

IMAGING OF LOWER LIMB MUSCLE INJURY

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Sports-related skeletal muscle injuries are a common cause of loss of playing time in both the amateur and elite athlete. Recent studies have demonstrated a clear relationship between magnetic resonance imaging findings and potential lay-off time from return to competitive sport.

This article illustrates the role of imaging in lower limb muscle injuries, from diagnosis and management to predicting time of return to competitive activity.

INTRODUCTION

Acute skeletal muscle injury is one of the major causative factors for loss of playing time in all athletes. While some injuries are said to be sports-specific, acute muscle injury is seen across all sports and is the most common injury in professional football. A recent study on male professional footballers showed that injuries to muscle represent more than 30% of all injuries and are responsible for approximately one quarter of total injury absence. Over 90% of

muscle injuries affect the four major muscle groups of the lower extremity: hamstrings, adductors, quadriceps and gastrocnemius. Injury to the hamstring muscle group is reported to be the most common injury subtype. This means that a professional male football team with 25 players in the squad suffer about five hamstring injuries each season, equivalent to more than 80 lost football days.

Recent studies of Australian Rules football players with hamstring injuries have indicated that lay-off could be related to magnetic resonance imaging (MRI) findings such as the longitudinal length or volume of the injury. In our recently published study¹, MRI findings were correlated with time out of competitive activity in UEFA Champions League footballers. We demonstrated that up to 70% of acute lower limb muscle injuries in these players do not demonstrate any macroscopically detectable architectural distortion (grade 0 or I) on MRI and yet are

the cause of the majority of absence days from play.

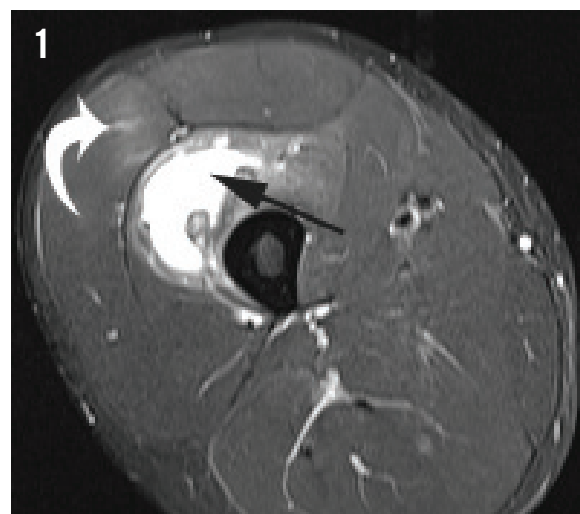
Muscle injuries are caused either by direct trauma, usually in the form of blunt impact, or indirect trauma following a powerful eccentric muscle contraction, typically at the onset of a sprint movement for hamstring or calf injury and while striking a ball for quadriceps injury. Imaging of sports-related injury is now pivotal to guiding management and aiding with prognosis in elite sport.

IMAGING TECHNIQUES

Cross-sectional imaging of muscle and muscle injury in elite sport is usually undertaken by magnetic resonance imaging and/or ultrasound (US). In the authors' experience of dealing with elite sportsmen from multiple disciplines, MRI is the main imaging tool in the diagnosis of muscle injuries, while US is reserved more for problem solving and for guiding interventions.



Figure 1: Axial STIR MRI of the thigh in a professional soccer player. There is a haematoma within the vastus intermedius muscle (black arrow). Note the oedema within the overlying vastus lateralis (curved white arrow).



Magnetic resonance imaging

MRI is the optimal tool in the detection and localisation of muscle injuries. The images are anatomical and easily understood by healthcare professionals and patients alike. The minimum set of sequences for the assessment of muscle injury on MRI includes one fat suppressed fluid-sensitive sequence such as short-tau inversion recovery (STIR), or fat-saturated proton density-weighted or T2 weighted imaging and one T1 weighted sequence to identify blood products and muscle atrophy. Images should be acquired in the axial, sagittal and coronal planes.

Imaging of sports-related injury is now pivotal to guiding management and aiding with prognosis in elite sport.

Ultrasound

Diagnostic US is becoming increasingly popular in the assessment of acute muscle injury and can be performed by radiologists and sports clinicians alike. Ultrasound has several important advantages over MRI including superior spatial resolution, lower cost, convenience, portability and dynamic evaluation of the injury.

Linear high-frequency probes are most commonly used (9-17MHz) which provide excellent near-field spatial resolution but may be limited by their lack of tissue penetration capability. Colour or Power Doppler imaging is occasionally useful in identifying muscle injury by demonstrating increased blood flow at the injury site. Extended-field-of-view imaging can be helpful in assessment of large muscle tears and provide a more anatomical image for the patient and referring clinician.

AETIOLOGY AND CROSS-SECTIONAL IMAGING OF MUSCLE INJURY

In clinical practice, muscle injuries can be divided into two aetiological groups: direct injury which is most commonly blunt trauma in the form of a direct blow to the lower limb and indirect injury in which excessive eccentric load on the muscle results in tearing of the junction between

muscle fibres at the musculotendinous junction or myofascial interface, this being the weakest point in the muscle-tendon unit. A third type of acute skeletal muscle injury is delayed onset muscle soreness (DOMS), which will be considered separately.

Direct muscle injury

Penetrating injury and muscle laceration is rarely encountered during sporting activity. Blunt trauma, conversely, is common and most frequently encountered in the lower limb in collision sports such as soccer and rugby. When a blunt force (usually the knee cap of the opposing player) is directly applied to the muscle of the recipient limb (usually the anterior mid-thigh), the dissipation of that force will determine the subsequent injury pattern. The severity of the injury ranges from a small muscle contusion to a large haematoma either within the muscle, between muscles (intermuscular), or at the muscle-bone interface. The vastus intermedius muscle is the most commonly injured muscle. MRI is the main imaging technique in the assessment of direct muscle injury.

MRI OF DIRECT MUSCLE INJURY

The injury typically affects different muscles along the line of force and crosses

fascial planes, a finding which is uncommon in muscle strain injury. Typically, there is subcutaneous oedema and the severity of the muscle injury increases with depth, as the force dissipation is greatest at the muscle bone interface, most commonly vastus intermedius in the middle third of the thigh. The direct blow causes oedema and interstitial haemorrhage leading to muscle swelling and ill-defined high signal within the muscle on fat-suppressed fluid sensitive sequences. On MRI, the extra-cellular blood products appear as areas of faint high signal on T1-weighted images. If there is a prominent bleed into the muscle, a haematoma will form.

The natural evolution of haematoma on MRI is as follows:

1. Immediately following injury, there is an irregular muscle laceration. The muscle surrounding the laceration is diffusely high signal on the fluid-sensitive sequences.
2. By 48 hours, there is an ill-defined irregular fluid collection within the muscle, which is high on T1 and STIR imaging. The signal characteristics of the haematoma will change in time depending on the nature of the predominant blood product within it.
3. After 7 days, the haematoma starts to heal by fibrosis, which begins at the margins of the haematoma and spreads inwards in a centripetal fashion. It is at this time, or shortly after, that the haematoma begins to liquefy and aspiration may be attempted to improve recovery time. Fibrosis of the margins of the haematoma will contract the lesion over time.
4. Calcification of the haematoma wall may occur leading to the development of myositis ossificans (Figure 7).

ULTRASOUND OF DIRECT MUSCLE INJURY

The initial contusion is seen as an ill-defined area of hyper-reflectivity within the muscle, which crosses fascial boundaries. In the next 48 to 72 hours, the haematoma develops into an ill-defined hypo-echoic fluid collection with an echogenic fibrotic margin. In our experience, attempting to aspirate the haematoma at this time often proves fruitless, as the clot is too solid.

The role of imaging in acute muscle injury has changed from merely confirming a clinical diagnosis to defining the exact location of the injury within the muscle, the size of muscle disruption at the tear site, and the longitudinal length and cross-sectional area of muscle oedema.

Aspiration of the clot may be necessary for symptomatic reasons and may accelerate healing time. The aspiration is performed under ultrasound guidance as the haematoma liquefies which typically occurs 10 to 14 days after the time of injury.

Indirect muscle injury

Sudden onset pain usually localised to a single muscle occurring during a period of powerful eccentric muscle contraction is the typical presentation of a muscle strain. In footballers, the quadriceps and hamstring muscle groups are the most commonly affected. Quadriceps injuries usually involve rectus femoris and typically occur during striking the football. Hamstring injuries most commonly involve biceps femoris and typically occur during a sprint movement. In general, calf muscle injuries are more common in older athletes and this is especially true for injuries to soleus. Pre-disposing risk factors may be athlete-related or muscle-specific. Athlete-related risk factors include age, male gender, improper warm-up and fatigue. Muscle-specific risk factors include previous injury within the same muscle and muscles that have a high proportion of fast-twitch (type II) fibres, cross multiple joints or are regularly subject to eccentric loading. Hence, the biceps femoris, rectus femoris and medial gastrocnemius are the most commonly strained muscles in elite sport.

Several clinical grading systems have been described based on the physical examination and history. The most commonly used system has a three-step clinical grading score as follows:

- **Grade I (stretch injury):** a small tear resulting in less than 5% loss of function,
- **Grade II (partial tear):** a larger tear with 5 to 50% loss of function,
- **Grade III (complete rupture):** more than 50% loss of function.

MRI is the index-imaging tool in the assessment of indirect muscle injury. It is more sensitive than US in the detection of grade I injuries and aids in defining the prognosis following indirect muscle injury.

MRI OF INDIRECT MUSCLE INJURY

The role of imaging in acute muscle injury has changed from merely confirming a clinical diagnosis to defining the exact location of the injury within the muscle, the size of muscle disruption at the tear site, and the longitudinal length and cross-sectional area of muscle oedema. These factors have all been used to assist with predicting outcome following muscle strain injury.

In our recent study of 516 hamstring injuries in UEFA Champions League (University College London [UCL]) foot-ballers, we found that 84% of

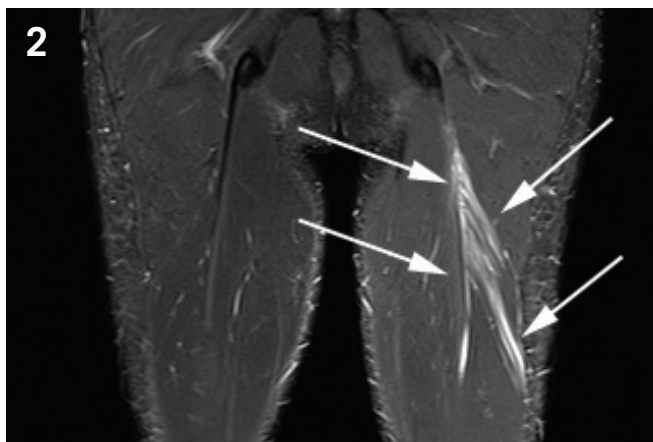


Figure 2: Coronal STIR MRI of the thigh in a professional athlete. There is a grade I injury of the proximal long head of biceps muscle (arrow).

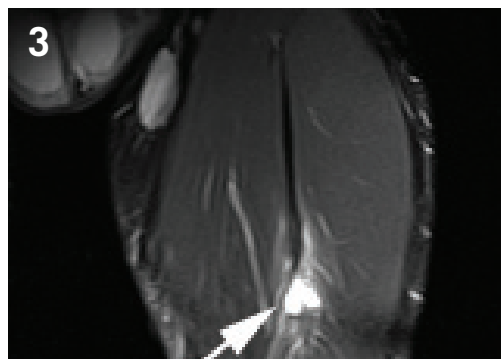


Figure 3: Coronal STIR MRI of the thigh in a professional footballer. There is a partial tear of the rectus femoris muscle (arrow).

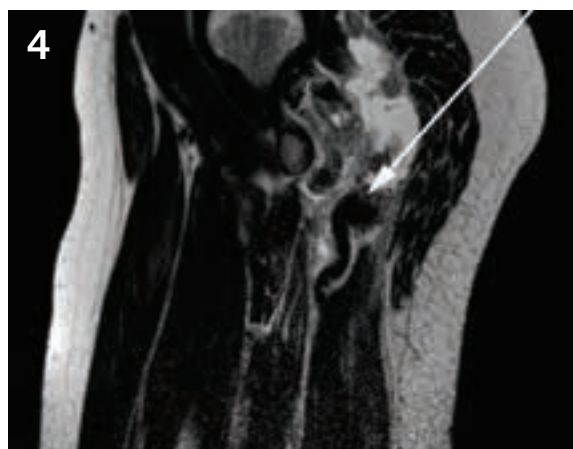


Figure 4: Sagittal T2-weighted MRI of the upper thigh in an amateur athlete. There is a full-thickness avulsion of the common hamstring attachment from the ischial tuberosity. Note the retracted tendons (arrow).

these injuries involved biceps femoris, 11% semimembranosus and 5% semitendinosus. There was no difference in lay-off time between the muscles involved. Interestingly, the re-injury rate was 16% in the study group and all these re-injuries involved biceps femoris. An index (initial) injury and re-injury had the same recovery time according to the radiological grade on MRI, potentially a result of the quality of the medical care afforded to this elite athlete population. We defined a new MRI radiological grading system as follows.

Grade 0

No visible muscle oedema or macroscopic architectural distortion. In the UCL study, the footballers with clinical evidence of acute muscle strain but normal MRI had an average lay-off time of 8 days. Several other studies have demonstrated that a negative MRI finding in the context of clinically suspected hamstring strain is associated with shorter recovery time. The actual cause of posterior thigh injury where MRI shows no pathology is unclear. It is possible that these injuries are below the sensitivity of MRI detection and are subtle muscle injuries. Another explanation is that such

athletes may have an alternative diagnosis such as back-related problems, neural tension or muscle spasm.

Grade I strain

Increased signal is seen within the muscle at the injury site on fluid-sensitive fat-suppressed sequences but there is no macroscopic architectural distortion of the muscle.

The high signal is due to oedema and blood radiating from the musculotendinous junction along the muscle fascicles producing a feathery-type pattern within the muscle. Perifascial fluid may be seen on MRI in grade I injury. In the UCL study, players with grade I injuries lost 17 days of playing time on average.

Grade II strain

The characteristic MRI finding of grade II injury is macroscopic distortion of normal muscle architecture at the injury site.

This results in a discrete ill-defined high signal fluid collection at the site of fibre disruption, indicating a partial tear in the muscle. This represents haematoma formation usually at the musculotendinous junction. The feathery muscle oedema pattern and perifascial fluid described

in grade I injury will also be present. Frequently, the perifascial fluid is extensive and spreads in a dependent fashion from the injury site. There may be some laxity of the central tendon within the muscle.

In the UCL study, players with grade II injuries lost 22 days of playing time.

Grade III strain

There is complete disruption of the musculotendinous unit with haematoma filling the space between the two. Grade III injuries are most frequently seen at the tendon proximal origin rather than the distal insertion.

Grade III injuries are rare compared to grade I and II injuries, comprising only 3% of the UEFA CL study group. Grade III injuries result in an average loss of playing time of 73 days. Surgery is rarely required but has been advocated in avulsion injuries in the skeletally immature patient with more than 2 to 3 cm of retraction.

ULTRASOUND OF INDIRECT MUSCLE INJURY

Grade I strain

Ultrasound may either be normal or show areas of increased echogenicity at the injury. This increased echogenicity may obscure

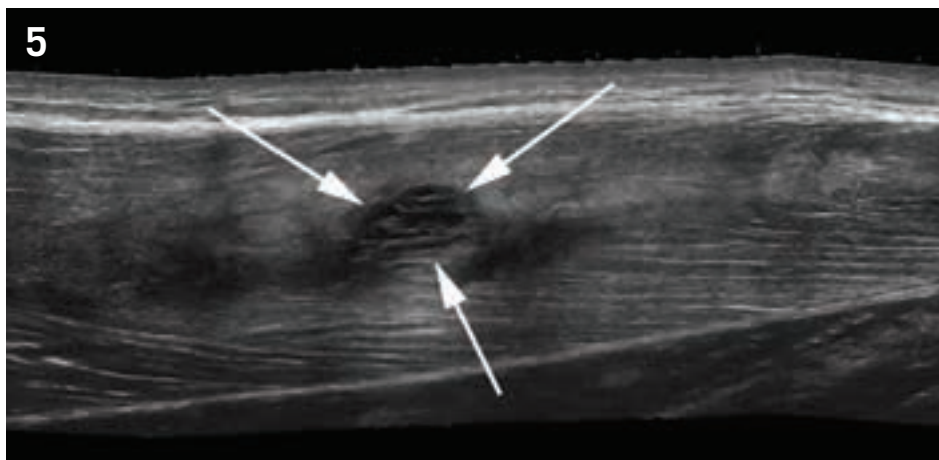


Figure 5: Extended field-of-view ultrasound scan of the thigh in a professional footballer. There is a defect within the muscle filled with loculated haematoma consistent with a grade II injury (arrows).

the musculotendinous junction. Perifascial fluid may be seen but is often missed on US as the fluid may be hyperechoic due to the presence of blood in the extra vascular space.

Grade II strain

Typically, there is discontinuity of the echogenic perimysial striae either at the musculo-tendinous or myofascial junction. Intermuscular and perifascial fluid collections are common in grade II injuries. It may be difficult to differentiate grade I from grade II injuries on MRI and this has significant implications to the prognosis of the injury.

Ultrasound may be useful to confirm the grade of injury by demonstrating macroscopic distortion of the muscle at the injury site during dynamic contraction in grade II injuries.

'Tennis Leg'

Partial detachment of medial gastrocnemius at the aponeurosis with soleus muscles is referred to as 'tennis leg'. Deep venous thrombosis is both a differential diagnosis and a complication of this condition and assessment of the calf veins at the time of the scan is mandatory. This injury is usually seen in the older amateur athlete, the so-called 'weekend warrior' (Figure 6).

Grade III strain

There is complete discontinuity of the muscle at the musculotendinous junction. The surrounding muscle is hyperechoic and intermuscular, perifascial and subcutaneous

fluid collections are common. There is frequently a heterogeneous haematoma that can obscure the tendon ends making an accurate diagnosis impossible. MRI performs much better than US at tendon end evaluation in this context.

Delayed-onset muscle soreness

DOMS is usually observed 12 to 24 hours following unaccustomed strenuous exercise. In elite sportsmen, this typically occurs following an increase in training load in pre-season or during rehabilitation from a different injury. The severity of symptoms correlates with the intensity and duration of the activity. The soreness increases to a peak between 24 and 72 hours then subsides by day 7. MRI typically demonstrates faint oedema frequently affecting more than one muscle and possibly more than one compartment. The feathery pattern of MRI intramuscular oedema seen in muscle strain is not usually evident in DOMS and the abnormality may be bilateral and symmetrical. The MRI findings of DOMS are occasionally found in asymptomatic athletes. Ultrasound may be normal, or demonstrate geographical hyper-echogenicity affecting several muscles across different compartments. Imaging alone may not be able to distinguish DOMS from grade I muscle strain and clinical correlation is required.

IMAGING THE COMPLICATIONS OF MUSCLE INJURY

The two potential complications of a direct and indirect muscle injury include scar formation and myositis ossificans

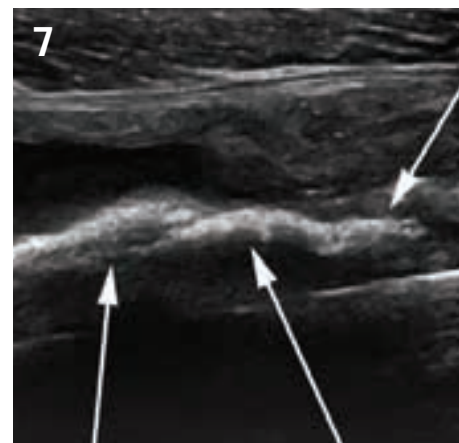


Figure 6: Coronal STIR MRI of the leg in an amateur athlete. There is a muscle tear (arrow) between medial gastrocnemius and soleus ('tennis leg').

Figure 7: Ultrasound scan of the thigh in a professional footballer. There is a large haematoma with irregular echogenic margin (arrow) paralleling the anterior femoral cortex. The appearances are characteristic for early myositis ossificans.

(MO). MRI is the main imaging tool in the detection of scar formation within muscle while alternative imaging techniques are recommended in the diagnosis of MO.

Intramuscular scar

On MRI, scar appears as an area of low signal within the muscle on all sequences adjacent to, or inseparable from, the musculotendinous or myofascial surface.

On ultrasound, an intramuscular scar appears hyperechoic, or heterogeneous hypoechoic, and morphologically linear or stellate typically adjacent to the musculotendinous junction. The stellate form usually follows muscle contusion, whereas the linear form typically follows a muscle strain and commonly surrounds the musculotendinous junction. Dynamic assessment may demonstrate muscle deformation at the scar site during contraction.

Myositis ossificans

In the setting of sports-related injuries, direct blunt trauma and muscle haematomas may be associated with the development of MO. Three clinically distinct stages are recognised:

1. The acute or pseudo-inflammatory phase,
2. The sub-acute or pseudo-tumoral phase and
3. The chronic healing phase.

Stages 1 and 2 myositis ossificans typically demonstrate non-specific areas of muscle inflammation on both MRI and

ultrasound. During the chronic healing phase, osteoid material is laid down at the margin of the haematoma in a lamellar fashion. Peripheral calcification is visible on CT and plain radiographs at approximately 6 weeks and ossification occurs by 6 months.

US has several advantages over MRI in making this diagnosis. Frequently MRI will simply demonstrate severe oedema throughout the muscle surrounding a haematoma. MRI is insensitive in the detection of early calcium deposition. More importantly, MO resembles a sarcoma on MRI. US detects the early stages of myositis ossificans 2 weeks before radiographic evidence of calcium is evident. CT scanning is considered the gold standard imaging technique in the diagnosis of MO. The peripheral 'egg-shell' calcification separate from the cortical margin of the adjacent bone is characteristic. Interval imaging may be needed, as percutaneous biopsy may also be misleading.

SUMMARY

1. MRI is the index method of assessing acute lower limb muscle injury.
2. MRI is able to accurately diagnose and grade muscle injuries and can be used to predict time to return to competitive sport in the elite athlete.
3. Both MRI and US can be used to identify the complications of muscle injury.
4. US is used mainly to guide intervention and can be useful in differentiating grade I from grade II injuries.

References

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DOMS is usually observed 12 to 24 hours following unaccustomed strenuous exercise.

