Diagnostic ultrasound of muscle injuries: what the sports medicine clinician should know

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ABSTRACT

Muscle injuries are among the most prevalent musculoskeletal conditions in athletes, contributing significantly to morbidity and time lost from competition. The use of ultrasound (US) is advantageous in assessing these injuries due to its low cost, accessibility, portability, dynamic real-time capabilities and utility in prognosis and rehabilitation planning. This state-of-the-art review offers a comprehensive synthesis of current evidence on the anatomical, technical and clinical aspects of diagnostic US in evaluating sports-related muscle injuries. Key topics include the differentiation between direct and indirect injury mechanisms, classification systems, prognostic indicators and common complications such as fibrosis, haematoma and myositis ossificans. Emphasis is placed on a practical, stepwise approach to US examination and reporting, incorporating anatomical detail and functional assessment to support individualised return-to-play decisions. Despite certain limitations, the US remains a cornerstone imaging modality in sports medicine. Emerging technologies, including advanced imaging techniques, hold promise for enhancing diagnostic accuracy and optimising clinical outcomes.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Ultrasound (US) is widely used in sports medicine for evaluating muscle injuries due to its accessibility, dynamic capabilities and safety.
⇒ Multiple classification systems for muscle injuries exist, but they often lack standardisation and specific application to individual muscle groups.
⇒ Real-time US monitoring guides rehabilitation and return-to-play (RTP) decisions.

WHAT THIS STUDY ADDS

⇒ A structured, muscle-specific US approach enhances diagnostic accuracy and improves prognostic stratification.
⇒ Dynamic manoeuvres and Doppler findings are essential components for the functional assessment of muscle injuries.
⇒ A standardised reporting framework improves communication and clinical decision-making.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE, OR POLICY

⇒ Adoption of muscle-specific scanning and classification approaches in routine clinical practice is recommended.
⇒ US findings should be integrated with rehabilitation milestones and RTP protocols.
⇒ Future research is needed to validate structured reporting systems and develop new US tools for muscle injury assessment.

INTRODUCTION

Muscle injuries are among the most common conditions encountered in sports medicine, often leading to substantial downtime and complex rehabilitation processes for athletes.[1] The specific muscles affected vary by sport: injuries to the soleus and gastrocnemius frequently occur during acceleration or deceleration, while the hamstrings and rectus femoris (RF) are particularly vulnerable in soccer players and sprinters.[2] Adductor-related injuries also account for a significant proportion of muscle injuries in sports.[3] Less frequently, injuries involve hip stabilisers and rotators—such as the obturator internus and externus, quadratus femoris, pectineus, iliacus, gluteus medius and gluteus minimus—which, despite being less common, should not be overlooked in clinical evaluation.[4 5]

Muscle injuries include indirect (non-contact) injuries, such as muscle tears, and direct injuries, including contusions and lacerations, all of which can significantly impair performance and limit participation in training or competition.[6] A premature return to play (RTP) increases the risk of re-injury and may prolong overall recovery.[7] Therefore, accurate and timely diagnosis is crucial for effective management, safe RTP planning and recurrence prevention.

MRI remains the most sensitive imaging modality for identifying muscle injuries, particularly subtle or deep lesions, and is considered the gold standard for diagnosis.[1] However, ultrasound (US) has become the preferred first-line imaging technique in many clinical settings due to its in-clinic accessibility, cost-effectiveness and ability to provide real-time, dynamic assessment.[8] In terms of clinical application, musculoskeletal US, which can also be used for tendinopathies,[9 10] joint effusions and guided procedures,[11 12] should be considered when muscle injury is suspected based on history and examination, particularly when RTP decisions are time-sensitive or when MRI is not readily accessible. Current literature supports the use of US as a primary diagnostic tool for lower-limb muscle injuries, with MRI reserved for complex presentations, elite athletes or hard-to-visualise muscles such as the soleus.[13 14]

For sports physicians, proficiency in musculoskeletal US is essential for establishing an accurate diagnosis, informing prognosis, monitoring healing, guiding interventions and supporting RTP decisions.[15] The US allows for immediate lesion assessment, injury classification and estimation of recovery time,[16–18] while also facilitating follow-up evaluations during rehabilitation and the early detection of complications.[17 19] Although it requires an often-underestimated steep learning curve, its repeatability, safety and dynamic capabilities make it particularly valuable when injury severity is unclear, recovery is prolonged or invasive procedures are being considered.[20]

This state-of-the-art review aims to provide a comprehensive, clinically focused synthesis of current evidence regarding the use of US in evaluating and managing sports-related muscle injuries, with a particular emphasis on practical application, classification systems, prognosis and RTP decision-making. Upper limb and trunk muscle injuries are excluded from this review, as the focus is on high-incidence lower-limb injuries in sports where evidence is most mature. However, many principles discussed are broadly applicable.

METHODS

Search strategy and literature selection

To develop this state-of-the-art review, we conducted a structured literature search across PubMed, Scopus and Google Scholar from January 2000 to March 2025. Search terms included combinations of the following keywords: *"muscle injury"*, *"ultrasound"*, *"sports medicine"*, *"muscle strain"*, *"myotendinous junction"*, *"return to play"*, *"ultrasound-guided injection"* and *"muscle healing"*. Boolean operators (AND, OR) were used to refine the search. The reference lists of relevant articles and reviews were also screened to identify additional sources.

Studies were included if they met the following criteria:

- Focused on skeletal muscle injuries in athletes or physically active populations.
- Evaluated or discussed the role of musculoskeletal US in diagnosis, prognosis or treatment.
- Included original studies, systematic reviews, meta-analyses, expert consensus documents or guideline papers.
- Published in English in peer-reviewed journals.

Exclusion criteria included: animal studies, cadaveric studies, case reports with insufficient clinical detail and papers not involving sports-related muscle injuries.

Evidence synthesis and topic selection

The author team, comprising sports physicians, musculoskeletal radiologists, physiatrists and imaging experts from multiple countries, independently reviewed the identified literature. Relevant articles were assessed based on methodological quality, clinical applicability and contribution to key themes.

The review was structured around key areas reflecting real-world decision-making in sports injury management: anatomical considerations, technical scanning principles, classification systems, diagnostic patterns, prognosis, complications, interventional techniques and structured reporting. Particular emphasis was placed on evidence that informs clinical decision-making and RTP strategies. Where applicable, recommendations are supported by available evidence and rated according to the Oxford Centre for Evidence-Based Medicine (OCEBM) criteria.

Development of recommendations

Where appropriate, recommendations were developed through consensus among authors, supported by the best available evidence. A simplified grading system was applied to highlight the strength of evidence in clinically relevant areas, based on the OCEBM levels of evidence. These ratings are included in tables or figure legends to aid clinical interpretation. Where high-quality evidence was lacking, recommendations were based on multidisciplinary expert opinion and consensus.

Patient and public involvement statement

Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this research.

Equity, diversity and inclusion statement

This review was conducted by a diverse author group representing a range of genders, career stages, clinical roles and geographical regions, including contributors from Italy, the UK, Spain, Canada, Qatar and the USA. All authors had equal opportunity to contribute to the study design, literature interpretation and manuscript drafting. The topic selection and interpretations were developed through collaborative discussion to minimise bias and enhance generalisability across international sports medicine contexts.

ANATOMY AND HISTOLOGY OF SKELETAL MUSCLE

A solid understanding of skeletal muscle anatomy and histology is crucial for accurately interpreting musculoskeletal US images.[21] The fundamental contractile unit of muscle is the sarcomere, composed of actin and myosin filaments that collectively form myofibrils. These myofibrils group into cylindrical muscle fibres (cells), each surrounded by the endomysium. Bundles of fibres are organised into fascicles, encased by the perimysium and together they form the muscle, which is enveloped by the epimysium, the outermost connective tissue layer.[22 23] Skeletal muscle architecture can be categorised into five structural types: pennate, fusiform (biceps brachii), parallel (sartorius), convergent (pectoralis major) and circular. Pennate muscles have fibres oriented obliquely to a central tendon and are further subdivided into multipennate (deltoid), unipennate (extensor digitorum communis) and bipennate (RF) configurations.

In the US, this hierarchical architecture appears as parallel hypoechoic bands (myofibres) interspersed with hyperechoic connective tissue elements, such as the perimysium, epimysium and tendons.[24] The epimysium is seen as a fine hyperechoic line surrounding the muscle, becoming thicker near bony insertions, where it contributes to the formation of the aponeurosis—a key structure often involved in injury and easily visualised with US.[24] Another critical region is the myotendinous junction (MTJ), the interface between muscle and tendon, which is a common site of injury and should always be carefully evaluated.[24]

An unexplained increase in muscle echogenicity, even without a visible structural lesion, may indicate non-structural pathology such as fibrillar oedema or sustained muscular contraction. However, such findings may also result from anisotropy, a common US artefact that causes normal muscle to appear hypoechoic due to suboptimal probe angulation—especially in muscles like the semitendinosus.[14]

In longitudinal (sagittal) views, muscle typically displays alternating hypoechoic and hyperechoic bands resembling 'veins on a leaf', influenced by the pennation angle (the angle between the longitudinal axis of the muscle and its fibres). In transverse (axial) views, the muscle appears predominantly hypoechoic with scattered hyperechoic foci, producing the classic 'starry night' appearance.[8]

TECHNICAL ASPECTS OF ULTRASOUND IMAGING IN SKELETAL MUSCLE EXAMINATION

A comprehensive US evaluation of muscle injuries involves the assessment of fluid, function and vascularity. Key goals include detecting haematomas to assess injury severity, monitoring muscle contractility during recovery and using colour Doppler to identify vascular changes suggestive of healing or complications.[16]

Equipment and transducers

Modern multifrequency linear transducers (10–22 MHz) provide high-resolution imaging for superficial muscles. For deeper structures—such as in muscular individuals or during evaluation of the gluteal and proximal thigh regions—lower-frequency linear probes (7–10 MHz) or curvilinear transducers may be required.[25] Most indirect injuries involve superficial muscle layers, which are typically well-visualised with linear transducers.[16] However, a trade-off exists between depth penetration and resolution: higher frequencies yield better resolution but reduce deep tissue visualisation due to signal attenuation.[26]

When available, extended field-of-view imaging allows for complete longitudinal visualisation of injuries exceeding the probe footprint (up to 60 cm).[16] Additional image-enhancing technologies—such as tissue harmonic imaging, compound imaging and beam steering—can further improve contrast resolution and reduce artefacts.[27]

Image optimisation and settings

Optimising machine settings is essential. Key parameters include gain, frequency, depth, focus and time gain compensation. The focal zone should be positioned at or just below the area of interest. The transducer should be held perpendicular to the target tissue to avoid anisotropy, and excessive pressure must be avoided, particularly during colour Doppler assessment, as it can distort vascular flow or displace fluid.[14 28] Beam steering can reduce anisotropy by electronically angling the US beam without changing the transducer's physical orientation when available. This is particularly helpful when imaging obliquely oriented structures, such as the central tendon of the RF or the soleus muscle, especially when the foot is dorsiflexed to stretch and align the fibres. Beam steering helps maintain optimal insonation, improving visualisation of muscle and tendon interfaces and minimising false hypoechogenicity. Dynamic probe manoeuvres—such as heel-toe tilting, gentle rocking and fanning—help align the US beam with muscle fibres and reduce anisotropy. This is especially important in muscles like the semitendinosus or central tendon of the RF, where anisotropy may mimic pathological findings.[29]

Key artefacts to recognise and manage include[30]:

- Anisotropy (angle-dependent hypoechogenicity, mimicking pathology)
- Acoustic shadowing (from calcifications or fibrotic tissue)
- Posterior acoustic enhancement (through fluid-filled structures, eg, haematomas)
- Comet-tail artefacts (from small, highly reflective interfaces)

Understanding image formation and artefact behaviour is essential when assessing deep muscles with varying acoustic impedances. Machine image quality should be optimised with periodic service and upgrades.

Technique and scanning protocol

A targeted clinical history and examination guide focused imaging.[1] The examination should begin with transverse views, followed by longitudinal scans, focusing initially on the symptomatic region and then proceeding systematically from the muscle origin to its insertion: proximal and distal entheses, MTJ, epimysium, intermuscular septa and fascia are essential hallmarks to evaluate (table 1).[24] Functional manoeuvres—such as heel raises for the gastrocnemius or resisted hip adduction for the adductors—can unmask subtle lesions. Contralateral comparison is essential, particularly in chronic or ambiguous cases. For example, in adductor imaging, the 'sunray sign' refers to the fan-like appearance of the gracilis muscle fibres extending distally and posteriorly from the pubic region, resembling rays radiating from a central point. This should not be confused with the oncologic 'sunburst' pattern seen in bone tumours.

While a complete scan of the affected region is recommended, the area of maximal tenderness should receive particular attention.[16] Echo-palpation (sonopalpation)—applying focused transducer pressure—can enhance lesion localisation but must be performed cautiously to avoid compressing haematomas or distorting fibre architecture.[31 32]

Dynamic and Doppler evaluation

Following static assessment, dynamic scanning is critical. Normal contraction produces synchronous fibre movement and maintains anatomical structure. Findings such as asynchronous motion, fibre separation (diastasis), haematoma or oedema suggest injury.[14] Functional testing—for example, resisted hip adduction, dorsiflexion or knee extension—can reproduce pain and reveal otherwise occult injuries. These tests also help assess the mechanical integrity of muscle fibres, aiding injury grading.[19] Bilateral comparison improves diagnostic accuracy, particularly in complex regions such as the soleus or posterior calf.[14]

Given the vascular nature of muscle tissue, colour Doppler imaging is an important adjunct. While hyperechoic fibroadipose septa may occasionally show blood flow in healthy individuals, hyperaemia within the lesion or surrounding scar tissue typically indicates active inflammation or repair (formation of granulation tissue). This feature is particularly important for follow-up evaluation, helping to distinguish between chronic tears and recent re-injuries. However, since there is no direct correlation between Doppler signal and RTP, these findings should always be interpreted in comparison with the contralateral side.[16]

Best practices for Doppler assessment include[32]:

- Minimise probe pressure to avoid compressing vessels
- Do not mistake perivascular pulsation for pathological flow
- Avoid overinterpretation of random colour artefacts
- Adjust colour gain just below the threshold for non-anatomic signals
- Reduce the colour box to include only the area of interest

A systematic approach to scanning improves diagnostic accuracy and ensures reproducibility (table 2, figure 1).

MUSCLE INJURIES: DEFINITION AND CLASSIFICATION

Muscle injuries are broadly classified into two categories based on their mechanism, as defined by a recent Delphi consensus[33]:

- Indirect (non-contact) injuries, typically muscle tears.
- Direct (contact) injuries, such as contusions and lacerations.

Muscle tears occur when muscle fibres are forcibly elongated, most commonly during eccentric contractions that exceed the tissue's viscoelastic limits—frequent during explosive athletic movements.[34] The MTJ is particularly vulnerable due to its lower elasticity compared with muscle fibres.[35 36] In contrast, direct injuries result from external impact—such as collisions with opponents, the ground or equipment—and are common

Table 1 Ultrasound evaluation of major muscle injuries

Muscle group	Anatomy	US identification	Dynamic evaluation
Adductors	▶ Origin: inferior pubic ramus and ischial tuberosity. ▶ Insertion: adductor longus, brevis and magnus insert onto the femur's linea aspera and adductor tubercle. Gracilis inserts at the medial proximal tibia as part of the pes anserinus.	▶ Position: supine, thigh abducted ~30°, externally rotated, knee flexed. ▶ Start with a short-axis view of the adductor longus. Identify the tendon protuberance with muscle tension. Rotate the probe 90° for the longitudinal view to the pubic symphysis. ▶ Use fanning to identify adductor longus (superficial), brevis (middle) and magnus (deep). Slide posteriorly to view the gracilis ('sun-ray' sign). ▶ Anterior/Posterior obturator nerves run between muscle layers. ▶ Key feature: horizontal intramuscular tendon of adductor longus.	▶ Resisted hip adduction (30° flexion/abduction): observe for focal pain, tendon thickening or fibre diastasis. ▶ Sonopalpation: apply the transducer over the adductor origin to localise pain or haematoma. ▶ Assess from different angles (neutral and flexed hip) to evaluate insertional stress. ▶ Gentle compression may help visualise fluid. ▶ Always compare with the contralateral side. ▶ Assess the integrity of the cortex of the pubic bone.
Rectus femoris	▶ Origin: direct head from AIIS of ilium; indirect head from superior acetabulum. ▶ Insertion: quadriceps tendon to patella.	▶ Position: supine, knee extended. ▶ Use a linear probe, scanning from AIIS down the muscle belly. ▶ Transverse view reveals comma-shaped hyperechoic central tendon: tilt probe to avoid anisotropy. ▶ Rotate to evaluate direct/indirect heads, MTJ and insertion. ▶ Key feature: the central tendon serves as a reliable landmark.	▶ Active hip flexion+knee extension against resistance: reveals tendon excursion, disruption or altered central tendon alignment. ▶ Sonopalpation at AIIS and MTJ can help identify pain. ▶ Eccentric loading may unmask subtle central tendon pathology.
Hamstring	▶ Origin: ischial tuberosity (conjoined tendons of BFLH and ST); SM has a separate origin. ▶ BF short head from femoral shaft. ▶ Insertion: BF at the lateral aspect of the proximal fibula; SM at the posteromedial tibia; ST at the medial tibia as part of the pes anserinus.	▶ Position: Prone, hip neutral, foot off bed. ▶ Place the probe on the ischial tuberosity to find the conjoint tendon. ▶ Tilt to follow the tendon parallel to the probe. ▶ Scan distally to differentiate bellies and tendons. ▶ Key features: 'Boomerang' raphe in ST, intramuscular tendon in BF. ▶ 'Mercedes-Benz sign': sciatic nerve underneath the common tendon between ST (medial) and BFLH (lateral). ▶ Position: prone, hip neutral, foot off bed.	▶ Isometric knee flexion: check for synchronous fibre movement, retraction or haematoma. ▶ Passive straight leg raise: assesses fascial glide and stiffness. ▶ Dynamic hip extension+knee flexion: helps visualise fibre coordination and tendon integrity. ▶ Sonopalpation around the ischial tuberosity can localise the pain origin.
Soleus	▶ Origin: posterior tibia (soleal line) and proximal fibular head. ▶ Insertion: posterior calcaneus via Achilles tendon.	▶ Position: prone, foot relaxed. ▶ A linear probe over the deep MTJ will be used to identify the central intramuscular aponeurosis. ▶ Evaluate medial, central and lateral aponeuroses, which converge into a common tendon. ▶ High anatomical variability.	▶ Active plantarflexion (heel raise): visualise synchronous contraction. ▶ Dorsiflexion under probe: assess fascial stretch and tendon alignment. ▶ Sonopalpation with deep pressure: may reproduce deep pain. ▶ Evaluate aponeurotic tearing and hypoechoic areas under compression. ▶ Always assess for asymmetry compared with the contralateral limb.
Medial head of the gastrocnemius	▶ Origin: posterior femur, medial supracondylar ridge and adductor tubercle. ▶ Insertion: joins the soleus and lateral head of the gastrocnemius to form the Achilles tendon, and inserts onto the posterior calcaneus.	▶ Position: prone, ankle neutral, foot over table edge. ▶ Scan from the proximal belly to the Achilles. ▶ Key features: feather-like muscle fibres; dynamic assessment with the soleus enhances evaluation.	▶ Alternating dorsiflexion/plantarflexion: observe synchronous movement with the soleus. ▶ Single-leg calf raise: detects MTJ gapping or irregular fibre contraction. ▶ Eccentric knee extension+dorsiflexion: assesses myotendinous tension. ▶ Tiptoe simulation or hopping: visualises fascial continuity. ▶ Sonopalpation at the medial femoral condyle may help detect periosteal involvement.

AIIS, anterior inferior iliac spine; BF, biceps femoris; BFLH, biceps femoris long head; BFSH, biceps femoris short head; MTJ, myotendinous junction; SM, semimembranosus; ST, semitendinosus; US, ultrasound.

in contact sports like American football and rugby.[30] The degree of damage in direct trauma depends mainly on the force of impact.[37] Importantly, the clinical presentation may not always align with the extent of structural damage observed on imaging,[6] and this must always be considered when evaluating an athlete.

Despite being the most common type of sports-related trauma, muscle injuries still lack a universally accepted classification system.[38] Since the 1980s, the growing use of US and MRI has led to the development of multiple classification frameworks. However, many of these systems overlap or offer limited clinical utility.[39 40] One of the main challenges in creating a unified classification is that different muscles have distinct anatomical and functional characteristics, making generalisation problematic.[41]

According to the Munich Consensus Classification, athletic muscle disorders are divided into functional (non-structural)

Table 2 How to perform a muscle ultrasound scan (evidence levels and recommendation strength based on OCEBM criteria)

Step	Description	Evidence level	Recommendation strength
Patient positioning	Position the patient according to the muscle group being evaluated (eg, supine for quadriceps, prone for hamstrings, lateral decubitus for gluteals).	5	Strong
Transducer selection	Use a high-frequency linear transducer for superficial muscles. For deeper structures (eg, gluteals, proximal thigh), opt for a lower-frequency transducer if needed.	4	Strong
Artefact avoidance	Adjust gain, frequency, depth, focus and probe angle to reduce artefacts. When available, use beam steering on the two-dimensional image to optimise insonation angle—especially useful in oblique fibres (eg, soleus with foot in dorsiflexion) or central tendons.	3	Strong
Initial scan	Begin with transverse scans and then rotate the probe in the area of pathology to obtain a longitudinal view. Use echo-palpation to guide the probe to the point of maximal tenderness.	3	Strong
Systematic muscle evaluation	Scan the entire muscle-tendon unit: from the tendon insertion through the MTJ into the muscle belly and intramuscular aponeuroses.	3	Strong
Dynamic assessment	Assess muscle function during active or passive movement. Look for abnormal fibre motion, gapping or loss of contraction symmetry.	3	Strong
Contralateral comparison	Always compare the injured side to the uninjured side to detect asymmetries or subtle abnormalities.	4	Strong
Doppler imaging	Use colour or power Doppler (or microvascular imaging, if available) to detect hyperaemia, neovascularisation or inflammatory activity.	3	Moderate

Evidence level based on the OCEBM 2011 criteria. Recommendation strength reflects expert consensus in the absence of high-level data.
MTJ, myotendinous junction; OCEBM, Oxford Centre for Evidence-Based Medicine.

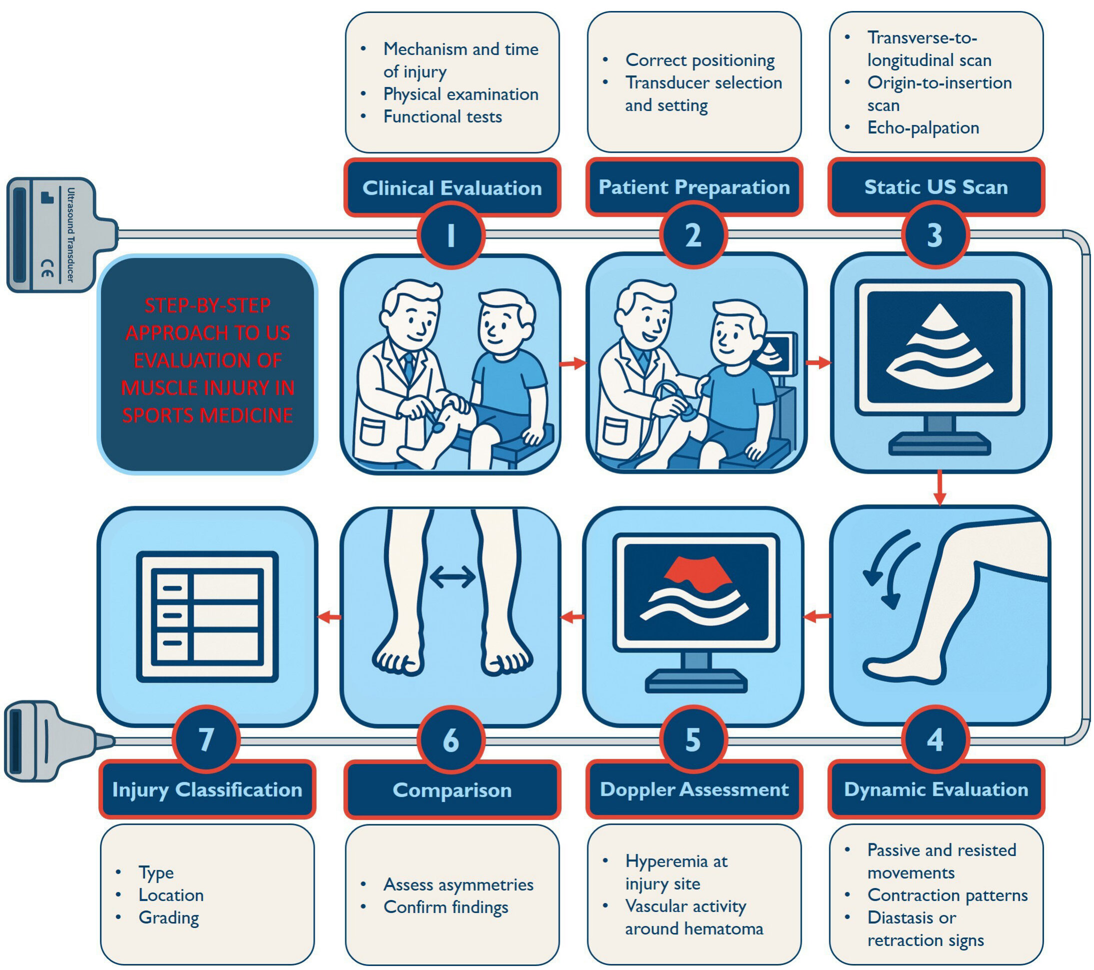

Figure 1 Central figure: step-by-step approach to ultrasound (US) evaluation of muscle injury in sports medicine. This flow chart summarises the recommended workflow for musculoskeletal US assessment in athletes with suspected muscle injury. It integrates clinical, static, dynamic, Doppler and comparative evaluation steps, ending in injury classification. This structured approach supports diagnostic accuracy and return-to-play decision-making.

injuries and structural injuries. Functional (non-structural) injuries are true clinical injuries without macroscopic fibre disruption,[33] often seen after heavy or unaccustomed eccentric load. Athletes typically present with pain, tightness and reduced function, but no fibre discontinuity is demonstrable on imaging or histology. Oedema may be present (MRI T2-hyperintensity or subtle US echogenicity changes), but it does not equate to a structural tear. Examples include type 1a and 1b (overexertion-related disorders) and type 2a and 2b (neuromuscular-related disorders).[42] By contrast, structural injuries demonstrate macroscopic fibre disruption (partial or complete tear), often associated with haematoma/diastasis and disruption of the fibrillar architecture. Examples are type 3a and 3b partial tears and type 4 subtotal/complete tears or avulsions.[42] The British Athletic Muscle Injury Classification, introduced in 2014, combines clinical and MRI data with anatomical subclassifications.[43] It also supports that division, introducing a grade 0 category for clinical injuries with normal MRI, which corresponds to functional disorders. Importantly, functional (non-structural) injuries are not traditionally 'mild strains'. The term 'strain' is deliberately avoided in current classifications, because once any fibre discontinuity is present, the injury is considered structural.[44] Functional disorders are instead managed with load control, neuromuscular re-education and graded RTP, usually with shorter lay-offs and minimal risk of scarring.[45]

Valle *et al*[13] proposed a consensus-based system with four taxonomic levels: mechanism, location, grade and re-injury status—although its complexity, with over 200 potential combinations, limits clinical utility. Similarly, the Italian Consensus Conference classification (2017) remains unvalidated and difficult to apply in routine practice.[46]

Several grading systems focus specifically on US-based criteria (table 3). Takebayashi *et al*[47] and Peetrons[48] categorised muscle injuries based on the percentage of the cross-sectional area affected. Lee and Healy[6] expanded this by including hypervascularity, fascial detachment and perilesional oedema. Chan *et al*[49] refined classification further by localising injuries to the proximal MTJ, muscle belly or distal MTJ, and categorising involvement as intramuscular, myofascial or myotendinous. Loizides *et al*[50] and Renoux *et al*,[17] in recent years, further proposed their classifications. Notably, the classification by Renoux *et al* distinguishes type C injuries (from connective tissue) and type M injuries (from muscle fibres), linking connective tissue damage with longer RTP times.

At present, Pedret *et al* proposed the only muscle-specific US classification with validated RTP correlations.[51] This system is tailored to individual muscle groups' unique anatomical and functional properties. Future research should focus on expanding similar classification models to other muscle groups, enabling more individualised and precise management of muscle injuries in athletic populations.

ULTRASOUND FINDINGS OF MUSCLE LESIONS

Indirect injuries

US evaluation of indirect muscle injuries—typically muscle tears—reveals hallmark findings such as disruption of standard muscle architecture (disrupted fascicular pattern with partial or complete discontinuity of fibres), fluid collections (interstitial haemorrhages up to haematomas) and alterations in echogenicity (hypoechoic and/or hyperechoic focal area within the muscle).[14] The appearance of a lesion in the US varies based on its type, extent, location and—critically—the timing of the scan.

From a histopathological perspective, muscle injury evolves over time. In the first 24–48 hours, there is diluted haemorrhage, inflammation and early fibre necrosis, followed by capillary ingrowth and fibroblast proliferation.[52] Collagen synthesis begins within 72 hours, while oedema and inflammation typically resolve in 1–2 weeks.[1] These evolving processes mean the sonographic appearance is time-dependent, and scanning too early (eg, <2 hours postinjury) may underestimate the injury due to hyper-reflective blood components. Within 48–72 hours, liquefaction renders haematomas anechoic, facilitating more accurate assessment and grading.[1]

In functional (non-structural) injuries, very common in athletes, US may reveal diffuse, ill-defined hyperechogenicity

Table 3 US-based grading systems for muscle injuries

Grade	Takebayashi *et al*[47]	Peetrons[48]	Lee and Healy[6]	Chan *et al*[49]	Loizides *et al*[50]	Renoux *et al*[17]
I	<20% CSA	Minimal elongation involving <5% of the muscle	Normal or increased echogenicity (focal or generalised)±perifascial fluid	Increased echogenicity with preserved architecture; no MTJ distortion	Muscle oedema with minor changes	C: hypertrophy with blurred septal contours M: faint hyperechoic area without architectural disruption
II	20%–50% CSA	5%–10% involvement; partial rupture; hypoechoic/anechoic gap; 'bell clapper' sign	Fibre discontinuity in echogenic perimyseal striae; hypervascularity; possible fascia/aponeurosis detachment	Fibre discontinuity with altered echogenicity and hypervascularity; perimyseal striation lost near MTJ	Loss of muscle fibre continuity; altered echogenicity; haematoma or perifascial fluid often present	C: partial rupture of fascia/connective septa or aponeurosis M: irregular hyperechoic area with disrupted architecture
III	>50% CSA	Complete muscle/fascial tear with extravasation	Complete myotendinous or osteotendinous avulsion; retraction; haematoma; 'bell clapper' sign	Complete fibre discontinuity with visible stumps and haematoma	Full-thickness rupture with haematoma in the defect	C: proximal or distal connective rupture (no retraction) M: myo-aponeurotic or myotendinous avulsion; rupture without retraction
IV						C: connective rupture with stump separation and tension of adjacent structures M: muscle bundle avulsion or rupture with retraction

C, connective tissue-origin injury; CSA, cross-sectional area; M, muscle tissue-origin injury; MTJ, myotendinous junction; US, ultrasound.

with preserved fibrillar continuity and no gap or haematoma[24] (figure 2). Dynamic US demonstrates synchronous contraction (although painful), no diastasis and increased tone (reduced compressibility on sonopalpation); Doppler findings are typically unremarkable. Even if very unspecific and subjective, and therefore with poor reliability, there are additional features that may describe a functional injury (level 4, weak recommendation)[24]:

- Increased pennation angle (compared with the contralateral side), without distortion of normal fibrillar structure.
- Mild increase in anteroposterior diameter on axial or longitudinal views.
- Reduced deformation during sonopalpation, indicating increased muscle tone.
- Decreased fibre mobility during isometric contraction.

In structural injuries, oedema and haemorrhage typically appear as anechoic or hypoechoic areas, while surrounding tissue may become more echogenic due to fluid or reactive changes.[48 53] Both short-axis and long-axis imaging are essential to assess lesion morphology and haematoma extent. Fibre discontinuity is typically visualised as a gap between muscle ends, which may be filled with haematoma in complete tears. Retraction of the muscle belly may occur, especially in high-grade lesions. A characteristic sonographic sign is the 'bell clapper' appearance, in which the retracted muscle belly swings within a fluid-filled haematoma cavity (figure 3).[54]

Involvement of intramuscular tendons (eg, central tendons) is associated with a worse prognosis[17] and must be identified early (level 3, strong recommendation) (figure 4).[16] For instance, proximal central tendon injuries of the RF—above the intersection of the sartorius (lateral) and RF (medial)—are predictive of prolonged RTP periods and should always be ruled out.[55]

Because different muscles have specific anatomical patterns, interpretation must be muscle-specific (online supplemental table 1).

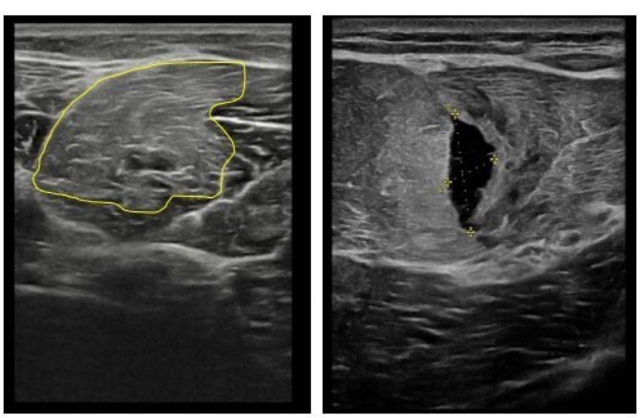

Figure 2 Ultrasound (US) presentation of two different biceps femoris injuries. First injury—left panel (transverse short-axis US scan over the sixth proximal hamstring region): non-structural lesion showing a hyperechoic area (highlighted in yellow), without evidence of fibre disruption, consistent with a functional muscle disorder. Second injury—right panel (transverse short-axis US scan over the sixth proximal hamstring region): structural lesion (type 3B muscle injury) demonstrating an anechoic area (outlined by yellow asterisks), indicative of an intramuscular haematoma due to disruption of muscle fibres.

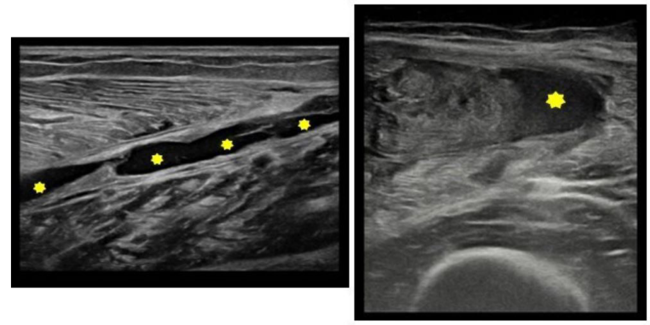

Figure 3 Ultrasound images of two different indirect muscle injuries. First injury—left panel: longitudinal view of a medial gastrocnemius tear (Pedret type 2A) in a tennis player. The image shows disruption of the muscle–aponeurotic junction with a visible intermuscular fluid collection (yellow asterisks) between the medial gastrocnemius and the soleus muscle. Second injury—right panel: transverse view of a distal peripheral rectus femoris tear in a basketball player. The classic 'bell clapper sign' is evident, representing the retracted muscle belly surrounded by a hypoechoic haematoma (yellow asterisk), consistent with fibre disruption and localised fluid accumulation.

Direct injuries

Direct muscle injuries most commonly affect the anterior and lateral compartments of the thigh and hip, although they can occur in any muscle group. When accompanied by skin disruption, the injury is classified as a laceration.[24]

Figure 4 Transverse ultrasound view of a biceps femoris tear involving the proximal conjoint tendon of the biceps femoris and semitendinosus in a sprinter. The outlined area includes both the partial tear, affecting the superficial two-thirds of the tendon, and the adjacent sciatic nerve. The image demonstrates disruption of the normal fibrillar pattern of the tendon, with fluid collection within and around the tendon, consistent with a structural tendon-related injury.

Blunt trauma leads to capillary and muscle fibre rupture, causing interstitial haemorrhage. This initially appears as a hyperechoic region with ill-defined margins in the US, gradually becoming more distinct and hypoechoic over time (figure 5)[56]:

- Acute phase (0–48 hours): haematomas are often hyperechoic, reflecting their corpuscular content.
- Subacute phase (48–72 hours): liquefaction of blood leads to a more anechoic or hypoechoic appearance.
- Chronic/Resolving phase: internal debris such as necrotic tissue or clot fragments may be seen, and focal scar tissue can form during the resorptive process.

Dynamic US is particularly useful in confirming the absence of significant muscle tears, evaluating the extent of tissue disruption and monitoring healing over time. Colour and power Doppler may reveal perilesional hyperaemia, reflecting granulation tissue formation and the onset of the reparative process.[56] Haematomas often contain a mixture of liquefied blood and coagulated material. In more advanced stages, haemorrhagic breakdown products—including haemosiderin, deoxyhaemoglobin and methaemoglobin—contribute to the heterogeneous MRI appearance. These products result in T1 shortening (from methemoglobin) and T2 shortening (from haemosiderin), which can help estimate haematoma age.[56] Most intramuscular haematomas resolve spontaneously within 6–8 weeks; however, persistent lesions may evolve into seromas, cystic haematomas or, in rare cases, myositis ossificans.

In some cases, tangential shearing forces may result in a Morel-Lavallée lesion—a closed degloving injury characterised by the separation of muscle fascia from subcutaneous tissue, leading to accumulation of haemolymphatic fluid.[57] These lesions most commonly occur in the peritrochanteric region and proximal thigh and are classified according to the Mellado and Bencardino system.[58] On the US, Morel-Lavallée lesions typically appear as well-defined, hypoechoic collections between the subcutaneous fat and deep fascia, although they may also be located within the subcutaneous layers.[24] Septations and mobile hyperechoic debris—representing necrotic tissue—are common findings. Excessive probe pressure may disperse the fluid and obscure the lesion, making gentle technique essential for accurate detection.

HEALING PROCESS AND PROGNOSIS OF MUSCLE INJURY

One primary advantage of US over MRI in muscle injury evaluation is its ability to facilitate serial, dynamic assessments throughout the healing process.[14]

Muscle healing occurs in three overlapping phases[1 35 36 59]:

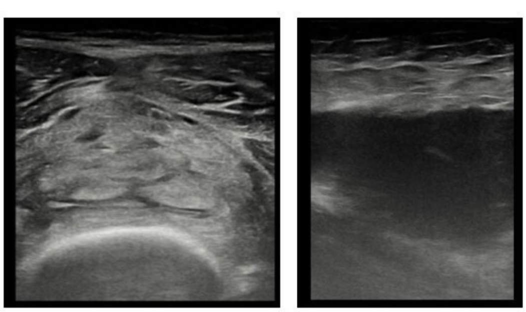

Figure 5 Ultrasound evolution of a vastus medialis haematoma in a young athlete. Left panel (acute phase, transverse view): a hyperechoic area is visible, consistent with recent haemorrhage and clot formation. Right panel (subacute phase, longitudinal view): the haematoma has become predominantly anechoic, indicating progressive liquefaction and resorption.

- Destructive phase (0–5 days): characterised by muscle fibre necrosis, inflammatory response and haematoma formation.
- Reparative phase (5–14 days): involves macrophage-mediated debris removal, fibrous scar formation, revascularisation and regeneration via satellite cell differentiation into myoblasts.
- Remodelling phase (beyond the second week): entails scar tissue reorganisation, myofibril maturation and progressive functional recovery.

Optimal US timing is 48–72 hours postinjury, when haematoma liquefaction improves lesion visibility. Early scans (<2 hours) may underestimate severity due to incomplete haemorrhage. The 48-hour window is both physiologically appropriate and logistically practical, particularly after weekend competitions or away games where on-site US may not be available.[16 42]

A recent article suggests a protocol for muscle injuries[14]:

1. 48–72 hours postinjury: initial US to confirm diagnosis and assess fluid collections, fibre disruption and echogenicity (level 2b, strong recommendation).
2. 7–14 days: follow-up to monitor fluid resolution, hyperaemia reduction and bridging fibre formation (eg, colour Doppler activity in the granulation zone). Supports rehabilitation progression.
3. 14–21 days: confirmation of tissue continuity before initiating advanced rehabilitation.
4. Pre-RTP scan: final evaluation to verify healing status and safe return to full activity.

Although US findings are central to clinical decision-making, they should always be integrated with physical and functional testing and sport-specific evaluation, as complete imaging resolution is no longer the sole criterion for RTP.[60] Even if relatively few studies have validated the prognostic utility of US, there are some US features—such as preserved architecture, absence of tendon involvement and rapid haematoma resolution—that have been associated with favourable outcomes and shorter recovery times (level 3, moderate recommendation).[16 19 61]

COMPLICATIONS OF MUSCLE INJURIES AND ATYPICAL LESIONS

US also allows for early identification of complications related to muscle injury,[62–64] which are often associated with improper timing or progression of rehabilitation[1 7 65] (table 4).

Among these, muscle fibrosis is the most frequent. It appears as hyperechoic, irregular areas with architectural distortion during contraction and significantly impairs muscle elasticity and performance.[2 7]

Myositis ossificans, occurring in up to 50% of post-traumatic cases—particularly in contact sports—is characterised by heterotopic ossification. The US is sensitive to early detection, showing a hyperechoic ring with a hypoechoic centre that may later calcify, producing posterior shadowing (figure 6). CT may be needed to differentiate it from bone-forming tumours when US findings are inconclusive.[56 66 67]

Chronic compartment syndrome typically affects the lower limbs. Although the US cannot measure compartment pressure, it can help exclude other causes (eg, deep vein thrombosis (DVT), haematoma) and reveal muscle swelling, fascial bowing or loss of standard architecture.[68–71]

DVT, while often overlooked, can occur in up to 10% of cases following calf injuries. US is the first-line imaging tool, identifying venous dilation, echogenic thrombus and lack of compressibility, with colour Doppler used to assess reduced or absent flow.[72 73]

Table 4 Common muscle injury complications and US characteristics

Complication	Description	US characteristics
Muscle atrophy	Loss of muscle mass and strength due to disuse or severe injury	Decreased muscle bulk; increased echogenicity due to fatty infiltration
Muscle fibrosis	Replacement of muscle fibres with fibrotic tissue after injury	Heterogeneous echotexture; increased echogenicity; reduced elasticity
Myositis ossificans	Heterotopic bone formation within muscle after trauma	Early: hypoechoic centre (fibroblastic matrix) with hyperechoic ring (disorganised osteoid) Later: peripheral calcification with acoustic shadowing
Chronic compartment syndrome	Increased muscle pressure during activity	Normal at rest; difference between muscle thickness before and after exercise
Recurrent tears	Re-injury at the previous site due to incomplete healing	New hypoechoic lesions adjacent to old fibrotic areas, surrounded by oedema as a hyperechoic intramuscular image within muscle fibres
Haematoma	Blood accumulation within muscle compartments	Initially anechoic or hypoechoic; it becomes complex and echogenic as it organises
Scar tissue formation	Excessive fibrosis impairs function	Irregular hyperechoic area, often tethering the surrounding tissue
Infection (pyomyositis)	Post-traumatic muscle infection (often in immunocompromised patients)	Diffuse swelling, fluid collections, internal gas (in advanced cases), and Doppler hyperaemia

US, ultrasound.

US-GUIDED INTERVENTIONAL THERAPY IN MUSCLE INJURIES

US-guided procedures are increasingly used in elite sport for their safety and precision.[11 74]

The most common is haematoma aspiration, indicated for chronic or symptomatic collections, particularly when rapid RTP is a priority (level 4, weak recommendation).[53] Ideal candidates present with compressible, anechoic fluid on US. The in-plane approach with colour Doppler guidance ensures procedural safety, avoiding vascular structures. A sterile 18–20 G needle with a 10 mL syringe is standard, followed by compression bandaging. Repeat aspirations may be required in some cases. Although beneficial, this technique remains individualised, with no universal protocol.[75]

PRP and orthobiologic injections are also performed under US guidance, although their efficacy remains under investigation due to a lack of standardised protocols.[11 76 77]

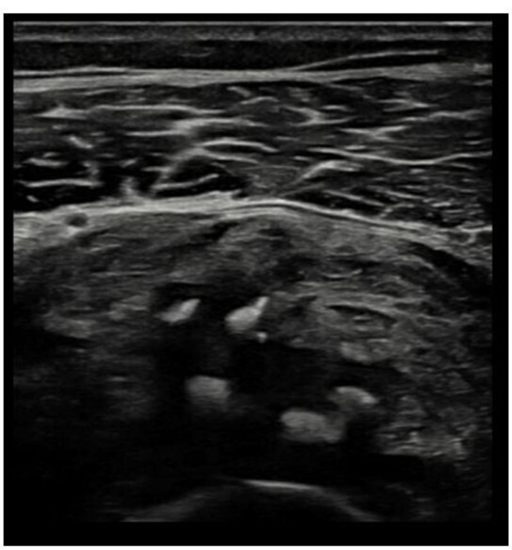

Figure 6 Early stage myositis ossificans of the vastus intermedius (transverse short-axis ultrasound scan). The image shows heterogeneous intramuscular hyperechoic lesions with irregular but smooth margins and no posterior acoustic shadowing, consistent with a recent stage of myositis ossificans. The absence of well-defined calcific borders and acoustic shadow suggests the initial phase of the ossification process.

STRENGTHS AND LIMITATIONS OF US IMAGING IN SPORT-RELATED MUSCLE INJURY

US offers key advantages in sports medicine: real-time, dynamic, bedside evaluation, low cost, no radiation and guidance for interventional procedures.[8] It is well-suited for monitoring healing, guiding rehabilitation and informing RTP decisions. It is particularly useful for visualising superficial tears and differentiating connective tissue structures masked by oedema in MRI imaging.

However, key limitations remain.[14] US is highly operator-dependent, requiring a steep learning curve and significant experience to interpret findings correctly. It also has limited sensitivity for detecting small or deep lesions, especially in challenging anatomical areas such as the proximal RF, hamstring origin, iliopsoas and soleus.[78] US also struggles to assess scar tissue quality and the extent of reinjury. Another relevant limitation is the variability in image quality across US machines. Lower-end devices may produce suboptimal image resolution in clinical practice, reducing diagnostic accuracy—particularly for subtle or deep injuries. The availability of advanced imaging features (eg, elastography, beam steering, panoramic view) also varies widely across systems, impacting consistency and reproducibility.

Despite this, it performs comparably to MRI for major injuries such as complete tears or large contusions.[79] While MRI remains the gold standard in many cases, it is not without flaws: it may overdiagnose higher-grade injuries, and the timing of MRI is crucial—too early a scan may miss structural damage or misrepresent oedema as more severe injury.

Therefore, US and MRI imaging complement each other in many clinical scenarios, with the choice of modality often based on the clinical setting, severity and location of the injury, specific diagnosis and therapeutic goals, and affordability.

Technological advances are helping to address some of the US's limitations. Features such as beam steering, elastography, panoramic views and contrast-enhanced US enhance diagnostic capabilities.[20] Integrating artificial intelligence (AI) holds promise to standardise interpretation, reduce subjectivity and support predictive decision-making. However, AI applications in musculoskeletal US are still in early stages, and future research should prioritise developing and validating AI tools specific to sports-related muscle injuries.[80 81]

REPORTING OF MUSCLE INJURIES: PRACTICAL TIPS FOR SPORTS MEDICINE CLINICIANS

US reporting of muscle injuries must go beyond merely describing anatomical findings. A good report should integrate clinical context,

Table 5 How to structure a muscle injury US report (evidence levels and recommendation strength based on the OCEBM criteria)

Section	Key elements to include	Evidence level	Recommendation strength
Patient data	Name, age, sport, dominant side, injury side	5	Strong
Clinical information	Mechanism of injury (direct/indirect), timing, symptoms, functional test	4	Strong
Technical details	Probe type, patient positioning, transducer frequency and settings used	4	Strong
Muscle evaluated	Specific muscle(s) and portion (proximal, belly, distal)	3	Strong
Key structure involvement	Note the integrity of central tendons, aponeuroses or conjoint tendons	3	Strong
Findings—static	▶ Fibre alignment (normal/disrupted) ▶ Presence of fluid collections ▶ Echogenicity changes	3	Strong
Findings—dynamic	▶ Muscle contraction symmetry ▶ Fibre separation (diastasis) ▶ Tendon movement	3	Strong
Doppler assessment	Presence/Absence of hyperaemia and vascular activity around lesion	3	Moderate
Contralateral comparison	Normal/Asymmetrical findings compared with uninjured side	4	Strong
Classification and grading	Injury type (direct or indirect—structural/functional), histological type (myofascial, myotendinous, tendinous), grading system (if used*)	4	Moderate
Secondary imaging	Recommend MRI or further testing if needed	4	Moderate
Complications (if present)	Haematoma, fibrosis, myositis ossificans, DVT suspicion	3	Strong
Conclusion and prognosis	Summary, estimated RTP time, recommendation for US follow-up	4	Strong

*Avoid overclassification or rigid adherence to complex scales unless they provide actionable insights. Tailor reports to support the athlete's clinical journey and rehabilitation.
Evidence level based on the OCEBM 2011 criteria. Recommendation strength reflects expert consensus in the absence of high-level data.
DVT, deep vein thrombosis; OCEBM, Oxford Centre for Evidence-Based Medicine; RTP, return to play; US, ultrasound.

imaging results, functional information and prognostic implications to guide rehabilitation and RTP decisions. This is especially powerful when the sports physician personally performs the musculoskeletal US, as they possess in-depth knowledge of the athlete's history, sport-specific demands, physical examination findings and team management dynamics.[4] Indeed, the sports physician–sonographer is uniquely positioned to perform bedside clinical correlation and initiate a tailored management plan during the same visit. This enhances efficiency, reduces delays in decision-making and fosters close communication with coaches, physiotherapists, trainers and the athlete.

A structured report facilitates clear communication between the physician, rehabilitation team, coaching staff and athlete, ensuring consistency and clinical relevance. It should summarise the injury characteristics, functional impact, estimated layoff time (when feasible) and recommendations for follow-up imaging or assessments (table 5).

US injury staging should be based on

1. specific muscle involved;
2. portion: proximal, belly, distal;
3. injury type: direct or indirect (structural/functional);
4. histological type (if possible): myofascial, myotendinous, tendinous;
5. key structure involved (tendons).

Injury grading (eg, British Athletics, Peetrons, Munich) helps categorise lesion severity, but should never replace individualised assessment. Grades should be interpreted in the context of:

- ▶ athlete's sport, position and competition calendar;
- ▶ US-guided functional findings;
- ▶ dynamic testing results.

Always avoid over-reliance on classification when it does not aid decision-making. Instead, using US to personalise prognosis and tailor rehab progression based on objective milestones (eg, bridging fibres, contraction symmetry, Doppler resolution) is recommended.

Indeed, US findings directly impact clinical management. For instance:

- ▶ Mild structural lesions with preserved central tendon, minimal haematoma and synchronous contraction may allow early functional rehab and a shorter RTP timeline (eg, 1–2 weeks).
- ▶ Large haematomas or diastasis >1 cm may prompt consideration of haematoma aspiration, especially if fluid persists beyond 7–10 days or causes functional restriction.
- ▶ Extensive fibre retraction or myotendinous disruption may indicate extended layoff time (>4–6 weeks), and in elite athletes, PRP or other injections could be considered to enhance tissue healing.
- ▶ Colour Doppler hyperaemia at 7–14 days may indicate active repair and justify continuing cautious loading.
- ▶ Persistent architectural distortion with fibrotic bands after 3–4 weeks may guide a more conservative progression and support delaying RTP testing.

CONCLUSION

Muscle injuries pose a significant challenge in sports medicine, necessitating precise diagnosis, individualised management and meticulous RTP planning. US plays a crucial role in this process, offering real-time dynamic assessment, early prognostic insights and support for both clinical and interventional decision-making. A structured, muscle-specific approach to US scanning and reporting enhances diagnostic accuracy, improves communication between multidisciplinary teams and optimises athlete recovery. Despite its limitations, ongoing technological advancements continue to expand the role of the US in the management of muscle injuries. Mastery of musculoskeletal US should be regarded as a core competency for sports physicians committed to providing high-quality, athlete-centred care.

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