Ultrasound of Skeletal Muscle Injury

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ABSTRACT

The professional and recreational demands of modern society make the treatment of muscle injury an increasingly important clinical problem, particularly in the athletic population. In the elite athlete, significant financial and professional pressures may also exist that emphasize the need for accurate diagnosis and treatment. With new advances in ultrasound technology, images of exquisite detail allow diagnosis of muscle injury that matches the accuracy of magnetic resonance imaging (MRI). Furthermore, the benefits of real-time and Doppler imaging, ability to perform interventional procedures, and relative cost benefits compared with MRI place ultrasound at the forefront for investigation for these injuries in many circumstances. Muscle injury may be divided into acute and chronic pathology, with muscle strain injury the most common clinical problem presenting to sports physicians. This article reviews the spectrum of acute and chronic muscle injuries, with particular attention to clinical features and some common or important muscle strain injuries.

KEYWORDS: Ultrasound, muscle, muscle injury, trauma, sport

With the development of high-frequency probes and advances in software technology, ultrasound has become an increasingly useful tool in the evaluation of skeletal muscle injury. Exquisite detail obtained from new-generation machines now allows detection of subtle abnormalities in low-grade injuries that approach the sensitivity of magnetic resonance imaging (MRI) in the acute setting.[1] Additionally, the accessibility, speed, and reduced cost of ultrasound examination offer significant benefits over MRI in the initial evaluation and follow-up of these injuries.

Muscle trauma may be divided into acute and chronic injury. Muscle contusions and muscle strains or tears account for the vast majority of acute skeletal muscle injuries presenting for ultrasound review and are most commonly seen in athletes. Muscle laceration is rarely imaged. Compartment syndrome is a serious consequence of acute skeletal trauma. Chronic injuries usually arise as the sequelae of acute injury and include muscle scar, muscle hernia, and myositis ossificans. In this article we review the sonographic features and utility of ultrasound in skeletal muscle injury.

NORMAL SONOGRAPHIC ANATOMY

Muscle fibers are the fundamental building blocks of skeletal muscle that form into bundles or fascicles that are beyond the resolution of ultrasound. These fascicles are surrounded by the perimysium, fine septated fibroadipose tissue arranged in parallel bands, whose orientation gives the "pennation" of the muscle. The perimysium appears as parallel echogenic striations on longitudinal sonograms (Fig. 1A) and "dots" or short lines on transverse images of muscle (Fig. 1B), with muscle fibers forming a hypoechoic background.

Individual muscles are surrounded by thick fibrous tissue, the epimysium, which is highly echo-

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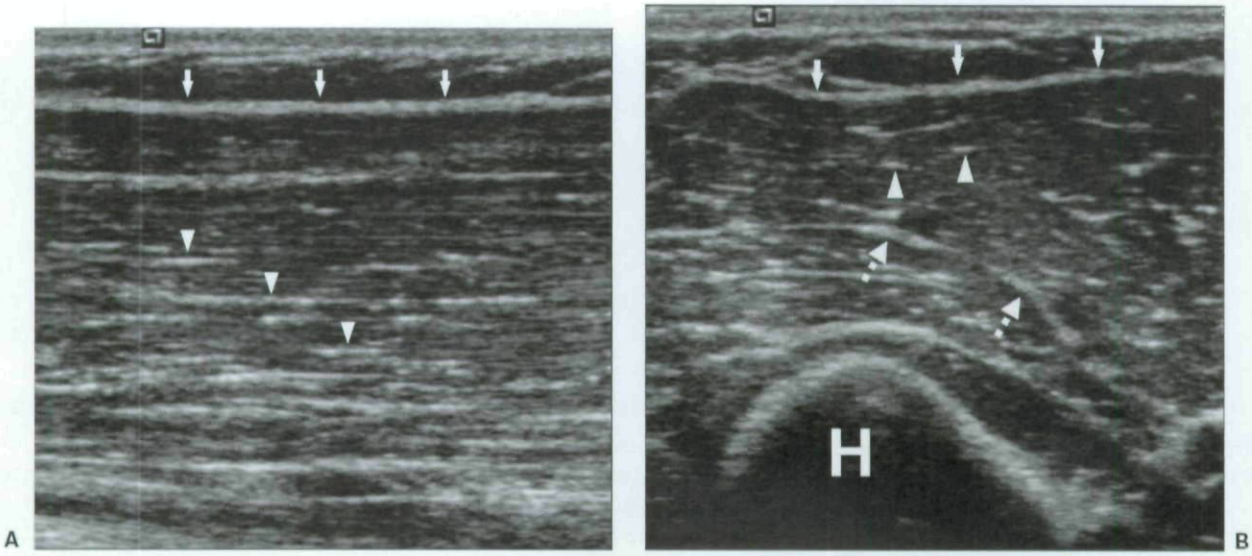


Figure 1 Normal biceps brachii muscle in a 23-year-old woman. (A) Longitudinal sonogram shows the perimysium as thin parallel echogenic lines (arrowheads). The perimysium of the biceps brachii parallels the epimysium (small arrows), having the typical configuration of a fusiform muscle. (B) Transverse sonogram shows the perimysium as multiple dots or short lines (arrowheads) on a hypoechoic background of muscle fibers. The epimysium is seen as a brightly echogenic band beneath the dermis and subcutaneous fat (small arrows). Prominent intramuscular septa (small dotted arrows) are also present within the muscle belly. H, humerus.

genic (Figs. 1A,B). Prominent echogenic intramuscular septae may also be seen (Fig. 1B). Unipennate and bipennate muscles have an oblique orientation of perimysium to the epimysium or the linear, echogenic fascial condensations that form the musculotendinous junction (Fig. 2A). The length of this interface is variable but may be extensive, spanning the entire muscle, as in the case of the biceps femoris muscle. In fusiform muscles the perimysium is oriented parallel to the long axis of the muscle (Fig. 2B).

TECHNIQUE

Ultrasound examination of muscle injury begins with a short history and physical examination, allowing the patient to identify the site of maximum symptoms with one finger, if possible. The nature of the injury, precipitating event, and pattern of symptoms following the injury may all assist with diagnosis. It should be appreciated that a history of trauma is not always present in patients with myositis ossificans. Palpation of the injured muscle both in the relaxed position and on contraction and assessment of muscle strength helps with further classification. Careful review of the symptomatic region in the longitudinal and transverse planes may then be performed. Evaluation of the remainder of the muscle in two planes is also undertaken from proximal to distal insertion, with serial examination of the enthesis, musculotendinous junction, intramuscular septae, and the epimysium in cases of suspected strain injury. Other muscles in the affected compartment are also reviewed. Dynamic imaging with active and passive movement plays an important role in evaluation of muscle tears, hernias, and scars. The examination is completed by assessing regional blood flow and proximity of any injury to neurovascular structures because muscle swelling or hematoma may result in impingement.

High multifrequency linear probes (minimum 5 to 13 MHz) are required to assess muscle injury, where the most subtle changes in muscle architecture need to be appreciated to provide a reasonable level of diagnostic accuracy. Occasionally, depending on patient size and the depth of muscle involved, a lower frequency (5 to 7 MHz) linear or even a low-frequency (2 to 4 Hz) curvilinear probe may be required; however, with frequency reduction, spatial resolution and the ability to detect low-grade or small injuries diminishes rapidly. Compound imaging and tissue harmonic imaging are software adjustments that may further improve lesion conspicuity.[2,3] Power Doppler is of use in identifying hyperemia associated with acute injuries. Extended field-of-view (FOV) imaging is helpful in the ultrasound of muscle, particularly to evaluate tumors and diffuse muscle pathologies and to improve image presentation and follow-up. In the setting of muscle injury, extended FOV may be helpful in assessing the length of muscle strain injury or gap following muscle tear. However in many cases, where lesions are localized and focally symptomatic, this technique may be of limited utility.

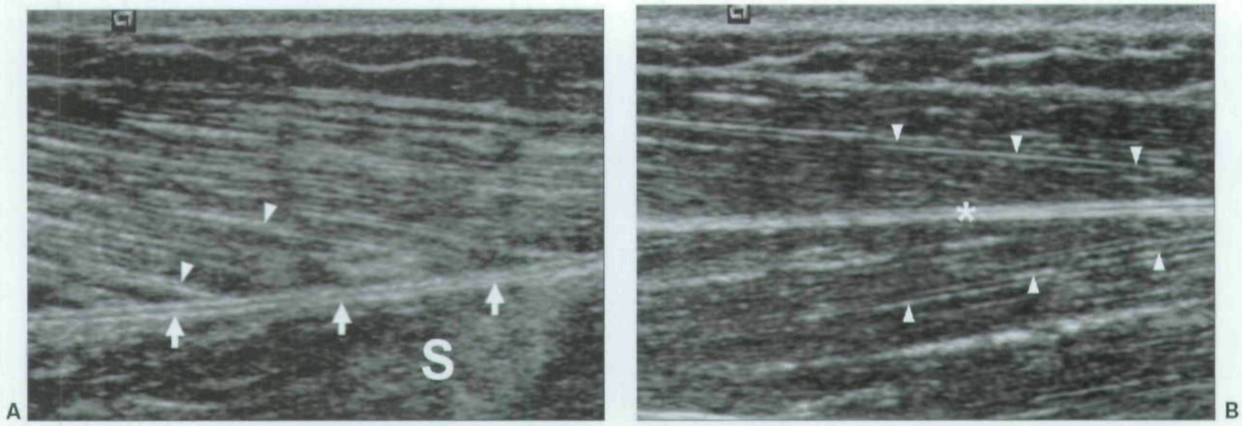


Figure 2 Normal unipennate and bipennate muscles in a 23-year-old woman. (A) Longitudinal sonogram of the medial head of gastrocnemius shows obliquely oriented perimysium (arrowheads) inserting onto the intermuscular fascia (arrows). Soleus muscle (S) lies deep to the fascia. This is the typical configuration of a unipennate muscle. (B) Longitudinal sonograms of the flexor carpi radialis muscle shows obliquely oriented perimysium (arrowheads) converging on the intramuscular tendon (asterisk). This is the typical configuration of a bipennate muscle.

ACUTE MUSCLE INJURY

Muscle Contusion

Muscle contusion injuries result from blunt, nonpenetrating trauma and are most frequently seen in the thigh in football sports and the upper arm in tackling sports. Symptoms and signs of muscle contusion injury include pain and stiffness, reduced range of movement, and a palpable swelling or mass. Diagnosis, most commonly of low-grade injuries in the so-called weekend warrior, is often clinical and based on a history of trauma and examination findings. However, ultrasound has several roles in the management of muscle contusion injury, particularly in athletes. The primary role of imaging is to exclude the presence of a significant muscle tear associated with muscle contusion. In the absence of a significant tear, immobilization in a stretched position is currently advocated with a short (24 to 48 hours)

Figure 3 A 26-year-old male football player with vastus intermedius hematoma following a high "tackle." (A) Longitudinal extended field-of-view (EFOV) sonogram shows large complex echogenic collection (between arrows) expanding the mid vastus lateralis muscle (VL). (B, C) Follow-up longitudinal and transverse EFOV sonograms at 4 weeks shows the organizing hematoma (arrows), which predominantly consists of loculated anechoic fluid.

course of nonsteroidal anti-inflammatories before early mobilization. With contusion and associated muscle tear, consideration may be given to longer rehabilitation or operative repair.[4] Ultrasound may also be used to make a diagnosis of muscle contusion in the absence of a history of recalled trauma, to evaluate post-contusion hematoma to assess suitability for drainage, and to diagnose complicating myositis ossificans or scar formation.

Ultrasound appearances of muscle contusion injury vary with the severity and age of the injury. Microscopically, disruption of capillaries and muscle fibers occurs, with hematoma lying between torn fibers and infiltrating around intact fibers.[4] Sonographically, in early or low-grade injury, focal muscle swelling secondary to edema and hematoma may be seen. In the first 24 hours, focal hematoma can have a variable appearance, from anechoic or hypoechoic to hyperechoic (Fig. 3A). Over the following 2 to 3 days, the collection becomes hypo- or anechoic (Figs. 3B,3C). Subsequently, increasing hematoma echogenicity may be seen and fluid-debris levels identified. Swelling and focal changes in low-grade or small injuries may rapidly resolve with a return to normal muscle architecture. Hematoma organization and development of focal scar tissue may occur over weeks in large injuries.[5]

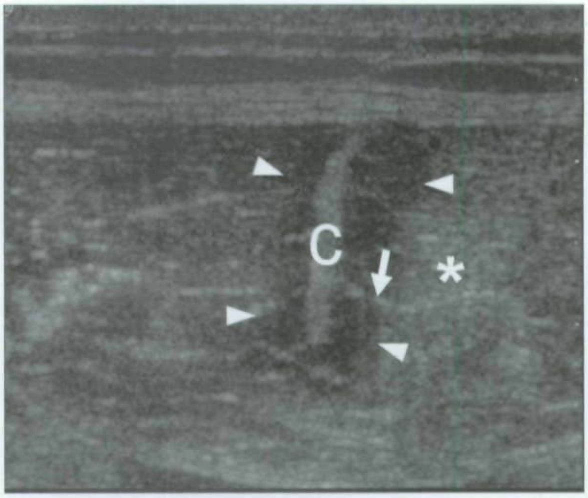


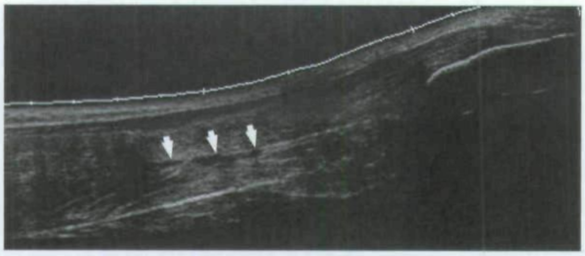
Figure 4 A 19-year-old male sprinter with strain (grade I injury) of the rectus femoris muscle. Transverse sonogram shows echogenic central tendon (C) surrounded by hypoechoic muscle (arrowheads). Perimysial fibers are intact (white arrow). The more peripheral rectus femoris muscle demonstrates normal echogenicity to the left and increased echogenicity (asterisk) to the right of the central tendon. Increase in echogenicity is also a feature of grade I muscle injury. These zonal changes correspond to the bull's-eye lesion seen on magnetic resonance imaging.

Muscle Strain, Tear, and Laceration

Muscle strains and tears constitute a spectrum of injury that typically occurs near the musculotendinous junction (MTJ), primarily arising from muscle overelongation (Figs. 4 and 5).[1,6] The musculotendinous junction includes not only the vicinity where the tendon emerges from the muscle belly but has a long intramuscular component where muscle tissue lies in close proximity to the intramuscular central tendon. Other important junctional zones include the area beneath the epimysium and where muscles are attached to periosteum. Muscles that cross two joints, including the hamstring muscle complex, quadriceps muscle, and calf muscles, are most susceptible to these injuries. Eccentric muscle contraction, when a muscle contracts as it undergoes passive lengthening, and the presence of increased fast twitch (type II) muscle fibers are further physiological factors that influence the occurrence of muscle strain/tear injury because both increase the degree of tension generated within these muscles.[1,6,7] Less commonly, muscle strains can occur at the epimysial fascia (Fig. 6) and within the muscle belly (Fig. 7). Some fascial injuries, such as those occurring in the medial calf (tennis leg) (Fig. 8) and biceps femoris muscle (Fig. 6), are thought to be related to forces generated by differential contraction of adjacent muscle bellies on the intervening fascia (aponeurotic distraction injury).[1] The pathophysiology of intramuscular strain is poorly understood. Muscle laceration is a form of muscle tear that arises from direct penetrating trauma, involving the epimysium and underlying muscle.

Symptoms and signs are similar to those with muscle contusion injury and typically occur during or after a period of intense activity. Additional findings include tenderness localized at the MTJ, muscle weakness, and a palpable defect in cases of complete muscle tear. As with muscle contusion injury, diagnosis of muscle strain injury is most often clinical. Imaging may be used to establish the presence of injury in those where there is a history of relatively minor trauma and to exclude an alternative diagnosis, particularly deep venous thrombosis. Because the severity of muscle strain injury is directly related to healing time, imaging may be helpful in determining recovery periods and rehabilitation, particularly in elite athletes.[8] Several clinical and imaging grading systems for muscle strain injuries have been described that are relevant for prognosis and patient rehabilitation (Table 1).[9] Low-grade injuries heal within 1 to 2 weeks, whereas high-grade injuries may take 4 to 8 weeks.[6]

Microscopically, edema and hemorrhage infiltrate around intact muscle fibers around the site of injury near the MTJ.[6] This results in a "feathered" appearance of muscle on MRI in low-grade injuries that may be occult (grade 0) or evident as subtle hypo- and/or hyperechoic change and swelling on ultrasound



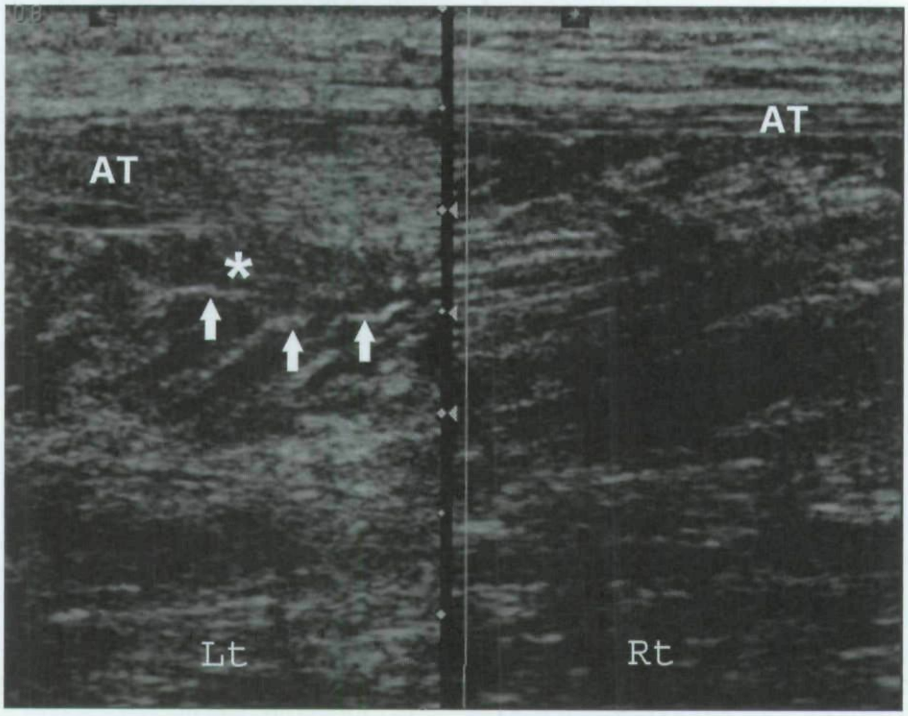


Figure 5 A 40-year-old man with acute partial tear (grade II injury) strain of the left soleus musculotendinous junction (MTJ) on background Achilles tendinosis, sustained while pushing a car. (A) Extended field-of-view sonogram of the left Achilles tendon shows diffuse midsubstance tendinosis and grade II strain at the MTJ (arrows). (B) Longitudinal sonograms of the right and left Achilles tendons (AT) show disruption of the perimysium (arrows) at the MTJ with isoechoic fluid (asterisk) adjacent to the tendon. The left Achilles tendon is thickened, compatible with tendinosis, when compared with the right.

(grade 1) (Fig. 4). Disrupted muscle fibers are seen as areas of altered echogenicity and loss of perimysial striation adjacent to the musculotendinous junction that may be associated with focal hematoma in the form of an anechoic or hypoechoic collection (grade 2) (Fig. 5). More complex collections may be seen and fluid may also track along fascial planes to collect remote to the site of injury. Retraction of torn tendon ends may also be identified on ultrasound; the "clapper in bell" sign refers to the sonographic finding of a torn, retracted central tendon, surrounded by hypoechoic hematoma (Fig. 9).[10] Measurement of the cross-sectional area of injury on ultrasound is of prognostic significance in the rehabilitation of hamstring injury in footballers.[7,8] In severe injury (grade 3), the torn ends of muscle can be identified, their presence accentuated by fluid and refractile shadowing (Figs. 10 and 11). In complete untreated tears, these ends become rounded and may tether to adjacent muscles or fascia. The healing of muscle strain injury follows a similar course to that described for contusion injury. As with injuries at the MTJ, fluid collections and disruption of perimysium are also seen in intramuscular tears and injuries to the epimysial fascia (Figs. 6 and 7).

For muscle strain or tear injury, ultrasound is most useful in the acute setting (between 2 and 48 hours), where the sensitivity equals MRI primarily because of its ability to detect post-traumatic fluid collections.[1] However, ultrasound underestimates the extent of injury both in longitudinal and cross-sectional dimensions when compared with MRI.[7] Furthermore, abnormalities seen on ultrasound resolve more quickly than MRI as acute hematomas resolve and the superior tissue contrast resolution of MRI comes into play. MRI is therefore felt to have a more significant role in the management of muscle injury in elite athletes, particularly where acute decisions regarding imminent participation in sport are necessary.

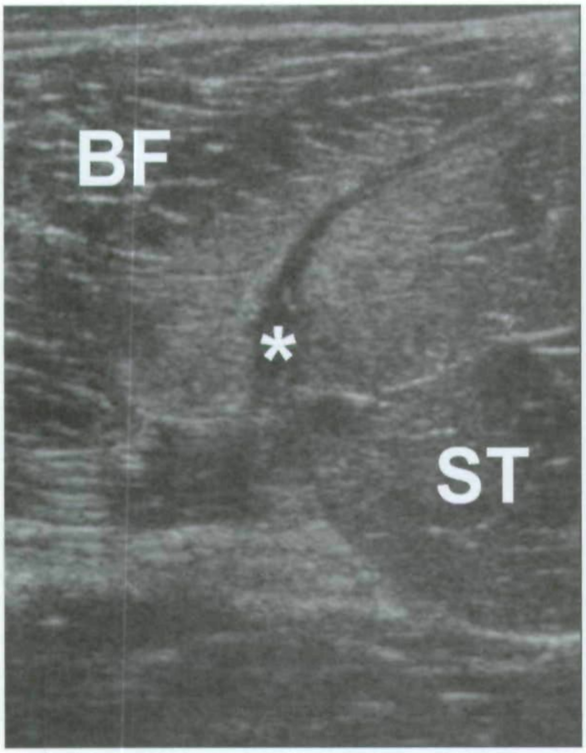


Figure 6 A 26-year-old rugby player with hamstring muscle epimysial fascia strain. Fluid (asterisk) is present adjacent to the semitendinosus muscle (ST) epimysial fascia as it lies beside the biceps femoris muscle (BF) in the midthigh. Also note the increased echogenicity in the fibers of both muscles adjacent to the epimysial fascia, typical of muscle strain injury.

Specific Injuries

PECTORALIS MUSCLE INJURY

Injuries to the pectoralis muscles, predominantly involving pectoralis major, are relatively uncommon and have been reported in athletic and nonathletic patients. Weight lifters, particularly during bench-press exercises, and those involved in tackling sports may suffer pectoralis major injury following an eccentric contraction of the muscle as it is actively stretched.[11] Pectoralis muscle injury may also occur during a fall with the arm abducted and extended.[12] Pectoralis major arises from the anterior chest wall as a broad "fan" from two major heads, the smaller clavicular and larger sternal head. A third minor abdominal or costal head arises more inferiorly. The muscle tapers to a complex trilaminar tendon that rotates 90 degrees before inserting into the lateral border of the bicipital groove.[11–13] Injuries occur both at the humeral insertion or MTJ probably with near equal frequency and may be partial or full thickness. Proximal muscle or aponeurotic injury is rare.[11,12] Pectoral muscle injury is readily visualized by ultrasound, which may be used as a viable alternative to MRI in preoperative assessment. As with MRI, imaging in the abduction and external rotation (ABER) position extends and improves visualization of the musculotendinous junction and allows more accurate localization of injury[12] (Fig. 10).

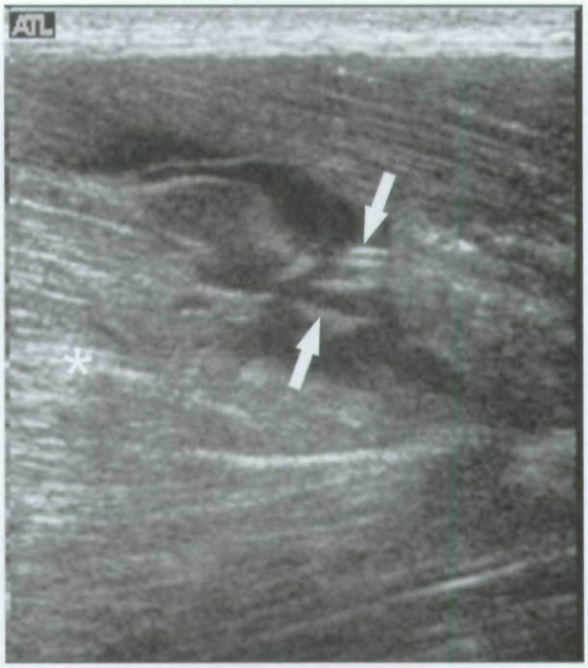


Figure 7 An 18-year-old football player with acute partial intramuscular tear of vastus lateralis. Hypoechoic hematoma is seen adjacent to disrupted perimysial fibers (arrows). There is diffuse increase in echogenicity to the left of the tear (asterisk) due to spread of hematoma between muscle fibers.

ADDUCTOR MUSCLE INJURY

Commonly injured in sports where frequent direction changes are required, such as soccer and Australian Rules football, acute injuries to the adductor muscles typically occur in young athletic patients in whom the lower limb undergoes forced abduction.[14,15] This muscle group comprises the adductor longus, adductor brevis, adductor magnus, and gracilis muscles and arises from the pubis, inferior pubic ramus, and ischial

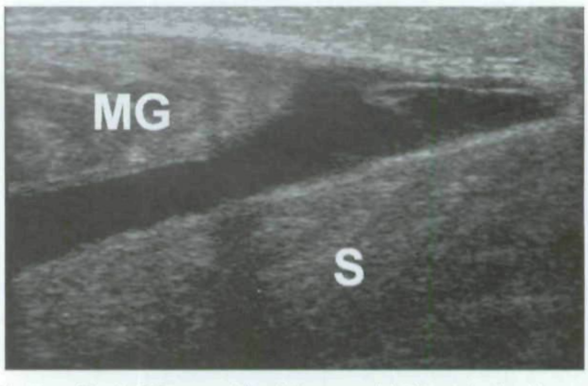


Figure 8 A 33-year-old cricketer with "tennis leg," sustained while batting. Longitudinal sonogram of the medial left calf shows the retracted fibers of the medial head of gastrocnemius (MG) and an anechoic fluid collection overlying the intervening fascia and soleus muscle (S).

Table 1 Muscle Strain Injury: Ultrasound Findings

Grade	Ultrasound Findings
1	Normal appearance or small area of focal disruption (< 5% muscle volume).
2	Partial tear with muscle fiber disruption (> 5%) but not affecting whole muscle.
3	Complete tear with frayed margins and bunching of muscle on dynamic stressing.

tuberosity by short tendinous attachments that may appear to be nonexistent in the case of adductor brevis. The adductors attach by long aponeuroses into the femur, predominantly onto the linea aspera and adductor tubercle, with the exception of gracilis that inserts with the other pes anserine tendons by a small round tendon into the medial aspect of the proximal tibia.[13,14]

Although adductor longus is commonly regarded as the adductor muscle most likely to be injured with overuse, injuries to adductor brevis are probably just as frequent. Both are best examined with the leg externally rotated and abducted, with the knee in flexion. The palpable medial border of adductor longus may be traced proximally to a narrow tendon that inserts into the pubis.[9] In older athletes, particularly soccer players, in whom chronic adductor tendinopathy is more prevalent, acute injuries may be seen proximally, involving the tendon or MTJ.[14] The other three adductor muscles lie posterior and medial to adductor longus. Acute rather than overuse injuries to the adductor muscle group tend to occur at the distal musculotendinous junction where the broad, thin aponeurotic attachment is vulnerable to injury.[9] They may be better assessed with the patient in the prone position, although in patients with bulky thighs, MRI may be a more suitable modality.

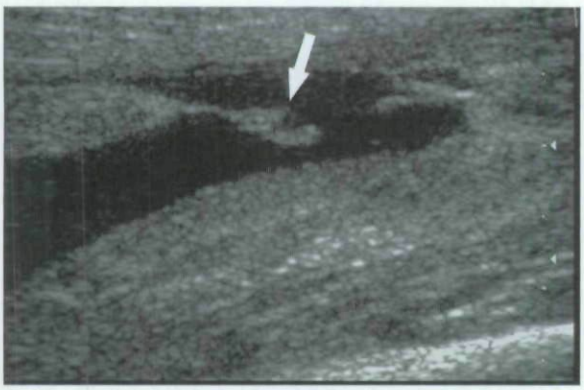


Figure 9 A 19-year-old male hurdler with acute partial tear of the biceps femoris tendon. Longitudinal sonogram shows the retracted end of the biceps femoris central tendon (arrow) surrounded by fluid—giving the "bell clapper" sign—and intact muscle fibers.

RECTUS FEMORIS INJURY

Rectus femoris is the only biarticular quadriceps muscle and, along with its higher percentage of fast twitch fibers and propensity for eccentric contraction, it is the most commonly injured muscle of this group. Its superficial position makes it particularly suitable for assessment by ultrasound. The muscle forms from two heads: the straight (anterior) head arising from the anterior inferior iliac spine and the reflected (posterior) head arising from the anterolateral aspect of the acetabular rim. The two tendons from each head form a superficial or anterior aponeurosis.[13] However, more recently a proximal sagittally oriented central tendon or aponeurosis has been described. Easily identified by ultrasound, particularly on axial imaging, it is located superficially within the upper two thirds of the muscle. Its presence gives the muscle a unique architecture, consisting of peripheral unipennate fibers and central bipennate fibers that attach to the central tendon and predispose the proximal rectus femoris to MTJ injury.[7,16] Within the lower two thirds, a broad flat aponeurosis forms posteriorly, forming the superficial lamina of the quadriceps tendon that inserts into the proximal pole of the patella.[13]

Athletes involved in kicking sports and sprinting are particularly prone to rectus femoris injury. The dominant kicking leg is most often affected.[17] It most commonly occurs at the distal MTJ as fibers insert into the posterior aponeurosis and may result in a palpable distal thigh mass related to muscle belly retraction (Fig. 11).[1] Proximal MTJ injury involving the central tendon has been more recently reported, along with a revised description of rectus femoris anatomy described earlier. It is of clinical significance in professional athletes because of its association with a significantly increased rehabilitation interval.[1] This injury may be difficult to detect clinically, primarily because of its deep location. Sonography is reliable in diagnosing proximal MTJ injury, which in grade I and II lesions is characterized by altered echogenicity around or obscuring the central tendon and a normal-appearing "peripheral portion," the "bull's-eye" lesion seen on MRI.[7,8] (Fig. 4) The earliest changes on ultrasound include loss of reflectivity within the muscle fibers that lie immediately adjacent to the central tendon. This decreased reflectivity contrasts with the more conspicuous connective tissue strands that attach to the central tendon itself. In the early stages the central tendon may appear normal, but with increasing severity of injury there may be swelling and decreased reflectivity. In more severe injury, frank interruption of the central tendon is seen. With healing the tendon becomes enlarged and markedly hypoechoic consistent with fibrosis. At this stage, patients are not infrequently referred with a clinical concern of sarcoma. The classic location and fibrous nature of the mass prompt questions about recent trauma that should lead to the correct diagnosis.

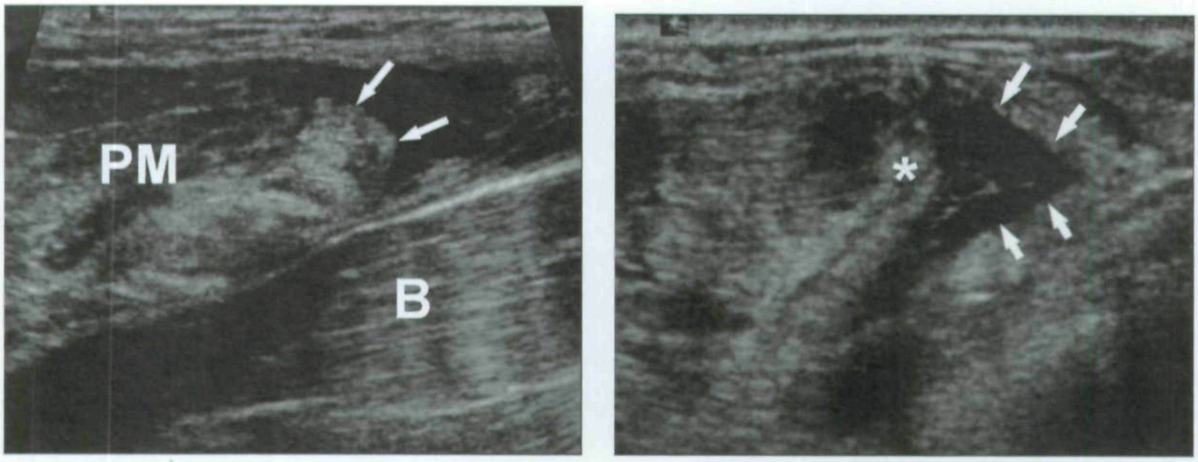


Figure 10 A 35-year-old rugby player with an acute complete rupture of the pectoralis major muscle at the musculotendinous junction while performing a bench press during training. (A) Longitudinal sonogram in the abducted and externally rotated position shows retracted pectoralis major (PM) sternal head fibers (arrows) with hypoechoic fluid in the muscle tendon gap. The medial head of biceps (B) is seen deep to the pectoralis major near its insertion. (B) Transverse sonogram of the pectoralis major sternal head tendon (asterisk) shows the medial extent of the injury to the musculotendinous junction. Fluid (arrows) lies adjacent to the forming tendon.

HAMSTRING MUSCLE INJURY

Consisting of biceps femoris, semimembranosus, and semitendinosus, the hamstring muscle complex (HMC) is responsible for hip extension and knee flexion and plays an important role in the gait cycle. Of all muscle injuries, this group is the most frequently affected, with HMC injury particularly common in sprinting athletes. As with rectus femoris muscle injury, the biarticular nature and eccentric contraction of the HMC during ambulation predispose this muscle group to strains and tears.[1]

Biceps femoris, as its name implies, arises from two heads. The long head arises from the medial facet of the ischial tuberosity via a conjoint tendon with semitendinosus. The short head arises from a more extensive attachment to proximal femur, adjacent intermuscular fascia. It spans only one joint (the knee) and has a separate innervation to the long head. Proximal and distal tendons traverse the entire muscle, with contributions from the two heads forming the distal tendon that inserts onto the fibula head, which has further distal expansions.[1,13]

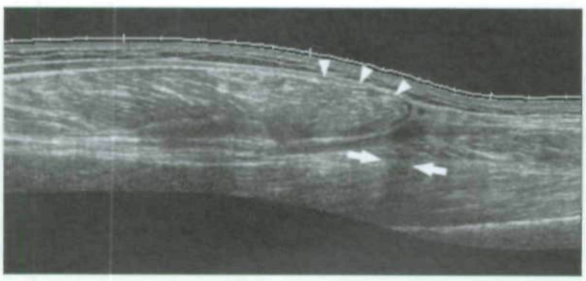


Figure 11 A 60-year-old man with a subacute complete tear (grade III injury) of the rectus femoris muscle. The patient presented with a 6-week history of palpable midthigh mass and an episode of pain. Extended field-of-view longitudinal sonogram shows the rounded, retracted muscle belly end (arrowheads) and refractile shadowing (between arrows).

Semitendinosus muscle arises from inferomedial ischial tuberosity as a conjoint tendon with biceps femoris. It has an intervening raphe, with proximal and distal bellies, giving it a "digastric" configuration. It inserts distally into the medial aspect of the proximal tibia with the other pes anserine tendons via an elongated distal tendon.[1,13]

Semimembranosus arises from the superolateral ischial tuberosity, deep to the semitendinosus origin, maintaining an anterior and medial relation to this muscle. It is predominantly a flat tendon proximally, becoming more muscular distally. It inserts into the posterior medial tibial condyle, having further insertions or expansions into the joint capsule and other posteromedial corner structures.[1,13]

Biceps femoris is the most frequently injured of the hamstring muscle complex, possibly related to its dual innervation (Fig. 6). There is some debate regarding frequency of injury to the other HMC muscles, but semimembranosus is probably more commonly injured than semitendinosus.[1] The musculotendinous junction is the most common site of HMC injury, with proximal strains more prevalent than those distally. This can present problems for ultrasound, particularly in athletes, where well-developed gluteal muscles can hamper imaging. MRI may be more accurate in evaluating the proximal MTJ region.[1]

MEDIAL HEAD OF GASTROCNEMIUS TEAR (TENNIS LEG)

Tears of the medial head of gastrocnemius occur due to stretch of the calf muscles with the ankle dorsiflexed and the knee extended, for example during "service" in tennis. Soleus and gastrocnemius muscles act as the major plantarflexors of the ankle attaching via a long, thin intermuscular aponeurosis to form the Achilles tendon distally. Differential contraction between the gastrocnemius muscle, which is rich in fast-twitch fibers, and soleus, dominated by slow-twitch fibers, results in a shearing force on the muscle-to-aponeurosis interface (aponeurotic distraction injury).[9] The distal fibers of the medial head of gastrocnemius may be involved, and a grade II injury is usually identified at the aponeurosis (Fig. 8). This injury is best visualized with a longitudinally oriented probe over the lower aspect of the medial head of gastrocnemius, which tapers as it inserts into the aponeurosis for the Achilles tendon.[9,18] On other occasions, the injury occurs more proximally involving the medial head of gastrocnemius at the level of the knee joint. Injuries to the plantaris muscle are also occasionally referred to as "tennis leg."

Compartment Syndrome

Acute compartment syndrome most commonly arises following trauma due to raised intracompartmental pressures caused by hematoma and muscle swelling. Intramedullary nailing, particularly of the tibia, is also known to cause this syndrome. Severe pain with active and passive movement of the affected muscle groups is characteristic. Vascular compromise due to raised compartmental pressure may result in ischemic necrosis despite the presence of normal peripheral pulses. When intracompartmental pressure rises above 30 mm Hg, venous pressure exceeds capillary perfusion pressure (around 25 mm Hg), resulting in collapse of capillaries; larger arteries remain patent.[19] The diagnosis should be suspected clinically and surgical decompression performed if there is any doubt. Delays in diagnosis may result in irreversible muscle death with contracture, and requests for imaging should not contribute to delays in definitive treatment. Imaging features include diffuse muscle swelling and increased echogenicity that may become more heterogeneous as the condition deteriorates. Occasionally, ultrasound may be helpful in identifying focal collections that may decompress the compartment adequately if drained percutaneously. More difficult to diagnose are the chronic compartment syndromes that are described later.

CHRONIC MUSCLE INJURY

Muscle Healing and Scar

Most acute muscle injury resolves, usually over a period of weeks to months, leaving no residual sonographic abnormality. Although rehabilitation of muscle sprain or tear in athletes is determined on clinical grounds, return to sporting activity is generally not advocated before resolution of sonographic abnormality.[10,15] In some instances, scar tissue may develop, most commonly in the setting of recurrent muscle injury in athletes. It may also occur as the consequence of a severe muscle contusion or tear. An intramuscular scar appears as a linear or irregular echogenic structure that may be surrounded by a hypoechoic zone or halo typically found at the MTJ or a fascial interface (Fig. 12).[5,9] The presence of scar tissue predisposes to recurrent tear and is a significant problem for elite athletes.[5,8,9] In addition to focal scarring, post-traumatic cysts may occur as the consequence of muscle hematomas. They may be symptomatic and have appearances typical of cysts within other soft tissues.

Muscle Hernia

Fascial defects following blunt or penetrating trauma may allow extracompartmental herniation of muscle. Muscle hernias most commonly occur in the lower limbs. The characteristic presentation usually allows clinical diagnosis, with imaging only required where there is clinical uncertainty or the patient requires reassurance. The patient describes a soft tissue lump that becomes prominent on standing or during muscle contraction. Most commonly the lump is painless, but occasionally pain exacerbated by activity is described. Sonographically, normal muscle tissue may be seen extending through a focal epimysial defect. Longitudinal images show perimysium bowed or "bulging" into the defect (Fig. 13). The hernia may become more prominent with muscle contraction, and it is useful to ask the patients to stand to demonstrate the defect more effectively. Care must be taken because probe pressure may keep the hernia reduced. Patient reassurance can also be helped by demonstrating that the ultrasound appearance within the herniation is the same as the underlying muscle.

Chronic Compartment Syndrome

Like its acute counterpart, chronic compartment syndrome is also the consequence of muscle anoxia secondary to increasing compartment pressure. The chronic variant is also most commonly seen in the lower limb. Increased blood flow induced by exercise, particularly in athletes or muscular individuals, causes muscle compromise sufficient to reduce exercise tolerance. In general, the history is sufficient to make a clinical diagnosis. Imaging studies when performed tend to be rather disappointing, although occasionally inflammatory changes in the intermuscular septa of the affected compartment may be demonstrated. Contrast-enhanced MRI may be helpful, but there are as yet no studies supporting a role for contrast-enhanced ultrasound.

A B

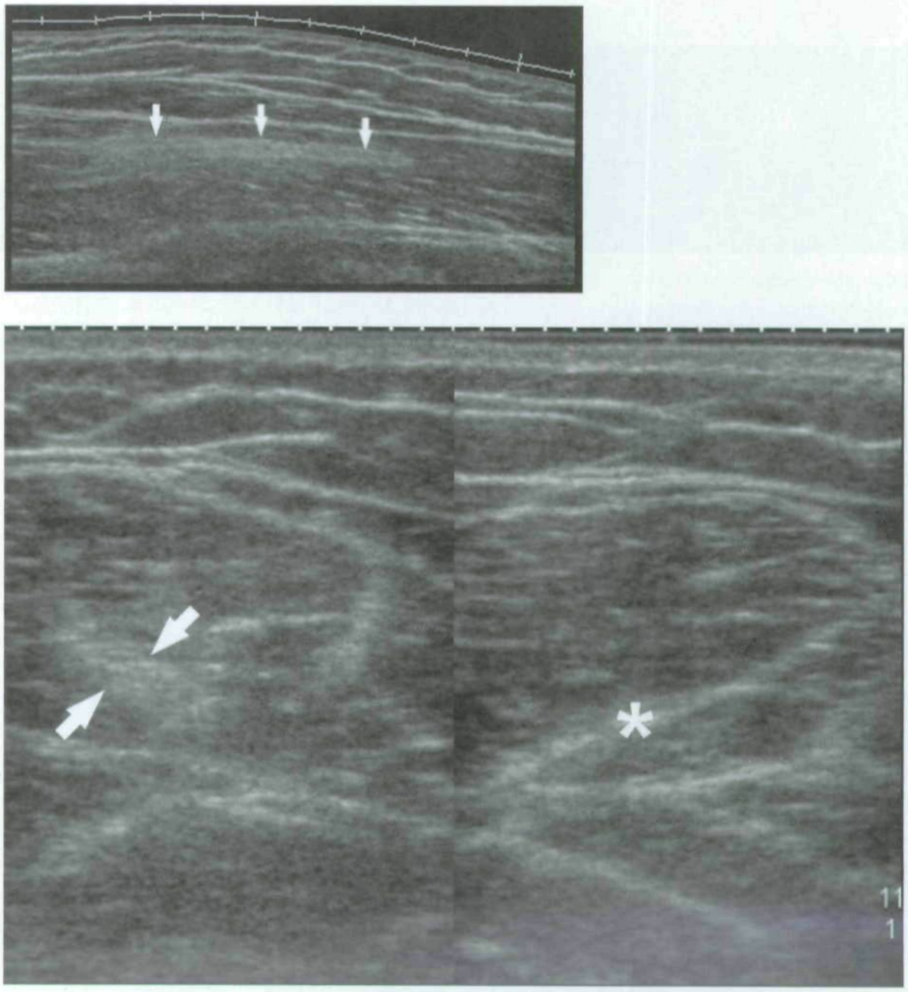


Figure 12 A 29-year-old weight lifter with longitudinal scar of the left biceps femoris muscle. (A) Longitudinal sonogram shows echogenic intramuscular fascial thickening over 6 cm (arrows). (B) Transverse sonograms show markedly thickened left-sided fascia (between arrows) when compared with the right (asterisk). The patient reported several previous episodes of hamstring strain, suggesting the scar may be due to recurrent injury.

Ultrasound-guided pressure monitoring during exercise may also be a useful investigation tool, particularly when the deep posterior compartment of the calf is involved and thus unguided electrode placement may be more difficult. There is a variant of chronic compartment syndrome that affects the upper limb, specifically the muscles of the volar aspect of the forearm. This condition has occurred in airport baggage handlers.

A B

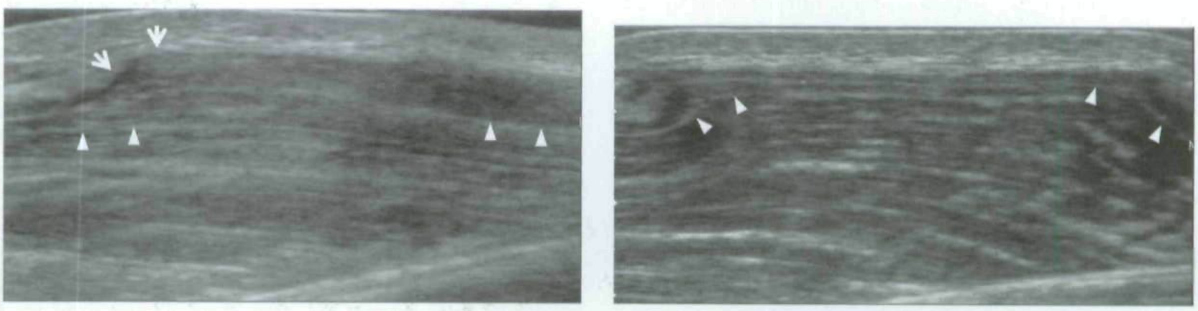


Figure 13 A 26-year-old triathlete with tibialis anterior muscle hernia. The patient presented with exercise-related focal anterior leg pain since the commencement of cycling training 3 months previously. (A) Longitudinal cine loop image of the tibialis anterior muscle demonstrates mild bulging of the tibialis muscle contour at rest (short arrows) but linear appearances of the perimysium (arrowheads). (B) Longitudinal cine loop image during muscle contraction shows focal bulging of the tibialis anterior muscle through a fascial defect. There is distortion of perimysium as the herniated muscle enters the defect (arrowheads).

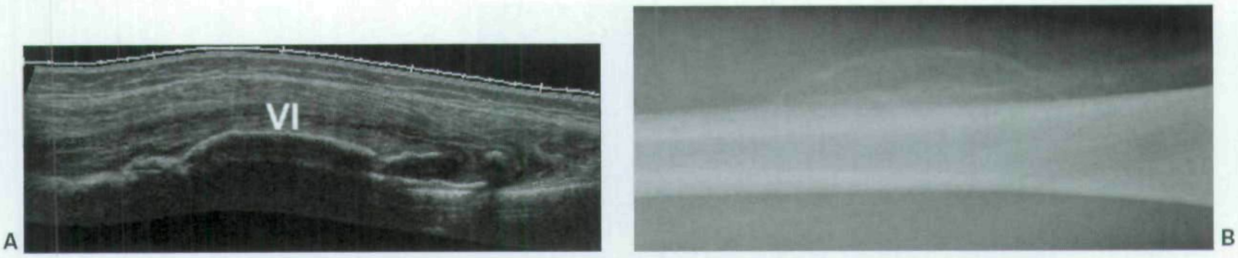


Figure 14 A 14-year-old young man with myositis ossificans of vastus intermedius. The patient presented with a tender midthigh mass 6 weeks after being kneed in the thigh while playing football. (A) Longitudinal extended field-of-view sonogram shows a 15-cm area of calcification within the deep aspect of vastus intermedius (VI) paralleling the femoral shaft, typical of established myositis ossificans. (B) Plain radiograph of the femur taken on the same day shows the well-circumscribed peripheral calcification that is typically visible on plain radiography after 3 to 6 weeks.

Myositis Ossificans

Myositis ossificans is a benign masslike disorder of intramuscular ossification whose pathophysiology is poorly understood. It most often arises in young adults in the setting of trauma that is frequently not recalled. Typically occurring in the large muscles of the limbs, particularly the quadriceps, it may be asymptomatic or present as a painful, tender mass. Early myositis ossificans may be difficult to diagnose on imaging and histopathology grounds because it may mimic soft tissue sarcoma. Clinical concern may arise when a history of previous trauma is absent. However, it has characteristic plain film and computed tomography (CT) appearances on serial imaging relating to maturing peripheral mineralization, usually appreciated between 3 to 6 weeks, which develop over several months.[9]

Phasic changes in the development of myositis ossificans are readily detected by ultrasound. The transition between the noncalcified and calcified stages is detected much earlier by ultrasound than most other imaging techniques, and in particular plain radiographs. The precalcified phase is the most problematic, and the sonographer should not be surprised to encounter a solid appearing mass with detectable Doppler signal throughout, especially at the periphery. It is these appearances that are most suggestive of sarcoma. Clinical clues that allow differentiation should be sought. As discussed previously, myositis ossificans may not necessarily be associated with a recalled history of trauma. Increase in size of the lesion is often more rapid than sarcoma. Rapid increases in size of sarcoma are usually due to intralesional hemorrhage and if this can be excluded by ultrasound, a very rapidly growing mass is more likely to be due to myositis ossificans than tumor. It is also worthwhile examining the pattern of increased vascularity within the lesion. Trifurcations and other markers of tumor angiogenesis may help distinguish myositis ossificans from sarcoma, although published work in this area is lacking.

Later, myositis ossificans may appear as a hypoechoic or heterogeneous mass, with sheets of echogenic calcifications that are visualized several weeks before they are visible radiographically.[20] As with plain film and CT findings, these calcifications are usually peripherally oriented. The mass may also demonstrate marked vascularity of the rim and central zone on Doppler imaging at this stage. Central vascularity helps distinguish this lesion from an intramuscular abscess.[9] As the lesion matures, acoustic shadowing due to peripheral ossification, often paralleling adjacent bone, is seen (Fig. 14).

CONCLUSION

With modern ultrasound technology, appropriate technique, and careful review, the ability to detect subtle abnormalities makes ultrasound a highly sensitive modality for the evaluation of acute and chronic skeletal muscle injury. Ultrasound also enjoys several other advantages over MRI for the imaging of muscle trauma with regard to convenience and cost. In most clinical settings, ultrasound should be the primary imaging choice for assessing skeletal muscle injury.

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