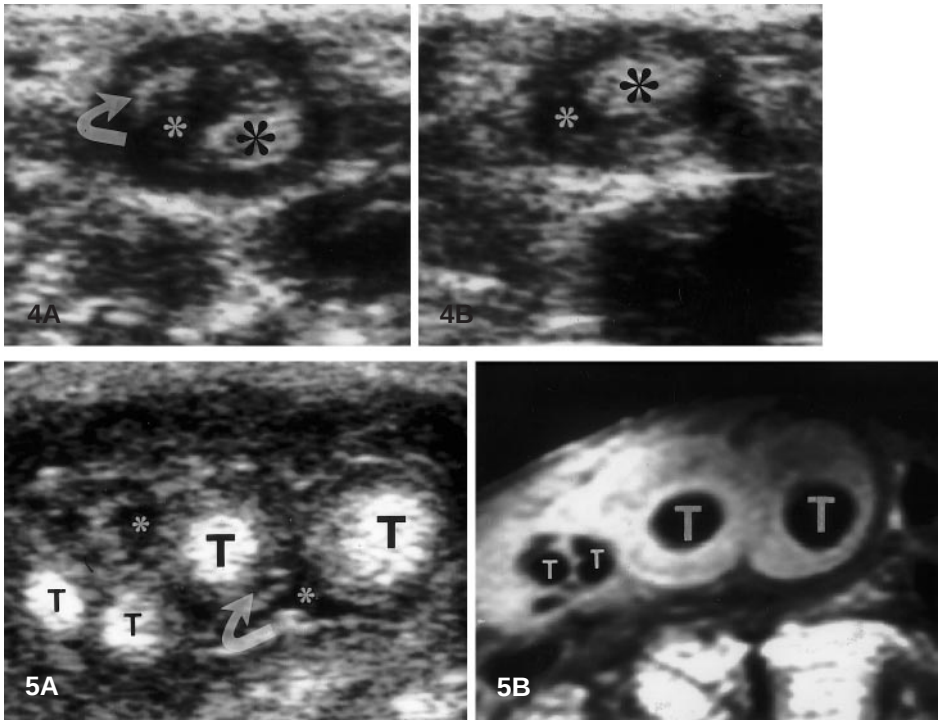


Fig. 4A, B Complete tear of the superficial flexor digitorum tendon. Transverse 10–13 MHz US scans in the index finger over the metacarpophalangeal joint (**A**) and the proximal phalanx (**B**). At the proximal level, the ruptured end of the superficial flexor tendon (*curved arrow*) and the intact deep tendon (*black asterisk*) are delineated by an effusion in the synovial space (*white asterisk*). At the distal level, only the deep tendon is seen

Fig. 5A, B Tuberculous tenosynovitis. Corresponding transverse US (**A**) and Gd-enhanced T1-weighted MR (**B**) images in the dorsal aspect of the wrist. In **A**, the synovial membranes (*curved arrow*) of the extensor tendons (*T*) appear markedly thickened and hypoechoic, and can easily be differentiated from the surrounding anechoic effusion (*asterisks*). In **B**, the correlative MR scan shows contrast enhancement in the thickened synovial sheaths of the extensor tendons (*T*) as an expression of the inflammatory hyperemia

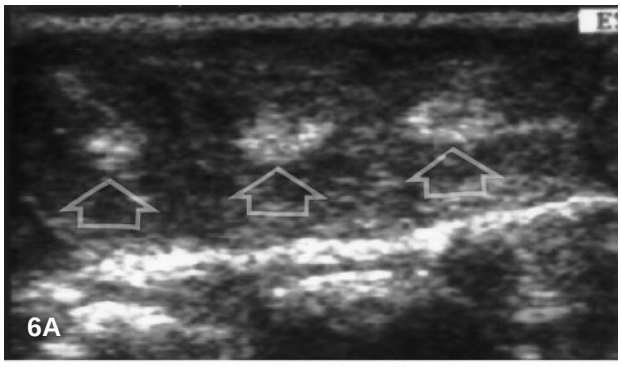
Inflammatory and degenerative diseases

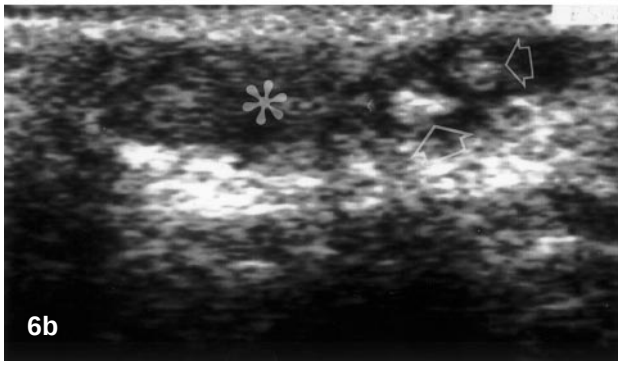
In normal states, the synovial sheath of flexor tendons can barely be detected as a thin and regular hypoechoic rim of less than 1 mm thickness on both ventral and dorsal tendon surfaces, while the extensor tendon sheath is too small to be appreciated. In tenosynovitis, the increased amount of synovial fluid typically appears as a hypoechoic collection surrounding the hyperechogenic tendon [27–29]. A thickened synovial sheath may be observed. Depending on the characteristics of fluid and synovial tissue, tenosynovitis can be classified as serous, infective or hypertrophic.

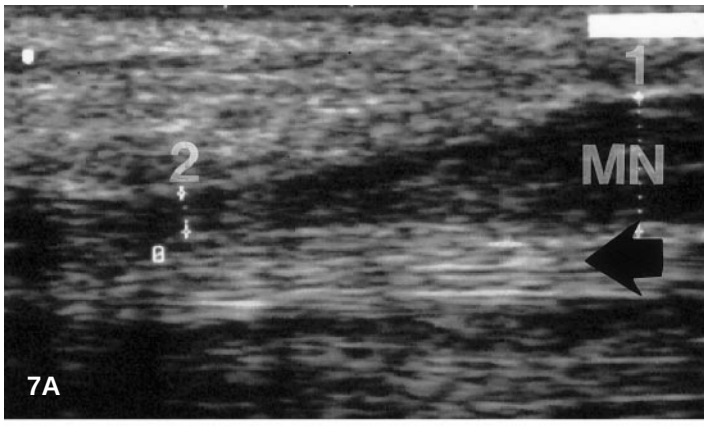
A typical example of serous tenosynovitis of the wrist is seen "De Quervain disease", in which chronic microtrauma at the level of the extensor retinaculum of the wrist leads to inflammation of the extensor pollicis brevis and abductor pollicis longus tendons with thickening of the retinaculum. The main clinical feature is pain around the styloid process of the radius that is exacerbated by movements of the thumb and by passive ulnar deviation of the wrist with the thumb maximally flexed (Finkelstein test). US shows swelling of the affected tendons, which appear hypoechoic and have an irregular echotexture [30]. In acute cases, a synovial effusion within the tendon sheath is usually demonstrated, thus making possible the detection of accessory tendons. US detection of a thickened and hypoechoic extensor retinaculum, usually observed in chronic cases, suggests the need for surgical decompression. In addition, US can identify postsurgical complications, such as the volar subluxation of tendons due to excessive division of the retinaculum.

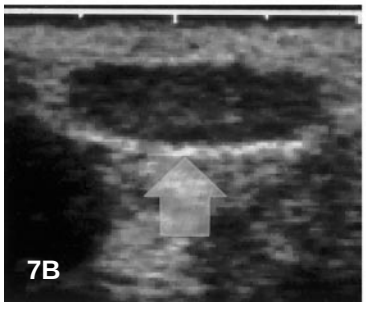
In the diagnosis of infective tenosynovitis, the main advantage of US is the possibility of early diagnosis [31] through the detection of an echogenic effusion [31, 32]. However, these textural characteristics may be subtle and US-guided aspiration of the fluid is usually required to confirm the diagnosis. In tuberculous tenosynovitis, the synovial membranes appear markedly thickened as a result of granulomatous changes (Fig. 5).

In hypertrophic tenosynovitis (i.e., rheumatoid, psoriatic), hyperechoic villous projections develop inside the effusion and can fill the tendon sheath [33, 34] (Fig. 6). In the acute phases of inflammation, color Doppler demonstrates a hypervascular pattern within the synovial folds, and may help gray-scale US to differentiate synovial pannus from the effusion. In addition, a consistent reduction of synovial hyperemia can be observed as a response to medical therapy. In longstanding tenosynovitis, US can help to assess the integrity of tendons. Although complete tendons tears can be affirmed on clinical grounds, US may be used to locate the proximal retracted









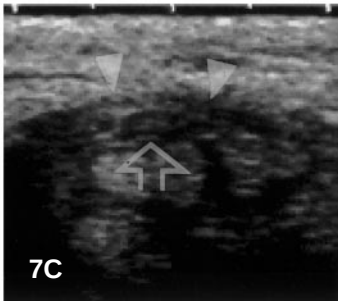


Fig. 6A, B Rheumatoid arthritis. Transverse 10–13 MHz US scans in the dorsal aspect of wrist obtained in the same patient at 2-year interval. **A** In the early study, the second to fourth extensor tendons are surrounded by a hypertrophic hypoechoic pannus. They appear as hyperechoic rounded structures (*open arrows*) with slight internal inhomogeneities and irregular outlines. **B** After 2 years, the third and fourth extensor tendons shown in **A** are not evident following complete rupture and proximal retraction. Within the synovial pannus (*asterisk*), only the second extensor digitorum and pollicis longus tendons (*open arrows*) can still be recognized

Fig. 7A–C Carpal tunnel syndrome. **A** Longitudinal 8–15 MHz US scan shows consistent flattening of the median nerve (*MN*) within the carpal tunnel and swelling of the nerve proximal to the compression point. *Arrow* flexor tendons. **B** Transverse image at the level *1* indicated in **A**. At the distal radius, the median nerve (*arrow*) is markedly enlarged. **C** Transverse image at the level *2* indicated in **A**. The median nerve (*open arrow*) is reduced in size within the tunnel and the appearance of the flexor retinaculum is convex (*arrowheads*)

end of the torn tendon [33], as well as to exclude nerve trauma, which can occasionally mimic tendon ruptures. The role of US in inflammatory joint diseases has mainly been assessed in rheumatoid arthritis [35–40]. US can differentiate the functional impairment due to primary joint disease from para-articular involvement, detect radiocarpal, mediocarpal and finger joints effusions [35, 36], rule out tenosynovitis and monitor the effects of therapy using soft tissue swelling [38] and color Doppler findings. Widening of the joint cavity, loss of definition of articular cartilage and bone erosions can be detected [35] and US can be used to guide synovial biopsy [39].

US has been reported as helpful in some degenerative diseases affecting the hand and wrist. In chronic diabetes this technique is able to demonstrate the thickening of the flexor tendon sheath, a finding associated with complications of diabetic microangiopathy [41]. In scleroderma, the measurement of the skin thickness by means of very high frequency US probes in both clinically involved and noninvolved areas can support an early diagnosis [42]. Finally, additional applications of US in degenerative disorders of the hand have been proposed in the assessment of chondrocalcinosis [43] and Dupuytren's disease [44].

Entrapment neuropathies

Nerves can consistently be depicted at the wrist with high-frequency probes [45–48]. They can be differentiated from adjacent tendons due to specific anatomic landmarks, different behavior during dynamic study and their fascicular versus fibrillar echotexture [22, 48].

In the carpal tunnel, the median nerve typically lies just deep to the transverse carpal ligament and superficial to the flexor tendons of the second and third fingers and the flexor pollicis longus tendon. On transverse scans, the nerve is elliptical and flattens progressively as it courses through the tunnel. The ability of US to depict the median nerve at the wrist may allow the detection of anatomic variants, such as accessory branches, the proximal bifurcation of the nerve or the presence of the

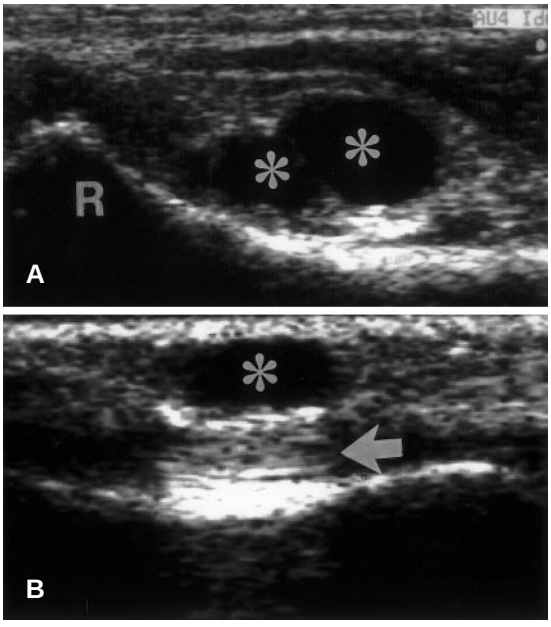


Fig. 8A, B Ganglion cysts. **A** Deep ventral ganglion. Longitudinal 10–13 MHz US scan in the ventral aspect of the wrist shows a well-defined bilobated cystic mass (*asterisks*) over the distal radius (*R*). The mass was nonpalpable. **B** Digital ganglion. Longitudinal 10–13 MHz US image obtained at the base of the index finger demonstrates an oval anechoic cyst (*asterisk*) with marked posterior acoustic enhancement superficial to the flexor tendons (*arrow*)

median artery. Identification of these variants may be important prior to endoscopic release to avoid inadvertent resection of aberrant nerve bundles. Carpal tunnel syndrome is caused by either a decrease in the size of the tunnel or an increase in the volume within the confined space of the tunnel. US signs of median nerve compression include: flattening or deformity of the nerve within the tunnel; bulbous swelling of the nerve portion proximal to the tunnel; and palmar bowing of the flexor retinaculum, which normally is straight or slightly convex (Fig. 7). US can be used effectively to identify extrinsic compression by soft tissue masses, cysts, tenosynovitis of flexor tendons, accessory muscles, etc. US may also be useful in patients with recurrent or unrelieved symptoms after carpal tunnel release; common pathologies are incomplete division of the flexor retinaculum and fibrous proliferation involving the nerve.

Guyon's canal is a fibrous tunnel, formed by the transverse and palmar carpal ligaments, which contains the ulnar artery and vein, the ulnar nerve and fat. In transverse scans, the ulnar nerve appears as a rounded structure, located medially to the ulnar artery. US can detect space-occupying lesions within Guyon's canal. Ganglia may cause compression of the ulnar nerve within the canal. Other causes of ulnar nerve entrapment include repeated local trauma and vascular diseases.

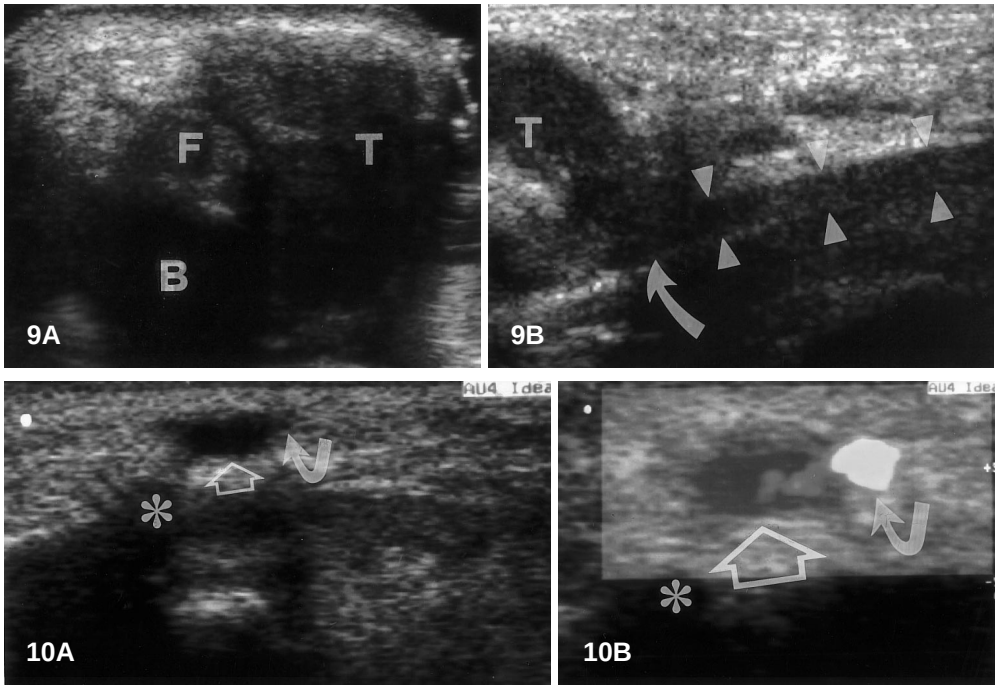


Fig. 9A, B Solid tumors. **A**, Schwannoma of the median nerve. Longitudinal 10–5MHz US scan in the mid-palmar region demonstrates a hypoechoic rounded mass (*T*). The neurogenic nature of the tumor is suggested by the continuity (*curved arrow*) between the mass and the nerve (*arrowheads*). **B** Giant cell tumor of the tendon sheath. Transverse 8–15 MHz sonogram obtained at the base of the middle finger demonstrates a solid hypoechoic mass (*T*) with a crescentic profile and irregular margins that grows circumferentially to the flexor tendons (*F*). *B* bone

Fig. 10A, B Arterial pseudoaneurysm. **A** Transverse gray-scale 10–13 MHz sonogram in the radial aspect of the wrist shows a small cyst (*open arrow*) adjacent to a pulsatile vessel (*curved arrow*) over the tubercle of the trapezium (*asterisk*). **B** Color Doppler identifies the vascular nature of the cyst by demonstrating internal flow signals. The pseudoaneurysm originated from the superficial palmar branch of the radial artery

Space-occupying lesions

In patients with localized swelling of the hand and wrist, US can be used to confirm the presence of a mass lesion. There are occasions when a specific diagnosis may be strongly suspected. These include: ganglion cyst, giant cell tumor of the tendon sheath, nerve tumor, lipoma, pseudoaneurysm, anomalous muscle and glomus tumor.

Ganglia, the most common space-occupying lesion of the hand and wrist, are cystic masses filled by viscous fluid and lacking a true synovial lining. They derive from degeneration of periarticular soft tissues [49]. US demonstrates ganglia as well-defined anechoic structures with posterior acoustic enhancement, located close to a joint [50–55]. Most ganglia occur on the dorsal aspect of the wrist. Dorsal ganglia have a larger component that lies superficial to the extensor tendons and a deep component located at the level of the joint capsule; the two components communicate through a thin and tortuous pedicle. Ventral ganglia are usually located on the radial aspect of the wrist: they originate from the scapho-trapezial joint and frequently expand to reach the distal epiphysis of the radius where they may compress and displace the radial artery and the superficial sensitive branch of the median nerve (Fig. 8A). Digital ganglia are palpable masses at the base of the fingers (the third and fourth are the most commonly involved) and may lead to significant discomfort and pain. US depicts them as small anechoic lesions usually located palmar to the proximal phalanx (Fig. 8B). In clinical practice, US is a valuable tool for the diagnosis of ganglia, especially in cases of small occult lesions [54], and shows their size, location and relationships with adjacent vessels, nerves and tendons [47]. In selected cases, US can be used to guide the aspiration of the ganglion and the local injection of steroids [51].

Giant cell tumor of the tendon sheath (GCTTS), also known as localized pigmented villonodular synovitis, is the second most common space-occupying lesion of the hand. It appears as a hypoechoic, solid mass with well-defined margins usually close to the flexor tendons [50]. Unlike digital ganglia, GCTTS has internal echoes, lacks posterior acoustic enhancement and can show internal vascular signals using color Doppler (Fig. 9A). Cortical bone erosions of the phalanges, secondary to pressure from the overlying lesion, can be demonstrated at US. After surgery, US may be helpful for screening recurrences due to the local invasiveness of GCTTS. Peripheral nerve tumors of the hand and wrist, including schwannomas, neurofibromas and neural fibrolipomas, are uncommon. Most involve the median nerve and typically present with a soft, slowly enlarging mass occurring in the volar aspect of the hand and wrist. Nerve tumors have a nonspecific appearance on US, usually as oval hypoechoic solid masses with well-defined margins. The feature of value in differentiating these tumors from other soft tissue masses is demonstration of the continuity between the tumor and the nerve of origin [48]. This requires careful scanning technique because the normal nerve at each end of the tumor may be displaced from its natural course by the enlarging mass (Fig. 9B). The nerve immediately adjacent to the tumor may be thickened with loss of anisotropy, thus producing a tapering appearance to the oval tumor. Tumors of the median nerve at the wrist may cause bowing of the flexor retinaculum, and carpal tunnel syndrome may be a late symptom. US may correctly suggest the diagnosis of neural fibrolipoma, also known as fibrolipomatous hamartoma, in the median nerve in patients with syndactyly or macrodactyly usually involving the index and middle fingers. This lesion is described as a fusiform enlargement of the median nerve by fibrofatty tissue which infiltrates the interfascicular epineurium, and US typically shows a relatively mobile mass of intermixed echogenicity with bowing of the flexor retinaculum [56].

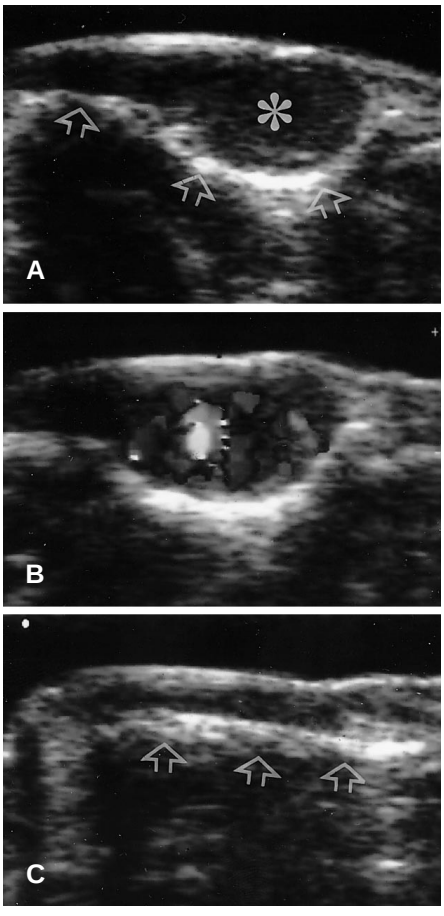


Fig. 11A–C Glomus tumor. Longitudinal 10–13 MHz US scan in the dorsal aspect of distal phalanx of the middle finger. **A** A solid homogeneously hypoechoic mass (*asterisk*) develops in the soft tissues interposed between the nail and the phalangeal bone. The concave surface of the bone beneath the tumor reflects phalangeal erosion (*open arrows*). **B** The tumor shows a peculiar hypervascular pattern at color Doppler. **C** Contralateral normal finger. Cortical bone of the distal phalanx is indicated with *open arrows*

Lipomas in the hand are often large and lobulated, and blending of the fat into the surrounding subcutaneous or muscular tissue usually results in ill-defined margins. US can easily characterize these lesions based on their typical striated echotexture with internal linear echogenic pattern.

Direct penetrating injuries to arteries can lead to pseudoaneurysm formation. Clinically, pseudoaneurysms are soft, slowly growing masses, which can be asymptomatic or cause ischemia and trophic changes. At US, they exhibit sharp margins and mixed echogenic (thrombus) and anechoic (flowing blood) content [57] (Fig. 10A). Color Doppler is able to detect the afferent artery and flow signals within the mass (Fig. 10B). These signs can avoid the need for further imaging including digital subtraction angiography.

Anomalous flexor and extensor muscles of the hand and wrist, such as the extensor digitorum manus brevis, present as soft tissue swelling that can cause nerve entrapment, when located in the carpal tunnel, or local pain during manual labor. Although MRI is helpful in evaluating the size and location of anomalous muscles, the signal intensity of the muscle can be similar to that of GCTTS [58]. US shows anomalous muscles as hypoechoic lesions in close relationship to tendons, with the typical striated appearance of muscle. Dynamic study during contraction shows the changes in the shape of the muscle mass.

Glomus tumor arises from the neuromyoarterial glomus, which is an end-organ apparatus with arteriovenous anastomoses, located in the subungual or palmar aspect of the finger. Excruciating pain exacerbated by local pressure or cold is a typical symptom. US shows a solid, homogeneously hypoechoic mass beneath the nail, possibly associated with erosion of the underlying phalangeal bone [59] (Fig. 11). The high-velocity flow of intratumoral shunt vessels makes this lesion a hypervascular mass at color Doppler. This finding is fairly specific for the diagnosis.

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