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PERSPECTIVE

What is the place of ultrasound in MSK imaging?

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Abstract

During the past four decades, ultrasound has become popular as an imaging modality applied to the musculoskeletal (MSK) system, particularly outside the USA, due to its low cost, accessibility, and lack of ionizing radiation. A basic requirement in performing these examinations is to have a core group of radiologists and ultrasound technologists with expertise in MSK ultrasound. The extent to which ultrasound will be part of the imaging offered by a particular radiology practice or in an academic institution will vary according to expertise, availability, and reimbursements. A brief discussion of the technical capabilities of the current generation of ultrasound scanners will be followed by a description of some of the more prevalent MSK ultrasound imaging applications. The extent to which training to perform these exams within and outside of Radiology plays a role is discussed. Applications that are unique to ultrasound, such as dynamic evaluation of musculoskeletal anatomy and some, US-guided interventions are an important part of MSK imaging. Ultrasound is increasingly important in the assessment of superficial structures, such as tendons, small joints, and peripheral nerves. These applications help to establish the place of ultrasound as an important part of the Radiologists approach to MSK imaging. Outside of radiology, for a variety of clinical subspecialties, ultrasound already plays an integral role in MSK imaging.

Introduction

During the past four decades, ultrasound has become popular as an imaging modality applied to the musculoskeletal (MSK) system, particularly outside the USA, due to its low cost, accessibility and lack of ionizing radiation [1–3]. In its current state, exquisite images of muscles, tendons, nerves, ligaments and joints can be obtained [2]. Paramount among these capabilities is the real-time nature of ultrasound enabling its use to provide guidance for a large variety of musculoskeletal interventions as well as performance of provocative maneuvers to accentuate a pathologic condition [4, 5]. Improvement in blood flow/vascularity detection and assessment of soft tissue mechanical properties further enhances the utility of ultrasound as an imaging modality [6–11]. A discussion of the technical capabilities of the current generation of ultrasound scanners will be followed by a description of some of the more prevalent imaging applications, which play an increasingly important role in musculoskeletal imaging. The latter discussion will, in part, relate to the author's own experience, which includes developing MSK ultrasound programs in three different academic institutions with strong orthopedic and rheumatology programs: the University of Michigan, Hospital for Special Surgery and New York University. The basic goal of this discussion, therefore, is to establish that ultrasound does have a place in MSK imaging.

Key points

- Guided interventions are among the most rapidly growing applications of MSK ultrasound.
- Ultrasound permits both anatomic and functional assessment of complex MSK anatomy.
- A core group of radiologists and technologists with expertise in MSK ultrasound, and adequate resident/fellow training is required to incorporate ultrasound as part of imaging services provided.

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Current technology

Many of the features incorporated in present day clinical scanners include improved assessment of soft tissue vascularity, improvements in anatomic depiction of superficial musculoskeletal anatomy, and characterization of soft tissue mechanical properties. The current generation of

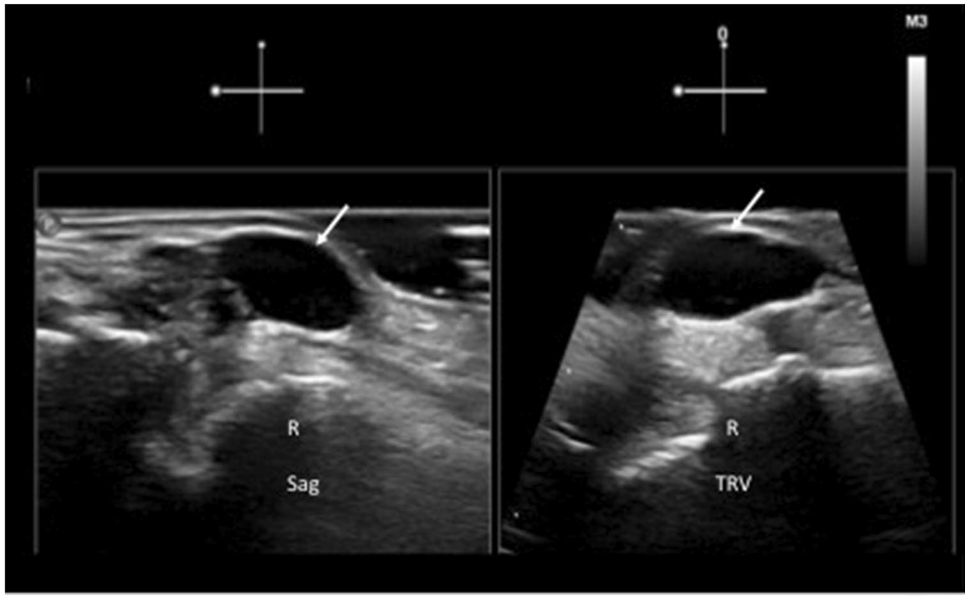

Fig. 1 Dorsal ganglion cyst (arrow) of the wrist obtained as a bi-planar image (left-sagittal, right- transverse) using a 14-MHz matrix array transducer. The transducer allows isotropic pixel size for real-time biplanar imaging, reformation to volumetric imaging, or alternate image planes. The radius (R) is labeled

multi-element linear array transducers may contain several hundred elements operating at high frequencies and wide bandwidths. This enhanced flexibility allows the imaging and operation of multiple modes within the same transducer at multiple frequencies selectable by the user or auto-selected according to depth. Rapid image acquisition and enhanced computational capabilities of newer systems allows for fast image processing. Incorporating these features, current ultrasound systems have evolved into digital architectures and beam formers, permitting beam steering, electronic focusing and continual miniaturization of electronics [12–15]. Smaller size components have additionally resulted new portable imaging systems, which weigh only a few pounds, in part resulting in rapid proliferation of ultrasound imaging and training programs by a number of clinical subspecialties outside of radiology (podiatry, rheumatology, sports medicine, physiatry, etc.) [16–18]. The current generation of scanners include 1.5- and 2-dimensional arrays allowing improved in- and out-of-plane (elevational) focusing, rapid image processing, 3-D and 4-D imaging (real-time volumetric imaging) [14, 15] (Fig. 1). One of the benefits of volumetric or multi-planar imaging is the reduction of "operator dependence," which has been one criticism of the utility of ultrasound [19, 20].

Gray scale imaging allows one to depict internal tissue morphology. A feature of gray scale images, however, is the appearance of an inherent granular noise within the image, known as speckle [21]. Current generation scanners offer improved gray scale imaging with various speckle reduction algorithms, resulting in more anatomic depictions of soft tissue anatomy [22–24]. In-plane speckle tracking algorithms, available in most systems, allow extended field of view imaging (EFOV or panoramic imaging), providing a large FOV image of MSK anatomy [25–27] (Fig. 2). Speckle tracking is also an integral part of calculation of local tissue displacement, which is used in compression-based elastography (sonopalpation) [8, 9, 28]. Many current systems also include acoustic radiation force impulse (ARFI) imaging, which when combined with speckle tracking techniques can produce parametric images and quantification of local shear wave velocity or Young's modulus [10, 11, 28] (Fig. 3).

Assessment of vascularity plays an important role in musculoskeletal imaging. Inflammation, repair processes and a variety of musculoskeletal tumors display varying degrees of vascularity which can serve as a measure of disease activity and/or response to a therapeutic intervention [6, 7, 29, 30]. In the musculoskeletal system, vascularity is characteristically low flow and often poly-directional. The limitations associated with conventional color Doppler maps include aliasing and drop out of signal when insonating at 90 degrees. In current ultrasound scanners, power Doppler (PD) provides an additional method to depict vascularity in which flow sensitivity is improved by encoding the demodulated Doppler signal intensity in color [31]. PD is not subject to aliasing artifact and it is not as sensitive to insonation angle.

PD is established to be a good indicator of hyperemic inflammatory states and can depict blood flow in soft tissues more readily than conventional color Doppler [6, 29, 30]. PD continues to be an important tool in assessing disease activity in inflammatory arthritis [30, 32] (Fig. 4). It is also more amenable to semi-quantitative estimates of vascularity, noting that it can provide a measure of fractional moving blood volume [33]. A fundamental problem with PD, however, is the presence of so-called blooming artifact, due to high amplitude low frequency motion at tissue interfaces (clutter). Newer generation high-end ultrasound scanners employ

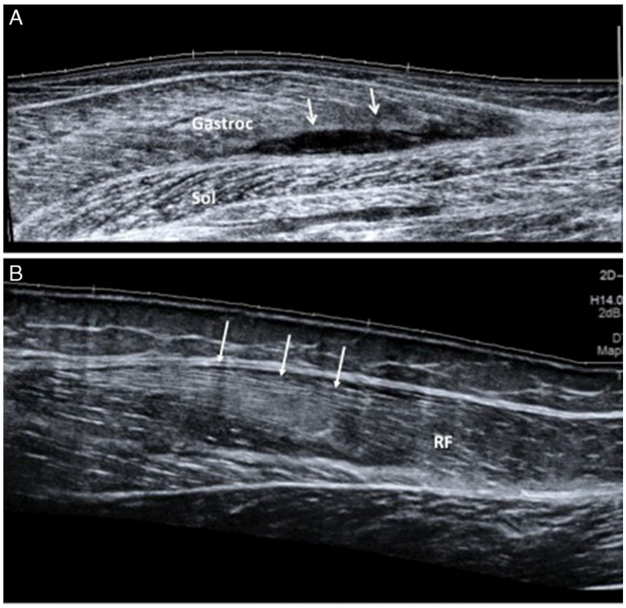

Fig. 2 **A** Extended field of view (EFOV) images of the right calf of a 36-year-old professional dancer with acute onset of pain following a jump. This image depicts the full extent of a myofascial tear of the distal medial gastrocnemius muscle (Gastroc) with a small hypoechoic collection (arrows) at the tear site. The soleus muscle (Sol) maintains normal morphology and echogenicity while the overlying gastrocnemius shows areas of patchy increased echogenicity, corresponding to edema and/or hemorrhage. No intramuscular extension of the hematoma is evident. **B** A 26-year-old professional dancer with stretch injury of the rectus femoris muscle. Subtle increased echogenicity (arrows) can be appreciated on the EFOV image relative to adjacent normal muscle

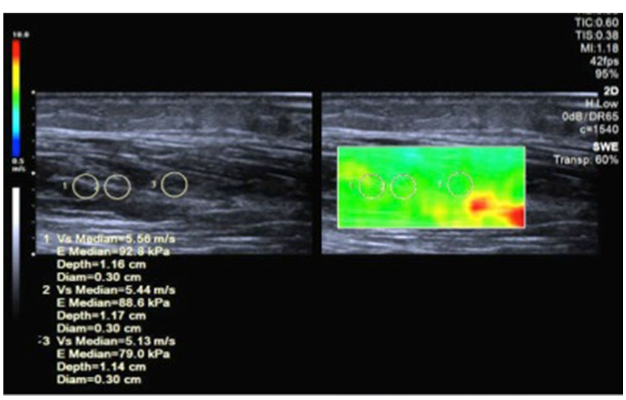

Fig. 3 Shear wave elastogram (right) obtained from the peroneal muscles (gray-scale image-left) in a patient with a foot drop. The color map is based on shear wave velocity within a specified rectangular region of interest (ROI) that can be further interrogated through a series of sample volumes (3-mm-diameter circles within the ROI). Numerical estimates of shear wave velocity (Vs) or Young's modulus (E) are listed for each sample volume. Corresponding gray scale image shows placement of sample volumes within the muscle

sophisticated adaptive clutter cancelling techniques, which are computationally intensive and are well suited to current technology [34]. These adaptive filters have a number of different names (slow flow, microvascular flow, etc.), but generally involve separation of the weakly scattering blood from low frequency motion of strong reflecting tissue boundaries. These microvascular flow techniques allow improved flow sensitivity and depiction of vascular anatomy while eliminating blooming artifact (Fig. 5).

The most sensitive method for blood flow detection requires use of ultrasound contrast agents, which are true capillary imaging agents. The current generation of contrast agents (second generation) display a good safety profile and have been used extensively in cardiology and abdominal imaging applications [35, 36]. Present day contrast agents are encapsulated microbubbles (2–10 microns in size) that undergo strong backscatter at certain resonant frequencies and are readily detectable, using harmonic imaging [36]. These agents are injected intravenously, pass through the pulmonary capillary bed and then appear in an arterial phase. The bubbles have a half-life of several minutes and the gas is ultimately exhaled in the lungs, while the outer shell is metabolized.

Contrast agents have been used in the musculoskeletal system in a limited fashion over the last 2 decades. They have been shown to allow robust quantification of vascularity and blood flow, but fall into the category of off label usage in the USA. Contrast has allowed remarkably improved flow sensitivity in the detection and quantification of hyperemic states, such as inflammatory myopathies, inflammatory arthritis, tendinosis and tendon repairs [37–40] (Fig. 6).

Clinical imaging applications

MSK applications of ultrasound generally fall into two categories: imaging that takes advantage of the real-time nature of ultrasound or conventional static high resolution imaging. Virtually all examinations have components of each. Examples of the former would include most ultrasound guided interventions or examinations in which a functional abnormality is elicited through some provocative maneuver, whereas the latter might include visualization of small peripheral nerve lesions and/or nerve injuries. For purposes of this discussion, some of the more common clinical MSK applications for ultrasound in the author's experience will be described and examples presented.

Intverventional ultrasound

Guided interventions are and will likely continue to be among the most rapidly growing applications of MSK ultrasound, due to the sonographic conspicuity of needles,

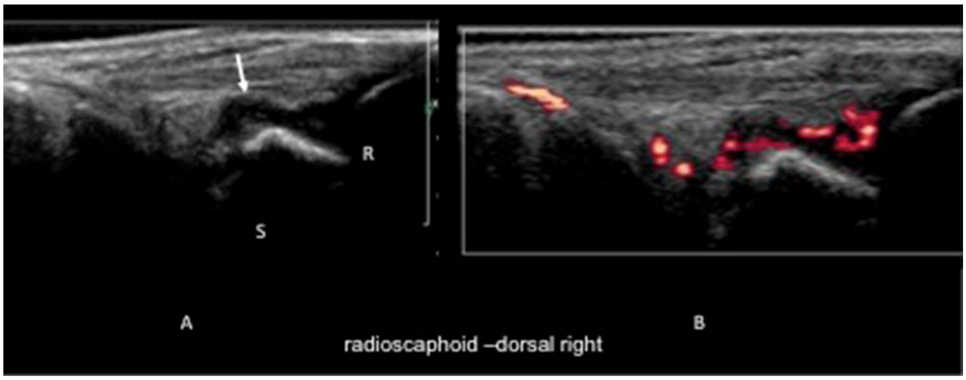

Fig. 4 A 35-year-old female with new onset rheumatoid arthritis (RA) presents with wrist swelling and normal radiographs. Sagittal gray scale (**A**) and power Doppler (**B**) image of the dorsal radioscaphoid joint shows distention of the dorsal recess (arrow) by hypoechoic soft tissue corresponding to inflammatory pannus. The power Doppler image (**B**) is optimized for maximum sensitivity without introducing noise. Prominent vascularity, depicted in color, within the inflammatory soft tissue is present. R = radius, S = scaphoid

excellent anatomic depiction as well as visualization of the distribution of injected and/or aspirated material in real-time [4]. Improved clinical outcomes in patients receiving ultrasound-guided intra-articular and soft tissue injections versus those performed by clinical landmarks or by palpation have been demonstrated [41, 42]. Currently, peripheral nerve blocks are largely performed under ultrasound guidance [43]. In our practice, ultrasound guided interventions comprise close to 50% of cases performed. Some of the earliest ultrasound guided interventions included aspirations of fluid collections, such as joint effusions, distended bursa or ganglion cysts [44, 45]. This has expanded to include injections and/or aspirations of both large and small joints, tendon sheath injections, peritendinous injections, barbotage of calcific deposits and perineural injections [4] (Fig. 7). For example, most MR arthrograms at our institution are currently injected under ultrasound guidance and virtually all small and medium size joint injections/aspirations utilize ultrasound guidance (Fig. 8). Additional procedures include injection of biologics (e.g., PRP), intralesional injections of neuromas, needle, or device placement in soft tissue masses for biopsy, ablations, wire or remote reflector placement pre-operatively for localization of a non-palpable lesion [4, 46–49] (Fig. 9). Ultrasound can also be combined with MR and CT through spatial registration to approach abnormalities that are less conspicuous on conventional real-time scans [50–52].

Diagnostic applications

Multiple different anatomic locations are accessible to ultrasound evaluation, including studies of complex anatomical structures such as the rotator cuff, hand and wrist, foot, and

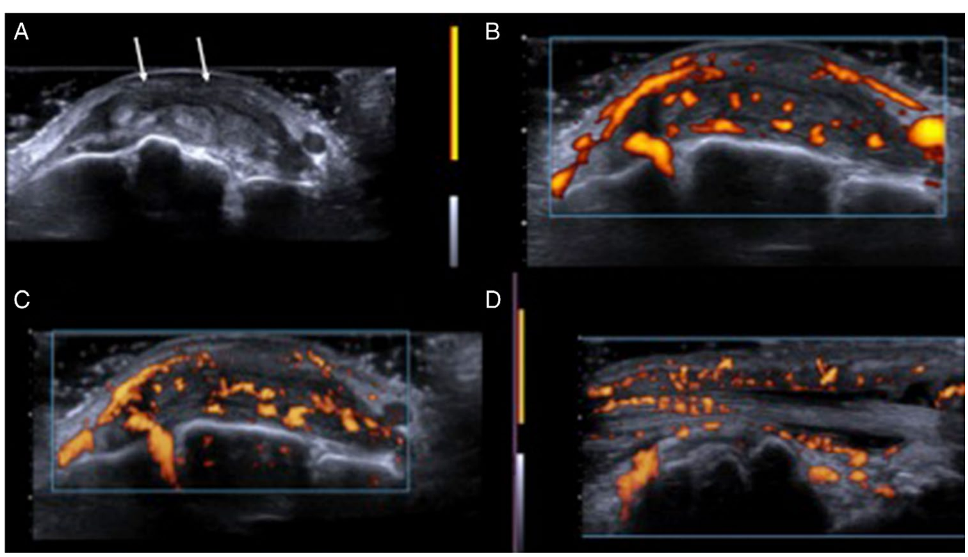

Fig. 5 A 42-year-old male with swelling over the dorsum of the left wrist. **A** Gray scale short axis image of a distended (arrows) 4th dorsal compartment showing abnormal soft tissue surrounding the tendons. Tendon margins are indistinct. **B** Conventional power Doppler image obtained in short axis demonstrates marked hypervascularity compatible with an inflammatory etiology. Short axis (**C**) and long axis (**D**) microvascular images of the 4th dorsal compartment shows finer vessel morphology as well as increased vascularity when compared to conventional power Doppler

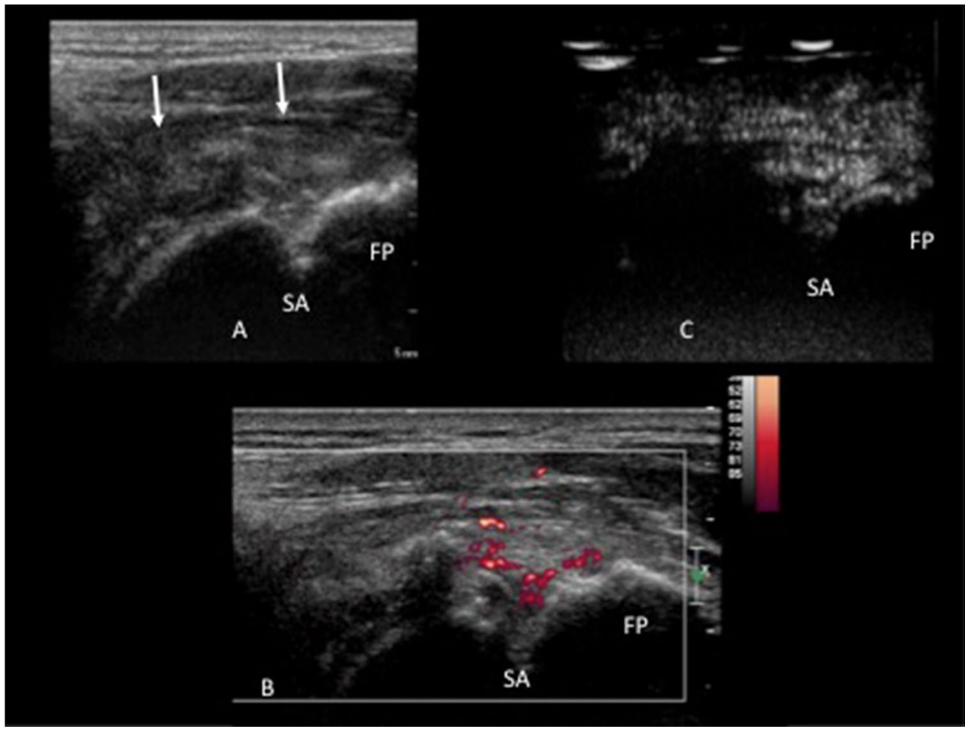

Fig. 6 A 64-year-old patient, 3 months following rotator cuff repair. **A** Gray scale long axis image of supraspinatus tendon demonstrates continuity and marked heterogeneity with loss of normal architecture. Arrows depict the bursal surface of the repair. **B** Power Doppler image optimized for maximal sensitivity without producing noise demonstrates vascularity at the suture anchor (SA), footprint (FP), and near the bursal surface of the repair in a spotty distribution. **C** Single frame from a contrast-enhanced study performed on the same day shows extensive microbubble enhancement in a peribursal distribution, throughout the footprint and suture anchor site

ankle [2, 3]. In addition to large joints, such as the knee, hip, and shoulder, ultrasound imaging is used for routine evaluation of small joint pathology [3]. These examinations include routine screens for inflammatory arthritis to assess for active synovitis and/or erosive disease. Ultrasound is particularly well suited to evaluate tendons in the hand, wrist, foot and ankle (Figs. 4, 5). A frequent use of the real-time capabilities in our practice is to assess tendon tears, integrity of surgical repair and possible adhesions, and tendon or joint subluxations [53]. One particularly important advantage is the absence of metallic artifact obscuring soft tissues when assessing tendon or nerve impingement (Fig. 10). In the foot, ultrasound is also routinely used to assess the plantar fascia for tears and fibromas, as well as interdigital neuromas, bursa, ganglion cysts, and plantar plate integrity [3, 54, 55].

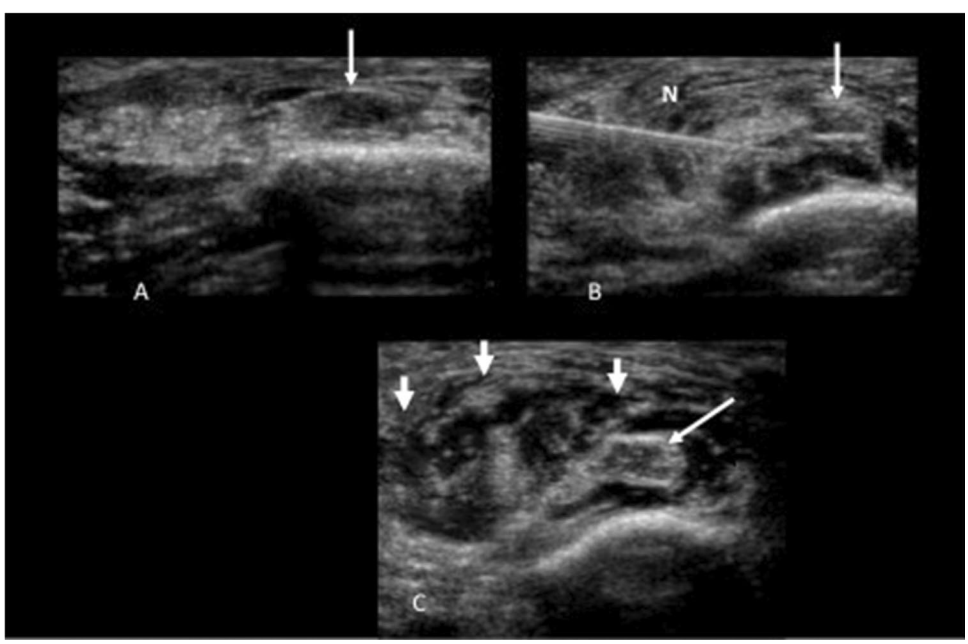

Fig. 7 A 19-year-old female athlete developed paresthesias following anterior compartment release. Injury to the superficial peroneal nerve was clinically suspected. **A** A small hypoechoic nodule (arrow) seen in continuity with the superficial peroneal nerve is compatible with a neuroma in continuity. **B** A 25-gauge needle (N) is positioned under ultrasound guidance adjacent to the nodule for purposes of a diagnostic injection to assess symptomatic relief. **C** Peri-neural injection of long acting anesthetic and cortisone (arrows) was performed to achieve a diagnostic nerve block and to assess pain relief

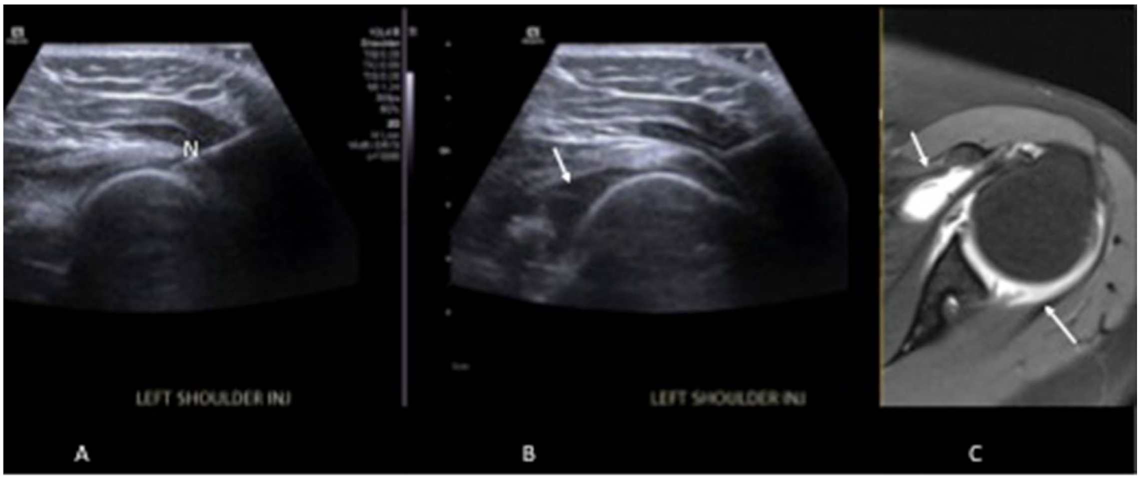

Fig. 8 A 28-year-old female with suspected labral tear sent for MR arthrography. **A** A 22 gauge needle (N) is positioned along the posterior recess of the glenohumeral joint deep to the infraspinatus tendon and superficial to the articular cartilage of the humeral head. **B** Distension of the posterior recess (arrow), seen in real-time, confirmed intra-articular distribution of injected material. **C** Subsequent T1-weighted fat-suppressed axial image displays distension of the glenohumeral joint capsule and communication with the superior recess of the subscapularis bursa (arrows) by a dilute gadolinium solution

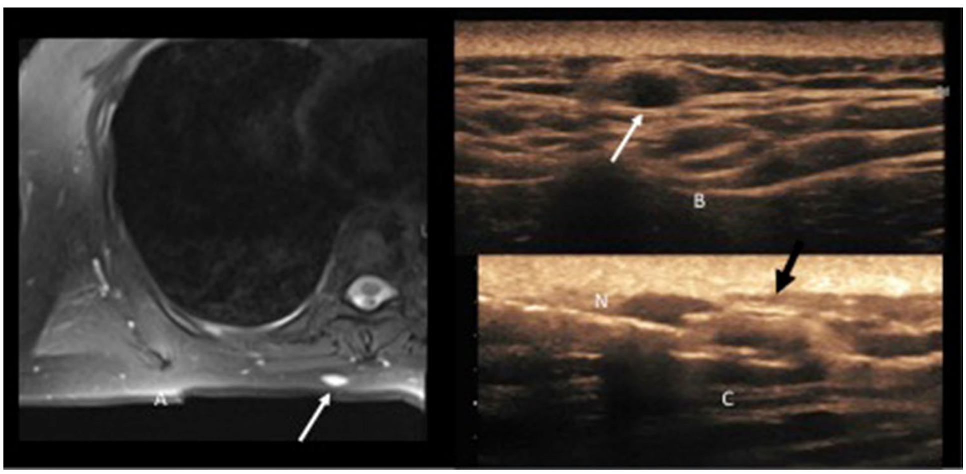

Fig. 9 **A** 52-year-old female with incidentally found small ovoid T2 bright nodule (arrow) in the back. The mass was non-palpable and measured less than 1 cm in maximal dimension. **B** The corresponding colorized gray scale image of the nodule (arrow) seen as a small ovoid hypoechoic mass in the subcutaneous fat abutting the dermis. **C** A savi scout needle (N) deploys a small radar reflector in the caudal aspect of the nodule (black arrow). The nodule was easily identified and surgically excised. Final diagnosis was dermatofibrosarcoma protuberans

The excellent near field resolution permits evaluation of small superficial nerves, such as the palmar digital nerves in the hand or posterior interosseous nerve in the elbow [53, 56]. Peripheral nerve evaluation using ultrasound in combination with MR neurography have become important complimentary imaging modalities for brachial plexus and peripheral nerve evaluation at our institution [57]. MR neurography allows examination of areas not easily accessible to ultrasound and provides a better overall gestalt of neural pathology and affected muscles. Intraneural architecture, partial or complete tears, perineural scarring, neuromas in continuity, and small nerve sheath tumors are often better visualized on ultrasound due to its superior spatial resolution (Fig. 11) [56].

Ultrasound is the best method to assess for foreign bodies, particularly those that are not radio-opaque, such as wood splinters and glass [58] (Fig. 12). Sensitivities and specificities ranging between 90–100% have been reported [59]. Foreign bodies are often linear with a surrounding inflammatory reaction that makes them conspicuous on

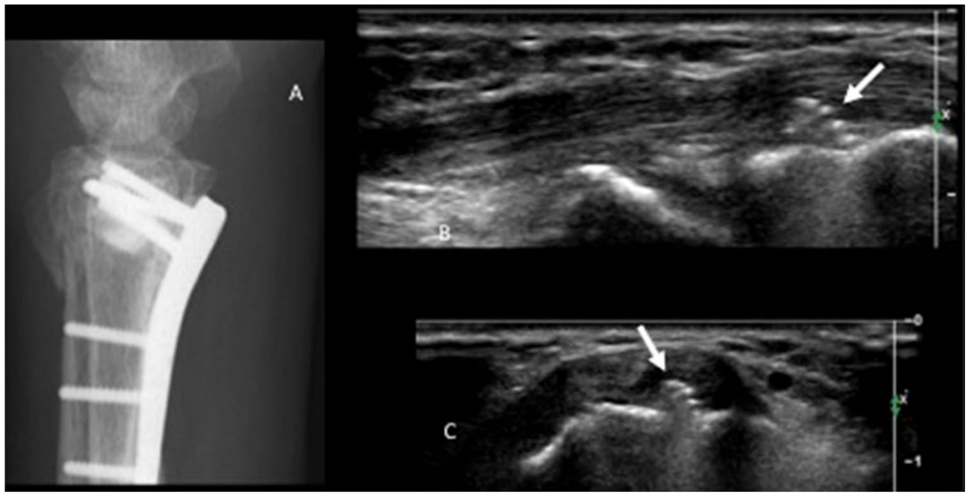

Fig. 10 Distal radial fracture in a 55-year-old female with indwelling volar plate. Patient developed dorsal wrist pain following the surgery. Lateral radiograph (**A**) shows volar plate and screw construct for treatment of a distal radial fracture. Patient was referred to ultrasound to evaluate dorsal wrist pain. Sagittal (**B**) and transverse (**C**) images along the dorsum of the wrist show a proud screw (arrow) in the distal radius impinging the deep surface of the extensor carpi radialis longus tendon (ECRL-arrows)

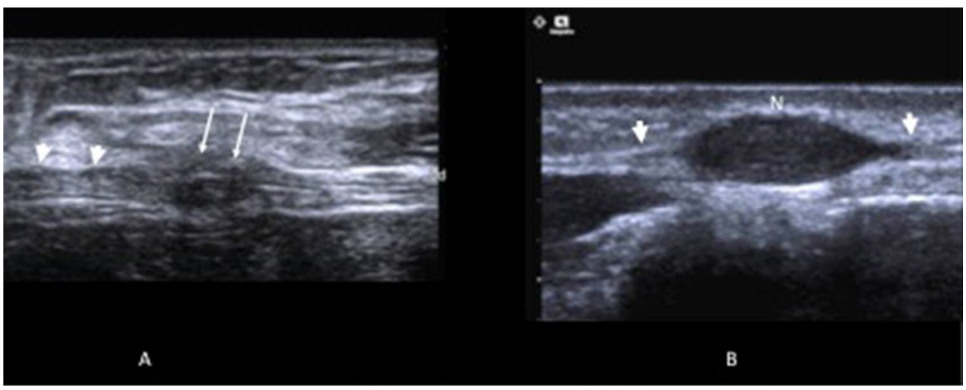

Fig. 11 **A** A 42-year-old male following laceration to the ulnar nerve. Long-axis gray scale image of the ulnar nerve shows an ill-defined hypoechoic nodule (arrows) along the superficial aspect of the ulnar nerve compatible with a neuroma in continuity. The proximal nerve appears morphologically normal, while the distal portion shows thickening and hypo-echogenicity along the superficial aspect of the nerve (short arrows). **B** A 20-year-old male with small symptomatic 5-mm nodule along the ulnar aspect of the forearm. No history of trauma. An ovoid hypoechoic nodule (N) with tapered margins is in continuity with a small muscular branch of the ulnar nerve (short arrows) is compatible with a small nerve sheath tumor

ultrasound [58]. While the primary role of ultrasound is identification and localization, ultrasound guided extraction under real-time guidance has been described [60].

The current generation of ultrasound scanners and transducers allows excellent depiction of the subcutaneous tissues. Consequently, ultrasound is increasingly important in evaluating patients with localized soft tissue swelling [53–55]. These assessments constitute up to 25% of our daily caseload. The most commonly seen mass is a subcutaneous lipoma which has a characteristic sonographic appearance. A variety of inflammatory or post-traumatic conditions may present as a mass and are frequently diagnosed. Ultrasound has been shown to be a highly sensitive modality for detection and characterization of superficial soft tissue masses [61–64]. The role of ultrasound here is primarily to assess for possible neoplasm and if necessary triage the patient appropriately for additional imaging, biopsy or possible surgical consult [62, 64]. In many cases, a precise diagnosis is possible, precluding the necessity for further imaging. If the lesion appears indeterminate but likely benign, short-term follow-up examinations (i.e., 3 months) are readily obtained. Masses are generally characterized by their location, internal morphology, vascularity, and more recently their internal elastic properties, providing useful information in determining appropriate work-up [61–65] (Fig. 13).

Ultrasound is likewise useful in assessing muscle pathology [66, 67] (Fig. 2). Internal muscle architecture in terms of fascicular organization is well depicted. Local stretch and compressive injuries that can present muscle edema patterns and/or tears are readily detected. Development of hematoma/seromas are accessible to guided

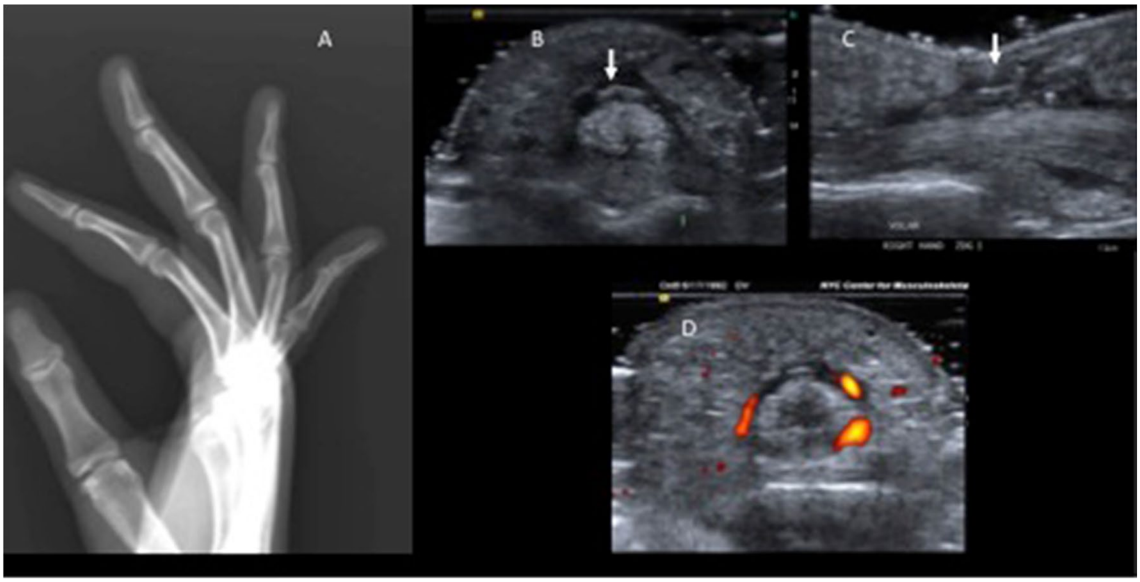

Fig. 12 A 23-year-old female had a puncture wound from a sea urchin spine in index finger of the right hand with the puncture site near the PIP joint. **A** Lateral radiograph shows no radiopaque foreign body. Short axis (**B**) and long axis (**C**) view of the volar aspect of the second digit shows a thin residual spine fragment (arrow) along the superficial margin of the tendon with thickening of the tendon sheath. **D** Power Doppler short axis image show peri-tendinous vascularity compatible with secondary inflammatory response

aspiration [4]. Ultrasound is excellent at demonstrating early dystrophic calcification or myositis ossificans. EFOV imaging often allows evaluation of the full extent of a muscle injury, although MR allows for greater global muscle assessment, such as in the inflammatory myopathies [68]. The role of shear wave elastography (SWE) assessment of muscle mechanical properties is expanding the use of ultrasound. Fatty infiltration, muscle spasticity, and fibrosis manifest characteristic changes on SWE, displayed as a parametric image or directly quantifiable in terms of Young's modulus [69, 70]. Novel therapeutic approaches to these abnormalities are currently being evaluated using these metrics [71].

Pragmatic considerations

The exact role of ultrasound in MSK imaging will undoubtedly vary between academic radiology and private practices, as well as by location. Ultrasound already is an important part of MSK point of care imaging by a variety of clinical subspecialties, as evidenced by the increasing number of training programs and utilization [17, 18, 72]. A recent (2023) survey of literature reporting educational methodologies for MSK ultrasound imaging spanned a number of fields, including radiology. Of the 67 articles cited by the authors, 62 were centered in non-radiology subspecialties or were considered

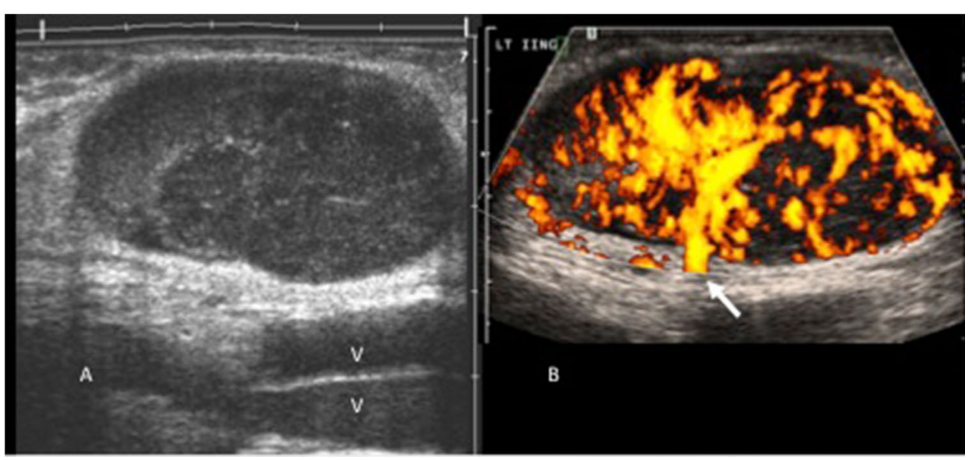

Fig. 13 A 70-year-old male with pulsatile left groin mass. Ultrasound ordered to assess for possible aneurysm. **A** Gray scale image over the pulsatile mass shows a heterogeneous hypoechoic soft tissue mass superficial to the femoral vessels (V). **B** Power Doppler image of the mass displays marked vascularity with a central vascular hilum (arrow) compatible with a pathologic lymph node. Lymphoma was diagnosed following excision

interdiciplinary [16]. A basic requirement in performing these examinations is to have a core group of radiologists and ultrasound technologists with expertise in MSK ultrasound. In order to achieve this goal, adequate MSK ultrasound training should exist in both residency and MSK fellowship programs. In a 2016 study, it was estimated that such training exists only in approximately 65% of academic radiology programs with greater levels of training offered in non-radiology clinical subspecialties (e.g., rheumatology, podiatry, etc.) [73]. Outside the USA, it is more common to have radiologists who are directly involved in scanning patients [18]. Within the USA, there is a greater emphasis on having trained technologists performing ultrasound examinations with variable input by the interpreting radiologist. In a positive note, MSK ultrasound has been adapted by ARDMS as one of the subspecialties for ultrasound training, producing increasing numbers of MSK-trained ultrasound technologists [74]. Additionally, ultrasound training is becoming more prevalent in MSK fellowship programs throughout the USA [73, 75]. The influx of trained physicians and technologists will have an impact on the availability of MSK ultrasound in the future. Ultrasound is, however, a physician-centric modality so that individual workloads, reimbursements, and availability can affect one's ability and interest to maintain high quality [76]. Consequently, the extent to which ultrasound will be part of the imaging offered by a particular radiology practice will vary, but in the author's opinion it will likely continue to grow. A second ingredient for ultrasound to become an important part of the MSK imaging is an interest on the part of clinicians to make referrals. In the author's experience, this entails both being directly approached by clinicians to perform certain examinations and being willing to learn how to do these examinations. Word-of-mouth following a positive outcome can also result in more referrals. There is also a misconception that increased Ultrasound volume negatively impacts MR volumes. In the author's experience, MR imaging continues to be the primary method to perform MSK cross-sectional imaging, and that growth of ultrasound has not detracted from this.

Summary

Ultrasound plays an important role in MSK imaging from both procedural and diagnostic applications. Some imaging examinations are uniquely suited to ultrasound and will likely continue to play a role in most academic radiology departments and private practices. Ultrasound is and will continue to be an important part of point of care MSK imaging in a variety of clinical subspecialties. A requirement for ultrasound to continue to be an integral part of MSK imaging performed by radiology is having a core group of trained MSK radiologists and ultrasound technologists to maintain quality and efficiency in performing these examinations. Incorporating adequate ultrasound training in academic radiology departments and MSK training for ultrasound technologists is an important part in fulfilling these requirements. A willingness to learn how to perform examinations outside ones comfort zone may also help promote growth of the modality.

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