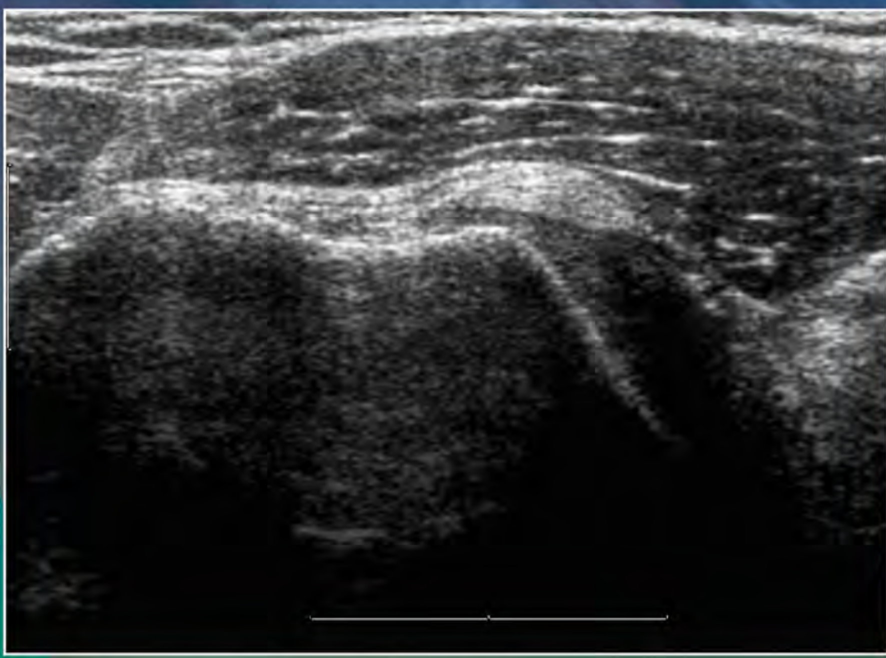
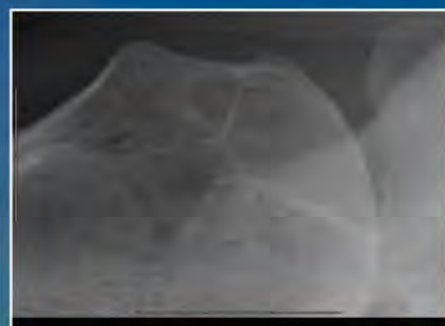
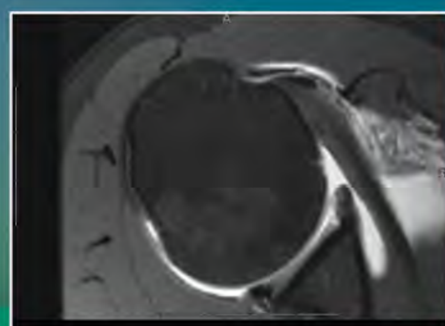
# Musculoskeletal ULTRASOUND







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3rd Edition

JAYPEE

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# 3

# Sonography of Muscle

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## INTRODUCTION

Ultrasound was the first imaging modality available for the evaluation of muscle pathology. Low-kilovoltage radiography lacks sufficient contrast resolution for the evaluation of muscle injury. Therefore, noninvasive imaging of muscle only becomes a reality with the first applications of musculoskeletal ultrasound in the mid-1980s. Over time, it became obvious that even multidetector computed tomography (CT) cannot define muscle structure sufficiently to detect the most common types of muscle pathology. Intravenous (IV) contrast enhancement does not improve the performance of CT in this area.

The multiplanar capability and improved tissue characterization provided by magnetic resonance imaging (MRI) have made it quite suitable for the evaluation of muscle pathology. Traumatic and ischemic injury can be well demonstrated using $T_1$-, proton density, and $T_2$-weighted images. In addition, MR 31P spectroscopy allows detailed analysis of the metabolic state of muscle.[1-4] However, MRI lacks the ability to perform a real-time dynamic examination. Cost and availability factors further limit the utility of MRI in the diagnosis of muscle pathology.

Sonography can provide all the information available with MRI and more with regard to muscle pathology. Its spatial resolution and definition of muscle structure are usually superior to those provided by MRI. Real-time examination available only with ultrasound elucidates some types of muscle lesions that are occult on static examinations.[5] The degree of functional deficit resulting from fibrosis, muscular cysts, or myositis ossificans can be fully assessed using real-time sonography. This information can have a major impact on decision making in competitive athletics, in disability, and in medicolegal cases. Currently, the only role we see for MRI of muscle is in the diagnosis of muscular dystrophies, inflammatory lesions of muscle,[6-8] and tumor staging if a malignant neoplasm involves a muscle compartment. These lesions are rare, with the exception of diabetic myonecrosis.[9]

**Box 3.1:** Ultrasound of muscle injury.

- Approximately 30% of sports injuries affect muscles
- Ultrasound is useful in staging; it assists in determining the date of return to competition

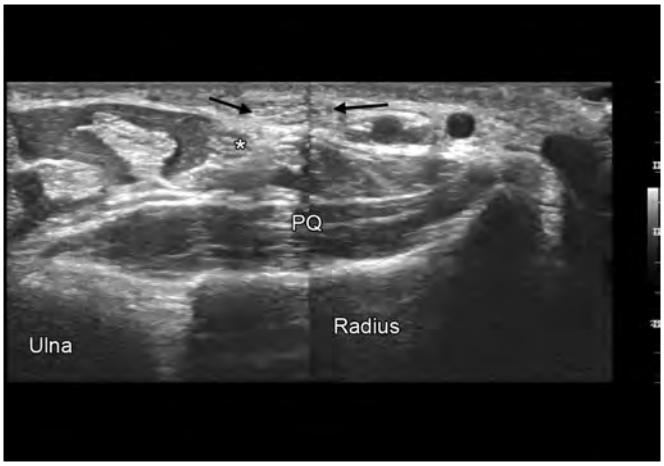
The availability, ease of examination, and low cost of sonography in contrast to MRI make the follow-up of healing lesions practical with ultrasound. The majority of patients referred to for the evaluation of muscle lesions are athletes. Several studies have demonstrated that approximately 30% of all sports injuries are muscular in origin.[10] In these patients, the decision on when to return to training or competition is extremely important (Box 3.1).

Reinjury resulting from premature resumption of activity can be costly for both the athlete and the team. Serial sonographic examinations can accurately evaluate the rate and stage of healing, significantly decreasing the likelihood of reinjury.

## EXAMINATION TECHNIQUE

Rarely do we examine the small muscles in the hands and feet. These examinations require transducers with very small footprints, such as compact linear or intraoperative “hockey sticks”. However, the majority of muscles are relatively large structures, some extending over two joints. The longest can measure >50 cm. A muscle tear tends to be a long fusiform lesion. In cases of complete rupture, the severed ends of the muscle may retract >10 cm. Keeping these factors in mind, it is clear that we must have the ability to examine a broad anatomical region. Therefore, long linear-array transducers are most desirable for the examination of muscles. The majority of examinations can be performed with a 7–15 MHz linear-array transducer. Deep muscles, especially in very muscular or in obese patients, require transducers with a frequency band of 3.5–10 MHz.[11] This technology will

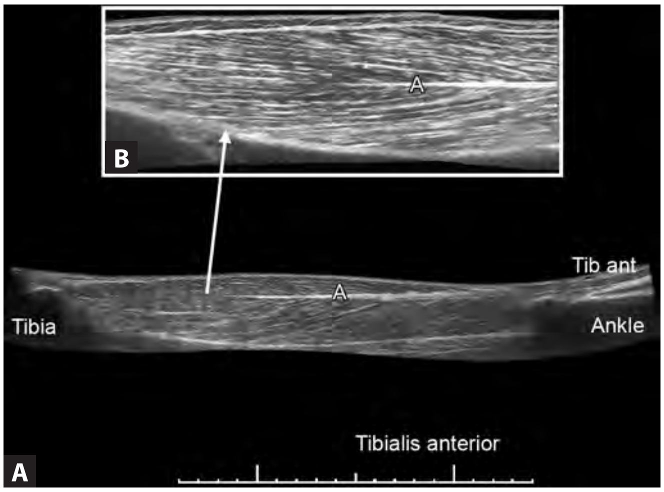
**Fig. 3.1:** Side-by-side display of the pronator quadratus muscle.




By placing two segments of the pronator quadratus (PQ) side by side, a more complete view of that muscle is now on display. For this image, a high-frequency transducer with a small footprint was used to image the wrist. The technique that allows us to paste two images side by side is often referred to as the dual-image mode. The scanning at 18 MHz shows us the relationship between the palmaris tendon (arrows) and the median nerve (*) in unusual detail.

provide excellent resolution. In addition to a long linear transducer, the ability to display two images side by side (dual-image mode) is essential. This ability allows the examiner to provide a composite image demonstrating a longer segment of muscle (Fig. 3.1). This technology also offers the capability of comparing the symptomatic with the asymptomatic muscle. Conventional ultrasound techniques are suboptimal because of their limited field of view (FOV). Linear-array transducers, which are most useful for the examination of muscle, have a width of 4–6 cm.[12] The maximum aperture of the view with large transducers would add up to no more than 12 cm using dual-image mode.[12] Fortunately, research has provided several possible solutions for overcoming the problem of limited FOV.[13-16] Transmission ultrasound is one solution, but this technique is in the very early stages of development and therefore will not be discussed further. Two other technical developments have emerged recently; three-dimensional (3D) sonography and extended FOV imaging. Three-dimensional sonography is not very different from 3D MRI or 3D CT data acquisition, and it proves to be a technique that allows human muscle volume measurements in vivo[17] with measurements that differ, on average, no more than 0.53 cm 3 from measurements with MRI. In 3D sonography, a series of images are stacked in memory and reconstructed as a volume.[18] One method of 3D ultrasound uses images from a single sweep with the transducer. Another method uses a bulky transducer that contains a curved array of piezoelectric crystals. The array of crystals can make a scanning sweep within the large container holding the crystals. This transducer is held over the area of interest and cannot be moved until the translation movement of the array is complete. The enhanced computing power of newer digital ultrasound equipment provides fast 3D volumetric reconstruction almost in real time. A recent technical advance is ultrasonic volume imaging. This technique allows real-time 3D imaging with conventional B-mode equipment. A cylindrical silicone rubber lens is applied to a conventional linear- or curved-array transducer. The lens defocuses the beam and insonates a volume of tissue. Three-dimensional imaging is attained when a structure reflects all the incident energy. The necessity for total reflection is a major limitation of this technique. Total reflection has been attained by examining structures at highly inclined angles, such as a baby's face in utero. All current 3D methods still have a fairly limited FOV. In addition, real-time ultrasound is a freehand technique, and the 3D images are often fraught with error because of motion- and position-related artifacts. Extended FOV imaging (Siescape, Issaquah, WA) is currently the best method for displaying musculotendinous anatomy using ultrasound.[16] Images are more easily interpretable by the novice. It is a valuable teaching tool that also improves cross-specialty communication.[12] Extended FOV imaging uses image registration between sequentially acquired image frames for motion estimation.[16] A large panoramic view is constructed in real time (Figs. 3.2A and B). The image looks somewhat like the image provided by static B-mode ultrasound scanning. Large high-resolution images up to 60 cm long can be obtained.[16] This technique allows sonographic demonstration of lower-extremity muscles extending across joints. The extended FOV can be applied to any transducer or image format. It requires a fast parallel processor computer because of its high computational demands. Current equipment that allows extended FOV imaging is capable of executing 4 billion operations per second.[16] The new technology incorporates the advantages and eliminates the disadvantages of both real-time and static B-mode scanners. Fuzzy-logic technique is applied in extended FOV imaging, allowing detection of and correction for small-scale tissue motion, such as arterial pulsation, muscle contraction, heartbeat, and respiration. Probe off-plane motion, a significant problem in conventional 3D imaging, is less of an issue with this technique. Extended FOV imaging allows the operator to track along the length of a structure

**Figs. 3.2A and B:** Extended field-of-view imaging of the tibialis anterior muscle.

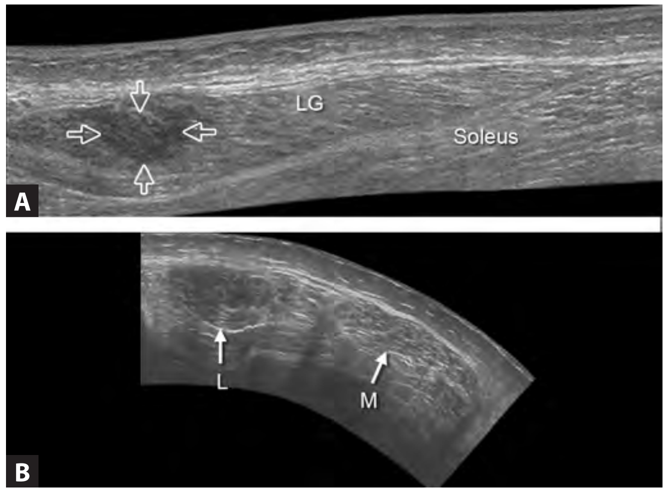



By moving the transducer in an uninterrupted motion over a particular anatomy, the examiner can get detailed musculoskeletal anatomy by following the landmarks on the skin. This technique is particularly well suited to examine larger muscles. (A) The tibialis anterior from its origin on the proximal tibia to its tendon (Tib Ant) at the ankle level. (B) A magnification of the proximal muscle with the contrast setting of the equipment optimized to show the circumpennate structure of the tibialis anterior. Notice how the tendon extends deep into the muscle as a strong aponeurosis [panel (A)].

without being confined to a single plane.[16] This technique is applicable to many structures in the extremities (Figs. 3.3A and B). A large number of musculotendinous structures and neurovascular bundles cross conventional anatomic planes. The oblique course of the sartorius muscle is a good example. An additional benefit of this technique is the accuracy of measurement over long distances. The majority of measurement errors are < 2% of the measured distance.[16]

A *standoff cushion* may be required for the examinations of muscles. This allows optimal visualization of the superficial fascia and the musculotendinous junction. Fascial defects, muscle hernias, and superficial muscle tears will be missed if a standoff cushion is not utilized.[169] Standoff cushions will also facilitate the production of composite images by conforming to the irregular contours of the skin surface. Regardless of the transducer utilized, a standoff cushion will help us to place the region of interest within the optimal focal zone of the transducer. Companies have made great efforts to improve the near-field resolution of most transducers. Those adjustments have been implemented for *small parts* and breast ultrasound. Abdominal sonography has benefited indirectly from this change, and the muscular abdominal wall can

**Figs. 3.3A and B:** Focal muscle mass.




(A) Longitudinal sonogram with extended field of view (FOV) technique. Over a 3-week period, pain and swelling developed in the calf of a 50-year-old woman. This longitudinal image of the calf demonstrates a focal hypoechoic area (arrows) within the lateral gastrocnemius (LG). Extended FOV imaging allows the examiner to track the anatomy along the length of a structure. In this case, ultrasound shows the anatomy along the oblique course of the gastrocnemius muscle belly. With this figure in hand, it was easy to explain to the clinician how this lesion affects the proximal lateral gastrocnemius only. The lesion respects fascial boundaries, as clearly demonstrated on the image. Extended FOV imaging improves the ability to interpret static images by providing greater perspective. However, the technique does not significantly improve diagnostic accuracy for the examiner who scans in real time. The type of information that the extended imaging adds is that which the examiner has in his/her mind during the real-time examination. Therefore, the principal benefit of the technique is to improve communication with referring physicians. (B) Transverse sonogram with extended FOV technique. Same patient as discussed in panel (A). By sliding the transducer over the calf, making a sweep from side to side, one notices the significant swelling and edema of the lateral gastrocnemius (L) when compared with the medial gastrocnemius (M). Two weeks later, biopsy of the muscle shows bone formation compatible with myositis ossificans.

now be studied routinely in great detail. This technological progress has enhanced musculoskeletal sonography in many aspects. Superficial tendons, ligaments, bursae, and cartilage are now visible with resolution unmatched by that of any other noninvasive imaging method.[19] Higher frequency transducers are utilized in clinical applications. Most companies offer a variety of multifrequency transducers. Modern linear-array and curved-array transducers can move the depth of focus electronically to the skin level. Popular for musculoskeletal use are transducers that have frequency ranges from 10 or 12 to 5 MHz.

Pain resulting from muscle injury is generally well localized, unlike chest or abdominal pain. Therefore, the examination is designed to find the point of maximal tenderness. This technique is called sonographic palpation. The patient is directed to point to the symptomatic region or the referring physician may mark a specific region of interest on the skin. Systematic examination of the indicated area is then performed by gentle compression with the ultrasound transducer. During the examination, the degree of compression should be kept as consistent as possible. Fascia and fibroadipose septa are the most echogenic elements of muscle structure. When these elements are approximated more closely by increased compression, the overall echogenicity of the muscle appears to be increased. If no abnormality is clearly evident at the point of maximal tenderness, comparison with the corresponding area on the asymptomatic side is mandatory.

Muscles are dynamic structures; therefore, they cannot be properly evaluated with static images alone. Real-time sonography allows examination of muscle structure under dynamic conditions. Ultrasound machines with cine-loop capability are very helpful during dynamic examinations. Digital video recording may also be valuable during this portion of the examination. Identification of muscles is made by location, origin, insertion, and function. This can easily be established under sonographic observation. Initial observation is performed without stress, followed by increasing graded isometric contraction (tightening without displacement). Small muscle tears may be occult on images obtained during relaxation but clearly visible during isometric contraction.

The examination is started with the transducer oriented in the long axis of the muscle using sonographic palpation. After the area of abnormality is established, images are obtained during relaxation and isometric contraction. Then the transducer is rotated 90°, and the process is repeated for transverse imaging. Comparable images of the asymptomatic side are obtained to facilitate the detection of subtle abnormalities.

## NORMAL SONOGRAPHIC ANATOMY

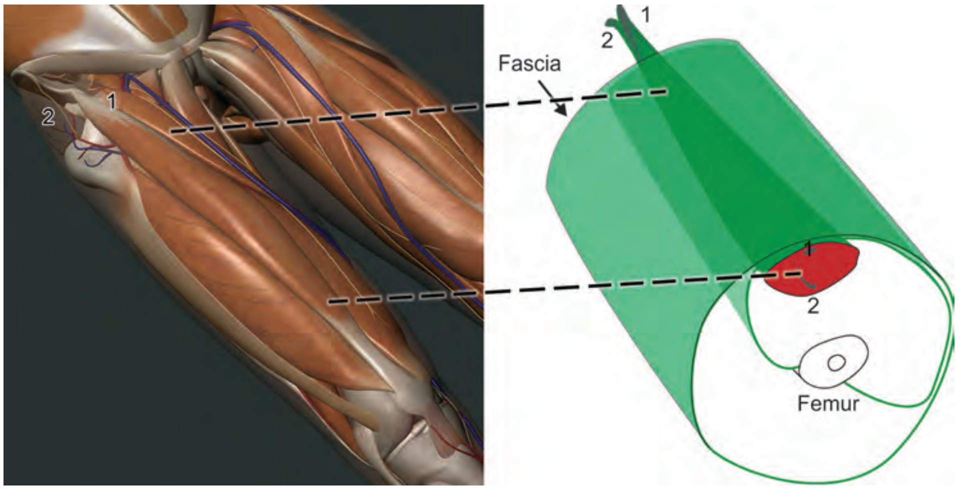
Muscles make up 35–40% of our body weight, therefore, representing the largest tissue mass in the body.[20] In men, that fraction of mass is higher accounting for an approximate 40–50% of total body weight compared to 25–35% in women.[11] At the microscopic level, individual skeletal muscle fibers are enveloped by the endomysium, connective tissue with an extensive network of capillaries and nerves.[21] The muscle fibers are grouped into sonographically detectable bundles (fascicles) surrounded by the perimysium, which is composed of connective tissue, blood vessels, nerves, and adipose tissue.[22] Some authors refer to the perimysium as fibroadipose septa[5,23] because in addition to the stromal connective tissue there are variable amounts of fat visible within these septae. The perimysium is a distinctly visible network of connective tissue, which is detectable on ultrasound and MRI of muscle. A sheath of dense connective tissue called the epimysium surrounds the entire muscle. A fascial layer may separate single muscles or groups of muscles. Fascial compartments are watertight compartments that will often act as a conduit for hematoma and drainage of other fluids (Fig. 3.4).

Over the length of a muscle, perimyseal septae converge to progressively increase in size. The thicker tendon-like connective tissue septa that connect muscle to tendon and bone have commonly been called aponeuroses, a term that dates back to the literature of the Ancient Greeks who were unable to distinguish small nerves from tendons, as we now can microscopically (Fig. 3.4).

The internal architecture of skeletal muscle varies depending on its designated function. Muscles with fibers and fascicles arranged parallel to the long axis of the muscle are best suited for movement over a long distance. The sartorius in the thigh and the rectus abdominis in the anterior abdominal wall are typical examples of such muscle arrangement.[11] In distinction to the parallel arrangement, muscle fascicles can be arranged obliquely relative to the main axis of traction force generated by the muscle. This orientation of fascicles has been termed pennate, because it resembles the plumes of a feather. Unipennate, bipennate, circumpennate, and multipennate muscle configurations are better suited for lifting greater weight over shorter distances (Fig. 3.5). Attachment of muscles to the bones is accomplished by tendons and the fibro-osseous junction (*Sharpey's fibers*). Each muscle has at least one belly, or venter, and two tendons. However, a muscle may have more than one belly with fibrous intersections separating them, such as the rectus abdominus. Multiple origins of a muscle with a single belly, another possible configuration, are seen in the biceps, triceps, and quadriceps muscles.

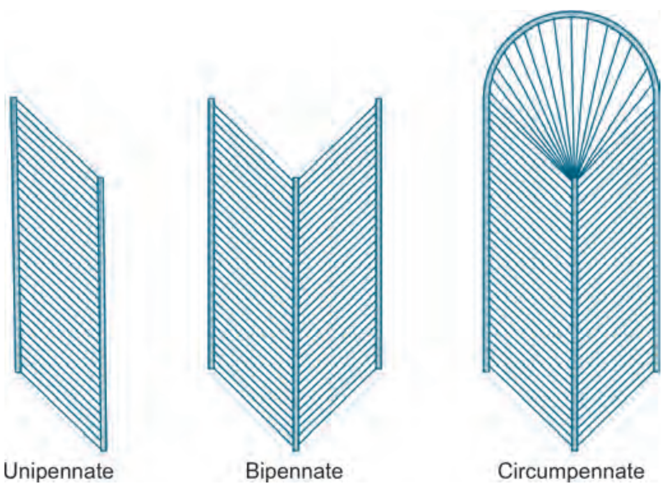
These different arrangements can easily be observed sonographically (Fig. 3.6). Variations from these systematic arrangements are easily detected with a thorough ultrasound examination. Muscle bundles have a hypoechoic

**Fig. 3.4:** Normal fascial and aponeurosis anatomy of the rectus femoris muscle.



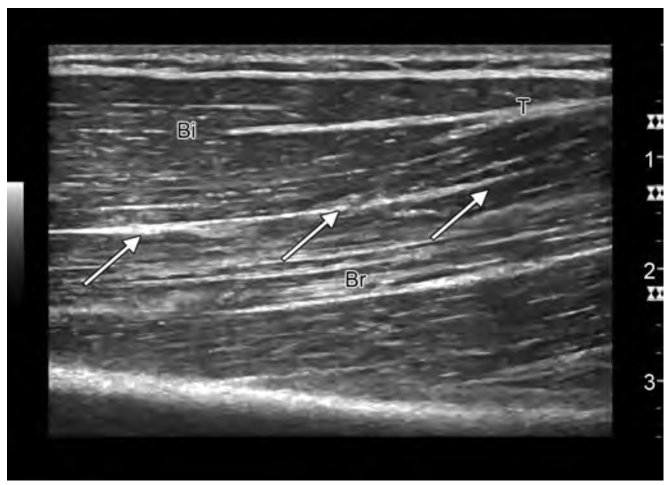

The rectus muscle has its own fascial covering (green). This watertight compartment fits within the larger extensor compartment located anterior to the femoral diaphysis. The fascia lata (arrow) is the fascia that covers all muscles of the upper thigh. A remarkable feature of tendons of long muscles is that these tendons continue to be visible as aponeurosis within the muscle belly for long distances. Often, these tendons continue from proximal tendons into distal tendons. The biceps of the upper arm is an example of this. In the thigh, the reflected head of the rectus femoris tendon is visible as a deep-seated and comma-shaped aponeurosis (2) in the center of the rectus femoris. The straight head (1) of the rectus femoris continues more anterior and deep to the fascia. Smaller perimyseal septa within the muscle converge on aponeuroses.

**Fig. 3.5:** Pennate structure of muscles.




The diagrams depict the most common arrangements of muscle fibers in the extremities. These arrangements allow greater weight to be lifted over a shorter distance. Parallel arrangements of muscle fibers, seen more commonly in the abdomen, head, and neck, are more suitable for lifting less weight over long distances.

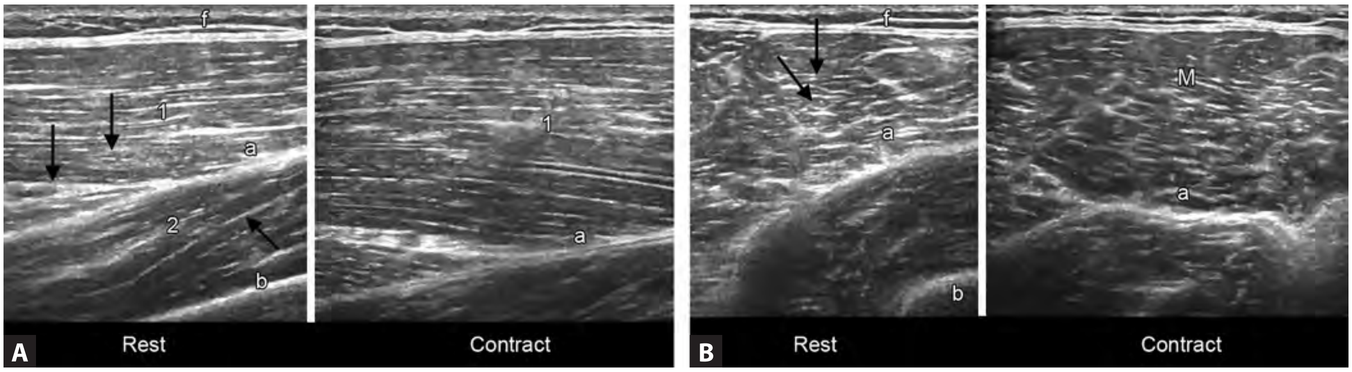
**Fig. 3.6:** Circumpennate arrangement of muscle.




The image along the longitudinal axis of the distal biceps brachii (Bi) muscle relative to the distal biceps tendon (T) and its central aponeurosis. The biceps is located superficial to the brachialis (Br). The arrows point at the fascial plane between the two muscles.

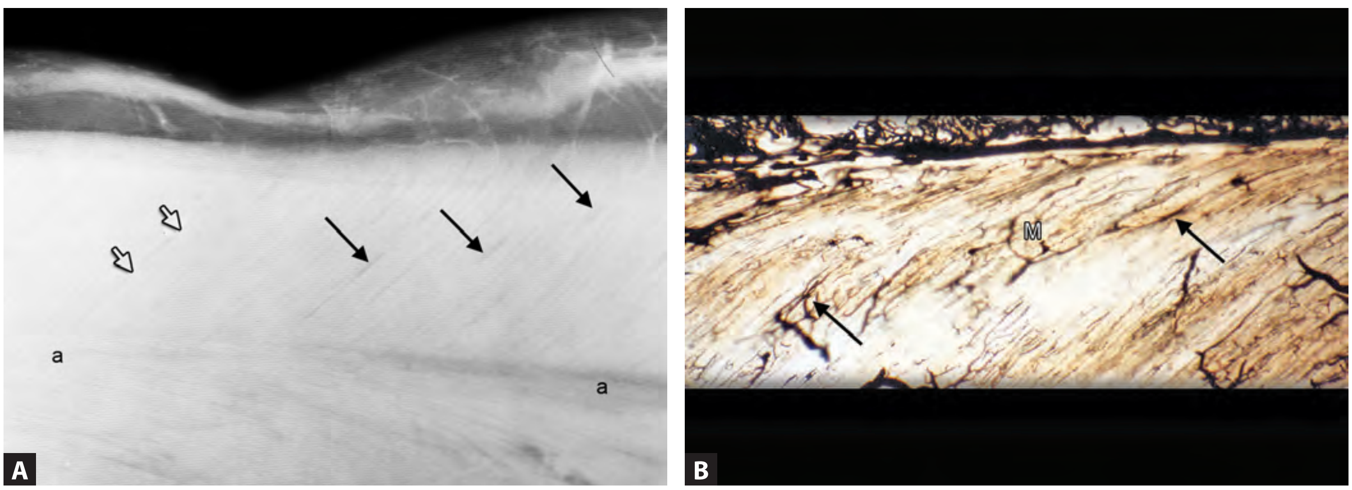
appearance. The fibroadipose septa of the perimysium are seen as hyperechoic lines separating the muscle bundles (Figs. 3.7 to 3.9). Epimysium, nerves, investing fascia, tendons, and fat also appear hyperechoic relative to the muscle bundles. These features allow easy recognition of the pennate structure of muscle. Fat planes between muscles will aid in the differentiation of separate muscles. The pennate structure is most easily identified in longitudinal images. In transverse images, muscle will have a *speckled appearance*. The hypoechoic and near anechoic appearances of well-developed muscle tissue are occasionally mistaken for a disease process. Accessory muscle

**Figs. 3.7A and B:** Normal anterior thigh muscles.




(A) Longitudinal sonograms. These split screen images were obtained in a 58-year-old athletic man. The fibroadipose septa (arrows) are seen as hyperechoic lines separating the hypoechoic muscle bundles. Look at how isometric contraction of muscle (on the right of the split screen) increases the muscle volume and observe how it makes the fibroadipose septa stand out more clearly. These septa converge on the highly reflective intermuscular septum that acts as aponeurosis (a), giving the appearance of a feather. The aponeurosis divides vastus lateralis (1) and vastus intermedius (2) muscles. Two highly reflective lines bound the muscles: the fascia (f) superficially and the bone (b) deep to the muscles. Subcutaneous fat lies superficial to the fascia. (B) Transverse sonograms. Same patient as discussed in panel (A). In transverse images the fibroadipose septa (arrows) appear as hyperechoic lines of varying lengths. In veterinary medicine, these septa that contain variable amounts of fat are referred to as "marbling" of the muscle. In musculoskeletal ultrasound terms, this marbling has been more poetically called the "starry-night" pattern after Vincent van Gogh's painting. The pennate arrangement seen in longitudinal images is not evident on oblique or transverse images. Note again how the quadriceps muscle (M) mass increases with contraction. (b: Femoral bone).

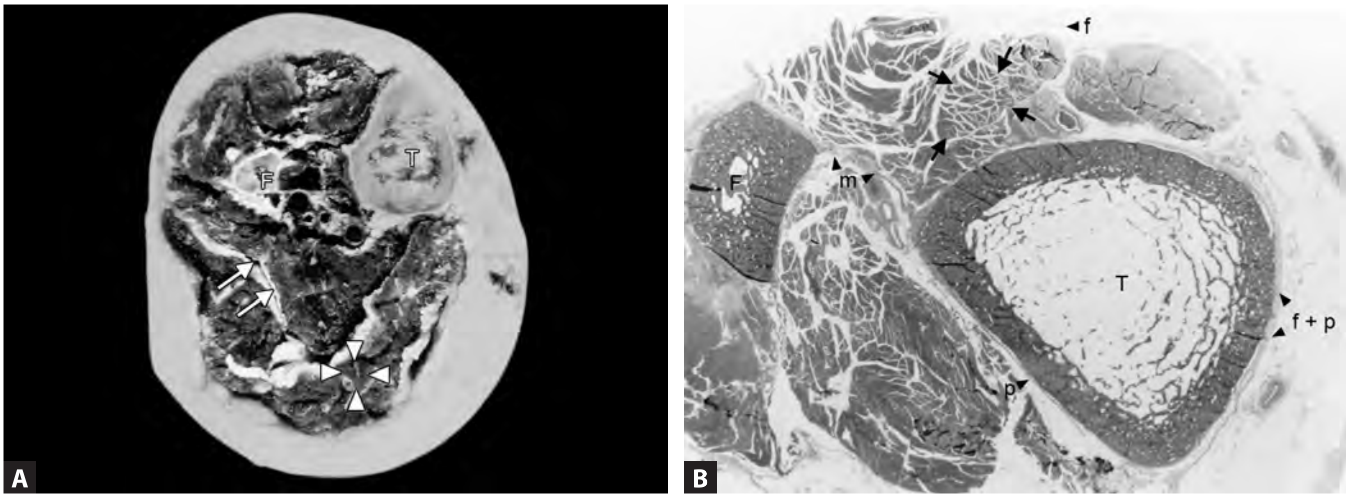
**Figs. 3.8A and B:** Specimen radiographs of the vastus lateralis muscle: Longitudinal anatomical sections.




The radiograph (A) was obtained using mammographic technique on a specimen of 1 cm thick. Note the pennate structure of the muscle defined by the radiolucent fibroadipose septa (open arrows) converging on the thick fibrous aponeurosis (a) or intermuscular septum. These septa contain collagen, nerves, and blood vessels in addition to fat. A periodicity can be seen in the presence of thicker septa (long arrows). (B) A specimen of rat muscle shows the blood vessels of muscle injected with India ink. Numerous capillary vessels follow the fibroadipose septa of muscle (M) along the feathery structure of pennate muscle. Periodicity is noted in this pennate structure with larger vessels (arrows) filling larger septa alternating with smaller vessels.
*Courtesy*: Jiang Yebin, MD, Professor of Radiology at the University of Michigan Hospitals, Ann Arbor.

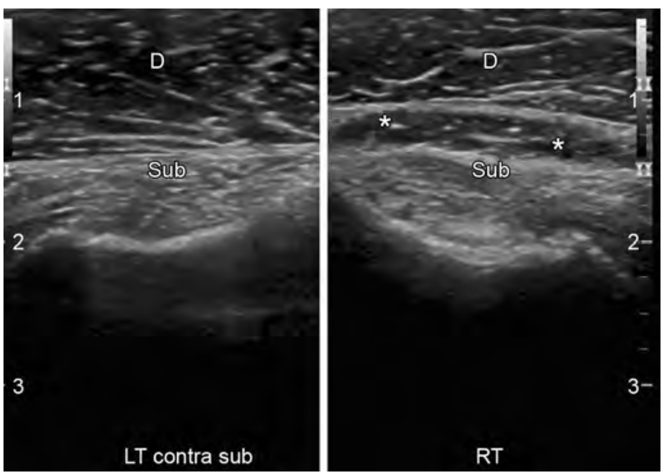
tissue in the shoulder (Fig. 3.10),[24] wrist, or ankle can appear mass-like or may mimic tenosynovitis.[11] There are accessory muscles that can cause nerve impingement[25] but most normal variant muscles are asymptomatic. We have observed such pseudomasses in the hand with accessory extensor musculature over the knuckles and above the heel with an accessory soleus (Figs. 3.11A to C) often appearing like a mass.[11] Palmaris longus muscle tissue in the wrist (Fig. 3.12) and aberrant peroneus brevis and peroneus quartus muscles in the ankle are among the

**Figs. 3.9A and B:** Normal muscle architecture.




(A) Muscles are divided into compartments by fibrous septa, which contain vessels (white arrows). Compare the appearance of the fibroadipose septa cut transversely with the sonographic image as in Figure 3.7B. The arrowheads indicate a muscle bundle surrounded by septa. Cross section of the tibia (T) and fibula (F). (B) For this transverse histological section, the hematoxylin and eosin preparation was made from a specimen proximal to that depicted in panel (A). The fibroadipose septa are seen as clefts due to the histological preparation. Arrows indicate a muscle bundle similar to that seen previously. Note the further division within the bundle by finer septa. The interosseous membrane (m), fascia (f), and periosteum (p) are composed of dense fibrous tissue, seen as hyperechoic lines sonographically. Fascia of the lower leg is intimately related to the periosteum covering the anterior medial surface of the tibia (f + p). (T: Tibia; F: Fibula).

**Fig. 3.10:** Accessory subscapularis-teres-latissimus muscle.



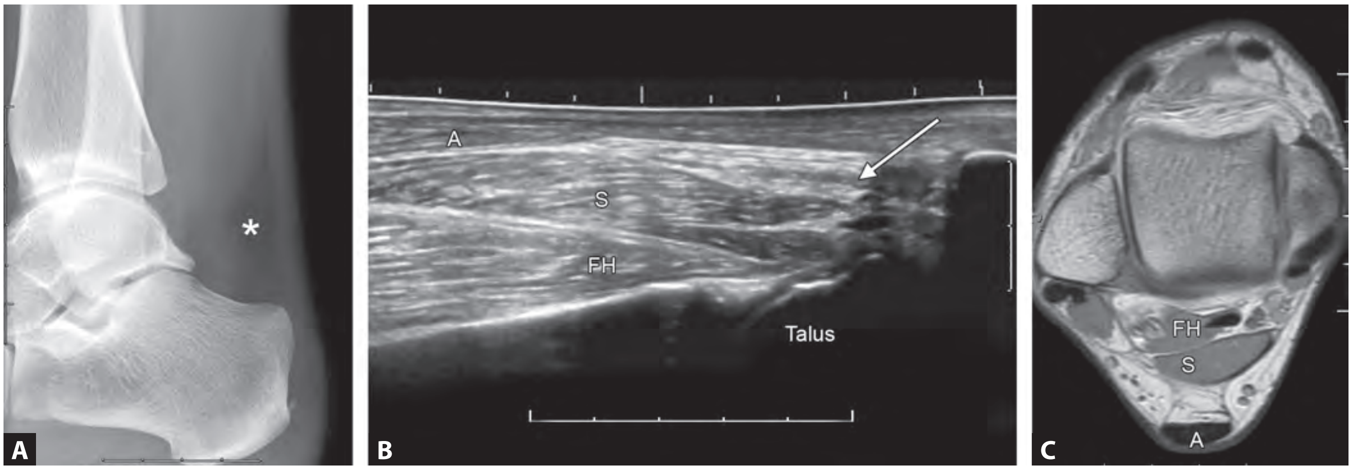

Right–left comparison in these split screen images shows the usual anatomy of subscapularis tendon (Sub) deep to the deltoid (D) on the left and an accessory muscle (*) sandwiched between the deltoid and the subscapularis on the right.

most common pseudomasses encountered. In the adolescent rotator cuff, muscle of the supraspinatus is longer than its counterpart in the adult shoulder.[26] This may result in hypoechoic areas within the cuff. Knowledge of this phenomenon will avoid the mistake of identifying muscle as a rotator cuff tear. Identification of the pennate structure of the muscle will help avoid an erroneous diagnosis and will allow the operator to distinguish reliably between muscle tissue and pathology (Figs. 3.13A and B).

Images obtained during isometric contraction will demonstrate an apparent increase in muscle mass. This is due to the thickening of muscle bundles during contraction. Since these muscle bundles appear hypoechoic, the overall echogenicity of the muscle decreases during isometric contraction. Hypertrophy of muscle bundles in a well-conditioned athlete will also result in decreased echogenicity. This may prove to be a valuable tool in evaluating the level of conditioning in athletes. Conversely, during relaxation, firm compression with the transducer will result in a more echogenic appearance of the muscle. In general, not too much pressure should be applied to muscle when the muscle surface is examined. Small fascial defects and muscle protrusions through these defects can be mimicked by excessive transducer pressure (Fig. 3.82).

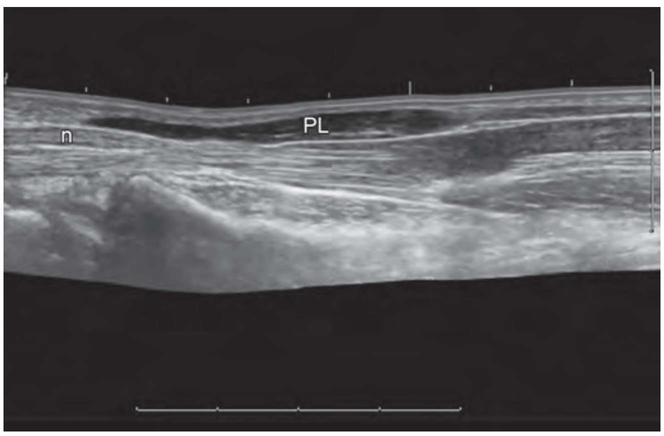
Another aspect of muscle physiology that must be kept in mind is blood flow. Although muscle comprises approximately 40% of body mass, it receives only 15% of total body blood flow at rest.[27] However, exercise can increase blood flow by 20-fold, resulting in a volumetric increase in muscle size by 10–15%. For example, tiptoe

**Figs. 3.11A to C:** Accessory soleus muscle.




A 38-year-old woman presents with chronic medial ankle pain and with palpable fullness medially in the posterior ankle. No significant osseous abnormality is demonstrated. A soft-tissue fullness (*) is noted posterior to the talus on this lateral radiographic projection (A). Ultrasound examination (B) of the posterior medial ankle reveals compression and posterior displacement of the normal pre-Achilles fat pad (arrow) by accessory soleus muscle (S), superficial to the normal flexor hallucis muscle (FH). This congenital anomaly is clearly identified by its normal striated skeletal muscle architecture demonstrated sonographically. The axial proton density magnetic resonance image (C) confirms the relationship of the accessory soleus muscle, a muscle sandwiched between the flexor hallucis muscle (FH) and the Achilles (A) resulting in the clinically palpable fullness at the medial aspect of the posterior ankle.

**Fig. 3.12:** Reversed palmaris longus muscle.




The palmaris longus (PL) tendon–muscle unit can vary significantly between individuals. In some patients, it can be entirely absent. In most patients, the muscle segment in the proximal medial forearm is short and the tendon is long and gracile. In this patient, the muscle extends over the carpal tunnel where it covers the median nerve (n) anteriorly. This muscle variant is typically referred to as the reversed palmaris longus.

exercise performed over several minutes will increase the volume of the posterior compartment of the calf sufficiently to cause anterior and lateral bowing of the interosseous membrane. The volume of the compartment will return to normal within approximately 10–15 minutes following exercise.[28]

## MUSCLE PATHOLOGY

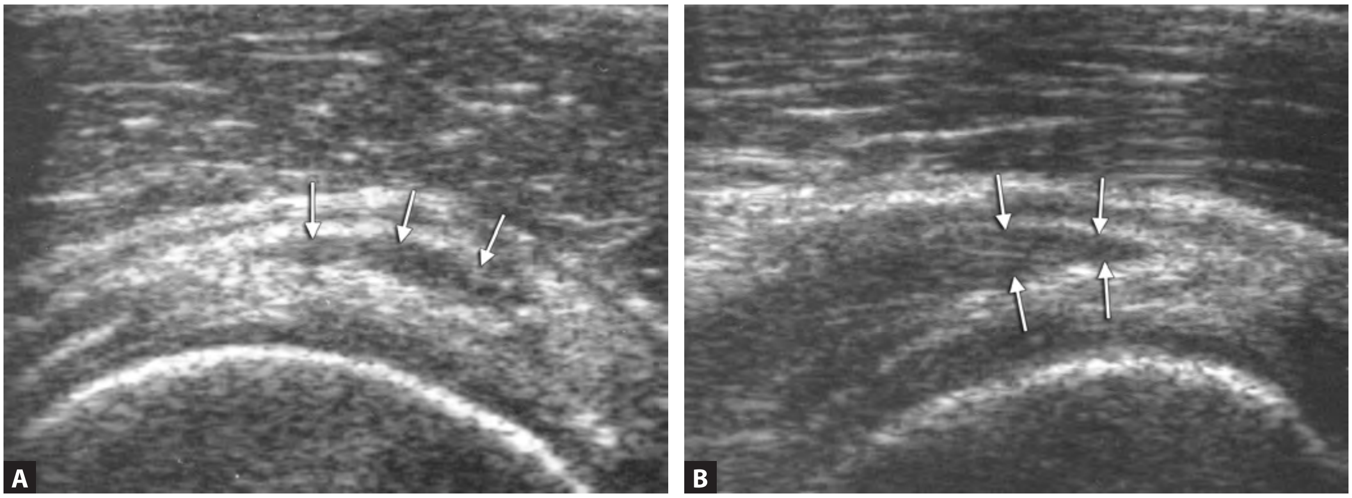
Muscle size can change according to functional requirements placed on that muscle. The overwhelming majority of muscle pathology is traumatic in origin, either occupational or sports related. Lesions can be further categorized as intramuscular or muscle boundary lesions. We consider the intramuscular lesions to involve the muscle belly or venter. Muscle boundary lesions are those involving the muscle–fascia interface.

### Muscle Atrophy/Hypertrophy

A muscle that is not used will atrophy. Denervation of a muscle, tear of a muscle, or disease of a muscle can all contribute to loss of function and subsequent loss of muscle volume resulting in atrophy (Fig. 3.14). When hypoechoic muscle atrophies, the fibrofatty septa approximate and stand out more prominently. In addition, fatty infiltration may occur. All these changes result in increased echogenicity compared to normal muscle.

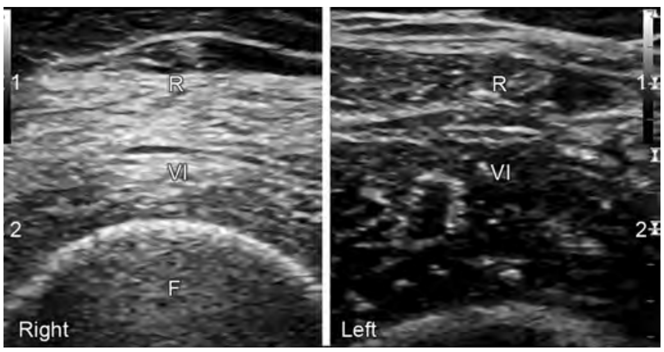
Muscle building in repetitive and sustained muscle exercise programs, compensatory growth when one muscle takes over for another muscle due to atrophy,[29] or muscle recruitment secondary to arthritis[30] can all lead to hypoechoic enlargement of muscle that can be mistaken for tumor, if the inexperienced examiner does not recognize the hypertrophic anatomy (Figs. 3.15A to G).

**Figs. 3.13A and B:** Normal rotator cuff of the adolescent.




(A) This transverse image of the rotator cuff of a young athlete demonstrates a hypoechoic area (arrows) within the supraspinatus tendon. Normal hyperechoic tendon surrounds this unusual area within the cuff. (B) On the longitudinal sonogram of the supraspinatus tendon, one notes that the hypoechoic area seen on transverse images is triangular in shape, with well-defined margins (arrows). The internal structure demonstrates the pennate architecture of muscle. Muscle tissue appearing lateral to the acromion has been observed only in patients under the age of 20.

**Fig. 3.14:** Denervation atrophy of the quadriceps.




A 48-year-old woman with a history of lupus and chronic femoral nerve palsy secondary to nerve compression due to a hematoma deep to the inguinal ligament. She experienced a complete loss of quadriceps function. The above split screen image was obtained 3 months following nerve injury. These transverse images obtained at the level of the midthigh anteriorly provide right—left comparison of the quadriceps muscle. In the affected right quadriceps, the muscle appears markedly echogenic due to the severe atrophy of muscle bundles and preservation of the echogenic fibroadipose septae. On the asymptomatic contralateral limb, we observe the normal mixed echogenic pattern observed in the transverse plane. Because of the marked quadriceps muscle atrophy in the right thigh, a greater circumference of the femoral diaphysis is visible. Pressure applied with the transducer was equal for both images. (F: Femoral diaphysis; R: Rectus; VI: Vastus intermedius).

Side-by-side comparison is extremely important in recognizing the individual hypertrophic tissue layers.

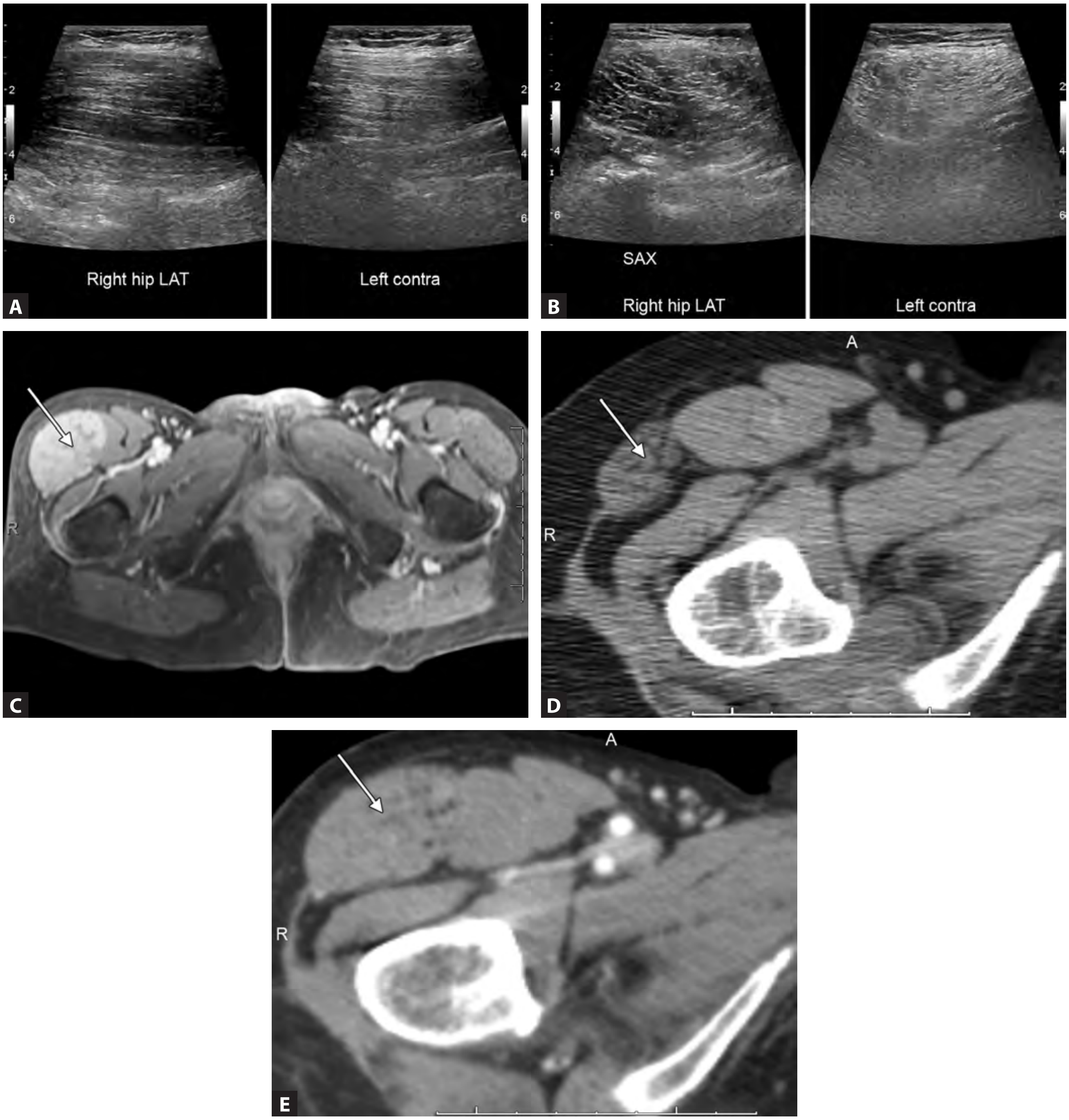
## Intramuscular Pathology

There are many etiologies of muscle pain, and not all of them are associated with an identifiable lesion. Delayed muscle soreness and muscle cramps are two well-recognized entities that are frequently encountered clinically. In exceptional cases, it may be difficult to distinguish these causes of muscle pain from the sequelae of muscle rupture. Sonography is extremely valuable in these cases to exclude anatomic lesions.[31]

Delayed muscle soreness is typically characterized by pain, tenderness, and frequently by swelling of the involved muscle groups. The onset of symptoms is usually observed approximately 12–24 hours following strenuous exercise. The symptoms slowly resolve over several days. Everyone has experienced delayed muscle soreness at some time. Usually, this occurs after playing three sets of tennis on the first day of a vacation. The remainder of the vacation is spent in a sedentary manner recuperating from the injury. Studies conducted with athletes and military recruits have demonstrated acute elevation of muscle enzyme levels measured in serum.[10,32] These changes are highly suggestive of microruptures and myofibrillar lysis. Histologic evidence of this injury has been observed. However, MRI and sonography have failed to demonstrate the microscopic lesions in these cases.

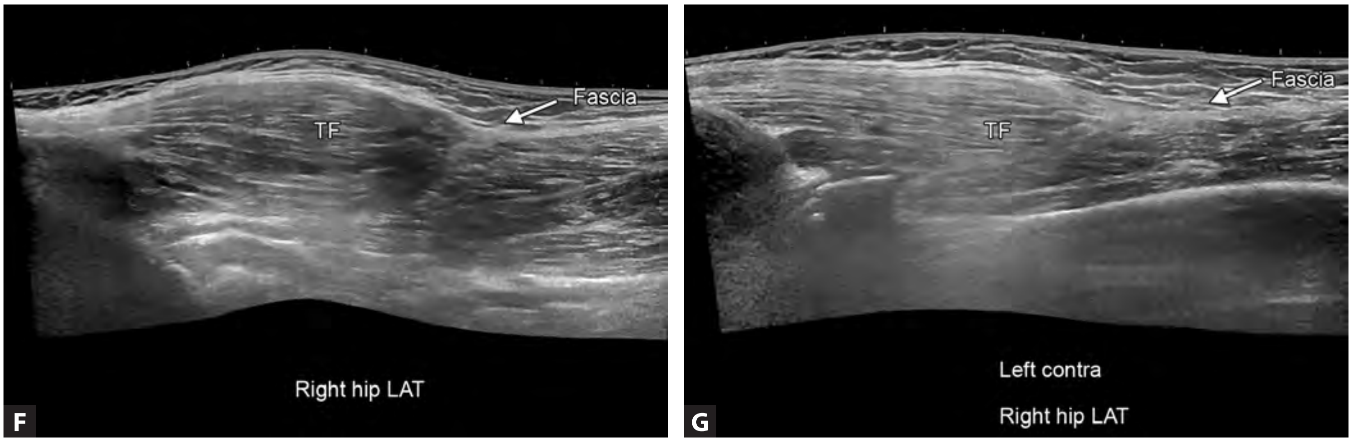
Muscle cramps affect a broad spectrum of people, ranging from well-conditioned athletes to the elderly. They are caused by a focus of spontaneous muscle activity

**Figs. 3.15A to E:** Hypertrophy of the tensor fascia lata.




(I) A 54-year-old man involved in a car accident. The posterior acetabular wall of the right hip requires surgical repair. Because of hip pain, the hardware is removed from the right hip 4 years later. During an intense physical therapy program, a mass is noted in the right anterior hip. Comparison long axis views (A) of the tensor fascia lata demonstrate hypertrophic right tensor fascia muscle on the left of the split screen, and normal left tensor fascia muscle on the right; short axis views (B) show hypertrophic right muscle on the split screen's left and normal muscle on the right. The gadolinium-enhanced fat-suppressed $T_1$-weighted axial image (C) demonstrates the enhancement (arrow) of the hypertrophic muscle in the right hip. The CT image of the right hip shows a normal tensor fascia muscle (arrow) at the time of the injury (D). Hypertrophy (arrow) is noted on the current CT image (E). Which was obtained at the time of the imaging in panels (A to C).

**Figs. 3.15F and G:** (*Continued*) Hypertrophy of the tensor fascia lata.




(II) The hypertrophic and hypoechoic tensor fascia lata muscle (TF) shows in the long axis image of the right hip (F) while the more normal tensor fascia (TF) shows in the left long axis (G). (CT: Computed tomography; F: Femoral diaphysis).

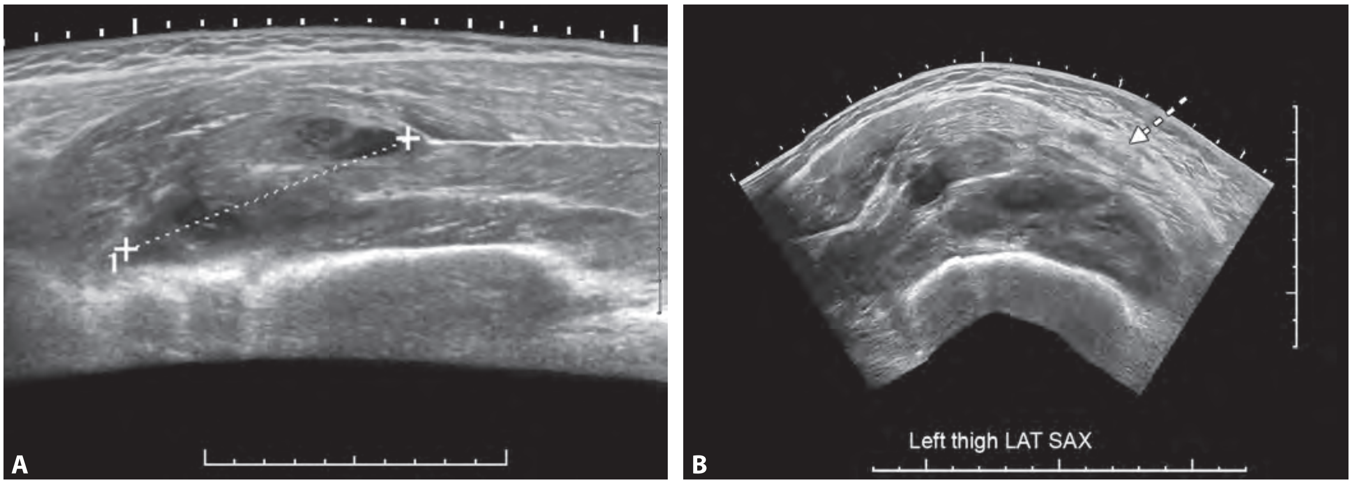
that results in muscle spasm and pain.[32] The pathogenesis of muscle cramps remains unknown, but multiple predisposing factors have been identified. Prolonged exercise, dehydration, electrolyte imbalances, extremes of temperature, lactic acidosis, chronic hemodialysis, atherosclerotic disease, and varicose veins are cited as predisposing factors to muscle cramps.[32,33] Muscle rupture may also result in muscle cramps, often leading the clinician away from the correct diagnosis. In the past, the correct diagnosis came to light only when the symptoms did not resolve after 3–4 days. The role of ultrasound in the evaluation of prolonged muscle cramping is to diagnose the underlying muscle rupture so that appropriate therapy may be instituted. Therapy for muscle cramps often includes passive stretching of the muscle. In simple cases, this maneuver will result in alleviation of pain and resolution of the cramp. However, this diagnostic/therapeutic maneuver will result in increased pain and progression of the lesion in cases where there is underlying muscle or tendon injury.

### *Muscle Rupture*

A muscle rupture may be caused by either compression (direct trauma) or distraction (indirect trauma). In compression injuries, the muscle is crushed against the underlying bone by an external force. Compression or contusion is frequent in contact sports and motor vehicle accidents. The collision of two football players, with the impact of one player's helmet on the quadriceps muscle of the other, is an example of how this injury may result. In other contact sports, e.g. soccer or basketball, the knee of a player can impact the vastus intermedius, vastus lateralis, or iliopsoas of an opponent. The involved muscle fibers are macerated along with the associated vessels, usually resulting in hematoma formation. The investing fascia may also be torn, with an extension of the hematoma beyond the muscle belly, possibly involving multiple fascial compartments (Figs. 3.16A and B). Healing of these lesions takes place slowly with considerable reparative tissue, which evolves into extensive scar tissue. This invariably results in a considerable long-term functional deficit. Laceration of a muscle with a sharp object can cause similar damage as in muscle compression. When damage to muscle and fascia is extensive, debridement of muscle and repair of fascia may be necessary to avoid infection and herniation of muscle.[11] In many patients, though, these lesions are treated conservatively with a prolonged history of disability as a result.

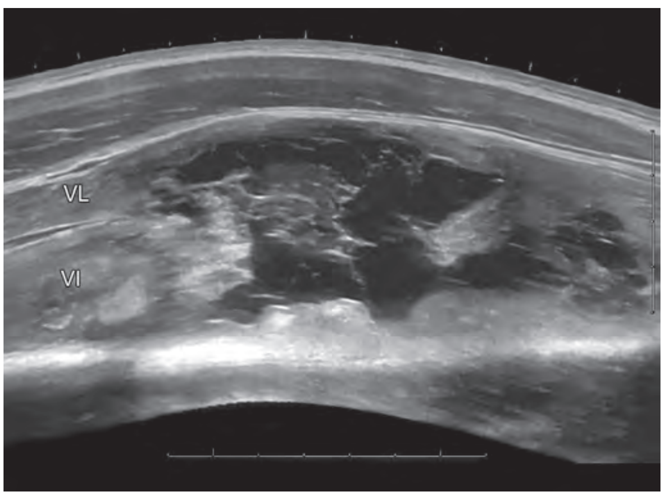
Sonography is well suited for the evaluation of compressive muscle ruptures.[34] These lesions are characterized by an irregular cavity with shaggy borders (Fig. 3.17). The disruption of the muscle tissue often crosses septal and fascial boundaries. When imaged acutely, the echogenicity of the hematoma may limit evaluation of the extent of the lesion, resulting in an underestimation of its size. Approximately 48–72 hours following injury, the collection becomes essentially anechoic, allowing measurement of the true extent of the injury. Follow-up examinations to evaluate healing will demonstrate progressive filling in of the lesion from the periphery with echogenic tissue. Scar tissue will appear hyperechoic, and acoustic shadowing will be seen deep to regions of myositis ossificans (a complication that can follow this type of muscle tear discussed below). Areas of myositis ossificans will have a pseudotumor appearance, which is detected significantly earlier with sonography than with conventional radiography.

**Figs. 3.16A and B:** Compression muscle rupture.




A 66-year-old man received a direct hit on the proximal quadriceps in the thigh by falling and hitting a cement curb. The compound longitudinal sonographic image (A) of the vastus lateralis obtained 1 week after injury demonstrates a muscle rupture (in between cursors) due to compression. The tear extends across fascial compartments. In transverse imaging (B) a fascial defect is clearly demonstrated (dashed arrow) adjacent to the extensive muscle rupture site that affects all four components of the proximal quadriceps. An associated fascial defect is commonly observed in compressive muscle injury. At the time of the injury, the patient was kept overnight because he was suspected to be developing compartment syndrome. This injury resulted in months of pain with ambulation.

**Fig. 3.17:** Compression muscle rupture.




A 16-year-old male soccer player received a direct hit to the vastus lateralis muscle (VL) in midthigh by an opposing player. The compound longitudinal sonographic image of the vastus lateralis and lateral vastus intermedius (VI) obtained 3 days after injury demonstrates a muscle rupture with very irregular fragments of torn muscle. The boundaries between the different components of the quadriceps are blurred and significant mass at the site of rupture is noted. The patient was unable to return to soccer that season.

Distraction muscle ruptures differ from compression ruptures in both their pathogenesis and their morphology. They are the result of the intrinsic force generated by sudden vigorous contraction of a muscle.[10] Sports that have a high incidence of distraction muscle ruptures are track and field, soccer, football, basketball, weight lifting, and gymnastics. Muscles of the lower extremity are most frequently affected, particularly those muscles that span two joints. Muscles that lengthen when they contract (eccentric contraction) and muscles with a high percentage of fast-twitch fibers are at greatest risk of distraction injury.[32,35-37] The most susceptible are the hamstrings and rectus femoris in the thigh, and triceps surae muscles in the calf. Distraction injury in the upper extremities and trunk is seen far less frequently.[38] Noonan and Garrett have shown in animal experiments that muscles tear less easily when they have a higher local temperature.[39] Interestingly, simple electric stimulation does not cause muscle tear, a muscle must be stretched past its resisting length for it to tear.[40] The pathologic changes of tear extend along the musculotendinous junction in all types of muscle strain.[37] In fact, microscopically, the tear is described as being a short distance from the musculotendinous junction. This is a distinction that cannot be made by ultrasound in part because of the extent of edema and local hemorrhage.[161] On ultrasound, the lesions occur most often where tendon and muscle join or where tendon and aponeurosis join. For this reason, some authors have called these injuries myotendinous strains (Figs. 3.18A to C3).[11] Sonographers, therefore, have to study the anatomy of individual muscles and their aponeuroses carefully.

# Musculoskeletal ULTRASOUND

"Musculoskeletal Ultrasound" is the third edition, intended as a print and electronic book, combines text, static and dynamic ultrasound images, line drawings, 3-D animations, and variable combinations of audio and video. The glossary and search functions now replace the old index. The glossary contains crucially important terminology often illustrated by graphic material. A truly interactive feature will be the Continuing Medical Education (CME) offering of this book, which will be available shortly. This third edition contains more information on ultrasound anatomy, indications for musculoskeletal ultrasound examinations, and information on pathology and ultrasound signs of disease. This new edition shows more maturity in part because the field has finally gained widespread acceptance. The recent rapid growth of this technique and evidence of an ever-increasing number of followers prove that musculoskeletal ultrasound represents an important tool in the hands of the contemporary musculoskeletal practitioner.

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