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Musculoskeletal ultrasound for sports injuries

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Each day, the role of musculoskeletal ultrasound (US) in the management of sports injuries is being consolidated. Yet, there is no doubt that the probe of US is (should be) the stethoscope of musculoskeletal physicians dealing with sports medicine. Not only for the diagnosis, but also for the close follow-up of the athletes and during likely onward interventions for their treatment, would US be of paramount importance. Accordingly, in this review paper on common sports injuries, we tried to shed light into the actual role of US in the clinical practice of sports medicine.

Key words: Athletic injuries - Ultrasonography - Muscles - Tendons.

In parallel with the improvements in ultrasound (US) technology and the production of portable machines that can be carried to the stadium/playing field or elsewhere,[1] there has been a spate of interest concerning the use of musculoskeletal ultrasonography (MSUS) in Sports Medicine. Aside from the general advantages, its potential to provide dynamic imaging and comparison is of paramount role in the diagnostic algorithm of a wide spectrum of injuries in sports medicine.[2] Yet, differential changes in various structures can readily be appreciated during active, resisted, and passive motion to observe the extent of the injury within the muscle fibers and/or tendons. Further, its high repeatability and sensitivity to alteration enable intimate monitoring during various stages of injury including response to treatment.[3] As at least important as the above quoted superiorities, its possible use for guiding an immediate intervention -which is usually what is expected in clinical practice for early return to play really makes ultrasound an indispensible imaging tool for the diagnosis, follow-up and treatment of sports injuries.

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Muscle injuries

One of the most common applications of MSUS in sports medicine is the evaluation of muscles. Since the muscle compartments lie over the bones, almost all types of injuries can technically be visualized by US.[4] Long linear probes are necessary for their examination as they are rather large structures. On long-axis views, the echotexture of normal skeletal muscle septae appear as hyperechoic structures, and are seen as thin, bright, linear bands (“veins on a leaf”). On short-axis views, the muscle bundles appear as spot echoes with short, curvilinear, bright lines spread throughout the hypoechoic background (“starry night”).[5]

The overwhelming majority of muscle pathologies is traumatic in origin, either being specific to

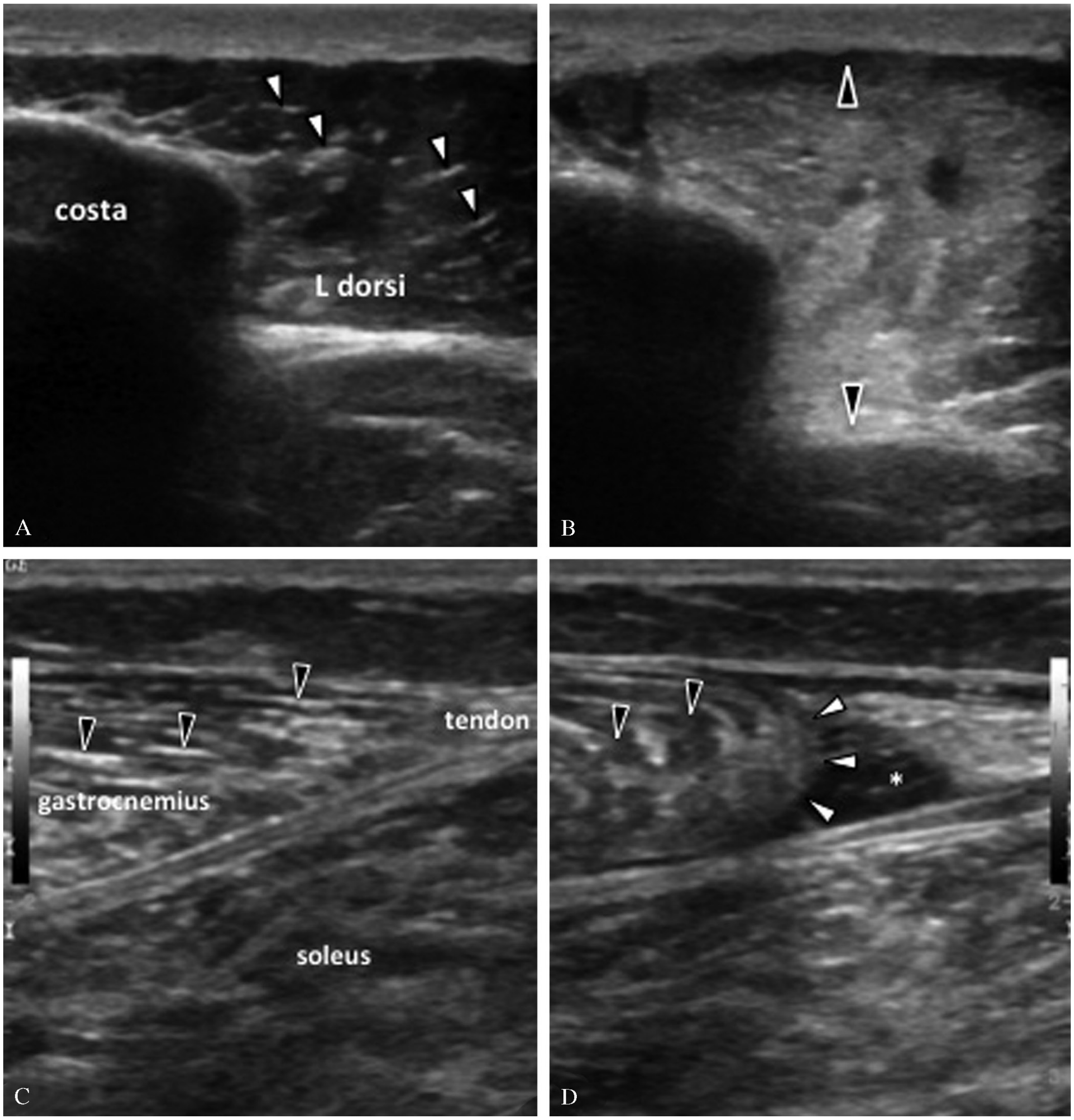

Figure 1.—A, B) Ultrasound image of a basketball player who was injuried two days ago while screening during the play. Latissimus dorsi muscle (axial view) is thickened (black arrowheads) with hyperechoic and deteriorated structural pattern (B) when compared with the normal side (L dorsi) "starry-sky appearance" (white arrowheads) (A); C, D) longitudinal ultrasonography of the gastrocnemius medial head myotendinous junction lesion (tennis leg) in a handball player. In contrast to the normal pennate architecture (black arrowheads) (C); the injured fibers have lost their normal pattern (black arrowheads) and are retracted (white arrowheads) from the tendon with a small hematoma (white star) in between (D).

a particular sports play or due to inappropriate exercise training.[6] Likewise, based on the relevant pathomechanisms, traumatic injuries can be divided into two main groups as extrinsic and intrinsic. The former group takes place after an external trauma, either a contusion or a penetrating injury, whereby the lesion is usually located under the site of trauma. The latter group stems from a contraction or simultaneous elongation of a given muscle and both types generally end up with hemorrhage and haematoma, and

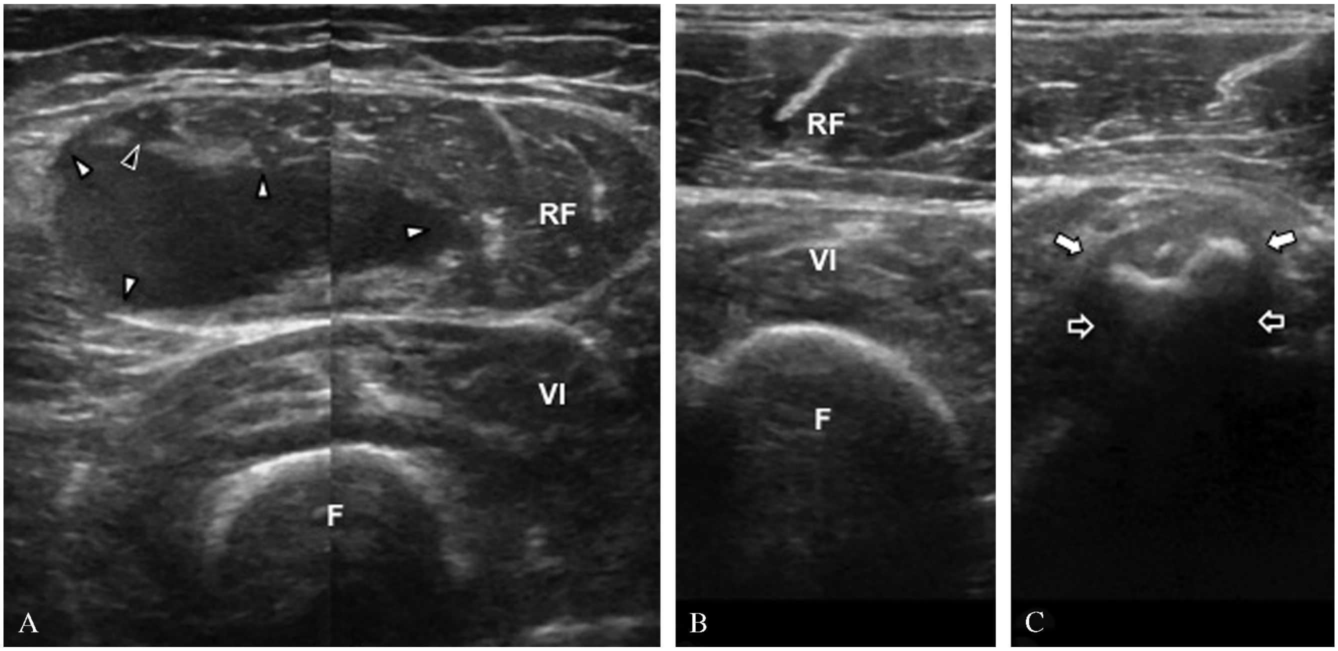

Figure 2.—A) Anterior thigh muscle ultrasonography (split screen axial image) in a volleyball player with a strain lesion. There is a large anechoic area (white arrowheads) -consistent with a hematoma- inside the rectus femoris muscle (RF). A small additional lesion (black arrowhead) is also observed to extend superficially within the muscle; B, C) Comparative muscle ultrasound during the follow up of a quadriceps strain in a basketball player. While the right quadriceps seems to be normal (B), there is a big calcification (white arrows) with its acoustic shadowing (black arrows) inside the left vastus intermedius (VI). F: femur.

mostly seen in the myotendinous juntion which is the weakest portion of the muscle-tendon-bone unit.[7]

Muscle injury results from a variety of mechanisms including strain, contusions, hematoma, lacerations, compartment syndrome and hernia.[8] Muscle strain is a common pattern of injury (generally tractional) and US can be very helpful in evaluating the severity of distruption, *i.e.*, whether a low-grade or high-grade injury is present. Ultrasonographically, muscle strains may have a normal appearance or show focal or general areas of increased echogenicity (Figure 1 A-B). Perifascial fluid, and in up to 50% of the cases, generalized hyperechogenicity may be seen.[9] Partial tears show discontinuity of muscle fibers with hypervascularity around the distrupted area and altered echogenicity with loss of perimysial striation adjacent to the musculotendinous junction. An intramuscular fluid collection may also be seen with a surrounding hyperechoic halo. A hematoma at the myotendinous junction could be pathognomonic for a partial tear.[10] Complete tears display full-thickness discontinuity of muscle fibers generally associated with a hematoma. Often, there is retraction of the tendon ends as well- making the diagnosis more obvious.[11]

The initial extent of muscle injury and degree of separation of the margins of the tear are good predictors of recovery and return to normal function. US can be helpful in predicting the expected recovery period and is ideal for serial evaluation to monitor muscle healing and recovery. Herewith, the amount of intramuscular scar formation is inversely proportional to the ability of a muscle to produce tension, and proportional to the risk of recurrent injury.[12, 13]

One typical example would be tennis leg (tear of the medial head of the gastrocnemius muscle) that usually occurs due to simultaneous stretch of the calf muscles via ankle dorsiflexion and knee extention (Figure 1 C-D). Differential contraction between the gastrocnemius muscle (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).[14]

Muscle contusion results from direct nonpenetrating external trauma and are most frequently seen in the thigh of footballers due to direct hard contact, frequently with accompanying hematoma (Figure 2). On ultrasonography, a contusion appears as an ill-defined area of hyperechogenicity in the muscle,

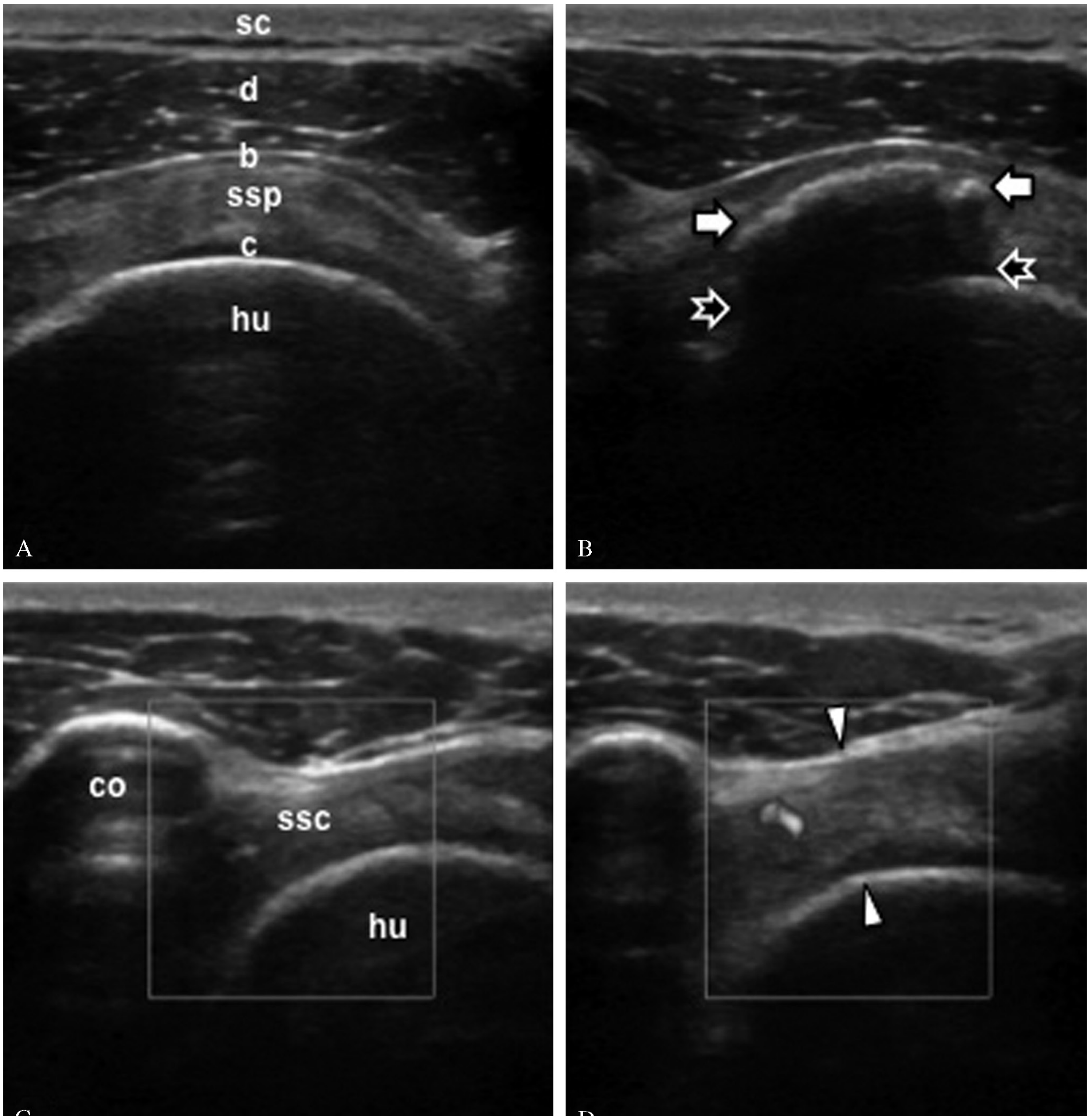

Figure 3.—A, B) Ultrasonographic images (axial view) of the rotator cuff in an overhead athlete demonstrating calcific supraspinatus tendinitis (B). Although the tissue layers seem to be unremarkable on the left side (A); a convex and rather linear hyperechoic lesion (white arrows) -which was also tender to "sonopalpation"- is present on the right supraspinatus tendon. It also displays a dense acoustic shadowing underneath (black notched arrows). sc: subcutaneous fat; d: deltoid; b: bursa; ssp: supraspinatus tendon; c: cartilage; hu: humerus; C, D) ultrasonographic evaluation (axial view) of the anterior rotator cuff using power Doppler in a ballet dancer. On the left side, the subscapularis (ssc) tendon is normal -as regards its shape, size and echogenicity- between the coracoid process (co) and the humeral head (hu) (C); whereas the left tendon seems to be thicker (white arrowheads) with Doppler signal inside (relevant with tendinitis) (D).

which may cross the fascial planes. In contrast, a hematoma is observed as a hypoechoic fluid collection and may contain debris.[9] In the first 24 hours following injury, the focal hematoma may display a variable appearance ranging from anechoic or hypoechoic to hyperechoic.[10] Imaging findings will change over the next two to three days, becoming hypoechoic or anechoic. Importantly, in small lesions, it is therefore

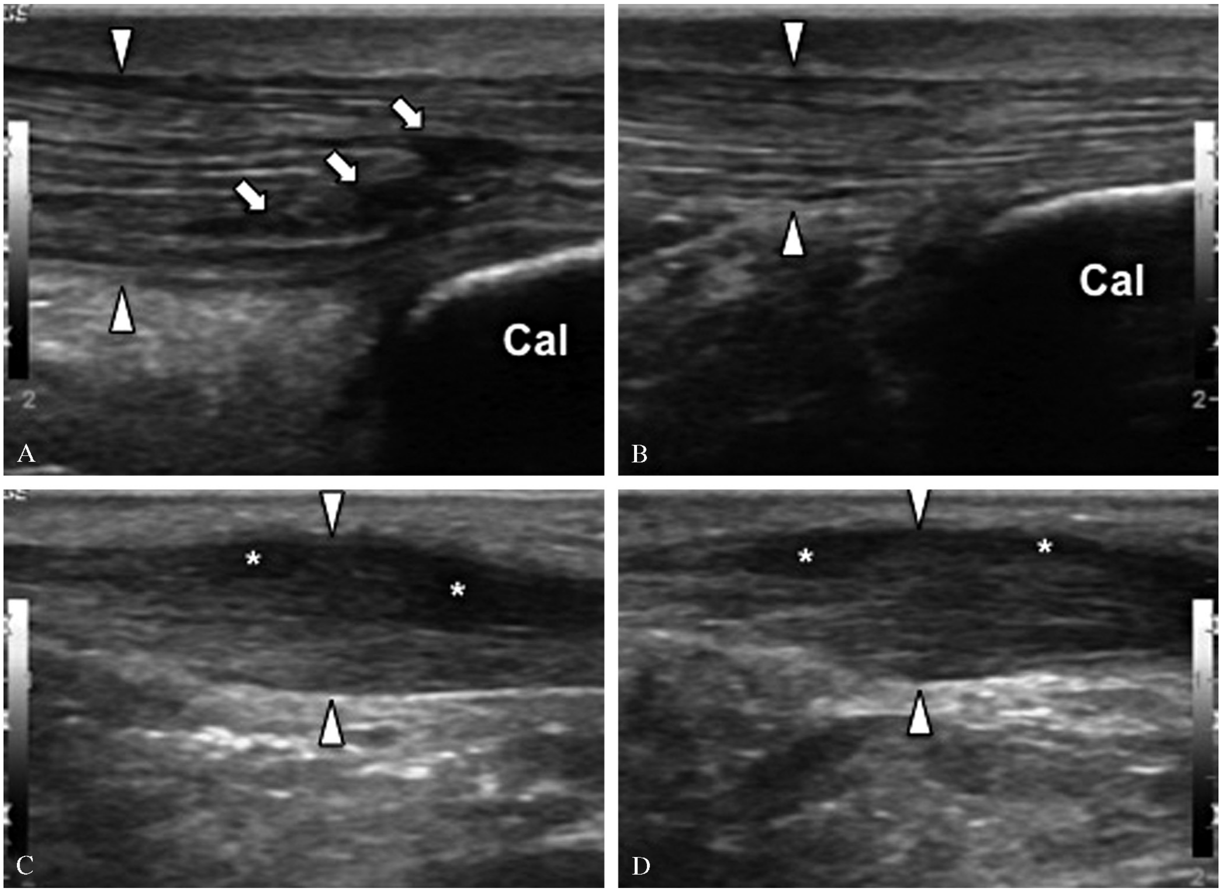

Figure 4.—A, B) Ultrasound images (longitudinal view) of a basketball player with unilateral achilles tendon rupture. While the normal achilles tendon is observed as a thick band of hyperechoic fibrillar structure (white arrowheads) inserting onto the calcaneus (Cal) (B); the right Achilles tendon seems to be thicker, containing small areas of anechoic intrasubstance partial tears (white arrows) close to its insertion (A); C, D) longitudinal images demonstrating irregular thickening (white arrowheads) and heterogenous anechoic areas (white stars) proximal to the calcaneal insertions in a patient with bilateral achilles tendinosis.

suggested to perform the US evaluation in this period for better delineation of the injury. Thereafter, the hematoma is expected to show increased echogenicity with possible fluid-fluid levels. Over the subsequent weeks, it will become more organized and can develop a focal scar.[15]

Muscle laceration is a form of partial muscle tear that arises from direct penetrating trauma, involving the epimysium and underlying muscle tissue.[16] Compartment syndrome most commonly ensues following a trauma -due to elevated intracompartmental pressures caused by a hematoma and muscle swelling. US may be helpful in identifying the possible underlying cause or in demonstration of increased size and echotextural changes of the pertinent muscle compartment. Further, it may also aid during imaging guided pressure monitoring or percutaneous drainage.[17]

Muscle hernias occur following trauma that causes a fascial defect. The hernia may become more prominent with muscle contraction. Likewise, on dynamic US, normal muscle tissue may be seen extending through a focal epimysial defect. Long-axis images will show perimysium bowed or “bulging” into the defect.[17]

Tendon lesions

Tendons are visualized as a hyperechoic band of parallel fibrillar patterns on long-axis US images. The parallel fascicles of collagen fibers produce hyperechoic lines, with the interfascicular ground sub-

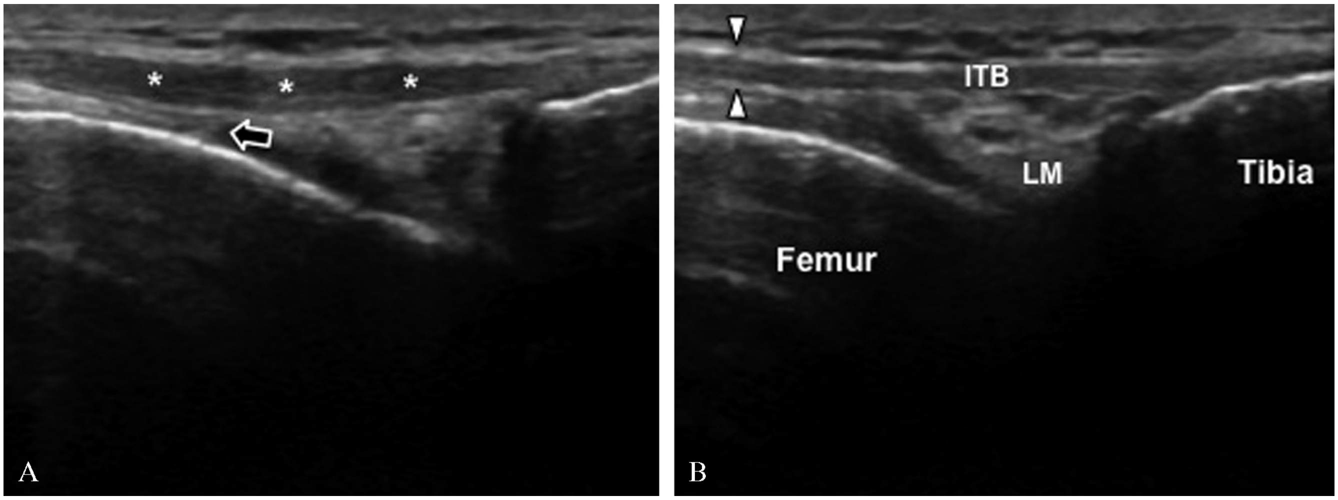

Figure 5.—Longitudinal ultrasonography of the lateral compartment of the knee joint in a runner. The normal iliotibial band (ITB) (white arrowheads) is observed down to its insertion onto tibia (B). On the other hand, the symptomatic iliotibial band is thicker and more hypoechoic (white stars) as it passes next to the lateral femoral condyle (black arrow). LM: lateral meniscus.

stance appearing as anechoic lines in between. In the axial plane, tendons appear as round or oval hyperechoic structures.[18] It is important to apply a correct orthogonal direction to the US beam, both for longitudinal and axial views, in order to avoid anisotropy artifact -whereby the tendon seems hyperechoic when the beam is perpendicular to the tendon, and becoming hypoechoic when the beam is directed at an oblique angle.[4]

Similar to muscle lesions, the spectrum of tendon pathologies detectable with US is quite wide and heterogenous. It encompasses various degrees of tendinosis or tears (*i.e.*, intrasubstance, partial-thickness, full-thickness or complete rupture).

Tendon degeneration, often referred to as “tendinopathy” or “tendinosis,” is not characterized by an inflammatory response but rather infiltration of fibroblasts and vessels.[19] Tendinosis is generally considered to be caused by repetitive microtrauma with an ongoing chronic cycle of tendon degeneration and repair resulting in a weakened tendon. The clinical scenario is usually that of swelling, tenderness, absent or moderate pain aggravated by activities and the coexistence of tenosynovitis. Degenerative tendon changes on US will comprise focal or diffuse thickening (sometimes with calcifications) and intratendinous hypoechoic areas with loss of fibrillar echoes (Figure 3C-D). The latter usually reflects a disorganized structure of collagen bundles seen in fibromyxoid degeneration or even partial tears.[7, 18, 20]

Tenosynovitis is detected with the aid of hypoechoic or anechoic fluid distending the tendon sheath, with inflammatory changes of the related tendon proper as well (*i.e.*, edema and heterogenous hypoechoic swelling). Synovial proliferation of the tendon sheath can be seen, thus confirming concurrent synovitis. Doppler US imaging may be helpful to further evaluate increased vascularity secondary to the inflammatory process inside/around the tendon.[3, 4]

Tendon heterogeneity on MSUS images does not always correspond to a tendinosis-related pathology, but it may also indicate a partial tendon tear.[21] Partial tears are detected by hypoechoic or anechoic focal defects involving either the surface or substance of the tendon.[22] Continuous fibers are seen adjacent to a partial tear, and retraction is not a significant hallmark. However, partial tears are not easy to differentiate from tendinosis, because both pathologies may coexist and the relevant imaging findings may be overlapping.[2] On the other hand, differentiating tendinosis and partial tears from a complete tendon rupture is important, given the fact that most complete tears require surgery whereas others are managed conservatively with surgical repair undertaken only if initial conservative regimens fail thereafter. In case of complete tears, full-thickness distruption of the tendon with retraction of the torn edges usually accompanied by a hematoma is the main finding.[7] Another way to better visualize

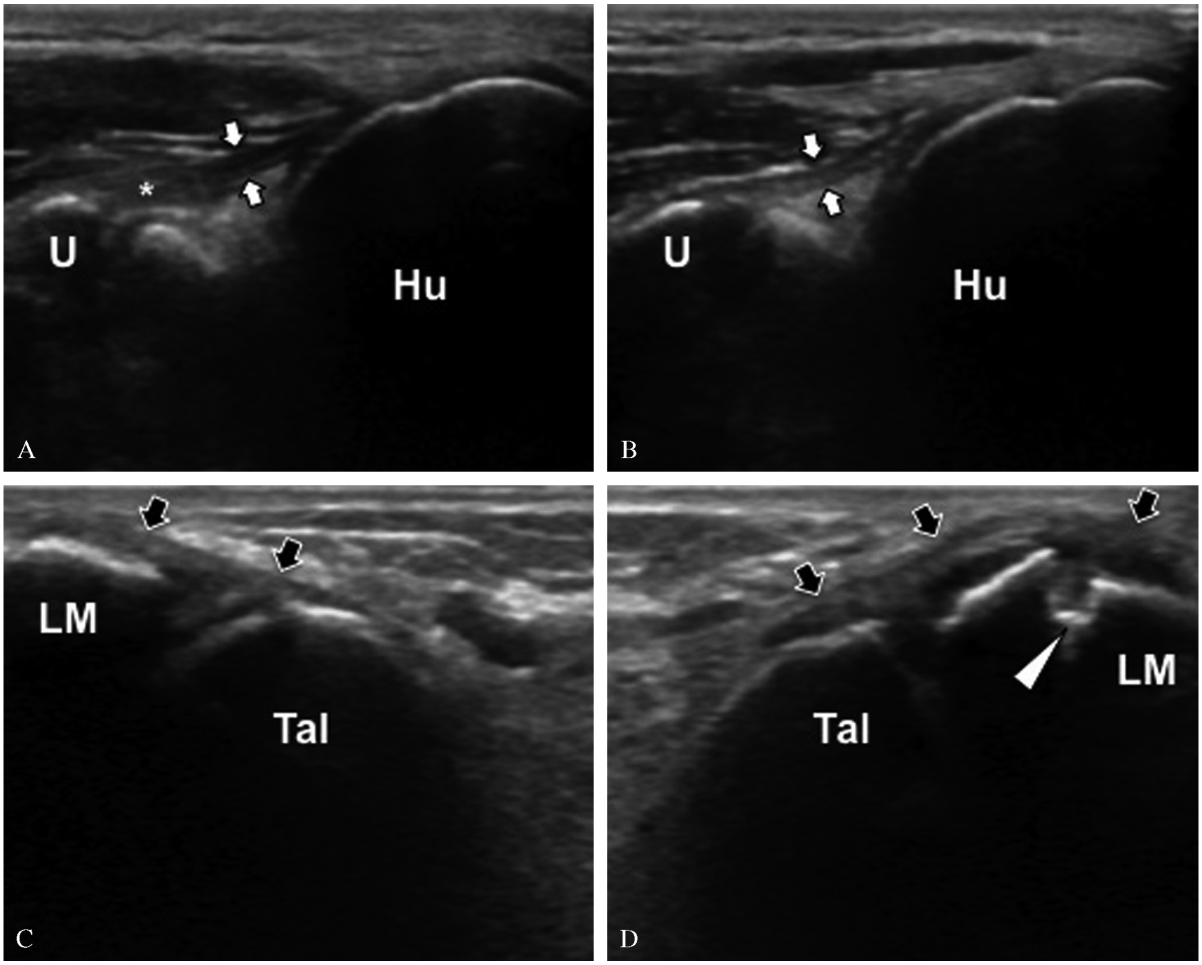

Figure 6.—A, B) Bilateral ultrasonographic imaging (longitudinal view) for the medial compartment of the elbow joint in a judo athlete. The normal ulnar collateral ligament (white arrows) is observed to lie between ulna (U) and humerus (Hu) (B). Although the ligament is intact on the contralateral side, it is thickened with edema on the distal attachment site (white star) (A); C, D) lateral longitudinal ultrasonography of a patient after a traumatic inversion type of ankle sprain. While the anterior talofibular ligament (black arrows), extending between the lateral malleolus (LM) and talus (Tal), is normal one side (C); it is found to be thicker along with a small erosion and a relative spur (white arrowhead) on the underlying bony surface (D).

all these types of injuries is definitely to use the dynamic imaging feature of MSUS whereby active and passive motions would open up the gap in the tendon. This sign is especially useful if the gap is otherwise filled with echogenic fluid or debris masquerading the discontinuity of the tendon during static imaging.[23]

Some typical examples of common tendon injuries that are promptly diagnosed and followed by US would be rotator cuff and achilles tendinopathies, jumper's knee, runner's knee and climber's finger.

Rotator cuff lesions that can be seen almost in all kind of sports (Figure 4) represent a wide spectrum of pathologies ranging from tendinosis to partial or complete tears being either partial-thickness or full-thickness. Joint fluid (usually observed around the long head of the biceps tendon) or fluid in the subacromial/subdeltoid bursa and cortical irregularities might often accompany ruptures whereby absence of the tendon or its compressibility is the mainstay for diagnosis.[24-27]

Achilles tendon injuries (Figure 5) mostly occur at the hypovascular region about 5-6 cm proximal to the calcaneal insertion where the fibers twist.[28] In case of a rupture, retraction of the proximal and distal edges may be demonstrated with dorsi/plantar

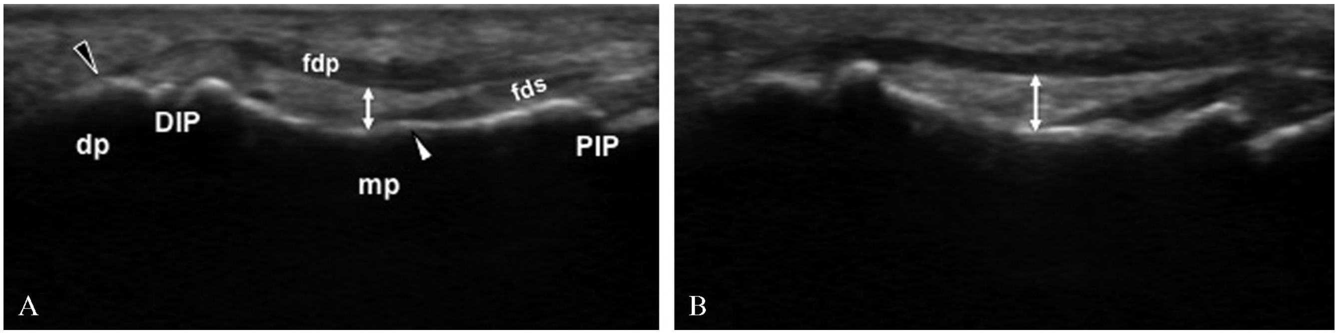

Figure 7.—Comparative ultrasound imaging (longitudinal view) of the long flexor tendons of the fingers shows -indirectly- a unilateral pulley lesion at the level of midphalanx (mp). A) One of the distal insertions (white arrowhead) of the flexor digitorum superficialis tendon (fds) is visualized distal to its chiasm. The insertion of flexor digitorum profundus (fdp) onto the distal phalanx (dp) is also observed (black arrowhead); B) the distance between the flexor digitorum profundus tendon and the midphalanx (white up-down arrow) seems to be increased on the right side. PIP: proximal interphalangeal joint; DIP: distal interphalangeal joint.

flexion maneuvers. Power Doppler signals may either indicate a certain degree of inflammation or neovascularization pertaining to the healing phase of the lesions.[29] Additionally, in some athletes, the distal insertion of the achilles tendon may be the actual problem as in form of an enthesopathy.

Similarly, Jumper's knee and Runner's knee are the overuse type of injuries of the patellar tendon and the iliotibial band respectively (Figure 5). The latter (frictional tendinopathy) usually ensues at the particular localization where the band is passing very close to the lateral femoral condyle and thus US often displays findings of tendinitis.[30] However, the former may occur in any type of tendinopathy.

Ligament lesions

Ligaments share similar sonographic characteristics to tendons and demonstrate a bright, echogenic and linear structure. They are best identified by placing the probe between the two bones that they connect. They may also demonstrate anisotropy. However, since the fibers of ligaments are more closely aligned, their echotexture is more compact and fibrillar. Ligaments are composed of dense connective tissue with different amounts of collagen, elastin, and fibrocartilage; thus their US findings can be more variable than those of tendons.[31]

Treatment of a ligament rupture varies depending on the site and extent of injury. Accordingly, rapid diagnosis and evaluation of the severity of injury are critical when the need for surgical repair is likely. The earlier the correct diagnosis and prompt surgical repair are accomplished, the more favorable the clinical outcome becomes. In this regard, MSUS provides an immediate and reliable means of detection for acute ligament injury. Ligamentous thickening, heterogeneity, hypoechoic foci, and surrounding edema or haematomas may be seen in acute ligamentous injuries (sprains) (Figure 6). In cases of a partial rupture, the involved area of the ligament appears markedly thickened with decreased echogenicity. Complete ruptures are demonstrated as discontinuity of the ligament, with the free ends often separated by hematoma. The fluid occupying the gap will appear hypoechoic or anechoic, depending on the timing of US imaging with respect to the actual injury. Again similar to the tendons, retraction of the ends of the ruptured ligament on static imaging (giving them a slightly rounded appearance) may be better visualized on dynamic imaging *via* stress testing. That way, evaluation of the joint stability could be performed as well. Small avulsion fractures of the adjacent bones (Figures 6 C-D) or calcifications may also be seen as the concomitant findings of ligament ruptures with US.[32]

A few typical examples of common sports injuries would be ankle sprains (anterior talofibular, deltoid, calcaneofibular ligament injuries) and climber's finger. Like in tendon injuries, US may show both statically and dynamically whether the ligaments of the ankle joint are intact, swollen or torn.[33] In the latter, US may also be used indirectly for diagnosing the rupture of the annular pulleys of the finger flexor tendons (Figure 7).

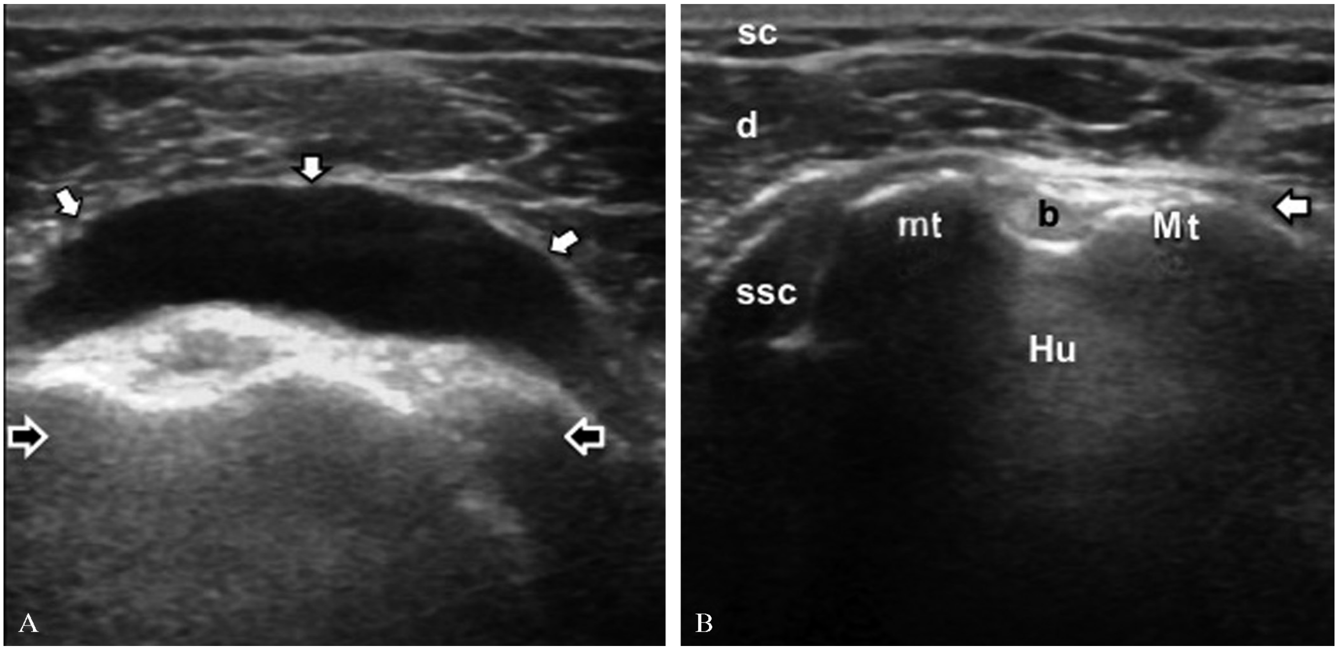

Figure 8.—Anterior axial shoulder ultrasound depicting subacromial-subdeltoid bursitis. All the tissue compartments are normal on the right side (B); however, there is a large amount of anechoic fluid collection in the left bursa (white arrows) (A). Due to the 'enhanced through transmission artefact'; increased echogenicity is observed underneath (black arrows). sc: subcutaneous fat; d: deltoid; ssc: subscapularis tendon; Mt: major tubercle; mt: minor tubercle; Hu: humeral head; b: biceps tendon.

Articular lesions

In general, MSUS examination of a joint reveals two interrupted sharp hyperechoic lines (bones) covered with a thin hyperechoic capsule and often with anechoic smooth linear band of hyaline cartilage on the opposing bony surfaces. A small amount of fluid can be normally found in the nearby synovial recess(es).[34]

In sports injuries, joint pathologies are frequently accompanied by adjacent tendon, ligament or bursa lesions. MSUS may be helpful in distinguishing simple effusions from other types. In a simple effusion, the fluid seems hypoechoic or anechoic, compressible, devoid of Doppler flow and is bounded by the joint capsule. In hemarthrosis or infection, there may be a diffuse increase in the echogenicity of the fluid, often with layering of fluid or particulate debris. However, US cannot always differentiate accurately whether the fluid collection is inflammatory, infectious or hematogenous. In such cases, it can facilitate precise aspiration (under real-time guidance) for further analysis though and aspiration of fluid — which is more successful with MSUS guidance — remains the gold standard. Besides, it can also give a basic estimate of fluid viscosity, aiding selection of the appropriate gauge size of the needle for aspiration. Additionally, in certain conditions with dense fluid collection or collections filled with synovial hypertrophy, US may even refrain from aspiration, avoiding a likely dry tap. Likewise, fluid can also accummulate in the bursae (normally observed as thin anechoic bands) causing bursitis. Simple bursitis may be characterized by anechoic fluid with or without septations (Figure 8), whereas chronic bursitis often displays moderately echogenic bursal thickening attributable to chronic impingement or overuse.[12]

Hemarthrosis exhibits a peculiar sonographic appearance that changes with time, quite similar to hematoma. Due to the presence of corpuscular content, hemorrhagic fluid collections are in fact homogeneously echogenic within the first two to three days following the onset. After the third day, the hemarthrosis shows a progressive reduction in echogenicity due to lytic enzymes' release. Eventually, MSUS shows echogenic branches, corresponding to fibrinous clots, crossing the anechoic appearing zone.[34, 35]

Some particular examples of joint lesions would be labral (shoulder and hip) and meniscal lesions

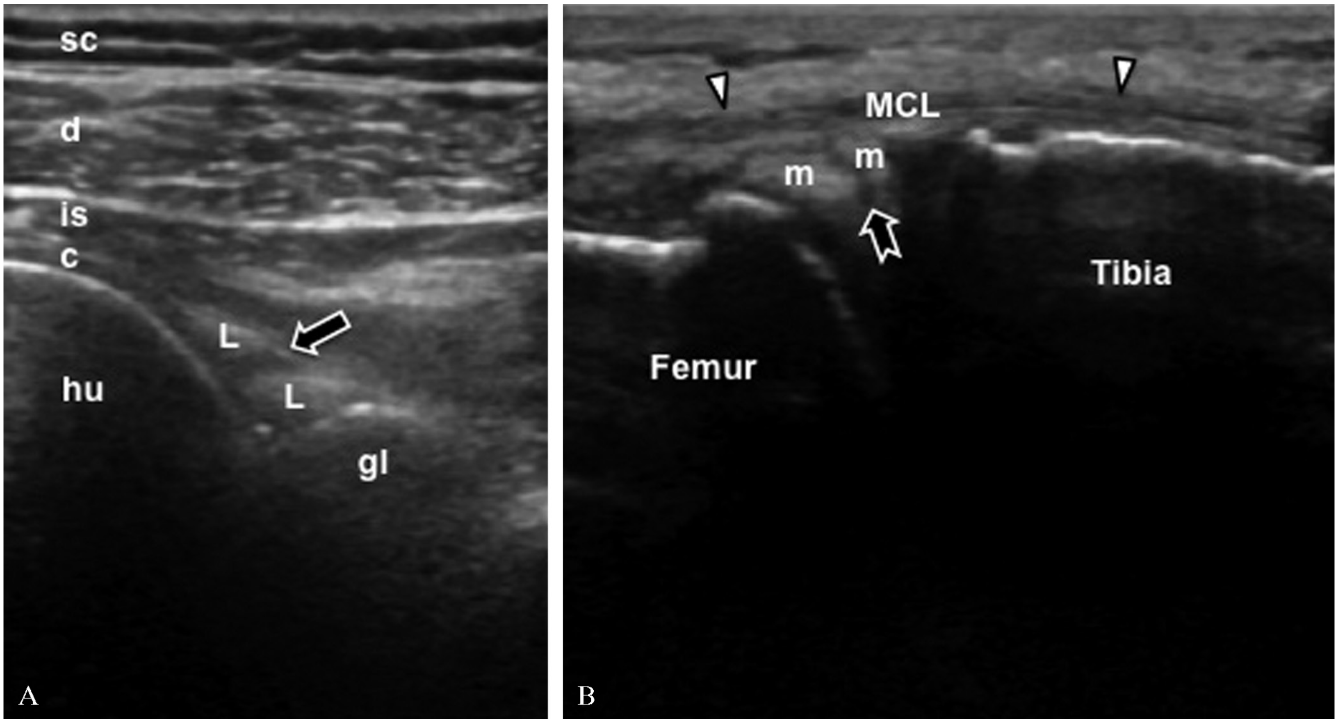

Figure 9.—A) Shoulder ultrasound image acquired while the probe is placed parallel to the alignment of infraspinatus tendon (is) distally on the humeral head (hu). An anechoic cleft reminiscent with a tear lesion (black arrow) is present on the posterior labrum (L). Note that the labrum is visualized as grey-white due to its fibrocartilage content, while the articular cartilage on the humeral head (c) is anechoic as it contains hyaline cartilage (sc: subcutaneous fat; d: deltoid; gl: glenoid); B) ultrasonographic evaluation (longitudinal view) of the medial compartment of the knee joint illustrating a meniscal tear (black notched arrow). Medial collateral ligament (MCL) is observed to overlie (white arrowheads) the medial meniscus (m) between femur and tibia.

(Figure 9). Both tissues are composed of fibrocartilage and thus seen as grey-white structures on US. Tears (anechoic clefts) or associated cysts of the posterior labrum of the shoulder and anterior labrum of the hip joints can be readily detected with static/dynamic US.[22, 36] Concerning meniscal lesions, US is able to show only the peripheral portions of them — which are in fact areas poorly evaluated with artroscopy. Again, meniscal tears (extending to the outer layers) or concomitant lesions/cysts can be visualized during knee US.[34, 37]

Enthesopathy

Enthesopathy is the pathology of tendon and ligament insertion areas onto the bones (entheses). It is an inflammatory-degenerative problem usually caused by the overload/overuse of entheseal regions. Therefore, the affected anatomical region varies according to the athletic task, resulting in the onset of typical pathologies associated with spesific sports such as golfer's elbow (medial epicondylitis) and tennis elbow (lateral epicondylitis) (Figure 10). MSUS imaging findings would pertain to both the bony (periosteal thickening or irregular bony contour like erosions and spurs) and the soft tissue areas (edema, thickening, decreased echogenicity, calcification and fluid). Especially for bony lesions, sonographic palpation may really be very helpful in depicting even small lesions that are not visible on radiographs (Figure 11).[38, 39]

Miscellaneous lesions

Shin splint would be a nice example in this regard. Focal thickening at the anchor points of the muscle compartment to the periosteum (a sort of periostitis) along the posteromedial and lateral bor-

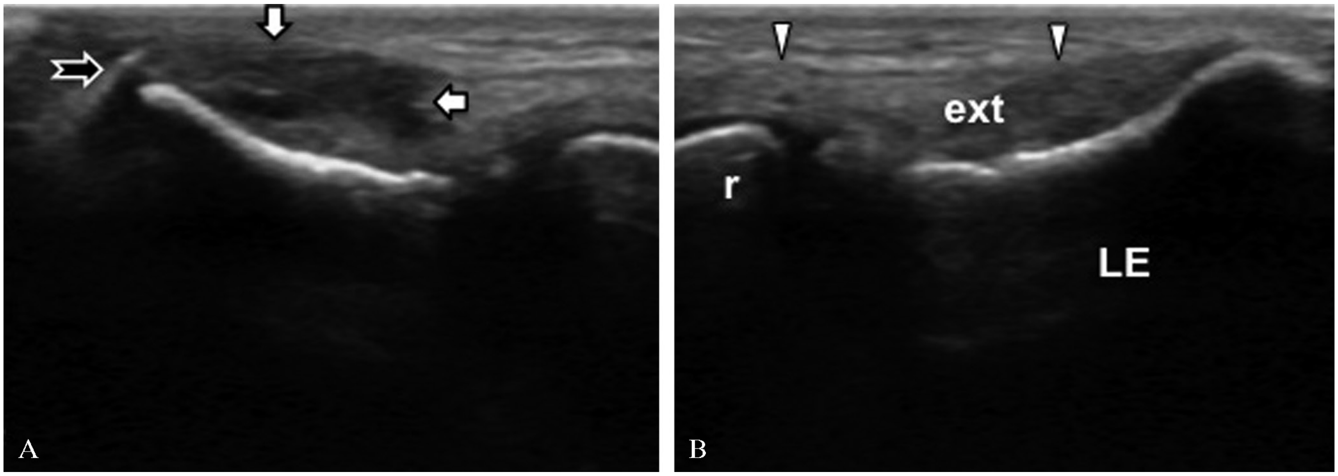

Figure 10.—Comparative elbow ultrasonography showing one-sided lateral epicondylitis. While the proximal insertion of the common extensor tendons (white arrowheads) seem to be homogenously hyperechoic (B); on the symptomatic side of the patient, a small bony spur (black notched arrow) is uncovered at the very proximal site of the tendons' insertion. There is also an irregular anechoic area (white arrows) within the tendon. r: radial head; ext: common extensor tendons; LE: lateral epicondyle.

ders of the tibia may be observed on US imaging. Doppler US imaging may also show inflammatory findings as well.[13]

Use of Doppler imaging

Aside from changes on B-mode US, Doppler US can be used for assessment of the tissue perfusion. It registers movements of erythrocytes in the scanned tissues while the transducer and the patient are immobile. Doppler imaging evaluates vascularization of the tissues which is increased under inflammatory conditions (an indirect sign of inflammation). The potential of high-frequency color and power Doppler imaging systems to determine low blood flow and to correlate hyperemic changes with structural abnormalities has opened new points of view in evaluation of various sports injuries. The combination of high-resolution probes and the latest generation of color/power Doppler US workstations allow a clear depiction of an even minimal increase of perfusion in several inflammatory conditions such as tenosynovitis, enthesitis, bursitis and other soft-tissue inflammatory processes.[40, 41]

Ultrasound guided interventions

In clinical practice, most of these procedures comprise aspiration of fluid collections or local injection of various substances like steroids, local anesthetics and platelet rich plasma into joint cavities, tendon sheaths, paraarticular soft tissues, muscles or around nerves.[42-44] Further, there has been increased attention toward using US guided application of shock waves, allogenic chondrocytes and bone marrow stem cells with bone morphogenetic protein in various sports medicine settings.[42]

Future development

Future innovations in clinical use usually parallel developments in US technology. For example, there appears new imaging methods like acoustic microscopy or histosonography.[45, 46] Using high frequency probes (>25 MHz), US enables depiction of structures down to the level of histological details. In this regard, the possibility of carrying out a histosonographic study would be a very attractive conception in order to understand histologic background of the sports injuries. Three or four-dimensional MSUS imaging are booming and maturing techniques as well. With continual refinement in image processing, the eventual search for virtual live anatomy may be attained with comprehensive impact. Other recent advances also include combined imaging with MRI and high-intensity focused US used mainly for confirmative diagnosis [3, 47] - and tissue velocity imaging or speckle tracking that provides very detailed

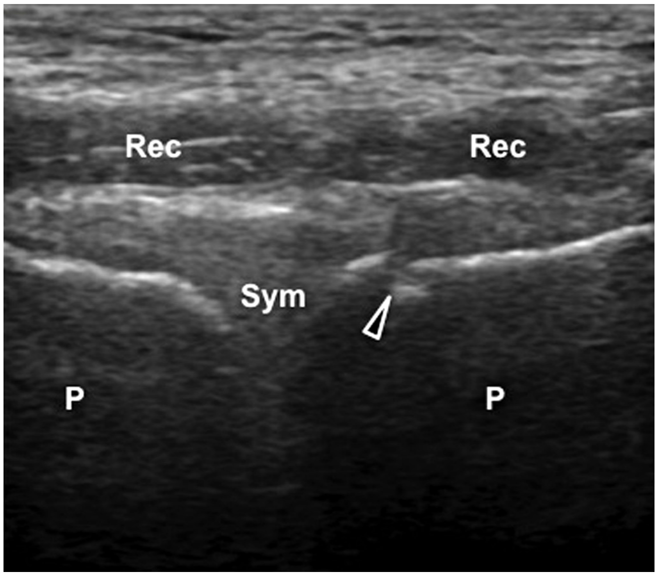

Figure 11.—Ultrasonographic imaging of a footballer with osteitis pubis. The probe is placed transversely on close proximity of the rectus abdominis (Rec) muscles' insertions onto the pubic bones (P). A bony erosion (arrowhead) that was also very tender to 'sono-auscultation' is clearly seen on the right side of symphisis pubis (Sym).

quantitative analysis for movement of the musculoskeletal structures.[48-50]

Conclusions

Being a very convenient imaging method,- US is a must-stop in the diagnosis, follow-up and treatment of sports lesions. Therefore, acquaintance with the use of MSUS definitely needs to be on the agenda of physicians dealing with sports medicine, and it is hightime that a standardized international approach to MSUS training and competency assessment for relevant sonographers is set.

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