London International Consensus and Delphi study on Hamstring Injuries

Part 1: Classification- Supplementary Material

Classification systems Review / Description

Current systems

There are multiple classification systems for HSI[1-6] but these differ significantly. These all link with anatomy and imaging findings but do not all comprise mechanism of injury or functional criteria. Early systems take into account examination findings as well as imaging, Some authors distinguish between classification (categorisation of injury) and grading (rating severity of injury).[7] These systems have evolved over many years and relate to systems to classify muscle injuries generally (not limited solely to HSI). More recent classifications refer to HSI only – with some authors arguing that ,similar to other organs or body tissues, muscle groups / or different muscles in different parts of the body should have different classification systems[8]. They are reported below in chronological order to discuss their evolution. The initial classification systems were put together for all muscles with system not specific to just hamstrings but have evolved to consider Hamstring specific systems.

Validation / reliability of the classifications systems

Many of the systems have not been tested for validity or reliability. Ideal validation of classification and grading systems would involve pathophysiological assessment of tissue and healing outcome. However, this is not possible and surrogate measures of tissue healing and recovery are typically used (clinical signs and symptoms, serum markers, and imaging). It is not always clear that clinical assessment or imaging findings solidly correlate with outcome and prognosis after HIS.[9] [10] Very few authors have made effort to prospectively investigate differences in prognosis for different grading levels in grading severity systems but the available studies pertaining to each section are reviewed below. Most authors use time to return to sport (TRTS) for prognosis outcomes, however, fewer authors use retear rates. Few authors however investigate performance measures in prognosis. Even when authors have used TRTS outcome to investigate classification – some classification systems have voluminous categories, and the low incidence rates for some of these categories, and the high variability in other categories make investigation difficult, and very large multicentre injury cohorts are required for properly powered studies. This may be an argument for making imaging categorisation simple with fewer categories. The high incidence of MRI negative injuries also causes problems for investigating the reliability of systems.[11] While these HSI generally have better prognosis, the imaging provides no extra utility beyond clinical examination findings.[10]

Early classification and Grading systems (BASED on clinical signs)

Early systems classified muscle injuries based on types of forces causing injury (Mechanism of injury (MOI)) or where they ruptured (i.e., anatomical location).[12-14] Mechanism of injury (MOI) classifications initially differentiated between direct or external forces ("contusion") and indirect or internal forces ("strain") in muscle injuries. They show some prognostic validity with some studies showing different time courses to recovery. Anatomical classification differentiated between rupture in the muscle belly, tendon or Muscle tendon Junction (MTJ).[13] Systems evolved to link MOI and location (especially with the advent of imaging technologies), with this approach are used also in later classification systems. For HSI , Askling et al used MOI to further sub categorise indirect injuries into stretching[15] (type 2) versus high speed running[16] (type 1), again, with evidence of a relationship between MOI, anatomical location and clinical prognosis (return to sport).[17-19]

Table 1 Classification systems- adapted from Hamilton et al[7]

Based On	Author	G0	G1	GII	GIII	GIV
Clinical Signs	**Odonoghue**		no appreciable tissue tear	Tissue Damge and reduced strength of the MTU	Complete tear of the MTU and conmplete loss of function	
	Ryan		tear of avery small number of fibres with Fascia remaining intact	tear of a higher number of fibres , fascia still remains intact	greater number of muscle fibres involved . The musclular fascia is at least partially torn	Complted tear of the muscle belly and fascia rupture
	Wise		min pain to palpation, localised	substantial TOP, poorly localised , 6-12mm change in circumf, developes 12-24hr <50% loss of ROM, pain on contraction, loss of power , disturbed gait	Intractable TOP, diffuse,develops in 1 hr, >50% loss ROM, severe pain on contraction, almost complete loss of power, unable to WB	
	Rachun		localised pain, min swelling, bruising, minor disability	local pain +TOP, moderate burising + disability, stretching tearing fibres without dysruption	Severe pain + swelling disability,severe hameatoma , loss of function, palpable defect	
Imaging	**Takebyashi**		no abnormalitiies or diffuse bleeding with or without local fibre rupture (less than 5% of the muscle involved)	focal fibure rupture - more than 5% of the msucle involved , with or without fascial injury	complete muscle rupture with retraction , fascial injury is present	
	Peetrons	lack of US lesion	minimal elongation with less than 5% of muscle involved - hypoechoic area	lesions involving from 5-50% of the musclevolume or cross sectional diameter	complete muscle tears with complete retraction	
	Lee		normal or focal/general areas of incteased echogenicity =/- peri fscial fluid	iscontinuity of muscle fibres in echogenic perimysial strae. Hypervascularity around distrupted muscle fibures . Intramusclar fluid collection, partial detachment of adjacent fascia or aponeurosis	complete myotendinous or tendo-osseous avulsion, complete discontinuity of muscle fibures and assoctiated haematoma . Bell clapper sign	
	Chan (ISmULT)		normal appearance . Focal or general increased echogenicity with no acrhitectural distortion	discontinous muscle fibures . Disruption site is hyper-vasculised and altered in echogenicity . No perimyseal striation adjacent to the MTJ	complete discontinuity of muscle fibers . Haematoma and retrction of the muscle ends	proxmial MTJ / muscle prox middle distal/ distal MTJ+ intramuscular - myotendionous
	Schneider-Kolsky		<10 degrees ROM deficit	10-25 degrees ROM deficit	>25% ROM deficit	
	Stoller		herintense edema +/- heamorrhage with perservation of the muscle morphology . Edema pattern = interstitial hyperintensity and feathery distribution on FSPD or T2FSE + STIR images hyperintense subcutaneous tissue edema + intermuscular fluid	hyperintense haemorrhage with tearing of upt to 50% of muscle fibures . Interstitioal hyperintensity with focal hyperintensity representing haemorrage in the muscle belly +/- intramuscular fluid . Hyperintense focal defect + patial retraction of muscle fibres . associated myotendinous + tendinous injuries . Hyperintenity a+ interruption +/- widening of muscle - tendon Unit	Compolete tearing +/- muscle retraction . Hyperintense fluid filled gap + hyperintense on FSPDFSE + STIR . Associated adjacent hyerintensee interstitial muscle changes	
Mixed	**Cohen**	point grading score - Age/ muscles/ location/ cross sectional area / retraction/ longitudinal axis T2 signal length				
	Munich	indirect	Functional muscle disorder (consider neuromeningeal) - negative imaging findings)			
			structural msucle injury : Grading on US/ MRI classification System			
		direct muscle injury				
	BAMIC	negative imaging findings	<10% cross sectional area	10-50% cross sectional areas - 5-15 cm	> 50% cross sectional area >15xm (tendon >5cm)	complete rupture
		myofascial tear (4 grades) incoorporating cradio-caudal length and cross sectional area for grading - Small / moderate/ extensive / complete				
		Muscle Tendon Junction tear (4 grades) incoorporating cradio-caudal length and cross sectional area for grading				
		Intra-tendinous tear (4 grades) incoorporating cradio-caudal length and cross sectional area for grading				
	Barcelona - (MLG-R) mechanism of injury / Location - muscle / Grade / previous injury	negative MRI but clinical suspicion	Hyperintense muscle fiber edema without intramuscular hemorrhage or architectural distortion (fiber architecture and pennation angle preserved). Edema pattern: interstitial hyperintensity with feathery distribution on FSPD or T2 FSE? STIR images	Hyperintense muscle fiber and/or peritendon edema with minor muscle fiber architectural distortion (fiber blurring and/or pennation angle distortion) ± minor intermuscular hemorrhage, but no quantifiable gap between fibers. Edema pattern, same as for grade 1	Any quantifiable gap between fibers in craniocaudal or axial planes. Hyperintense focal defect with partial retraction of muscle fibers ± intermuscular hemorrhage. The gap between fibers at the injury's maximal area in an axial plane of the affected muscle belly should be documented. The exact % CSA should be documented as a sub-index to the grade	
		mechanism of injury	direct / indirect / stretch or sprint			
		Location	Location of lesion - proxmial / middle / Distal			
		Extracellular matrix	When codifying an intra-tendon injury or an injury affecting the MTJ or intramuscular tendon showing disruption/retraction or loss of tension exist (gap), a superscript (r) should be added to the grade			
Surgical	**Wood**	Prox Hamstring attachment rupture based on		MTJ vs Tendon injury / avulsion - bony vs tendon/avulsion- partial vs complete/ retraction distance/ sciating nerve involvement		
	Lampainen			number of tendons involved (1-3) / level of athlete(demand)/ level of symptoms (pain + function)		

Assessment/ Grading of severity

Early classification systems attempted to grade injury severity using clinical symptoms and signs as a surrogate measure of the severity of the tissue damage – levels of pain and functional loss were thought to relate to the amount of muscle damage.[20] A quantitative approach attempted to quantify the amount of anatomical tissue damage to grade the severity of muscle injuries with a system similar to ligament grading systems.[21] O'Donoghue set out a classification system with grade from 1-3 related to tissue damage and amount of function loss.[21] The American Medical Association (AMA) sports medicine group published the first grading system for acute muscle injuries [22] with mild, moderate or severe (I-III) grades.

For athletes, coaches and rehabilitation specialists however, the severity of injury could be measured by the amount of time taken to return to full function (i.e. prognosis) and very few of these grading systems were measured against pathophysiology outcome, or prognosis[23], although there are some early reports.[24] This means that these systems may not be valid, despite their ongoing use. Ryan 1969 graded 1-4 based on the number of torn muscle fibres and adding tear of fascia in this grading system, with a grade 4 injury, a complete tear of the muscle and fascia.[25] These systems did not consider the exact location of the injury or involved tissue but were more concerned with the size of the injury.

Classification and Grading systems based on imaging

With the advent of Ultrasound and MRI – the exact location and extent could be determined; however, this was not always incorporated into grading and classification systems, and the grading continued to follow the above 1-3 grading system related to the amount of muscle damage. Takebayshi published a grading system using both ultrasound and MRI, with grading based on the percentage of fibres torn, with grade 1 at less than 5% of fibres torn, grade 2 presenting partial tear with >5% of fibres torn and grade 3 with a complete tear.[26]

Imaging may still not be able to prognosticate as well as simple clinical examination signs, and some authors recommend relying more on clinical signs rather than MRI in studies investigating return to sport times post HIS.[10 27] A more recent clinical signs paper outlined daily clinical subjective and objective measures in a cohort of 131 athletes recovering from HSI.[28] They found that the most useful variables to map progression included - length of pain on palpation, strength measured in the outer range position (as a per cent of the initial value for the uninjured leg), the Maximal Hip Flexion Active Knee Extension (MHFAKE) Test (expressed as a percentage of the uninjured leg at initial examination) for flexibility and assessment of pain during daily activities. However, they included only grade 1 and 2 injuries and excluded grade 3 or MRI negative injuries (grade 0)

Peetrons Classification system

Peetrons' classification is an ultrasound-based system using a grading of the muscle tissue on US.[3] Ratings were 0 with lack of any lesion on US to gr 1 less than 5% of muscle involved (cross sectional area 2-10mm). Grade II represent partial muscle tears with 5-50% of the cross-sectional diameter involved. A hypo or anechoic gap noted, and torn fibres are often noted floating in the haematoma (bell clapper sign), with MTJ or boundary tears most common. Grade III are complete tears with retraction, with a palpable gap and bunched muscle belly and identification of haematoma size and location assists diagnosis. This system was modified and applied to MRI for a prognostic validation study in 516 footballers with MRI and concurrent US. They found that 70% of injuries had no signs of fibre disruption on MRI (grade 0) and that Grade of injury did correlate with lay off times after injury. Other studies have been undertaken in Australian rules football[29 30] and other sports[16 23 31-34], with similar findings, although some studies do not find correlation with TRTS, showing less prognostic validity with this approach.[10 35] A further high quality study undertaking multivariate analysis in 74 athletes found no significant difference in TRTS between the grades 1 and 2 and recommended using clinical criteria for prognostication in these grades.[11]

Chan system

In previous systems the different components of the Musculotendinous Muscle tissue were not considered different in grading systems. Chan et al proposed an MRI and US based system, but with a difference based on not just the extent or size of the injury but on: -

1/ the site of the lesion – proximal, middle, or distal, and

2/ on the musculotendinous tissue involved – either the musculotendinous junction (MTJ) or the muscle tissue involved –intramuscular / myofascial / perifascial / myotendinous

This acknowledged differences in Musculotendinous tissue for healing rates and severity of injury and was based on imaging observations or studies considering differential injury risk between myofascial/ myotendinous tissues in muscle.

Munich Classification system

The Munich muscle injury classification system was established in 2013 on the back of a consensus process with UEFA and the IOC and took a generic approach considering all muscle injuries – without considering regional differences in muscle injuries.[1] The Type of injury was incorporated int the classification system including contusion from direct blow, and DOMS and fatigue induced muscle disorders. Sports medicine experts reviewing and grading both structural and functional muscle disorders, with negative imaging findings, and acknowledged spinal or neuromuscular control disorders. They incorporated sub grading (A or B) according to the cross-sectional area of fascicle bundles affected and recommended using the team “tear” rather than muscle “strain”.

British Athletics Muscle Injury Classification System (BAMIC)

Pollock et al, in the BAMIC system, adopted a similar approach used by Chan et al to include the involved anatomical tissue, as well as a grading system on size and extent of injury[2]. They split up the involved anatomical tissue more simply into (A- myofascial, B- Musculotendinous junction (MTJ), C- intratendinous) and included a numerical grading on the extent of the injury (grading from 0-4). They have also followed with a practical review paper applying this approach to rehabilitation of track and field athletes, demonstrating its utility to rehabilitation decision-making.[36] Due to its simplicity and ease of use this system has been widely used and adopted and subsequent study showed good intra and inter-rater reliability.[37]

Its prognostic validity has been investigated in a retrospective cohort of 44 track and field athletes with 65 HSI[38], assessing the time to return to full training (TRFT) and recurrence rate. They found that recurrence was higher in the C – intratendinous injuries and TRFT was less in grade 0 but higher in grade 3, however Grades 1 and 2 injuries did not differ in TRFT. There was also difficulty in discrimination or prognosis between myofascial and myotendinous injuries. Grade 0 also encompasses the functional muscle disorders of the Munich system with negative MRI findings but does not consider direct or contusion injuries to muscles as these are rare in Track and field.

Barcelona Classification system

Valle et al reported a new consensus classification system in 2017 using the current anatomical location and grading components to evaluate severity, but adding further components related to – mechanism of injury (MOI) (direct or indirect-stretch/sprint) and injury recurrence. The goal was to enhance communication but further rehabilitation and RTS decision-making. This evidence-informed and expert consensus-based classification system for muscle injuries is based on a four-letter initialism system: MLG-R, respectively referring to the mechanism of injury (M), location of injury (L), grading of severity (G), and number of muscle re-injuries (R). They considered ambiguity of terms – particularly related to nomenclature of muscle tissue (and used the term extracellular matrix (ECM). This classification system focusses on the amount and severity of the ECM damage as a correlation with severity and prognosis. They also focused on the Musculotendinous junction due to evidence of greater vulnerability with injury and worse prognosis. The found that the intramuscular tendons were also associate with worse prognosis. They also suggested that the functional / non- structural disorders suggested in the Munich Classification were not incorporated into this system as they were insufficiently understood.

Cohen classification system and MRI based Scoring systems

Cohen et al showed the utility of a combined classification or grading score, using six radiological (MRI) observations to comprise a single injury score. The variables they evaluated from MRI were: - Age, Number of muscles involved, Location, Insertion, Cross sectional percentage of muscle or tendon involvement, Retraction, Longitudinal axis T2 Signal length + final grading of fibre disruption from T2 signal intensity.

They also used a grading 1-3 on MRI.

Grade I: T2 hyper-intense signal about a tendon or muscle without visible disruption of fibres

Grade II: T2 hyper-intense signal around and within a tendon or muscle with fibre disruption spanning less than half the tendon or muscle width

Grade III: Disruption of muscle or tendon fibres over more than half the muscle or tendon width.

They evaluated the score with HSI in 43 AFL players, finding that a combined score of >10 corresponded to a worse prognosis (games missed) and found that the % muscle tendon involvement, the number of muscles and amount of retraction were significant predictors of time to return, but age and location did not show correlation. Another study, however, using 110 HSI in male soccer players to investigate this system, found that it did not provide a clinically useful prognosis for RTS, reflecting the challenges of attempting to accurately determine RTS duration from imaging performed at a single point in time.[39]

Surgical Classification for proximal Hamstring injuries

Surgery may be required in significant tears, although these tears may represent only a very small cohort of HSI – 1-5% in many studies ref. Classification systems however do not include components to determine whether surgery may be effective/ indicated. While many bony injury classification systems assist with orthopaedic surgical decision-making and planning[40], classification systems for muscles have historically not included surgery as part of their scoring systems. Some scoring systems discuss level of muscle retraction but other factors such as sciatic nerve involvement must be considered in surgical management.

Lempainan Classification

Lempainen gives a recommendation for a classification system for proximal hamstring rupture based on the number of anatomical tendons avulsed from the ischial tuberosity.[41] He gives recommendation on surgery based on the level of functional disability and based on the sporting demands of the patient. Elite athletes and high demand patients are suggested to consider surgical management even with single tendon partial avulsion if they are very symptomatic. In two tendon avulsion, even recreational athletes or sedentary patients should consider surgery if they are symptomatic. But with 3 tendon (complete) avulsions and with 2 tendon avulsions in athletes – surgical opinion should be sought early for the best chance of an optimal result with surgical repair.

Wood Classification system / SHORE score

Wood et al set out a classification system related to need for surgery and prognosis of repair – Six types are outlined based on the location of the tear and the amount of retraction and bony or sciatic nerve involvement.[42] Onto the above Lampainen classification, he adds components related to the degree of retraction, bony and sciatic nerve involvement.

There has not been reliability work on this system, but he published prognostic information in a surgical cohort study with a cohort of 72 surgeries, giving incidences and outcomes for the subtypes above. Reliability and validity are not assessed but some prognostic information is given for strength and return to sport for the athletes undergoing surgery. This was also used to evaluate and validate a patient reported outcome Score (prom) – The SHORE score.[43]

The surgical case series do not report on lower grade injuries and necessarily focus on a smaller cohort with more extreme HSI, which show extremely low incidence in other HSI cohorts – i.e., the grade 3-4 injuries, which represent a smaller cohort of the whole HSI population. There are very few systems to grade severity in terms of requirement for surgery and robust classification and grading systems are needed for this smaller but more severely injured cohort. Several recently validated PROMs may help with this[43 44], however these scores relate to proximal hamstring ruptures and there are other types of hamstring injury that where surgery may be indicated, Including intramuscular tendon or distal avulsion injuries.

Classification for high GRADE INTRAMUSCULAR tendon or MTJ injuries

There are no available classification systems for intramuscular injuries that may require surgery, and systems that can classify and prognosticate to aid surgical or conservative treatment decision-making are needed. Injuries such as Biceps T junction[45], proximal Biceps MTJ[46] , conjoint (intramuscular) tendon[47] or semimembranosus injuries[48], are consequential.

While they may be classified in similar manner with the current classification systems – their prognosis and treatment, both conservatively and surgically can differ significantly.

Imaging modalities in Hamstring Diagnosis

Ultrasound

Initial imaging available- convenient – pitch side, cheap but operator dependant, and allows real time scanning and movement and contraction during scan as well as intervention such as platelet rich plasma (PRP). A linear probe is recommended, using both longitudinal and transverse direction and using probe to palpate to determine location of maximum tenderness. Frequencies of 7.5-13 MHz with higher frequency give better resolution, lower frequency gives better penetration. The information yielded includes fluid collection, with areas of echogenicity – oedema or haemorrhage and pennation angles. The recommended timing of imaging – recommendation is 2-48 hrs to ensure haematoma has sufficient time to form. But some muscles may still show haematoma 2-3 days post.

The role of Ultrasound

In the acute phase US can be used to determine: - the location and extent of injury, the measurement of separation between the images, the stage of healing and the magnitude of scar formation (scar hyperechoic zones) which can increase risk of retear but US may not be useful to determine safety for loading, and it relies on the experience of an operator. It may miss lower-level injury – and it is less effective for prognostication on TRTS.

MRI

MRI is more expensive, more time consuming and less convenient but due to the resolution and visualisation of all the musculoskeletal tissue has become the investigation of choice. It also yields multiple pathologies – ideally whole kinetic chain – pelvis and spine may reveal pathology, although this may be incidental. MRI is less operator dependant and may be performed on either a 1.5 or 3 T system, ideally at 24–48 h following injury. Skin markers should be placed at the site of maximum pain prior to imaging. The MRI study should include a combination of acquisitions in three planes. The closest muscle insertion to the injury site should be included and possibly the whole thigh to ensure an optimal study. Sequences include axial, coronal and sagittal short tau inversion recovery (STIR)/T2-weighted fat suppressed/proton density-weighted fat suppressed sequences followed by axial and sagittal T1-weighted. Coronal and sagittal sequences assess the longitudinal extent of the injury and tendon involvement, and the axial images give cross-sectional area of oedema. The slice thickness of imaging acquisition should allow accurate definition of small injuries often necessitating a slice thickness of 4 mm or less.

Role of MRI

MRI can be helpful for Initial diagnosis with features shown, including oedema on hyperintense T2 lesion on the axial fat suppressed views and loss of tendon continuity. This will give the extent and severity of injury. MRI can be used to investigating healing [23 49 50],as well as give prognosis. Some authors have investigated MRI findings associated with TRTS.[30 34 50-52] Some features of MRI examination may be more pertinent for prediction. Gibbs et al investigated grade 1 HSI vs those with negative MRI findings – they found that the length of the hyperintense T2 lesion on the axial fat suppressed views on MRI had a greater correlation with TRTS than the cross-sectional area. They also found the recurrence rate higher in the positive MRI group. The most pertinent features were synthesised into a system by Cohen et al discussed above.[53] Other authors, however, suggest that MRI has less value in predicting RTS[10], and that features of examination are more pertinent. Some authors have investigated the prognostic value of MRI to predict recurrence.[54 55] The most recent review in 2017 suggested no strong evidence for any MRI finding in predicting hamstring re-injury risk. This is corroborated in a recent study showing that complete MRI resolution of a HSI is not required for successful RTS.[56] Intratendinous injuries and biceps femoris injuries showed moderate evidence for association with a higher re-injury risk. MRI has also been used to assess muscle response to exercise [57-59] and to evaluate nerve involvement in HSI.[60]

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