Musculoskeletal ultrasound (MSK-US) is a rapidly developing diagnostic tool that may be utilized by clinicians at the bedside. By directly visualizing muscles, tendons, nerves, ligaments and bone, physicians can immediately and definitively diagnose many entities only suspected on physical exam, leading to improved diagnosis, treatment and patient satisfaction.\textsuperscript{1-5} MSK-US is comparable to magnetic resonance imaging (MRI) in its diagnostic capability of many MSK disorders, but consumes significantly less time and resources.\textsuperscript{6} In addition, MSK-US can be used in real time to aid the clinician with procedures such as arthrocentesis and reduction of fractures or dislocations.\textsuperscript{7}

The focus of this chapter will be to introduce concepts and terminology necessary for understanding point of care MSK-US and to review applications commonly encountered in urgent care and emergency department settings.
Transducer selection depends on the structure being imaged.
Comparing to normal contralateral side can be helpful.
Dynamic imaging is a major advantage of ultrasound.
Use slight probe pressure to isolate area of possible pathology.

Indications and Probe Selection
The indications for performing MSK-US include trauma, signs of inflammation or infection, or the presence of an abnormal musculoskeletal physical examination. A high frequency linear array transducer is ideal and suitable for most MSK-US applications; however, if the structure of interest is deep or requires a larger field of view then a lower frequency curvilinear probe may be necessary (Image 11.1).

Image 11.1 - Ultrasound Transducers
Left: high frequency linear probe. Right: low frequency curvilinear probe.
The techniques used in MSK-US hold true across most other forms of ultrasound examination. The operator should hold the probe like a pencil while using the fourth and fifth digits to anchor the hand on the patient. The area of interest should be systematically scanned in two orthogonal planes. With MSK-US, the patient should be positioned so that a dynamic examination is possible. Examination of the contralateral extremity should be performed. Assuming the absence of bilateral pathology, contralateral examination makes identification of pathology easier and more obvious by providing a normal comparison (Image 11.2).

Light transducer pressure can help isolate the point of maximal tenderness and help reveal certain pathologies, such as tendon ruptures or fractures (Movie 11.1).

**IMAGE 11.2 - Comparison of Contralateral Tendons**

Side-by-side comparison of contralateral tendons aids in identifying pathologic (left) from normal (right) tendon.

**MOVIE 11.1 - Light Probe Pressure**

Sternal fracture with intact periosteum exaggerated by light probe pressure.
Finally, obtaining a dynamic exam may help in demonstrating muscle or tendon pathology. This is accomplished by actively or passively moving the extremity of interest during the exam (Movie 11.2).

**Movie 11.2 - Passively Ranging the Ankle During Exam**

Achilles tendon rupture exaggerated by passively ranging the ankle.

Color and power Doppler aid in identifying inflammatory conditions associated with increased vascularity or inflammatory reaction.\(^2\)\(^4\) When necessary, copious amounts of gel, standoff pads or water baths should be utilized to improve imaging of very superficial structures, such as tendons and ligaments in the hands and feet (Image 11.3).

**Image 11.3 - Water Bath for Sonography of the Hand**

Proper technique. Note the complete structure to be imaged and the relatively shallow submersion of the transducer head.
Ultrasound of an extremity using a linear probe will allow visualization of multiple tissue layers, which can be divided into superficial and deep (Image 11.4). The superficial portion includes the epidermis, dermis and subcutaneous tissue. The epidermis and dermis are seen together as a solid, hyperechoic line of varying thickness at the top of the screen. Below the dermis, the subcutaneous tissue appears hypoechoic with occasional hyperechoic reticular strands. It may be of varying thickness depending on the location. In the ED, common pathology of the superficial soft tissue layers typically includes cellulitis, abscess and foreign body identification and removal, which are discussed in the Soft Tissue chapter. This chapter focuses on the deeper tissue layers and regions: muscles, tendons, ligaments, bones and joint spaces. Fascial planes serve as the border between superficial and deep structures and divide tissue layers. They are hyperechoic and may contain blood vessels and nerves.

In transverse, nerves are hyperechoic with a unique pattern of “honeycombing” as a result of the hypoechoic axonal areas with interdigitations of the hyperechoic peri- and epineurium (Image 11.5). Sonography of nerves is further discussed in the Peripheral Nerve Blocks chapter.
Muscle is composed of hypoechoic groups of fibers called fascicles with surrounding hyperechoic connective tissue called epimysium. Fascicles are arranged longitudinally within each muscle belly causing a speckled appearance in transverse and a pennate appearance in longitudinal\(^8\) (Image 11.6). The arrangement of fascicles varies based on muscle and can be either parallel or oblique.

When scanning for muscle pathology, it is important to place the patient in a position of comfort and apply probe pressure to determine the area of maximal tenderness.

**IMAGE 11.6 - Transverse and Longitudinal Views of a Muscle**

Note the hypoechoic muscle fascicles (stars) surrounded by hyperechoic investing perimysium (arrows).
EXAMPLES

**IMAGE 11.7 - Biceps Brachialis Muscle**

Note the heterogeneously echogenic biceps muscle (B) and the echogenic surface of the humerus (H).

**IMAGE 11.8 - Gastrocnemius & Soleus Muscles**

Note the heterogeneously echogenic muscle bellies of the gastrocnemius (G) and the soleus (S) separated by a linear hyperechoic fascia.

**MUSCLE INJURIES**

Muscle injuries can occur from either direct or indirect trauma. Direct trauma is the result of either a blunt or penetrating insult to the area of the muscle. Indirect trauma occurs when a muscle has been overstretched, which can damage or disrupt the elongated muscle fibers. Muscle injuries are classified as grades 1 to 3, depending on the extent to which the muscle has been undermined. In grade 1 injuries, the muscle sheath and fascia remain intact. Ultrasound may reveal swelling or enlargement of the muscle body, a loss of the normal pennate echotexture, or an intramuscular hematoma (Image 11.9, Movie 11.3).

**IMAGE 11.9 - Views of Intramuscular Hematoma**

Transverse (left) and longitudinal (right) images of a muscular injury, with a resulting intramuscular hematoma. Note the hypo- and anechoic regions present within the injured area of muscle, representing blood within muscle tissue.
The echotexture of hematomas varies with the age of the injury, and may appear as hypoechoic or heterogeneous. Grade 2 injuries occur when the muscle sheath and fascia are torn, and sonography may reveal blood traveling between muscle groups (Movie 11.4, Image 11.10).

Finally, grade 3 muscle injuries represent complete rupture of the muscle body, appearing as swollen, retracted muscle with surrounding hemorrhage⁵,⁸ (Image 11.11).
**Calcifications**

Muscular calcifications commonly occur as a sequela of muscle injury, resulting from the healing hematoma\(^8\) (Image 11.12). A more insidious cause of muscular ossification is the presence of a sarcoma. Distinguishing these calcifications can be aided sonographically, as those associated with trauma begin calcifying at the periphery of the lesion, whereas sarcomas begin their ossification at their necrotic center. Calcifications will appear hyperechoic with posterior acoustic shadowing presenting later in the healing process.\(^8\)

**Image 11.12 - Intramuscular Hematoma with Peripheral Calcification**

Note the posterior acoustic shadowing present deep to a calcified mass.

**Myositis/Pyomyositis**

Causes of myositis include trauma, infection, and autoimmune etiologies. Pyomyositis is muscular inflammation of bacterial etiology. Sonography will reveal an enlarged overall muscle diameter, hyperechoic muscle fibers, and exudate-filled hypoechoic septa\(^4,8\) (Image 11.13). However, these findings are not specific, and should be correlated with the clinical picture.

**Image 11.13 - Myositis of the Sternocleidomastoid Muscle**

Note the loss of normal muscular echotexture and surrounding anechoic inflammatory fluid.
A tendon is a compact group of collagen fibrils, organized longitudinally, similarly to muscle. Tendons tend to have a more uniform hyperechoic brush-like appearance.\(^4,5,9\) They appear longitudinally as hyperechoic fibrillar bands, and transversely as bundles of punctate hyperechogenicity (Image 11.14).

Depending on which tendon is being viewed, they may be surrounded with either a paratenon or synovial sheath.\(^9\) Paratenon is made up of loose areolar connective tissue, while synovial sheathes consist of two distinct layers separated by a tiny potential space, which makes them easier to sonographically image. Sheathed tendons occur more frequently in the hands, wrist, shoulders, and
ankles. They should be viewed along their entire course, as they attach their respective muscle to a bony prominence (Image 11.15, Movie 11.5).

In addition, a dynamic examination, having the patient move the distal extremity, helps evaluate tendon integrity (Movie 11.6).

**IMAGE 11.15** - Achilles Tendon Inserting into the Calcaneus


**MOVIE 11.5** - Achilles Tendon Inserting into Calcaneus

**MOVIE 11.6** - Tendon Visualization as Patient Actively Flexes Finger
EXAMPLES

**IMAGE 11.16 - Quadriceps Tendon**

Left: Proper technique for longitudinal imaging of the quadriceps tendon. Right: Resulting sonographic image of the quadriceps tendon (T) as it joins with the patella (P).

**MOVIE 11.7 - Quadriceps Tendon**

**IMAGE 11.17 - Hand Flexor Tendons**

Left: Proper sonographic examination of flexor tendons of the hand in longitudinal axis. Note the palmar approach. Right: Flexor tendon (T), third metacarpal (M), and proximal phalanx (P) in long axis.

**IMAGE 11.18 - Achilles Tendon**

**Anisotropy**

Anisotropy is an important concept in MSK ultrasound.\(^4,5,10\) This term means “directionally dependent”, and exists in the imaging of many structures, such as tendons and nerves (and to a lesser extent muscle), due to their fibrillar structures. This translates to an ultrasound image that varies depending on the angle of insonation between the tendon and the ultrasound waves. When this angle is perpendicular, the tendon creates a strong reflection, revealing normal tendon structure. As the angle varies, however, the tendon can quickly become hypoechoic (Image 11.19, Movie 11.8).

**IMAGE 11.19 - Anisotropy in Flexor Tendons of the Hand**

Left: Sonographic image obtained when probe is positioned at a perpendicular angle to the course of the tendons (tendons labeled with asterisks). Note the overall hyperechoic appearance of these tendons. Right: Sonographic image obtained when probe is positioned at an angle other than perpendicular to the tendons. Note the overall hypoechoic appearance of these structures.

**MOVIE 11.8 - Demonstration of Anisotropy**

Note how the biceps tendon becomes anechoic as the sonographer fans the probe and quickly becomes hyperechoic when the probe is at 90 degrees.

When a portion of muscle or tendon fails to demonstrate anisotropy it is often due to pathology, such as muscle injury, tendon tear or tendinitis (Image 11.2).
Ruptures

Tendons are musculoskeletal structures that can also be torn, usually as a result of over-stretch. These tears can be partial or complete. Partial tendon ruptures are tears that do not span the entire tendon. Tears may occur within the tendon creating a hypoechoic fluid collection that is not anisotropic (Image 11.20), or the tear may involve the tendon surface leading to fluid surrounding the tendon or traveling along the fascial plane.\(^4,5,9,11\) Complete tendon ruptures, on the other hand, do span the entire tendon and appear as two separate tendon fragments with surrounding hemorrhage and retraction\(^4,5,9\) (Images 11.21, 11.22).

**Image 11.20 - Tendinosis and Tear**

Left: Tendinosis of the biceps tendon, represented by a hypoechoic region within the tendon (star). BG = bicepital groove. Right: Partial tear of the Achilles tendon (AT) represented by an anechoic region within the tendon.

**Image 11.21 - Complete Achilles Tear**

Sonogram of a complete tear of the Achilles tendon with retracted tendon and surrounding hemorrhage.

**Image 11.22 - Complete Tear Vs. Intact Quadriceps Tendon**

Complete tear of the quadriceps tendon shown in side-by-side comparison with an intact quadriceps tendon. Note the interrupted echotexture of the tendon on the affected side, with interposing areas of anechoic and hypoechoic fluid.
Both of these tears can result in swelling of the tendon, with loss of the normal “brush pattern” echotexture. As always, comparison of the pathologic side to the normal side can highlight the sonographic changes that have occurred in the affected side. Applying probe pressure and having the patient move the extremity can help reveal muscle and tendon tears (Movies 11.1, 11.2).

Tendons may also be damaged due to penetrating trauma and laceration. Typically, the wound is explored and the tendon is visually inspected for damage; however, MSK-US can be a useful adjunct to exploring a laceration for possible tendon injury\(^5\) (Image 11.23).

**TENOSYNOVITIS**

Tenosynovitis is inflammation of the synovial sheath surrounding a tendon. Clinically, this may present as a swollen, red “sausage-like” digit. Sonographic imaging of these cases shows anechoic regions surrounding the tendon, which represents fluid extravasation in the potential space between the layers of the synovial sheath.\(^12\) Ultrasound may also show swelling of the involved tendon with loss of the expected echotexture and surrounding fluid\(^12\) (Image 11.24).

**IMAGE 11.24 - Tenosynovitis of 3rd Digit Flexor Tendon**

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Sonographic tendon exploration, performed in long axis. This patient sustained blunt trauma causing a skin laceration and fracture (as labeled). Decreased range of motion of the finger led to concern for tendon injury. US reveals normal fibrillar appearance of this intact tendon.

**TENDINITIS**

Tendinitis is inflammation of the tendon. It can affect any or all of a tendon and is often the result of injuries or repetitive motions. US of an inflamed tendon appears thickened, with areas of heterogeneous echogenicity and disrupted fibers that fail to demonstrate anisotropy (Image 11.2). Additionally, inflamed tendons are often hyperemic, which may appear as increased flow on the use of color Doppler.\(^4,13\)
Ligaments are also groups of collagen fibrils arranged similarly to tendons connecting bone to bone. They have a similar sonographic appearance, however since they run interosseously and often at varying angles, they can be more difficult to ultrasound.

Examples

**Image 11.25 - Anterior Talofibular Ligament**

Left: Proper sonographic examination of the anterior talofibular ligament is demonstrated. Right: Resulting sonogram, revealing anterior talofibular ligament (L) coursing from fibula (F) to talus (T).

**Image 11.26 - Patellar Ligament**

Left: Proper sonographic examination of the patellar ligament is demonstrated. Right: Resulting sonogram, revealing the patellar ligament (L) as it attaches to the tibia (T).

**Movie 11.9 - Video of Longitudinal Patellar Ligament**

Quadriiceps tendon rupture. Retracted tendon and surrounding hemorrhage (anechoic fluid).
Ligamentous Injury

Ligamentous injuries include sprains, rupture or avulsion. Similar to tendons, the ligament may be enlarged or with signs of hemorrhage within or surrounding the ligament and loss of anisotropy.\textsuperscript{5,14} A partial rupture may have fluid within or surrounding the ligament, but with some preservation of fibril orientation and alignment. With complete rupture, there is retraction of the ligament and visualization of torn edges with fluid. In cases of avulsion, a bony fragment may be seen at the end of a retracted ligament. Commonly seen ligamentous injuries in the ED include injuries to the patellar ligament (Image 11.27, Movie 11.10), ankle ligaments, and the ulnar collateral ligament of the thumb, also known as “gamekeeper’s thumb,” which commonly occurs in skiers.

**Image 11.27 - Patellar Ligament**

Top: Normal intact patellar ligament (arrowheads) inserting on patella. Bottom: Complete patellar ligament (arrowheads) rupture. The two ends of the ligament are seen both retracted and swollen.

**Movie 11.10 - Patellar Ligament Rupture**

Note: There is discontinuity of the ligament with retraction and swelling.
HIGHLIGHTS

Ultrasound is capable of picking up fractures that are frequently not visible on X-ray.

Ultrasound can both detect and facilitate the drainage of effusions.

Dislocations can be diagnosed by ultrasound.

Bone

Bone is typically the deepest tissue when performing MSK-US and appears as a hyperechoic structure with acoustic shadowing\(^2\,^3\) (Image 11.6).

EXAMPLES

**IMAGE 11.28 - Rib**

Left: Long axis. Right: The resulting sonogram. Note the hyperechoic line (arrowheads), which represents the cortex of the osseous rib.

**IMAGE 11.29 - Sternum**

Left: Long axis. Right: The resulting sonogram. Note the hyperechoic line (arrowheads), which represents the cortex of the osseous sternum.
FRACTURES

Sonography is capable of detecting occult fractures that are unseen on radiographs.\textsuperscript{3,14-18} It is particularly sensitive for rib fractures, detecting up to 6 times more patients than X-ray.\textsuperscript{19} Ultrasound is at least as accurate as X-ray for detection of breaks in the long bones, but may miss fractures in complex areas such as the hands, feet, and pelvis.\textsuperscript{3,15} Sonography of a fracture typically reveals a discontinuity on the surface of the bone, with or without a step-off deformity, angular deformity of the bone cortex, and/or a subperiosteal hematoma\textsuperscript{3,19} (Gallery 11.1).

Light probe pressure can be useful to help reveal occult fractures (Movie 11.1). Ultrasound has been shown to be up to 90% sensitive in detecting radio-occult scaphoid fractures.\textsuperscript{20} The scaphoid can be examined with the hand held in ulnar deviation (Image 11.30). Again, decortication or hematoma suggests fracture.

**IMAGE 11.30 - Scaphoid**

Sonogram of a fractured humeral shaft. Note the interrupted hyperechoic line, which represents decortication of the humeral shaft.

**GALLERY 11.1 - Fractures**

Left: Proper sonographic examination of the scaphoid in long axis is demonstrated. Right: Resulting sonogram. Note the hyperechoic surface of the scaphoid (arrowheads).
**Fracture Reduction**

MSK-US can be used similarly to fluoroscopy for reduction of fracture dislocations. Performing bedside ultrasound pre-, post-, and during reduction improves the success of the procedure and decreases the need for additional analgesia and sedation. This has been well described for reduction of distal radius fractures\(^{21-22}\) (Image 11.31), but it is potentially applicable to any location. Advantages of ultrasound over fluoroscopy are the avoidance of radiation, need for a technician, and visualization of real-time dynamic images.

**IMAGE 11.31 - Fracture Reduction**

Sonograms of a distal radius fracture before (left) and after (right) reduction.

**Joint Spaces**

MSK-US has been shown to improve the diagnosis of joint effusions over clinical exam alone.\(^{23}\) In the absence of effusion, visualization of a joint space with US can be more difficult than imaging the diaphyseal portion of bone, as the acoustic shadowing created by the surrounding bone may obfuscate the joint.\(^{24-25}\) However, when a pathologic collection of articular fluid is present, imaging of the joint space becomes more straightforward. When the probe is properly placed along the joint line, sonography will accurately demonstrate effusions\(^{25-27}\) (Image 11.32, Movies 11.11, 11.12).

**IMAGE 11.32 - Ankle Joint**

Left: Proper sonographic examination of the ankle joint in long axis is depicted. Center: Normal ankle sonogram, revealing the tibia and talus. Right: Ankle sonogram, revealing an ankle joint with anechoic effusion (E).
The sonographic appearance of an effusion depends on the composition of the fluid. In mechanical or inflammatory fluid, the collection will appear anechoic, while in bloody effusions the collection can appear hyperechoic.\(^\text{23}\)

**MOVIE 11.11 - Supralateral Knee Effusion**

**MOVIE 11.12 - Knee Effusion in Case of Septic Joint**

**ARTHROCENTESIS**

Frequently, a joint effusion will need to undergo arthrocentesis for diagnostic work-up. With large joint effusions, drainage often provides pain control. Ultrasound can help identify the effusion and allow the clinician to precisely mark its location for needle drainage, or the clinician can use the ultrasound in real-time to dynamically guide needle drainage\(^\text{28}\) (Movies 11.13, 11.14).

**MOVIE 11.13 - Arthrocentesis of Elbow Joint Effusion**

**MOVIE 11.14 - Arthrocentesis of Ankle Joint Effusion**
In addition, ultrasound can help the clinician identify and avoid surrounding neurovascular structures when inserting the needle (Gallery 11.2).

**GALLERY 11.2 - Arthrocentesis**

US assisted marking of knee effusion, in preparation for arthrocentesis. The anechoic effusion is first centered on an image in long axis (top left), and marks are made at either end of the probe. Same is done in transverse (top right). The center of the effusion is located beneath the center of the resulting four marks (bottom left), where a needle can now be accurately placed (bottom right).

**DISLOCATION REDUCTION**

Similar to fracture reductions, ultrasound may assist in joint dislocation reductions (Image 11.33), particularly in cases where it is unclear whether reduction has been successful based on physical exam alone. By using the contralateral side as a reference, MSK-US can quickly confirm joint reduction by demonstrating that articulation is equal bilaterally. If it is not, the clinician can attempt a repeat manipulation immediately instead of waiting for an X-ray.

**IMAGE 11.33 - Shoulder Dislocation**

Left: Proper sonographic exam of the shoulder joint in long axis. Center: Sonogram revealing an anterior shoulder dislocation. Note the increased distance between the humerus (H) and acromion (A). Right: Same shoulder after reduction.
**Bursitis**

The bursae are small, fluid-filled potential spaces that surround areas prone to friction, such as joints and areas between bone and tendon. Acutely, bursitis appears as an anechoic fluid collection\(^4\) (Image 11.34). In the chronic stage, however, debris accumulates and forms a complex collection with heterogeneous echogenicity. Power Doppler may also reveal hyperemia in the region.\(^4\)

**IMAGE 11.34 - Bursitis**

Note the presence of a large irregular anechoic fluid collection, representing increased fluid in the bursa.

**Baker’s Cyst**

Popliteal or “Baker’s” cysts represent an outpouching of synovial fluid from the knee joint. On ultrasound, it is typically a cystic, often serpiginous, fluid collection located in the popliteal region that can be traced back to the joint space\(^4,5,29,30\) (Movie 11.15).

**MOVIE 11.15 - Baker’s Cyst**

**Summary**

MSK-US is a useful tool for many clinical settings and allows for improvement in diagnostic capabilities over physical exam alone. It improves success of commonly performed procedures including arthrocentesis and dislocation reduction. Important techniques include systematic scanning in two orthogonal planes, contralateral examination, dynamic examination, and application of probe pressure.
REFERENCES


