Hamstring injury is one of the most common acute musculoskeletal injuries sustained by amateur and professional athletes, particularly in sports requiring explosive sprinting, jumping or flexibility – such as football or dancing. Correctly diagnosing the type and grade of hamstring injury is crucial in treatment planning; chiefly at the elite level where immense pressure is placed on sports physicians and physiotherapists to return athletes to competition as quickly as possible. Medical imaging plays a pivotal role in guiding the immediate management of athletes while also helping to predict the risk of recurrent injury.

PATIENT DEMOGRAPHICS
The risk of sustaining a hamstring injury increases with age. Athletes aged 25 years or older have been shown to be up to 4.4 times more likely to suffer an injury when compared to their younger counterparts.

Race and ethnicity have also been associated with increased rates of injury with Aboriginal Australian Football League and African English Premier League players suffering more hamstring strains than their Anglo-Saxon colleagues.

ANATOMY AND FUNCTION
The Hamstring Muscle Complex (HMC) is located in the posterior thigh, comprising the semitendinosus, semimembranosus and biceps femoris (long and short head) muscles. The three ‘true’ hamstrings arise from the ischial tuberosity crossing both the hip and knee joints. The short head of biceps arises from the linea aspera and lateral supracondylar line of the femur and only crosses the knee joint. With its divergent origin and innervation, the short head of biceps femoris is sometimes excluded from the ‘hamstring’ characterisation.

Biceps femoris is a double-headed muscle similar to biceps brachii of the arm. It is the most lateral muscle in the posterior thigh. Both heads form a common tendon inserting onto the fibular head, lateral tibial condyle and fascia of the lower leg. The long and short heads are innervated by the tibial and common fibular divisions of the sciatic nerve, respectively. Arterial supply of the biceps femoris is via perforating branches of the profunda femoris, inferior gluteal and medial circumflex femoral arteries.

Semitendinosus resides medial to biceps femoris and overlaps the majority of semimembranosus. Its origin is by way of a common – known as the conjoint – tendon with biceps femoris at the inferomedial aspect of the ischial tuberosity. It inserts onto Gerdy’s tubercle, medial to the tibial tuberosity, as part of the pes anserine complex. Innervation and arterial supply are through the tibial division of the
sciatic nerve and perforating branches of the profunda femoris and inferior gluteal arteries respectively.

Semitendinosus courses medial and anterior to the other hamstring muscles. Its origin is at the superolateral aspect of the ischial tuberosity and its insertion contains five arms, the medial tibial condyle (anterior, direct and inferior arms), posterior oblique ligament and oblique popliteal ligament. Nerve supply is from a single branch of the tibial division of the sciatic nerve. Arterial supply is obtained through branches of the profunda femoris and gluteal arteries.

**BIOMECHANICS**

The muscles of the HMC are important hip extensors and knee flexors during the gait cycle. They become active in the last 25% of the swing phase to actively extend the hip and prevent extension at the knee. Thus, the HMC acts as a dynamic stabiliser, working alongside the corresponding static stabiliser, the anterior cruciate ligament (ACL). Dynamic stabilisation occurs particularly when the knee is flexed at 30 degrees and the foot reaches its greatest distance forward from the body. With take-off, the HMC again contracts with the quadriceps to provide push-off from the support leg.

**MECHANISM OF INJURY**

HMC strain is due to concurrent passive muscle stretching with active contraction, known as eccentric contraction – a process that creates far greater tension than concentric contraction (contraction while muscle length shortens). Studies have observed a 130 millisecond period during the late swing phase of the gait cycle where the biceps femoris reaches a peak musculotendinous junction (MTJ) length, 12% beyond that seen in an upright posture and exceeding the normal maximal length of the medial hamstrings. The biceps femoris is the most commonly injured hamstring muscle and it is at this point of the gait cycle when it is considered at highest risk.

Simultaneous truncal hyperflexion and knee extension, which results in tension of the HMC at both the hip and knee, seriously predisposes the hamstrings to rupture. This scenario is often observed when one is bending over to pick up a ball at full stride. The ischial apophysis has united with the remainder of the pelvis by age 25 and hence rupture in adults is ligamentous, whereas in the immature skeleton the unbonded ischial apophysis is the most common avulsion fracture.

**CLINICAL DIAGNOSIS**

Hamstring injury is usually characterised by a sudden onset of posterior thigh pain, sometimes with a popping/tearing sensation followed by dramatic loss of function. It can be followed by localised tenderness and loss of strength. Examination findings may include localised swelling, tenderness, muscle weakness or a palpable defect. Pain may be reproduced with passive straight leg raising, active knee extension or via manual resistance applied to knee flexion.

Hamstring injuries are clinically graded from I to III with respect to their severity. These grades are based on the degree of pain, weakness and loss of motion experienced by the patient. Grade I is considered mild with only tearing of a few muscle or tendon fibres. Grade II is moderate with severe muscle tearing, however without disruption of the MTJ. Grade III represents complete tear or avulsion.

**IMAGING FINDINGS**

Ultrasound (US) and Magnetic Resonance Imaging (MRI) can both be used in the diagnosis of HMC injury, however US is often used as the first-line investigation in the acute setting due to its ease of accessibility and low cost. Dedicated high-frequency musculoskeletal sonographic probes have improved spatial resolution and soft tissue contrast, which together with multiple focal zones have helped improve image quality, particularly of the deep soft tissues of
muscular athletes. Unfortunately, US remains highly operator-dependent and considerable experience and interpretive skill is required. Furthermore, it can occasionally be difficult to accurately localise muscular tears on US as the three hamstring muscles in very muscular athletes are large with minimal intermuscular fat, which provides natural soft tissue contrast. This is particularly the case at the level of the ischial tuberosity, where the biceps femoris and semitendinosus tendons share a common origin.

MRI is less operator-reliant with high spatial resolution and clear anatomical delineation, however the modality is costly and time consuming. Injury may also be overestimated due to the depiction of subtle oedema, not often seen with US. Muscle injury manifests as hyperintense (bright) signal on T2-weighted imaging secondary to oedema when the tear is entirely intramuscular. T1 imaging is rarely used, however it can be useful in demonstrating areas of low or high signal intensity if haemorrhage has occurred, which is age-dependent. Blood degeneration products are inevitably reabsorbed over a period of 6 to 8 weeks and fluid-fluid levels are often observed. Intermuscular haematomas do not form mass-like collections, however instead rapidly dissipate between muscle, fascia and fat before being quickly absorbed due to the large exposed surface area. In contrast, intramuscular haematomas are slower to resolve and may require intervention. They can also impair the healing process by acting as a chemical irritant to muscles leading to spasm, reflex inhibition of normal contraction and atrophy. Haematoma can also cause mass effect on the sciatic nerve, directly irritating it and leading to radiculopathy (Figure 1).

Figure 1: MRI demonstrates a hyperintense haematoma (star) surrounding the sciatic nerve (arrow).

Figure 2: Transverse plane ultrasound of the conjoint tendon demonstrating a heterogeneous mass with mixed hypo- and hyperechogenicity compatible with a haematoma in the acute trauma setting (callipers).

Haematoma

On US, haematomas are hypoechoic in the hyperacute setting prior to the coagulation of blood, hyperechoic when acute, gradually becoming hypoechoic with time. If persistent, they form anechoic seromas. Skeletal muscle haematomas have a variable appearance on MRI according to injury age, which differs from the predictable time course observed in the brain. This often results in difficulty accurately discriminating haematoma from muscle oedema when the tear is entirely intramuscular. T1 imaging is rarely used, however it can be useful in demonstrating areas of low or high signal intensity if haemorrhage has occurred, which is age-dependent. Blood degeneration products are inevitably reabsorbed over a period of 6 to 8 weeks and fluid-fluid levels are often observed. Intermuscular haematomas do not form mass-like collections, however instead rapidly dissipate between muscle, fascia and fat before being quickly absorbed due to the large exposed surface area. In contrast, intramuscular haematomas are slower to resolve and may require intervention. They can also impair the healing process by acting as a chemical irritant to muscles leading to spasm, reflex inhibition of normal contraction and atrophy. Haematoma can also cause mass effect on the sciatic nerve, directly irritating it and leading to radiculopathy (Figure 1).

Strains

Strains can range from microscopic foci of myofibrillar disruption beyond the resolution of imaging, to large areas of fibre separation with intramuscular haematoma, just short of an avulsion injury. Predicatably, strain injury occurs at the MTJ, which forms the weakest link in the muscle-tendon-bone unit in the skeletal mature athlete. The earliest manifestation of muscle injury follows unaccustomed exercise, known as delayed onset of muscle soreness, having a similar appearance to that of a minor muscle strain on MRI. Delayed onset of muscle soreness is characterised by pain on the days following exercise, whereas muscle strain pain results in the immediate cessation of activity.

Minor tears are notoriously difficult to diagnose on US as the small degree of oedema (which is dark or hypoechoic) is hard to distinguish from the normal dark grey muscle background. With increasing severity, the normal monotonous muscle structure is disrupted and interposed with fluid or blood, making the injury more obvious (Figure 2).

Strains on MRI appear as ill-defined regions of T2 hyperintensity on fat-saturated or short-tau inversion recovery sequences, representing haemorrhage or oedema, usually dissecting between the fibrils of isointense skeletal muscle near the MTJ and forming a feathered appearance (Figure 3). With increasing injury size the normal low signal intensity of muscle fibres become disrupted and disorganised resulting in a wavy pattern (Figure 4). If the tear is severe enough, free blood extravasates between and through fascial
layers into the subcutaneous tissue, where the pathognomonic bruising of muscle injury becomes visible. Bruising is typically inferior to the site of injury due to gravity.

Strains are typically graded from I to III. Grade I strains show T2 signal around a tendon or muscle without visible disruption of fibres. T2 hyperintense signal surrounding and within a tendon or muscle, with fibre disruption spanning less than half the tendon or muscle width is considered grade II. Grade III strains involve disruption of the muscle or tendon fibres over more than half the muscle or tendon width. Other classification systems classify grade III as full thickness ruptures, with grade II strains falling in between the minimal changes seen in a grade I strain and the dramatic changes seen with a grade III rupture.

Avulsion

Avulsion injury is classically proximal, with distal avulsion exceedingly uncommon. Ultrasound diagnosis is difficult in this setting, as firm compression is required to maximise visualisation of the hamstring origin, which may be troublesome in the presence of pain. The well-developed gluteal musculature in an athlete also often results in poor beam penetration necessitating additional probe pressure. Finally, distinguishing hyperechoic
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as well as increasing age, are strong predictors of re-injury, the former linked to a two- to six-fold increase in risk of a repeat strain\textsuperscript{1,40-42}. An increasing degree of muscle disruption manifests with an increase in the longitudinal extent of the tear and has been shown to be of prognostic value with larger tears more likely to lead to future injury\textsuperscript{7}. Repeat hamstring strains are typically larger, thought to be due to weakened and inadequately rehabilitated muscle undergoing further deleterious disruption\textsuperscript{41-43}.

MRI studies that fail to show any intramuscular signal abnormality in an athlete with acute posterior thigh pain are associated with a shorter period of convalescence and do not carry the same risk of re-rupture\textsuperscript{1,21,44,45}. In this group of patients it is debatable whether a hamstring injury has even occurred. Pain may be referred from the lumbar spine secondary to neuromeningeal tension, or it is possible that a hamstring injury has occurred on the microscopic level and thus beyond the resolution capabilities of current imaging\textsuperscript{1,21}.

Discriminating the type of muscle injury may be of prognostic value as patients with deep muscle tears remain out of competition longer than those with superficial tears. Other findings resulting in prolonged convalescence include fluid or haemorrhagic collections greater than 50 per cent of the muscle cross sectional area, or volume greater than 21 cubic cm\textsuperscript{1,46}. ACL reconstruction is associated with an increased risk of recurrent hamstring injury through altered gait biomechanics. It is hypothesised that increased forces and higher workloads are required of the hamstrings when the native ACL is absent. Furthermore, loss of joint proprioception and ACL-hamstring neural feedback/reflex lead to abnormal hamstring contraction during the gait cycle, predisposing to strain.

**CONCLUSION**

Despite most hamstring muscle injuries healing with conservative treatment, the high recurrence rate and often prolonged period out of competition has led to an increase in imaging of this region, particularly in the elite athlete. Both MRI and US have been shown to be effective in assessing the extent of injury, providing a useful guide to the clinician as to the anticipated period of convalescence.