# London International Consensus and Delphi study on hamstring injuries part 1: classification

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## ABSTRACT

Muscle injury classification systems for hamstring injuries have evolved to use anatomy and imaging information to aid management and prognosis. However, classification systems lack reliability and validity data and are not specific to individual hamstring muscles, potentially missing parameters vital for sport-specific and activity-specific decision making. A narrative evidence review was conducted followed by a modified Delphi study to build an international consensus on best-practice decision-making for the classification of hamstring injuries. This comprised a digital information gathering survey to a cohort of 46 international hamstring experts (sports medicine physicians, physiotherapists, surgeons, trainers and sports scientists) who were also invited to a face-to-face consensus group meeting in London . Fifteen of these expert clinicians attended to synthesise and refine statements around the management of hamstring injury. A second digital survey was sent to a wider group of 112 international experts. Acceptance was set at 70% agreement. Rounds 1 and 2 survey response rates were 35/46 (76%) and 99/112 (88.4%) of experts responding. Most commonly, experts used the British Athletics Muscle Injury Classification (BAMIC) (58%), Munich (12%) and Barcelona (6%) classification systems for hamstring injury. Issues identified to advance imaging classifications systems include: detailing individual hamstring muscles, establishing optimal use of imaging in diagnosis and classification, and testing the validity and reliability of classification systems. The most used hamstring injury classification system is the BAMIC. This consensus panel recommends hamstring injury classification systems evolve to integrate imaging and clinical parameters around: individual muscles, injury mechanism, sporting demand, functional criteria and patient-reported outcome measures. More research is needed on surgical referral and effectiveness criteria, and validity and reliability of classification systems to guide management.

## BACKGROUND

Hamstring injuries (HSIs) continue to cause significant time lost from high intensity running sports, despite an exponential growth in research on HSI prevention and management. The role of HSI classification and how this might guide management is of interest but currently unclear. The main purpose of HSI classification systems is to categorise and grade the severity of an injury,[1] to aid communication and enhance clinical decision making. We present an evidence review to outline our current understanding of HSI classification systems and identify knowledge gaps, followed by an international expert Delphi study to advance the classification of HSI.

## Muscle injury classification systems

There are multiple, differing muscle injury classification systems.[2–7] Anatomy is key to most systems[3 5 7 8] and most use some form of imaging (particularly MRI and ultrasound (US)).[4–6 9] There is a high incidence of MRI negative HSI, from 17% to 31%,[9–12] and many systems incorporate a grade 0 for HSI with negative imaging.[2–4 6 13] Some classifications use components of subjective and objective examination or function,[11 14–16] which may associate with time to return to sport (TRTS) following HSI.[11 17 18] Several reviews on classification systems in muscle injury are available.[1 19–24] None of these systems are specific to individual hamstring muscles but the specific muscles have anatomical and functional differences that are relevant in management.[25] While early classification systems for muscle injuries traditionally followed a severity of injury approach (ie, grading system),[2 14 15 26 27] they have evolved to also consider the anatomical tissue involved (ie, fascia/muscle vs tendon and connective tissue),[3 13] and the mechanism of injury[2 13] (table 1).

## Limitations of current muscle classification systems

These classification evolutions have assisted clinicians in planning management and prognostication. Different anatomical tissues have different healing time frames and load capacity, resulting in differences in optimal rehabilitation prescription, progression, readiness to return to sport (RTS),[28] and risk of reinjury.[29] Current muscle injury classification systems are generic and do not differentiate between muscles, even though muscles have different anatomy and architecture. Intramuscular connective tissue and myotendinous junction (MTJ) architecture, for example, differ considerably between hamstring muscles and within individuals.[30 31] The individual hamstring muscles have different roles,[32] even within components of a single movement.[33] Clinicians should consider these factors when prescribing rehabilitation as the management of an injury with the same classification, within a

**Table 1** Classification systems—abbreviated from online supplemental material

| Based on | Author | G0 | G1 | GII | GIII | GIV |
|---|---|---|---|---|---|---|
| Clinical Signs | Odonoghue | | No appreciable tissue tear | Tissue damage and reduced strength of the muscle tendon unit | Complete tear of the muscle tendon unit and complete loss of function | |
| | Ryan | | Tear of a very small number of fibres with Fascia remaining intact | Tear of a higher no of fibres, fascia still remains intact | Greater number of muscle fibres involved. The muscular fascia is at least partially torn | Completed tear of the muscle belly and fascia rupture |
| | Wise | | Min pain to palpation, localised | Substantial TOP, poorly localised, 6–12 mm change in circumference, develops 12–24 hours <50% loss of ROM, pain on contraction, loss of power, disturbed gait | Intractable TOP, diffuse, develops in 1 hour, >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 bruising+disability, stretching tearing fibres without disruption | Severe pain+swelling disability, severe haematoma, loss of function, palpable defect | |
| Imaging | Takebyashi | | No abnormalities or diffuse bleeding with or without local fibre rupture (less than 5% of the muscle involved) | Focal fibre rupture—more than 5% of the muscle 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% to 50% of the muscle volume or cross-sectional diameter | Complete muscle tears with complete retraction | |
| | Lee | | Normal or focal/general areas of increased echogenicity—perifascial fluid | Discontinuity of muscle fibres in echogenic perimysal strae. Hypervascularity around disrupted muscle fibres. Intramuscular fluid collection, partial detachment of adjacent fascia or aponeurosis | Complete myotendinous or tendon-osseous avulsion, complete discontinuity of muscle fibres and associated haematoma. Bell clapper sign | |
| | Chan (ISmULT) | | Normal appearance. Focal or general increased echogenicity with no architectural distortion | Discontinuous muscle fibres. Disruption site is hyper-vasculised and altered in echogenicity. No perimysal striation adjacent to the MTJ | Complete discontinuity of muscle fibres. Haematoma and retraction of the muscle ends | Proximal MTJ/ muscle proximal/ middle distal/ distal MTJ+intramuscular - myotendionous |
| | Schneider- Kolsky | | <10° ROM deficit | 10°–25° ROM deficit | >25% ROM deficit | |
| | Stoller | | Hyperintense oedema+/- haemorrhage with preservation of the muscle morphology. Oedema pattern=interstitial hyperintensity and feathery distribution on FSPD or T2FSE+STIR images hyperintense subcutaneous tissue oedema+intermuscular fluid | Hyperintense haemorrhage with tearing of up to 50% of muscle fibres. Interstitial hyperintensity with focal hyperintensity representing haemorrhage in the muscle belly+/-intramuscular fluid. Hyperintense focal defect+partial retraction of muscle fibres. associated myotendinous+tendinous injuries. Hyperintensity+interruption +/- widening of muscle - tendon Unit | Complete tearing+/-muscle retraction. Hyperintense fluid filled gap+hyperintense on FSPDFSE+STIR. Associated adjacent hyperintense 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 muscle 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 >15 xm (tendon >5 cm) | Complete rupture |
| | | A -Myofascial tear (4 grades) incorporating cranio-caudal length and cross-sectional area for grading—small/moderate/extensive/complete | | | | |
| | | B - Muscle Tendon Junction tear (4 grades) incorporating cranio-caudal length and cross-sectional area for grading | | | | |
| | | C -Intra-tendinous tear (3–4 grades) incorporating cranio-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 fibre oedema without intramuscular haemorrhage or architectural distortion (fibre architecture and pennation angle preserved). Oedema pattern: interstitial hyperintensity with feathery distribution on FSPD or T2 FSE? STIR images | Hyperintense muscle fibre and/or peritendon oedema with minor muscle fibre architectural distortion (fibre blurring and/or pennation angle distortion) ± minor intermuscular haemorrhage, but no quantifiable gap between fibres. Oedema pattern, same as for grade 1 | Any quantifiable gap between fibres in craniocaudal or axial planes. Hyperintense focal defect with partial retraction of muscle fibres±intermuscular haemorrhage. The gap between fibres 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 subindex to the grade | |
| | | Mechanism of injury | Direct/indirect/stretch or sprint | | | |
| | | Location | Location of lesion—proximal/middle/Distal | | | |
| | | Extracellular matrix | When codifying an intratendon 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 | Proximal hamstring attachment rupture based on | | MTJ versus Tendon injury/avulsion—bony versus tendon/avulsion—partial versus complete/ retraction distance/ sciatic nerve involvement | | |
| | Lampainen | | | No of tendons involved (1–3)/level of athlete(demand)/level of symptoms (pain+function) | | |

BAMIC, British Athletics Muscle Injury Classification; CSA, cross-sectional area; FSE, fast spin echo; FSPD, fat-suppressed proton density; MTJ, musculotendinous junction; ROM, range of motion; STIR, short tau inversion recovery; TOP, tender on palpation; US, ultrasound.

different hamstring muscle, may require individualised management to optimise outcome. Anatomical architectural considerations, including loss of tension, anatomical displacement and sciatic nerve involvement may also be important in surgical decision making. HSI classification systems may benefit from considering muscle-specific differences in anatomy, function or injury pattern when assessing validity, outcomes and in the further evolution of classification systems.[19 22]

## Reliability and validity of classification systems

Many classification systems do not have validity or reliability evaluation, often because it is difficult to assess pathophysiology and healing outcomes at a tissue level. Surrogate measures of healing and recovery are typically used. Clinical assessment and/or imaging findings correlating with HSI severity, prognosis and outcomes are most pragmatically useful and are often used to validate systems.[17 34] Most use TRTS,[35] but time to return to full training (TRFT),[10] reinjury rates[29] and performance metrics[36] have also been studied. The complete resolution of HSI signs on imaging is unlikely to be necessary for successful RTS.[37] There is a high incidence of MRI negative injuries[9–12] but this may not impact reliability or validity of classification systems as many systems incorporate a grade 0 and these HSI generally have a better prognosis.[10 38] Online supplemental material 2 describes current HSI classification systems and available validity reliability data)

The British Athletics Muscle Injury Classification (BAMIC) group have investigated the prognostic validity of their system,[28] and they, and others, have also demonstrated good intra and inter-rater reliability of the BAMIC system.[12 39] In a study of 44 track and field athletes with 65 HSI,[29] they observed that increased TRFT and injury recurrence was associated with injuries that involved hamstring tendon tissue (‘c’ classification). TRFT was also significantly associated with grading severity (less in grade 0 (10±4.7 days) but higher in grade 3c (84±49.4 days)). In that study there was no significant difference in TRFT between myofascial (A) and myotendinous (B) injuries or between grade 1 and grade 2 injuries. The study did not include direct or contusion muscle injuries, described in the Munich system, as these are rare in track and field. The BAMIC group have also outlined a rehabilitation approach, informed by the athlete’s BAMIC classification[28] and completed a further 4-year follow-up study after implementation of this rehabilitation approach.[10] This did note a significant difference in TRFT between grade 1 and grade 2 HSI classified by BAMIC and again a significant difference in TRTS for injuries that involved the tendon (‘c’ classification). The reinjury rates in this 4-year study were very low at 2.9% overall and 0% in the ‘c’ classification.

Wangensteen *et al* compared the level of agreement between BAMIC, Chan, and modified Peetrons classifications using a mixed sport cohort comprising 176 HSI with MRI images,[12] reporting ‘substantial’ to ‘almost perfect’ intrarater and inter-rater reliability when scored by experienced radiologists. For BAMIC, there was an association between TRTS for grades 0 and 2 and 1 and 3. For HSI location, there was no association in TRTS between types a and b and a and c, but there was between b and c. The Chan system demonstrated no associations between anatomical site related to proximity, but differences were found on anatomical site within the muscle (2a–e). The Chan authors reported difficulties with association due to the low frequency of injury in many of the categories (3a, 4b and 4c categorised just 1, 2, 2 injuries, respectively). Many categories had large individual TRTS, which means an individual with a HSI 3c injury would have a 95% chance of returning to sport anywhere between 3.9 and 57.5 days. In this study, for MRI positive injuries (87% of this cohort), the grading systems and the BAMIC anatomical site accounted for only 7.6%–11.9% of total variance in TRTS.

These studies suggest that anatomical site and severity grading are likely to be helpful, but not fully sufficient to explain TRTS. There is likely to be a role for clinical findings and reasoning and other individual athlete and sporting factors alongside classification systems to enhance prognostication. Considering all of these contributors is the role of the expert clinician in sport.

Some authors suggest difficulty in grouping all three hamstring muscles together when classifying these injuries and suggest that each muscle should be classified separately, to consider differences in connective tissue, fascia, and tendon architecture that produce different injury types, healing rates and prognoses.[19 20 22] The BAMIC classification paper comments that the specific injured hamstring muscle should be named with the associated classification, but outcome papers are challenging with this approach due to small numbers in the subsequent classification groups. Differences in rates of healing or prognosis between hamstring muscles, or locations such as the T junction injury, are not consistent and subclassification may not be required,[10] although these studies contain small numbers. Many systems make no differentiation between tendon injuries in the proximal, distal or intramuscular tendons, which may have different healing rates and reinjury risk, requiring modifications to rehabilitation and possible surgical consideration.[40–42] Most authors have found differences in rehabilitation outcomes or reinjury risk with intratendon injuries,[43] but not all.[35] Further discrimination of class c injuries to include the distance of retraction and categorisation between the intramuscular tendon and free tendon may be helpful with respect to surgical decision making.[44]

Classifications that use a scoring system (examination, history and imaging findings carrying different weight) produce a combined score, such as that of Cohen *et al*,[6] who observed that a combined score of >10 corresponded to a worse prognosis (games missed) and demonstrated that the percentage of muscle tendon involvement, the number of muscles, and the amount of retraction were significant predictors of TRTS, but age and location were not. Conversely, Hamilton *et al* observed that this combined score did not provide a clinically useful prognosis for RTS, reflecting the challenges of attempting to accurately determine RTS duration.[45] This is due to rarity of severe injuries and therefore studies contain insufficient numbers of these injuries to validate classification.

## Classification systems for surgical decision making

Surgery may be required for some HSI, although these tears only probably represent 0%–5% of HSI in certain athlete groups. While many bony injury classification systems assist with rehabilitation and orthopaedic surgical decision making,[46] classification systems for muscles, have historically not included surgical considerations as part of their system, due to the lack of evidence to inform surgical indications.[44] Two classification systems have attempted to describe different types of proximal hamstring tendon injuries and consideration of surgical repair. Wood *et al* described five types of injury, detailing amount of displacement, sciatic nerve involvement and location.[8] Lempainen *et al* have attempted to separate each tendon proximally to allow surgical consideration even in partial injuries such as semimembranosus.[47] Treating these proximal free tendon injuries non operatively can cause significant morbidity and failure to RTS.[48]

Unfortunately, there are no reliability data for these surgical systems. Prognostic information using a cohort of 72 operations provides incidence and outcomes for the subtypes in the Wood System.[8 44] Several recently validated patient-reported outcome measures (PROMs) may help,[49 50] although these scores relate to proximal hamstring ruptures, and there may other types of HSI where surgery may be indicated. As knowledge advances on key indications for surgery, HSI classification systems should evolve to optimise decision making around the role of surgery.

### Classification for high-grade intramuscular tendon or MTJ injuries

There are some intramuscular HSI for which surgical intervention has been considered. These include injuries at the 'T junction' of the biceps long head, proximal biceps MTJ, conjoint intramuscular tendon and semimembranosus separation injuries.[51–53] Injuries at these sites are classified within the constructs of existing classification systems rather than as defined entities. Further work is required to clarify clinical outcomes and surgical indications for injuries at these sites and to establish whether existing classification systems should be adapted to incorporate further understanding of these injuries and to assist with decision making.

### Summary

There are a number of classification systems available for use by clinicians, but no single system allows optimal treatment planning or prognostication. Current classification systems are nonspecific for the individual hamstring muscle injured, despite each muscle having different anatomy, innervation, functional roles and injury patterns.[54] Apart from direct contusion injuries, the mechanism of injury has been largely overlooked in classification systems, but different mechanisms of injury may cause specific injuries such as slow stretch versus high intensity running HSI.[55–57] Pattern recognition, however, is complex as a single mechanism of injury (eg, high speed running) may cause multiple different types of HSI.[10]

Management of HSI must consider the demands of the particular sport, such as the differences in injury patterns for sprint versus pivot type sports, or those with and without physical contact. Elite level sports require a higher performance demand and often aim to reduce TRTS. The management decisions in elite sport may be different depending on sporting demand, time of season, patient goals and many other contextual factors.[58] Different sporting levels are currently not considered in classification systems.

Clinicians managing high-grade injuries may benefit from classification systems that aid rehabilitation or surgical decision making. Furthermore, while some classifications consider proximal HSI avulsions, further evidence is required regarding the optimal management of intramuscular tendon injuries that may help inform rehabilitation guidelines and surgical indications. Finally, the testing of reliability and validity of HSI classification is a priority. No current classifications are able to predict TRTS or the risk of reinjury.

In view of these classification gaps and lack of robust evidence, we undertook a consensus process, including an international Delphi Study, seeking expert opinion to enhance decision making in the classification of HSI in order to inform clinical management for athletes presenting with HSI.

Due to the limitations of small athlete numbers in studies that evaluate muscle injury classifications, and the vital importance of clinical expertise, a consensus with international Delphi process was conducted to aid progress in this area of significant interest.

### Aims

1. To determine the current global practice of classifying HSI.
2. To determine the key aspects of decision making in the classification of HSI.
3. To provide best practice for decision making in the classification of HSI.

## METHODS

### Study design

A modified Delphi study design was used, including an international panel of experts, with the aim of reaching a consensus on best practice for classification after HSI. In the situation where clinicians must make assessment and treatment decisions based on incomplete, weak and poor-quality evidence, clinical expertise and experience become vital. A research approach to gain insight from practitioners' expertise is useful. Single experts can be useful but a scientific approach that aims for a consensus/agreement among a group of experts can provide more optimal recommendations.[59] The London 2020 international hamstring consensus group was established as a multidisciplinary collaboration to advance the assessment and management of HSI. The Delphi methodology was thought to present a systematic and scientific approach to capture the decision-making experience and expertise of global experts to identify and investigate areas in HSI where new decision making approaches could be developed. There have been previous Delphi consensus studies in muscle injuries,[2 60] injury prevention[61] and aspects of management of HSI, such as return to play[62 63] but other aspects of hamstring assessment and treatment may also benefit from this approach such as classification systems, decision making in rehabilitation and the justification for surgery, particularly given the disparate and conflicting approaches used currently.[22 64]

The description of our modified Delphi methods is described below, following guidance on Delphi studies[65 66] and web survey design,[67] but can also be found in online supplemental file 1.

### Participants: expert panel

Identifying appropriate experts is vital to the Delphi process[68] and an international, representative, multidisciplinary group of expert clinicians and researchers were invited to participate in this study, based on their expertise in the assessment and management of HSI. A purposive, heterogeneous representative sample of experts was chosen to ensure a mix of—professional discipline (sport and exercise medicine physicians, physiotherapists, surgeons, sport and exercise scientists/researchers, strength and conditioning specialists and athletic trainers), international experience, sex and sporting discipline in line with Delphi methodology.[69]

The criteria for expert inclusion were— a high level of expertise assessing, managing and/or researching HSI, based on—the number of injuries seen; years worked managing HSI; peer-reviewed publication (authorship) in hamstring research; willingness to complete the digital survey and or attend the consensus meeting and sufficient level of written and spoken English.

Possible experts were excluded if they had (1) insufficient experience of assessment or management of HSI, (2) insufficient time to fully complete the online survey. Clinicians and non-clinicians were included but asked to answer only those survey questions related to their fields of expertise. (see methodology supplement). Domains of surgery, postsurgical recovery and rehabilitation were also identified and experts were chosen, with sufficient expertise in these combined areas as well as classification.

Coaches and trainers comprised 6% of the experts for the final survey. Athletes were not included; however, we would acknowledge their voices as vital. Many of our experts have also been athletes and 38% of the final survey expert respondents reported a personal history of HSI.

There is no guideline for number of experts to be involved in a consensus,[69] but the sample size was set at 30 for the initial survey to ensure a full international and multidisciplinary sport/profession mix. A possible drop-out and non-response rate was predicted. The study aimed to follow research recommendations with opinion-based research questions.[65 70]

## Modified Delphi process

The study comprised two rounds of a purposive digital survey interspersed with a face-to-face meeting round. Each round was modified, based on feedback, to achieve a consensus among the international panel of experts. Each Delphi round comprised a digital questionnaire, an analysis, and a feedback report. The study was undertaken after a review of decision-making aspects of the assessment and management of HSI. The literature was searched, the evidence discussed and the author team led a review of the evidence presented as a narrative summary to inform the consensus rationale and knowledge gaps (see online supplemental file 2).

Round 1 involved a digital survey, with open-ended questions to a global group of clinicians and researchers with expertise in HSI. The round 1 survey (see online supplemental appendix 1) aimed to gather information, and understand, from the experts' viewpoint, where are the gaps in the literature evidence and clinical practice in HSI decision making. The initial round 1 survey comprised open-ended qualitative information gathering questions and some quantitative data questions using Likert scales to determine level of agreement. The survey used a digital institution-based software package—Opinio V.7.12 (copyright 1998–2020 ObjectPlanet, Oslo Norway). The surveys in this study followed the Checklist for Reporting Results of Internet E-Surveys[67] and the reporting standard for conducting and reporting Delphi studies[66] to avoid bias.

The responses from the initial survey were collated and analysed with a thematic and factor analysis[71] (see online supplemental table 1). The expert panel identified four key domains classification and diagnosis, surgery, rehabilitation and return to running (RTR) and sport) (and key questions for these domains (see tables in online supplemental appendix 3). This paper deals with results of classification and diagnosis, with subsequent papers covering surgery and rehabilitation. The questions on diagnosis and classification were outlined and presented for discussion. All the panel members who completed the survey were invited to the discussion meeting. The discussion took place via a group consensus 2-day meeting, alongside an international conference, to allow as many of the participants to join as possible. A nominal group consensus model was followed with a facilitated, structured approach to gather qualitative information, from this group.[72] This approach has been followed in other consensus projects.[73 74] In discussions, facilitators maintained impartiality and ensured balanced discussion to avoid 'eminence bias'.[65] They aimed to work towards agreement but not force consensus. Dissenting and outlier views were considered important, representing differences in practice. This approach aimed to avoid 'herding bias'.[75 76]

After discussions, the key consensus statements were synthesised and refined. These sessions were chaired by each steering committee author related to their area of specialisation—classification (JM), Rehabilitation (BMP), RTR/RTS (MG) and surgery (FH). Statements were gradually refined through a process of facilitated debate until the entire panel were satisfied and on day 2 were put to the group for anonymous electronic voting. See online supplemental appendix 4 for the list of statements—rehabilitation, RTS/RTR, classification and surgery.

The consensus steering committee (established an a priori criterion threshold of 70%, with ≥70% agreed/yes responses constituting statement acceptance. 70% has been used successfully by other Delphi studies.[77–79] Eighteen statements on the diagnosis and classification of HSI reached sufficient group agreement.

The final Delphi round involved a further online survey was developed, to test these statements with this survey to a wider global international group of experts who met the previous inclusion/exclusion criteria. The participants voted on the statements with yes, no, uncertain ('forced choice') responses. This made the final survey shorter and less onerous for participants, but some further Likert or factor ranking questions determined level of agreement. (See examples within methodology supplement).

These experts voted on statements and ranked their key decision-making factors or justifications related to the domain areas found in the round 1 survey.

## Expert panel for final round

The final survey with voting on the consensus statements, was split into domain sections—classification, surgery, rehabilitation, RTR/RTS. Participants were asked to complete only the domains (sections of the survey) that were within their field and scope of expertise. The survey responses were evaluated for completeness. Survey responses in each domain were evaluated by two steering group members and any incomplete responses from non-experts in that particular domain were removed from the analysis. Within their expertise areas, panel members were asked to complete sections as carefully as possible and provided with response options such as 'uncertain'. Open-ended boxes after each consensus statement also allowed them to comment, and comments and areas of disagreement were collated and analysed.

## Steering committee

The surveys were designed by two experienced clinical academic physiotherapists, and a professor of orthopaedic surgery, who each have greater than 20 years clinical experience treating HSI and research expertise in HSI, as well as previous experience with Delphi research. A structured, iterative process was undertaken to develop the survey and it was piloted by a mixed group of five sports medicine physicians, five physiotherapists and five orthopaedic surgeons, and the survey was further refined based on their feedback. The expert panel were approached by email located from publicly available correspondence information on peer reviewed journal articles. Information was provided prior to participation but actively completing the survey was implied (and stated) as the consent to participate. Any participant who withdrew had data removed.

## RESULTS

### Respondents

The volume of responses made reporting in one single paper difficult. For this reason, three papers are presented with

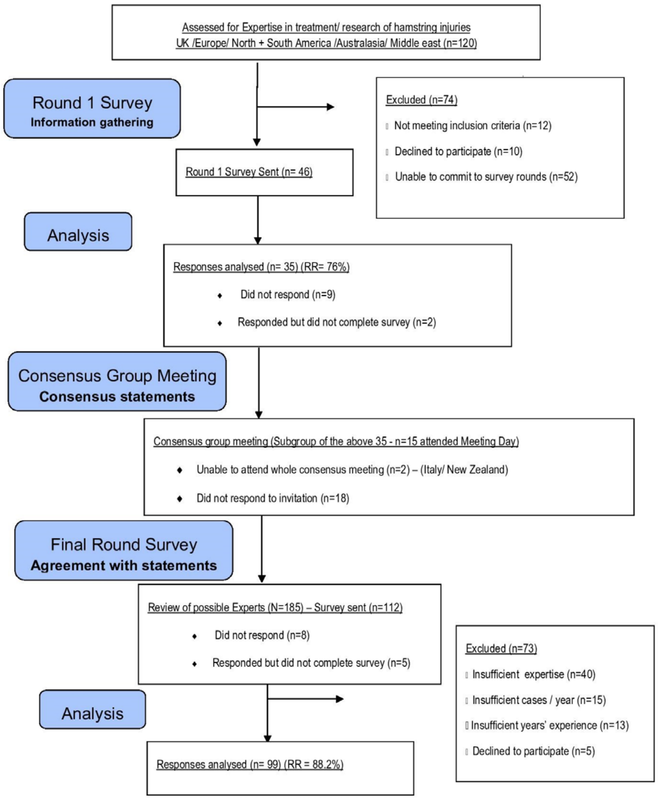

**Figure 1** Flow diagram of expert participants and response rates (RR).

decision-making domain areas of—classification, surgery and rehabilitation and RTS.

The response rates and the inclusion and exclusions for each survey round are given in the flow chart in figure 1. The compositions and characteristics of the expert panel for each round survey and the face-to-face meeting are reported below in table 2.

### Preferred HSI classification system

Table 3 presents the participants preferred HSI classification system. For both surveys 1 and 2, BAMIC, Munich and Barcelona ranks 1, 2 and 3, respectively.

In the initial survey, we asked participants what questions need answering in HSI classification. The initial survey results are presented in tables 4–6. Top three questions are: (1) are there different clinical presentations for fascial/muscular/Iintramuscular tendon and free tendon injuries, (2) which HSI classification system most effectively guides management and (3) does the classification of injury relate to recovery time (return to performance)?

When considering the key factors that influence clinician's decisions for requesting imaging, the top three answers were (1) loss of range of motion and/or strength and/or tension and/or integrity on examination, (2) symptoms and (3) injury mechanism. Tables 5 and 6 (initial survey) deal with the key factors in referral for imaging and key examination considerations for diagnosis.

Table 7 reports the consensus statements from our meeting days and reports the results of round 2 digital survey from the 99 respondents. The levels of agreement for each of these statements is reported and those that achieved more than 70% are highlighted.

## DISCUSSION

This paper presents the results of a modified Delphi study and consensus in the decision making of classification of HSI. The final Delphi round comprised a digital survey determining the level of agreement (LOA) from global HSI experts on the consensus statements from the London 2020 international Hamstring consensus group meeting.

### Areas of agreement/disagreement

We observed that clinicians use multiple sources of information in their decision making to inform diagnosis, classification, management and prognosis of HSI. Both imaging and clinical examination findings were considered essential and informed each other when making decisions on treatment of HSI

### Justification for imaging

- ► Imaging is vital in the classification system (LOA 70.5%).
- ► Anatomical (radiological) classification is essential in the diagnostic process (LOA 62.0%).

Imaging was deemed vital for classification; however, the survey respondents did not agree that imaging was vital for diagnosis. Survey respondents and our consensus meeting panel noted that a proportion of HSI present without positive imaging findings, and the failure of MRI to accurately predict TRTS.[17 80] Clinicians expressed that they prioritised loss of range of motion (ROM)/loss of tension and symptom levels to decide on imaging, with some external factors considered important such as the type or level of sport and cost or patient expectations.[81]

While these findings are similar to the literature on the justification of imaging in HSI, there are few specific MRI or US guidelines for HSI.[82–85] These are often incorporated into general guidelines for musculoskeletal imaging.[83 86] The low range of clinical justifications may leave out some significant imaging justifications—and knowing examination features that trigger early investigation may save time and enable an athlete to receive appropriate and targeted rehabilitation.[56 87 88] Although minor and low grade HSI may not require imaging,[11] intramuscular tendon injuries cannot be easily diagnosed solely with clinical examination features[89] and if this is an important potential diagnosis for that athlete, imaging should be obtained. In the second-round survey, (table 7) respondents commented that imaging and anatomy were important, but their votes showed lower levels of agreement for imaging being essential for classification (70.3%) but not for diagnosis (56.6%) and stronger agreement on preference for clinical examination, functional markers and history findings to be considered.

### Clinical features

- ► Immediate physical examination signs including bruising, loss of muscle tension, palpable defects and/or significant weakness and excessive/no response on provoking activities warrant further investigation (LOA 92.6%).

In the area of clinical investigation to aid diagnosis or assessment of severity, our consensus panel and survey respondents put great weight on clinical assessment findings to help diagnose and classify HSI. Immediate physical examination signs like bruising, loss of muscle tension, palpable defects and/or significant weakness and excessive/no response on provoking activities showed strong agreement as justifications for ordering imaging. Many clinicians suggested these could be diagnostic and put most emphasis on loss of tension or muscle/strength function to aid diagnosis. Second to this were symptoms and the mechanism

**Table 2** Participant charactreristics of the expert panels

| Characteristic | Categories | Survey round 1 N=35 | Meeting N=15 | Survey final Round N=99 |
|---|---|---|---|---|
| Sex | (M: F) | 33:2 | 14:1 | 81:18 |
| Age (years) | 27–36 | 11 (31.4%) | 6 | 32 (31.6%) |
| | 37–46 | 13 (37.1%) | 4 | 33 (33.7%) |
| | 47–56 | 9 (25.7%) | 4 | 20 (20.4%) |
| | 57–70 | 2(5.7%) | 1 | 14 (14.3%) |
| Role clinician | Clinician only | 3 (5.7%) | | 26 (25%) |
| | Researcher/scientist only | 2 (8.6%) | | 11 (11 %) |
| | Clinician+researcher | 30 (85.7%) | 15 (100%) | 62 (63%) |
| | Neither clinician nor researcher | 0 | | 1 (1%) |
| Hamstring cases/year | None | 0 | | 5 (5%) |
| | 0–4 | 1 (2.9%) | | 6 (6%) |
| | 5–9 | 6 (17.1%) | | 25 (24%) |
| | 10–14 | 7 (20%) | | 12 (12%) |
| | 15–19 | 10 (28.6%) | | 13 (13%) |
| | 20 or more | 11 (31.4%) | | 38 (38%) |
| Healthcare profession | Sports medicine physician | 4 (10%) | 1 (7%) | 21 (18 %) |
| | Orthopaedic surgeon | 8 (21%) | 5 (35%) | 18 (17 %) |
| | Physical therapist | 22 (55%) | 10 (64%) | 43 (40 %) |
| | Sports scientist | 1 (3%) | | 25 (24 %) |
| | Athletic trainer/strength and conditioning coach | 2 (5%) | | 7 (6 %) |
| | Other | 2 (5%) | | 2 (2%) |
| Country of practice | North America | 4 (11%) | | 10 (10%) |
| | Europe | 26 (66%) | 12 (80%) (UK, Neth, Ir) | 65 (64%) |
| | Middle East/Africa | 4 (11%) | 1 (7%) SAf | 12 (12%) |
| | Southeast Asia | | | 1 (1%) |
| | South America | | | 1 (1%) |
| | Australasia/pacific | 5 (13%) | 2 (13%) (Aust) | 10 (10%) |
| Sports | football | 31 (29%) | 4 (27%) | 79 (80%) |
| | athletics | 19 (19%) | 2 (13%) | 59 (60%) |
| | Rugby codes | 13 (12%) | 4 (27%) | 40 (40%) |
| | NFL (North American football) | 5 (5%) | | 9 (9%) |
| | AFL (Australian Rules football) | 3 (3%) | | 9 (9%) |
| | Basketball | 9 (9%) | | 30 (30%) |
| | Volleyball | 4 (4%) | | 1 (1%) |
| | Skiing and winter sports | 9 (9%) | | 21 (21%) |
| | Hockey | 3 (3%) | 1 (7%) | 22 (21%) |
| | Judo/martial arts/wrestling | 2 (2%) | | 24 (24%) |
| | Cricket | | | 15 (15%) |
| | Ice hockey | | | 12 (12%) |
| | Acrobatics/gymnastics/dance | | | 17 (17%) |
| | Gaelic football | | | 7 (7%) |
| | Racquet sports | | | 17 (17%) |
| | Handball | | | 20 (20%) |
| | Other | 9 (8%) | 4 (27%) | 6 (6%) |
| Years working with HSI pathology | 0–4 | 5 (14.3%) | | 17 (17%) |
| | 5-9 | 8 (22.9%) | | 13 (13%) |
| | 10-14 | 9 (25.7%) | | 22 (21%) |
| | 15–20 | 4 (11.4%) | | 23 (23%) |
| | More than 20 | 9 (25.7%) | | 24 (24%) |
| Highest academic achievement | Bachelor/diploma | | | 14 (14%) |
| | Masters | | | 35 (35%) |
| | PhD | | | 34 (35%) |
| | Clinical doctorate | | | 15 (15%) |
| Had hamstring injury personally | Hamstring problem | | | 38 (38%) |
| | Not applicable | | | 61 (62%) |

Aust, Australia ; HSI, hamstring injuries; IR, Ireland; Neth, Netherlands; SAf, South Africa.

**Table 3** Survey results round 1—ranking of classification systems

| Classification system | Survey 1 vote (%) | Meeting vote (%) | Survey 2 vote (%) |
|---|---|---|---|
| British Athletics Muscle injury | 17 (40) | 15 (35) | 56 (58) |
| Munich | 9 (21) | 10 (24) | 11 (12) |
| Barcelona M Injury | 5 (12) | 6 (14) | 6 (6) |
| Modified Peetrons US/MRI | 6 (14) | 3 (7) | 9 (9) |
| Chan | 2 (5) | 1 (2) | 1 (1) |
| Cohen | 0 (0) | 2 (5) | 3 (3) |
| Wood | 1 (3) | 4 (10) | 5 (5) |
| Takebayashi | 0 | 1 (2) | 1 (1) |
| Nil used | 2 (5) | 0 | 2 (2) |
| Totals | 43 | 42 | 96 |

US, ultrasound.

of injury. The failure of the athlete to improve also triggered further investigation (see table 5).

**Table 5** Key factors triggering referral for imaging

| Factors | No of responses | % of total |
|---|---|---|
| Loss of range of motion/ strength/ tension or integrity on examination | 14 | 16 |
| Symptom levels | 12 | 14 |
| Injury mechanism or sound (pop) | 8 | 9 |
| Failure to improve | 7 | 8 |
| Severity | 6 | 7 |
| Diagnosis | 6 | 7 |
| Prognosis Questions (need for surgery) | 4 | 5 |
| Suspected tissue type | 5 | 6 |
| Particular muscle | 3 | 3 |
| Athlete level | 3 | 3 |
| Player or coach expectation | 3 | 3 |
| Bleeding bruising | 5 | 6 |
| Availability of imaging modalities | 2 | 2 |
| Timing | 3 | 3 |
| Local protocol | 1 | 1 |
| Cost | 1 | 1 |
| Red flag | 1 | 1 |
| Scientific evidence | 1 | 1 |
| Athlete susceptibility (including previous HSI) | 1 | 1 |
| Total | 86 | 100 |

HSI, hamstring injuries.

## Types of imaging

- MRI is the preferred imaging for diagnosis and classification (LOA 89.5%).

MRI was the investigation of choice over US. This is consistent with literature which focuses on MRI based classification systems. Koulouris and Connell compared the use of US to MRI for the diagnosis of acute HSI, finding MRI detected proximal hamstring avulsion injuries in 100% of cases compared with only 58.3% of cases with US scan.[90]

MRI side to side differences were felt to be less important (LOA 49.5%) due to negative MRI findings in a high proportion of HSI,[11] but also financial reasons and the degree of contralateral incidental pathology often found on MRI. The consensus group and survey respondents were also discriminating in their use and timing of US, with use in the early stage (pitch side)—within the first 48 hours (LOA 14.8%) or even for primary diagnosis—after the first 48 hours (LOA 21.8%) was not practiced. There was more agreement on its use in the rehabilitation phase, possibly to monitor healing stages (LOA 61.8%), however, this did not reach our threshold LOA. This finding agrees with literature[91] and guidelines on the use of US.[83 84 86] US has some advantages for imaging muscle including evaluation of fluid/haematoma and scar, as well as real time movement and opportunity to support intervention. It can be used in conjunction with MRI,[92] but the panel was in agreement that MRI was the most helpful imaging modality.

## HSI classification systems

- Classification systems should have agreed Terminology (LOA 91.8%).

**Table 4** Questions requiring answers in hamstring injury classification systems

| Category of question | Responses | % of total | Typical responses |
|---|---|---|---|
| Classification versus anatomy | 17 | 24 | Difference in clinical presentation between fascial/muscular/tendon/intramuscular tendon |
| Classification versus treatment planning | 8 | 11 | Which classification system most effectively guides management? |
| Classification versus prognosis/recovery | 8 | 11 | Does the classification of injury relate to recovery time (RT performance)? |
| Subclassification | 6 | 8 | Are we missing any important subcategories with current classification systems? |
| System of choice | 5 | 7 | Which classification system most closely predicts improvement, recovery and duration? |
| Classification versus clinical examination | 5 | 7 | Can we use a simplified system that uses clinical examination outcomes? |
| Classification versus mechanism of Injury | 5 | 7 | What is the association between injury type and outcome (return to play and reinjury) without too much outcome in overlap between groups? |
| Muscle group specific system | 5 | 7 | Do we need to develop a classification system that is muscle (group)-specific? Do we need to consider different muscles, in grading systems? |
| Classification versus imaging | 4 | 6 | Are we basing rehab outcome timeframes mainly on MRI? can we develop holistic criteria including athlete history, mechanism, presentation, clinical testing? |
| Classification versus surgery | 3 | 4 | Can systems encompass surgical criteria? Is surgery indicated—early vs late surgery? |
| Multivariable system | 2 | 3 | Is there a combination of radiological findings, functional characteristics (biomechanics, speed, strength, range of motion) that can be added to create a composite score? |
| Classification versus function | 2 | 3 | Is there a combination of functional characteristics (biomechanics, speed, strength, range of motion) that can be added to create a composite score? |
| Sport specific system | 1 | 1 | Can we develop a classification system that is sport-specific? |
| Validity/reliability of systems | 1 | 1 | Are classification systems reliable and valid prior to implementation? |
| Total | 72 | 100 | |

**Table 6** Key factors to make HSI diagnosis

| Examination aspects | No of responses |
|---|---|
| Strength | 18 |
| Palpation findings | 13 |
| Function | 8 |
| Pain | 4 |
| Examination | 4 |
| Neural findings | 3 |
| Haematoma/swelling | 2 |
| n/a | 2 |
| History | 1 |
| Tone | 0 |
| Flexibility | 0 |
| Total | 55 |

HSI, hamstring injuries; n/a, not available.

- There is a need for one main classification system (agreed terminology and nomenclature) (LOA 84.8%).

Most of the survey respondents use the BAMIC system (57%), although they concurrently use Munich and the Barcelona systems, but less commonly used US or earlier grades 1–3 systems. While they wanted a single classification system with agreed nomenclature and terminology, they indicated that none of the classification systems were perfect, and all had areas that required improvement. Clinicians wanted a classification to help with prognosis and outcome information and provide guidance for treatment decisions, as well as allowing them to grade severity. While they acknowledged that no one classification system may be able to meet all these requirements, there was strong agreement that terminology should be consistent and agreed.

## Areas where classifications must evolve

- We should differentiate between muscles in the classification (LOA 88.9%).
- Classification needs clear parameters such as (but not limited to):
  - Free tendon versus central tendon (LOA 86.1%).
  - Anatomical, radiological classification (LOA 95.1%).
  - Should evolve to include surgical criteria (LOA 51.2%).
- Mechanism of injury should be commented alongside the classification (where appropriate/known) (LOA 82.0%).
- Beyond anatomical classification, there is a need to have:
  - Functional criteria running alongside (LOA 90%).
  - PROMs running alongside (LOA 80.4%)

While the survey respondents acknowledged that imaging and the involved anatomical tissue were important, many expressed the need to individualise muscles—in part, due to the differing architecture and functional roles between the hamstring muscles. This is reflected in the types of injuries, with the muscles differing in their injury patterns. Our panel agreed that it was likely to be important to consider individual muscle factors such as function and anatomy.[19 22] Muscle architecture was also a factor in the agreement on free tendon versus the intramuscular tendon.

Some comments suggested a gap in the current classification systems in classifying intramuscular tendon injuries, for example, the BF central tendon[40] or the connective tissue T junction between BF long and short head.[41] These pathologies have typical injury patterns within the BF. Some clinicians reported that the implications of these injury pattens may differ between sports. This may be one significant reason why some respondents suggested muscle specific classification was required while others suggested that sports specific classification should be considered. There are also anatomical differences within individuals, making specific classification more challenging.[54]

The panel acknowledged the importance of clinical history and examination findings in classification. They suggested a place in the classification systems for mechanism of injury and functional criteria. Surgical criteria were rated as important, but this statement did not reach consensus, reflecting differences in opinion on the role of surgery. HSIs that need surgical consideration are uncommon but ideally would be highlighted early to prevent delays in treatment and risk of reinjury, longer recovery and complications.[93] However, further evidence on the indications for surgery is required to enable subsequent clear classification and identification of these injuries so rare injuries are not misdiagnosed by clinicians who may not deal with these types of injury regularly.[42] Finally, many suggested a multicomponent, multivariable classification system was important, and clinicians voted highly on the inclusion of functional criteria such as walking and running/sprinting in classification systems. They also wanted more effective PROMs that have received much attention, validation and reliability work in other injury types.[94]

## Are HSI registries relevant?

- There is a need for a registry for HSI (LOA 68.7%).

Clinicians came close to agreement on the need for HSI registries. Some clinicians operated in countries where registries are common for high volume injuries, such as anterior cruciate ligament injuries. These registries, however, have been set up under an orthopaedic framework. In HSI, the percentage of patients requiring surgery is small. In elite sports, such as football, registries may already exist in some form, and it may be more appropriate for the most impacted sports to use an international sporting framework (ie, PHAROS, UEFA, FIFA).

## Limitations

The panels for our three Delphi rounds were international, The London international hamstring consensus meeting face-to-face group comprised 15 out of 35 respondents (43%) to the initial digital survey. This may set up a bias, however, the panel attending were heterogenous, with a multidisciplinary mix of profession, location, sport, age and domain expertise in treatment of HSI. They comprised clinicians from Australia, Netherlands, Ireland, the Middle East but the majority of the face-to-face meeting panel were UK based. We sought and invited experts from Asia, Africa and South America, however, there were less identifiable experts (clinical or published) from these locations, and they could not attend due to pandemic travel restrictions. This may mean their HSI management practices are not represented, possibly introducing bias. However, our meeting panel all worked in elite sport with work schedules that included the management of international patient/athlete cohorts . Most did not train professionally in the UK and their work experience and current work schedules comprised USA, Africa, Middle East, Australia and Asia. They reported that many of their athletes trained internationally, and with international coaches, reflecting the current international nature of elite and Olympic sport. To further reinforce the integrity of the consensus, and provide more international perspective, authors were included with significant Middle East hamstring work experience.

Our group of experts had multiple domains of expertise and scope of practice. This consensus project involved disparate domains of—surgery, postsurgical and non-surgical

**Table 7** Consensus statements and percentage agreement for round 2 survey—global expert panel (n=99)—classification

| Consensus statements related to classification | | True | False | Undecided | Samples of typical responses—discussion points or areas of disagreement |
|---|---|---|---|---|---|
| Anatomical (radiological) classification is essential in the diagnostic process | | 62.0% | 22.0% | 16.0% | It is essential in the higher-grade hamstrings to determine the tendon involvement however with smaller strains radiology is non-essential. |
| There is a need for One main classification system (agreed terminology and nomenclature). | | 84.8% | 2.0% | 13.1% | A 'one-size-fits all' may not be appropriate. Different sports have different mechanisms of injury, demands and therefore RTP times, and re injury rates.<br>Seems logical that what may work for track and field doesn't necessarily hold true for football. Difficult to fit everything into one main classification anatomy, function, and prognostication. |
| Classification needs clear parameters such as (but not limited to):- | Anatomical, radiological classification | 95.9% | 0.0% | 4.1% | It appears research remains undecided for the influence of anatomical location and free vs central tendon involvement in classification systems. |
| | Free Tendon versus Central Tendon | 86.9% | 6.1% | 7.1% | Again, the evidence is limited in the classification of tendon versus MTJ injuries (as an example). No evidence suggests central tendon involved injuries are better off with surgical intervention or not.<br>The only evidence we do have is that treating without the MRI and using clinical markers to guide progression is the only consistent approach, whether central tendon is involved or not. |
| | Should evolve to include surgical criteria | 52.1% | 19.8% | 28.1% | Surgical criteria would be useful for practitioners deciding on prognosis and management. |
| Classification systems should have agreed terminology | | 91.8% | 2.0% | 6.1% | Diagnostic classification system should be clear in reports and research. Only for consistency's sake from both a scientific and clinical perspective. |
| There is a need for a registry for hamstring injuries | | 68.7% | 10.1% | 21.2% | more data is useful, but I fear people will bias their interpretation of it (eg, all central tendon injuries take longer to rehab than MTJ—but this is because you treated them based on the MRI which showed central tendon and you were conservative as a result). This bias is tough to avoid in these registry datasets and people will misconstrue the data. Would be difficult with so many sports. Maybe intrasport registry. |
| Mechanism of injury should be commented alongside the classification (where appropriate/known) | | 82.0% | 11.0% | 7.0% | This always allows for a clearer prognosis/ This is more useful than the classification system. Affects anatomical involvement, prognosis, and rehab decisions. |
| We should differentiate between muscles in the classification? | | 88.9% | 4.0% | 7.1% | Obvious/different muscles have different functions so a classification that guides rehab is desirable hamstrings have different structure and therefore function which needs to be clearly stated to understand if certain muscles are at greater reinjury risk or require longer/requires a very demanding system that may be too difficult to adhere to. |
| Beyond anatomical classification, there is a need to have: - | Functional criteria running beside | 90.0% | 6.0% | 4.0% | Time to walk pain free/Confidence to Sprint/ patient expected time to return to sport. |
| | PROMs running beside | 80.4% | 10.3% | 9.3% | Current PROMs for hamstring injury may not be particularly useful/ PHAT LEFS/ Marx score/ FASH. |
| Imaging is vital in the classification system | | 70.5% | 14.7% | 14.7% | To decide between conservative or surgery, not otherwise/ Would prefer that classification would guide us to ask for imaging. Not that imaging is always essential especially in low grade injury/ in professional sport, imaging is more often required than not, however does not always change management. |
| Immediate physical examination signs like bruising, loss of muscle tension, palpable defects and/or significant weakness and excessive/no response on provoking activities warrant further investigation | | 92.6% | 2.1% | 5.3% | In this presentation you are suspecting a free tendon or complete rupture which may require surgery/pain level and mechanism (suggesting a complete tear, avulsion, or anything else that might require a surgical opinion. |
| MRI is the preferred imaging for diagnosis and classification | | 89.5% | 4.2% | 6.3% | If used, I prefer MRI/ultrasound imaging can be very useful if conducted by a physician/ sonographer with lots of training. Ultrasound is also very suited to examine the damaged muscle- connective tissue area under movement. Ultrasound can also be a good cheaper alternative. |
| MRI side to side comparison is ideal for classification | | 49.5% | 25.3% | 25.3% | This does not happen that often due to financial restrictions. Enough information can likely be gained from a unilateral MRI to give an accurate diagnosis. /Contralateral side is not always a 'healthy' side/Should be used together with US/I prefer a correct protocolised MRI only of the affected side. |
| When is ultrasound most useful/relevant as | Primary imaging after injury preE 48 hours | 14.8% | ***58.0%*** | 27.3% | Ultrasound is not particularly useful when there is a lot of oedema, in the early post-injury period. |
| | Primary imaging after injury post 48 hours | 25.8% | ***42.7%*** | 31.5% | 4 day deadline is best to see well the haematic collection. |
| | In the rehabilitation phase | 61.8% | 16.9% | 21.3% | It depends in what aspect. Architecture—yes. Lesion tracking—no. |

Highlighted values indicate LOA >70%/ large uncertain or false values are given in italics/ bold.
MTJ, myotendinous junction; PROMs, patient-reported outcome measures; RTP, return to play.

## Box 1 Recommendations from consensus

1. Imaging is important for outlining the anatomical muscle, location and tissue involved in the injury. MRI is the investigation of choice and should be performed 24–48 hours postinjury. US can be used as an adjunct, as it is less useful for diagnosis but could be useful in rehabilitation to assess healing. Imaging should assist grading, using—volume, cross sectional area, length of lesions, as well as any discontinuity in tendon or connective tissue, which may be predictive of, slower/poorer outcomes and/or recurrence.
2. A thorough history and physical examination are vital. Clinicians identified key history and examination findings that trigger imaging referral. These include loss of—ROM, tension or contraction capability, pain, presence and pattern of bruising, swelling, the mechanism of injury and the sound (popping) or feeling (tearing/instability) at the time of injury, failure to progress in rehabilitation, and athlete factors such as previous injury, sporting type and level.
3. Classification systems need to perform multiple functions, including grading of severity and anatomical description and need to have agreed terminology to be pragmatically useful. Currently, British Athletics Muscle Injury Classification (BAMIC) is the most widely used classification system for hamstring injuries (HSI), with Munich and Barcelona systems also used. Some clinicians use multiple systems, as they acknowledge strengths and weaknesses with each system. Systems are based on imaging and anatomy but have evolved to encompass mechanism of injury. Our expert clinicians preferred a single classification system to aid in decision making around treatment and prognosis.
4. Classification and grading systems may evolve to include multiple components that combine—imaging findings—MRI / US, clinical presentation on history and examination, mechanism of injury data and athlete susceptibility data such as previous injuries and age. Hamstring function may have a place in classification, particularly running and sprinting, although this may relate more to a management outcome than a component of classification. Classification systems should also evolve or have the capacity to deal with muscles individually, due to their different architecture, functional roles and injury patterns.
5. Intramuscular tendon injuries are recognised in the BAMIC system and appear to have an increased risk of recurrence or delay returning to sport. Loss of tension and cross-sectional area of tendon injury appear to be prognostic variables.[43] Further work is required to determine optimal management pathways and further develop classification of the intramuscular tendon injury.
6. Further information in classification systems, such as inclusion of individual muscles, mechanism of injury, patient demands may aid treatment and prognostication for these injuries. High level research is needed assess if outcomes such as return to sport or injury recurrence improve by using this information.
7. The smaller cohort of higher-grade HSI that commonly recur, are harder to manage, and may benefit frodetailed classification with criteria to aid decision making around surgical management. This lacks global agreement and there are only two classification systems with surgical criteria, both focussing on proximal hamstring free tendon tears.

Continued

## Box 1 Continued

8. Development of key functional components and best methods of measurement for classification will be important, as are the development of adequate patient reported outcome measure.
9. The systems should be sports specific, again acknowledging the different loads, risk situations, and injury patterns in different sports.
10. Very few classification systems have validation studies to ascertain their ability to accurately prognosticate and guide treatment decisions. Outcomes should include time to return to running, sprinting and full performance, as well as risk of recurrence. The type of numbers required for these studies may only be reached by large scale injury registries.

rehabilitation, classification, diagnosis, running and RTS. It was harder to evaluate expertise in classification and diagnosis and the criteria chosen for expertise were harder to establish, academic criteria were thought to be important, but very few experts had published on classification, although they used classification systems. Many trainers and coaches had less expertise in the diagnosis and classification domain and were not included as experts, although in some countries, trainers will have this expertise. Choosing criteria for expertise is difficult for any Delphi study and this represents one weakness of this methodology.[76] Our classification section received the most responses. While we trusted the survey respondents to complete only those fields that encompassed their expertise, it may be possible that some respondents completed sections outside their domain and level of expertise or scope of practice. This was the reason for lack of full response rate for every section. Open-ended questions in the first round meant that we only took information

## Key points

- ⇒ While classification systems exist for hamstring injuries (HSIs) and encompass anatomical and imaging criteria, current classification systems are not specific to individual (hamstring) muscles.
- ⇒ Classification systems have evolved to include the specific anatomical tissue (ie, muscle, myotendinous, tendon) as well as severity of injury gradings, and some include the mechanism of injury and athlete factors.
- ⇒ Clinicians most commonly use the British Athletics Muscle Injury Classification (BAMIC) system, with Munich and Barcelona systems also used for the classification of HSI.
- ⇒ This expert panel recommends MRI as the imaging of choice for diagnosis with few panellists prioritising diagnostic ultrasound. Neither modality is recommended as a means of monitoring rehab progression or deciding on readiness to return to sport.
- ⇒ Experts agree classification systems for HSI should evolve to include parameters around: individual hamstring muscles, intramuscular injuries, mechanism of injury, sporting demand, functional criteria and patient-reported outcome measures.
- ⇒ There is a need for more research into criteria that determine the need for surgical intervention.
- ⇒ There is a need for more research into the effectiveness of classification systems to prognosticate and guide treatment decision making.

that our experts submitted, which was used and adapted for the basis of subsequent rounds. We did not include athletes/patients in these surveys, as domain-specific professional knowledge was required, but statements suggesting athletes should lead and guide decision making in their own treatment received high (unanimous) LOA. Also 38% of respondents to our survey reported had undergone HSI, possibly contributing to the patient/thlete voice. Further work would ideally include athletes, coaches and other sport stakeholders, whose perspective is vital.

While we attempted to be inclusive, the representation of women is low in our panels, (2/39, 1/15 and 18/99). We found less publicly available information directing to women experts, and it was found that female rates of publication are lower in HSI, with less publicly available information on expertise. Although we attempted to invite these clinicians/researchers, the response rates lower for the women we surveyed and invited to our meeting. This has been a weakness in other consensus research. We recognise this as a significant limitation of our consensus and recommend that future work specifically prioritises endeavours to enhance representation of women within consensus and Delphi group methodology as their voice is also vital.

Where possible we aimed to include equity-deserving groups while maintaining our expertise criteria for inclusion and further work should aim to include these groups. Balancing inclusion and expertise can be challenging but should be prioritised in any Delphi study.

Recommendations from Consensus on diagnosis, classification and grading of HSI (box 1).

## CONCLUSION

A narrative review of classification in HSI showed that systems have evolved from clinical signs only, to imaging-based systems. They have evolved to include injury mechanisms, and the anatomical tissue and site, as well as the grading of injury severity. The relationship between imaging findings, grading/severity, reinjury risk and prognosis, however, is still not fully clear. While many clinicians would like to use classification systems to allow prescription of rehabilitation and an accurate prognosis, there are very few studies that have investigated this. Our consensus group and Delphi survey rounds suggest that, in order of use, expert clinicians most frequently use BAMIC, then Munich, then Barcelona muscle injury classification systems for HSI, for the reasons of utility and simplicity. They have highlighted the need to differentiate between the three hamstring muscles and exact anatomical location to help classify these injuries. They acknowledge limitations of any classification system but suggest they could evolve to consider additional information (functional parameters, injury mechanisms, athletic sporting demands, surgical indications and PROMs) to more optimally treat HSI. Using the current systems along with this additional data may allow more tailored and effective rehabilitation for each specific injury.

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# London International Consensus and Delphi study on Hamstring Injuries

# Supplementary material - Methodology

## Modified Delphi design methodology

The current assessment and treatment of hamstring injury presents a challenge in many sports, with the incidence increasing despite incremental volumes of literature, and while this literature has provided many answers and solutions, there are still large gaps. Recent systematic reviews in aspects of hamstring injury (HSI) management report high risk of bias in many studies[1-3], making some treatment recommendations unreliable. Evidence is more often available for recreational, amateur, or sub-elite sport from multisport cohorts, with less clinical applicability / generalisability to elite populations. In this situation clinicians must make assessment and treatment decisions based on incomplete, weak, and poor-quality evidence. Clinical expertise and experience therefore become vital. A research approach to gain insight from practitioners' expertise would be useful. Single experts can be useful but a scientific approach that aims for a consensus/ agreement among a group of experts can provide more optimal recommendations.[4] The Delphi methodology was thought by this group to present a systematic and scientific approach to capture the decision-making experience and expertise of global experts to identify and investigate areas in HSI where new decision-making approaches could be developed. The London 2020 international hamstring consensus group was established as a multidisciplinary collaboration to advance the assessment management of HSI. An information gathering project was established to investigate current international decision-making, in the assessment and treatment of HSI. It was hoped that this could attain consensus on best practice decision-making in HSI and identify areas of research need in HSI and new decision-making approaches that could improve the outcomes after HSI.

## Aims

1/ To Examine whether global decision-making practice is aligned with best available evidence

2/ To identify areas where research evidence is lacking or of insufficient quality for clinicians to make assessment and treatment decisions.

3/ To achieve a consensus agreement on current global best practice in assessment and management of HSI.

## Study Design

This study used a modified Delphi design aiming to bring an international panel of experts to a consensus on current best practice for decision-making in HSI.

The Delphi process is an iterative staged process utilising the opinion and expertise of a group of experts to achieve consensus on a topic. It is useful in topics where limited literature is available to guide decisions[5 6] and relies on expert opinion and expert clinical practice.[7]

A Delphi expert consensus approach was applied to decision-making after HSI. There have been previous Delphi consensus studies in muscle injuries[8 9] , injury prevention[10] and aspects of management of Hamstring injury, such as return to play [11 12] but other aspects of hamstring assessment and treatment may also benefit from this approach such as classification systems, decision making in rehabilitation and the justification for surgery, particularly given the disparate and conflicting approaches used currently.[13] [14] The reporting standard for conducting and reporting Delphi studies (CREDES) was followed.[15]

## modified Delphi Process

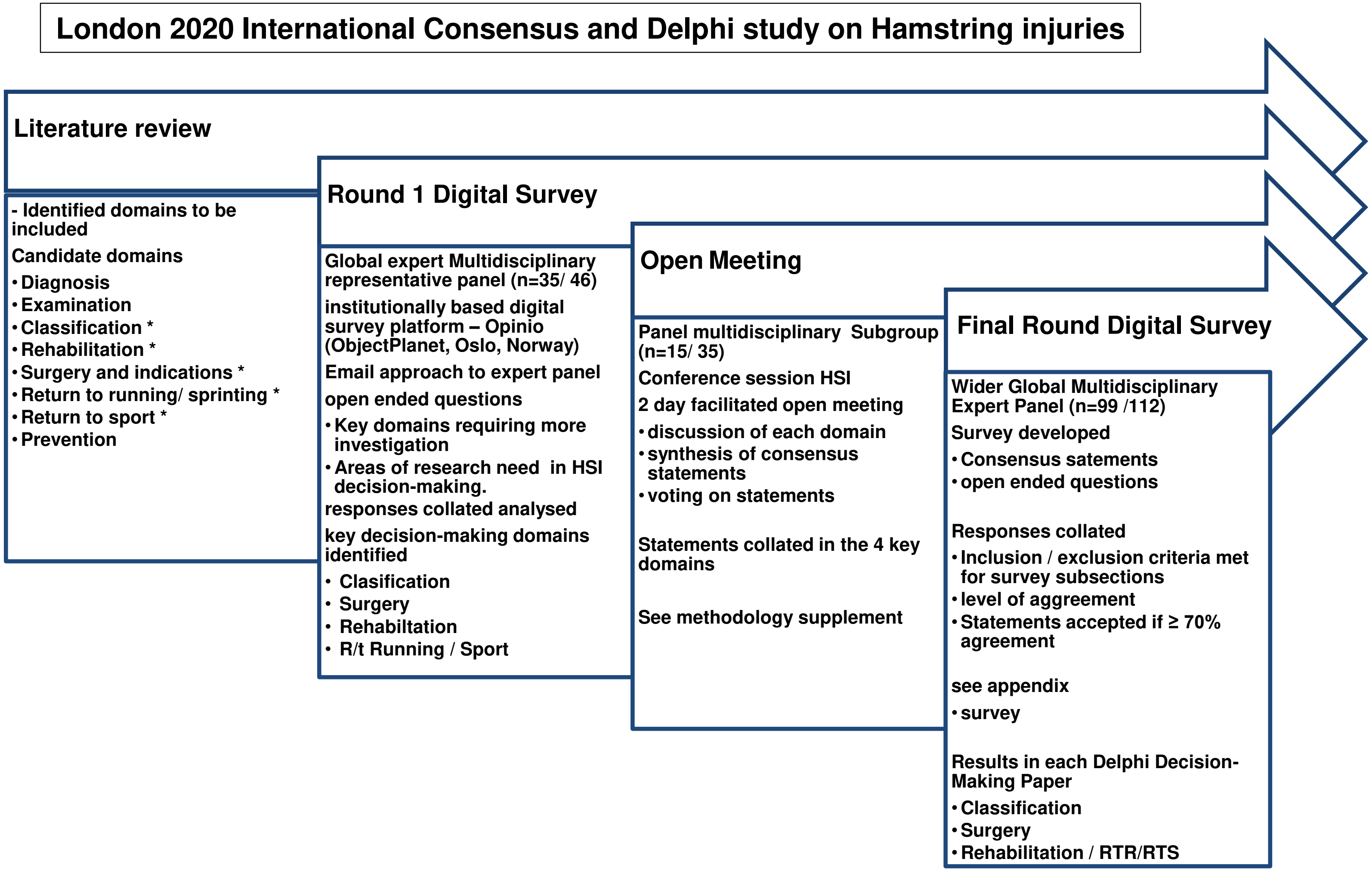
This modified Delphi study focussed on decision-making in aspects of HSI. It was undertaken after a reviews of decision-making aspects of the assessment and management of HSI[16 17] (also see appendix 1 with paper 1 Classification). Ethical approval for the study was sought and obtained from the institutional ethical review board (Project ID 5938/002). The study comprised two rounds of a purposive digital survey interspersed with a face-to-face meeting round (see figure 1). Each round was modified based on feedback to achieve a consensus among an international panel of experts. Each Delphi round comprised a digital questionnaire, an analysis, and a feedback report.

Stage 1: A review of the literature informed the domains to be included in an online survey which was undertaken from November 2019 to January 2020.

Stage 2: The round 1 online survey gathered the opinions of a global expert panel, with open ended questions to identify the key domains requiring more investigation in HSI decision-making. The survey used institutionally based digital survey platform – Opinio (ObjectPlanet, Oslo, Norway), with a link to an online questionnaire sent out to each of the experts with an invitation to participate.

Stage 3: Open Meeting - The responses from the survey were collated and analysed, and the key domains were identified where there were gaps in literature evidence and clinical practice in Hamstring injury decision-making. This was fed back to a subset of the expert panel attending in 2 days of an open meeting during an international conference. They formed the ISEH hamstring injury consensus group They had an opportunity to discuss each key domain and produced a series of statements for consensus voting.

Stage 4: A round 2 survey was then developed to allow a wider international vote on the consensus statements produced. This included those experts who participated in round 1 but also others identified with significant hamstring expertise to ensure a representative global sample. Those clinical academics with expertise in rehabilitation completed the relevant sections of the survey. The survey responses were collated



**London 2020 International Consensus and Delphi study on Hamstring injuries**

**Literature review**

- Identified domains to be included

Candidate domains

- Diagnosis
- Examination
- Classification *
- Rehabilitation *
- Surgery and indications *
- Return to running/ sprinting *
- Return to sport *
- Prevention

**Round 1 Digital Survey**

Global expert Multidisciplinary representative panel (n=35/ 46)

institutionally based digital survey platform – Opinio (ObjectPlanet, Oslo, Norway)

Email approach to expert panel

open ended questions

- Key domains requiring more investigation
- Areas of research need in HSI decision-making.

responses collated analysed

key decision-making domains identified

- Clasification
- Surgery
- Rehabiltation
- R/t Running / Sport

**Open Meeting**

Panel multidisciplinary Subgroup (n=15/ 35)

Conference session HSI

2 day facilitated open meeting

- discussion of each domain
- synthesis of consensus statements
- voting on statements

Statements collated in the 4 key domains

See methodology supplement

**Final Round Digital Survey**

Wider Global Multidisciplinary Expert Panel (n=99 /112)

Survey developed

- Consensus satements
- open ended questions

Responses collated

- Inclusion / exclusion criteria met for survey subsections
- level of aggreement
- Statements accepted if ≥ 70% agreement

see appendix

- survey

Results in each Delphi Decision-Making Paper

- Classification
- Surgery
- Rehabilitation / RTR/RTS

**Figure 1 Study design for Delphi and Consensus**

## Participants – Expert Panel

An international representative multidisciplinary group of expert clinicians / researchers were Invited to participate in this HSI decision-making project, based on their expertise in the assessment and management of hamstring injuries. Identifying appropriate experts is vital to the Delphi process.[6] The criteria for expert inclusion comprised Academic criterion of peer reviewed publication (authorship) in hamstring research and or clinical criteria: - a high level of expertise assessing, managing and/or researching injuries, based on the number of injuries seen and years worked in HSI. All participants needed to be willing complete the digital survey and or attend the consensus meeting and a sufficient level of written and spoken English.

Possible experts were excluded if they had 1/ insufficient experience of assessment or management of hamstring injury ( 2) insufficient time to fully complete the online survey. Clinicians and non-clinicians were included but asked to answer only those survey questions related to their fields of expertise. A purposive, heterogeneous representative sample of experts were chosen with a mix of:- professional discipline (Sport and exercise medicine physicians, physiotherapists, orthopaedic surgeons, sport and exercise scientists/researchers), international location, gender, sporting discipline in line with Delphi methodology.[18]

Decision-making in HSI management crosses multiple domains of expertise, and a multiprofessional panel of experts was sought . This involved disparate domains of surgery, post-surgical and conservative rehabilitation, classification, diagnosis, running and return to sport. It was difficult to find experts with this combined domain expertise. This heterogenous group , meant that the criteria for expertise were difficult to choose, Academic criteria are important, but achieving publication alone was thought to be too narrow, with the potential to miss important stakeholders[15], as some academics have less clinical HSI diagnostic, decision-making and injury management expertise in some domains. Clinical criteria were also deemed important, as many experts have not published research. For clinical experience criteria, the number HSI/ year ( requirement >5) and years of practice with HSI (requirement >5) were chosen, but to avoid eliminating important stakeholders, the respondents with <5 years of practice and seeing <5 HSI/yr were assessed and responses were included if they were researchers and had academic publication in HSI. They were also included if they had <5 year working with HSI if they worked in elite sport but their annual case number was greater than 10. It was difficult to gauge clinical experience, as the range of injury types and severity, and the quality and recency of practice with these injuries varied between our experts. Some experts deal with only one aspect of the management pathway and surgeons, physiotherapists and athletic trainers/ coaches have very different domain expertise. Choosing criteria for expertise is difficult for any Delphi study and represents an area of possible bias and weakness in this methodology.[19]

Representation is also key to Delphi/ consensus methodology and lack of representation may allow for insufficient challenge of flawed current practice, or exacerbate current inequalities.[19] To avoid bias every effort was made to include multiple professions and regions/ countries globally, although it was found that there were more experts in HSI in some global locations. We sought to be as inclusive as possible to encompass all views , but to maintain appropriate expertise. This balance is difficult to maintain in Delphi studies.

There is no guideline for number of experts to be involved in a consensus[18], but the sample size was set at 30 for the initial survey to ensure a full international and multidisciplinary sport/ profession mix . A possible drop out and non-response rate was predicted. Research recommendations for the Delphi technique were followed with opinion-based research.[5 20]

## Procedure Stage One and Two – Survey Round 1

The initial literature review allowed us to generate candidate decision-making domains in HSI (see table 1). The round one survey (Appendix 1) aimed to gather information, and understand, from the experts' viewpoint, where are the gaps in the literature evidence and clinical practice in Hamstring injury decision-making. We aimed to identify which were the key domains requiring further research. Expert opinion was then sought on these key domains in the meeting day and round 2 survey and a best expert consensus was produced on these domains. Four domains were identified – Classification and diagnosis, Surgery, rehabilitation (including rehabilitation post-surgery), return to running and sport.

**Table 1 Topic/Domain areas for discussion around assessment and treatment in hamstring injury**

| **Items for Survey Hamstring decision-making**<br>**Candidate Domains identified from Systematic review** | |
|---|---|
| **Examination post HSI** | |
| **Imaging and Diagnosis** | |
| **Injury Classification systems** | * |
| **Surgical vs Conservative treatment** | * |
| **Surgical methods** | |
| **Injury Prognostication** | |
| **Prevention of HSI** | |
| **Rehabilitation of HSI** | * |
| **Exercise prescription** | |
| **Dosage of rehabilitation** | |
| **Progression of rehabilitation** | |
| **Returning to running** | * |
| **Returning to sprinting** | * |
| **Returning to sport** | * |

(* Domains chosen by panel in round 1 Survey)

The initial round 1 survey comprised open ended qualitative information gathering questions and some quantitative data questions using Likert scales determined level of agreement (see Appendix 1). The survey used a digital institution-based software package – Opinio 7.12 (copyright 1998-2020 ObjectPlanet, Oslo Norway). For the two surveys we followed the Checklist for Reporting Results of Internet E-Surveys (CHERRIES)[21] to avoid bias.

## Steering Committee

The rehabilitation survey was designed by 2 experienced clinical academic physiotherapists, and a Professor of Orthopaedic surgery, who each have greater than 20 years clinical experience treating HSI and research expertise in HSI, as well as previous experience with Delphi research. A structured, iterative process was undertaken to develop the survey and it was piloted by a mixed group of 5 sports medicine physicians, 5 physiotherapists and 5 orthopaedic surgeons, and the survey was further refined based on their feedback. The expert panel were approached by Email located from publicly available correspondence information on peer reviewed journal articles, or on their publicly available institutional profile pages. Institutional ethical approval was obtained for the study from the institutional academic ethics committee (Project ID 5938/002) and information was provided prior to participation, but actively completing the survey was implied (and stated) as the consent to participate. Any participant with who withdrew had data removed.

## Procedure Stage 3 – open consensus meeting

The above review, and the results of the initial survey were collated and analysed with a thematic and factor analysis.[22] The expert panel identified key domains (see * in table 1) and key questions for these domains (see tables in appendix 3), which were outlined and presented for discussion. All of the panel members who completed the survey were invited to the discussion. The discussion took place via a group consensus two-day meeting, alongside an international conference, to allow as many of the participants to join as possible. A nominal group consensus model was followed with a facilitated, structured approach to gather qualitative information, from this group.[23] This approach has been followed in other consensus projects.[24 25] After discussions, the key consensus statements were synthesised and refined. Note was made of key discussion and dissention points. Sessions were facilitated to encourage discussion and also draw out dissenting[26] and outlier views as these were considered important to avoid a "herding bias" as a consensus may not necessarily produce 'the correct' answer to a question.[19] The research was led and facilitated by a less published researcher/expert (BP) to maintain impartiality, to balance any opposing professional viewpoints and avoid any "Eminence bias". These sessions were chaired by each author related to their area of specialisation – classification

(JM), Rehabilitation (BP), Return to running/sport (MG) and surgery (FSH). Consensus statements were gradually refined through a process of facilitated debate, not forcing consensus, until the entire panel were satisfied and on day 2, were put to the group for anonymous electronic voting. See Appendix 4 for the list of statements – rehabilitation, RTS/RTR, classification and surgery.

The consensus committee (FSH, BP, and JM) made a criterion decision that the consensus threshold was set a priori at 70%, with ≥70% of agreed / yes responses constituting consensus acceptance of statement. This cut off has been used by other authors in Delphi studies.[27-29] Statements not achieving consensus were removed and new items were added based on comments in the discussion, with further voting until consensus was achieved.

## Procedure Stage 4 – Final Round Online Survey

A further online survey was developed, to test these statements with a final round survey to a wider global international group of experts who met the previous inclusion / exclusion criteria. The participants voted on the statements with yes, no, uncertain responses. Some further Likert or factor ranking questions determined level of agreement. (See Example Question Appendix 2).

Candidates voted on statements and ranked their key decision-making factors or justifications related to the domain areas found in the round 1 Survey. See Appendix 4 – tables, for consensus statements, voting results and typical discussion points or areas of disagreement (open ended questions)

### *Expert Panel for the final round*

The final survey was split into domain sections – Classification, surgery, rehabilitation, return to running / Sport. Participants were asked to complete only the domains (sections of the survey) that were within their field and scope of expertise. The survey responses were anonymous and were evaluated for completeness.. Within their expertise areas, panel members were asked to complete sections as carefully as possible. The participants voted on the statements with yes, no, uncertain ("forced choice") responses. This made the final survey shorter and less onerous for participants but some further Likert or factor ranking questions determined level of agreement. Open ended boxes after each consensus statement also allowed them to comment, and comments were collated and analysed Survey responses in each domain were evaluated by 2 steering group members and any non-completed forms or incomplete responses from non-experts in that particular domain were removed from the analysis.

## Time Frames

September 2019 to Jan 2020 Round 1 - design of questionnaire to be delivered online with round 1 questionnaire and collation of round 1 responses.

January 2020 consensus days and conference consensus meeting, with Feedback of round 1 responses to face to face expert panel and synthesis of consensus statements for voting, - initial small panel vote on consensus statements.

August 2020 - May 2021 – Final Round – design and online delivery of international survey based on consensus statements to obtain wider sample level of agreement.

May 2021 –Dec 2021collation of consensus day information and write up for possible publication.

## Respondents

The volume of responses made reporting in one single paper difficult. For this reason, three papers are presented with decision-making domain areas of – Classification, surgery and rehabilitation and RTS. The compositions and characteristics of the expert panel for each round survey and the face-to-face meeting are reported below in table 2.

The response rates and the inclusion and exclusions for each survey round are given in the flow chart in figure 2 below.

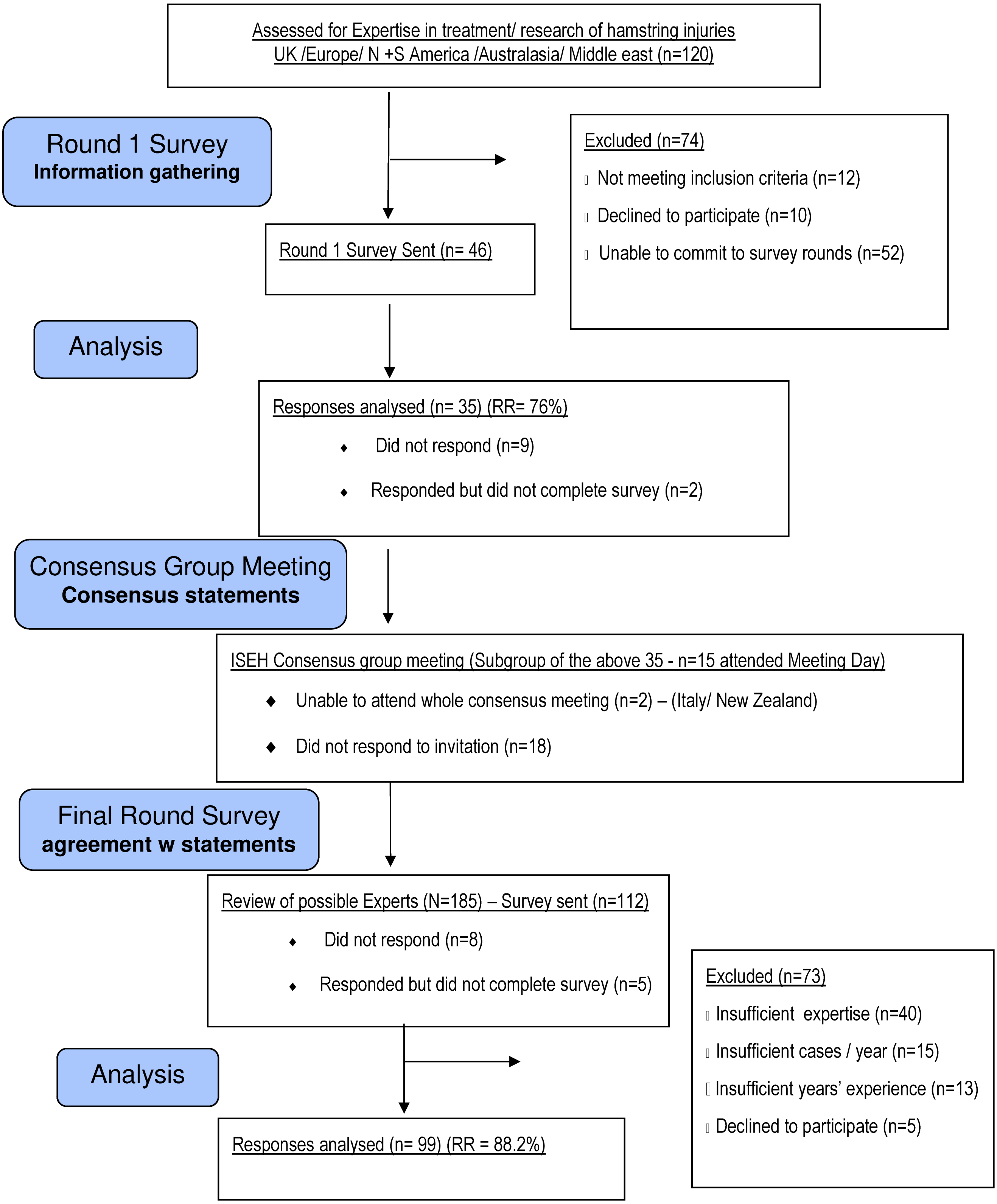


**Figure 2: Flow diagram of participants and response rates (RR)**

**Table 2 participant charactreristics of the Expert Panels**

| Characteristic | Categories | Survey Round | Meeting | Survey Final Round |
|---|---|---|---|---|
| **Sex** | **(M: F)** | 33:2 | **14:1** | **81:18** |
| **Age (years)** | **27 - 36** | 11 (31.4 %) | **6** | **32 (31.6%)** |
| | **37 - 46** | 13 (37.1%) | **4** | **33(33.7%)** |
| | **47 - 56** | 9 (25.7%) | **4** | **20 (20.4%)** |
| | **57 - 70** | 2( 5.7%) | **1** | **14 (14.3%)** |
| **Role clinician** | **clinician only** | 3 (5.7%) | | **26 (25%)** |
| | **researcher/scientist only** | 2 (8.6%) | | **11 (11 %)** |
| | **clinician + researcher** | 30 (85.7%) | **15 (100%)** | **62 (63%)** |
| | **Neither clinician nor researcher** | 0 | | **1 (1%)** |
| **Hamstring cases / year** | **none** | 0 | | **5 (5%)** |
| | **0-5** | 1(2.9%) | | **6 (6%)** |
| | **5-10** | 6 (17.1%) | | **25 (24%)** |
| | **10-15** | 7 (20%) | | **12 (12%)** |
| | **15-20** | 10 (28.6%) | | **13 (13%)** |
| | **20 or more** | 11 (31.4%) | | **38 (38%)** |
| **Health care profession** | **Sports medicine Physician** | **4 (10%)** | **1 (7%)** | **21 (18 %)** |
| | **Orthopaedic surgeon** | **8 (21%)** | **5 (35%)** | **18 (17 %)** |
| | **Physical Therapist** | **22 (55%)** | **10 (64%)** | **43 (40 %)** |
| | **Sports scientist** | **1 (3%)** | | **25 (24 %)** |
| | **Athletic trainer / Strength & Conditioning coach** | **2 (5%)** | | **7 (6 %)** |
| | **Other** | **2 (5%)** | | **2 (2%)** |
| **Country of practice** | **North America** | **4 (11%)** | | **10 (10%)** |
| | **Europe** | **26 (66%)** | **12 (80%) (UK,Neth,Ir)** | **65 (64%)** |
| | **Middle East/Africa** | **4 (11%)** | **1 (7%) SAf** | **12 (12%)** |
| | **Southeast Asia** | | | **1 (1%)** |
| | **South America** | | | **1 (1%)** |
| | **Australasia / pacific** | **5 (13%)** | **2(13%) (Aust)** | **10 (10%)** |
| **Sports** | **football** | **31 (29%)** | **4 (27%)** | **79 (80%)** |

| | | | | |
|---|---|---|---|---|
| | **athletics** | **19 (19%)** | **2 (13%)** | **59 (60%)** |
| | **Rugby codes** | **13(12%)** | **4 (27%)** | **40 (40%)** |
| | **NFL** | **5 (5%)** | | **9 (9%)** |
| | **AFL** | **3 (3%)** | | **9 (9%)** |
| | **basketball** | **9 (9%)** | | **30 (30%)** |
| | **volleyball** | **4 (4%)** | | **1 (1%)** |
| | **Skiing and winter sports** | **9(9%)** | | **21 (21%)** |
| | **hockey** | **3 (3%)** | **1 (7%)** | **22 (21%)** |
| | **judo/ martial arts/wrestling** | **2 (2%)** | | **24 (24%)** |
| | **cricket** | | | **15 (15%)** |
| | **Ice hockey** | | | **12 (12%)** |
| | **Acrobatics/ gymnastics / dance** | | | **17 (17%)** |
| | **Gaelic football** | | | **7 (7%)** |
| | **Racquet sports** | | | **17 (17%)** |
| | **handball** | | | **20 (20%)** |
| | **Other** | **9 (8%)** | **4 (27%)** | **6 (6%)** |
| **Years working with HSI** | **0-4** | **5 (14.3%)** | | **17 (17%)** |
| | **11-14** | **8 (22.9%)** | | **13 (13%)** |
| | **5-10** | **9 (25.7%)** | | **22 (21%)** |
| | **15-20** | **4 (11.4%)** | | **23 (23%)** |
| | **more than 20** | **9 (25.7%)** | | **24 (24%)** |
| **Highest academic** | **Bachelor/Diploma** | | | **14 (14%)** |
| | **Masters** | | | **35(35%)** |
| | **PhD** | | | **34 (35%)** |
| | **Clinical Doctorate** | | | **15 (15%)** |
| **Had hamstring injury** | **hamstring problem** | | | **38 (38%)** |
| | **not applicable** | | | **61 (62%)** |

UK-United Kingdom, Neth-Netherlands, IR-ireland, Aust-Australia , SAf- South Africa

# Appendix 1 Hamstring Injury Survey

## Hamstring survey

1. what is your profession

○ Sports medicine physician

○ Orthopaedic surgeon

○ Physical Therapist

○ Sports scientist

○ Athletic trainer / Strength & Conditioning coach

○ Coach

○ Other

2. Which sports do you work with

☐ football

☐ athletics

☐ Rugby codes

☐ AFL

☐ basketball

☐ volleyball

☐ skiing

☐ other winter sports

☐ Other

3. How many Hamstring injuries do you assess and or treat per year?

| less than 5 | 5-10 | 10-20 | 20-30 | more than 30 |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

4. What are the questions that need to be answered on mechanism of Hamstring injury

5 top questions on Mechanism of Injury (in order of importance)

5. What are the questions that you would like to be answered on Pathology of hamstring injury?

   list your top 5 key questions on pathology in hamstring injury (in order of importance)

6. what do you see as the most important risk factors for hamstring injury?

   please list the most important risk factors (in order of importance)

7. what questions are most important to answer in terms of risk of hamstring injury?

   Please list your top 5 questions (in order of importance)

8. what questions are most important to answer in terms of risk of RECURRENCE of Hamstring injury?

   Please list your top 5 questions (in order of importance)

9. what exercises do you use for the prevention of injury?

☐ Eccentric

☐ concentric

☐ isometric

☐ hip based

☐ knee based

☐ other

what dosages do you prescribe

10. please rank the above exercises in terms of importance for prevention of Hamstring injury.

Rank your top 5 in order of importance

11. What are the questions you would most like answered around prevention of hamstring injury?

Please list your top 5 questions (in order of importance)

12. What are the key questions you would like answered around prevention of RECURRENCE of hamstring injury?

Please list your top 5 questions (in order of importance)

13. Which Hamstring injury classification systems do you use?

List your top 5 classification systems in order of preference

14. What are the questions you think need answering regarding Hamstring injury classification?

List your top 5 questions in order of importance

15. Which imaging do you use after hamstring injury?

☐ ultrasound

☐ Magnetic resonance imaging (MRI)

☐ Xray

☐ other

16. What are the key factors that influence your decisions for ordering imaging?

top 5 decision making factors for ordering imaging (list in order of importance)

17. What are the most important questions that need answering around Imaging in hamstring injury?

Please list your top 5 questions (in order of importance)

18. What are the questions you would most like answered regarding diagnostic tests after Hamstring injury?

please list your top 5 questions in order of importance

19. What other aspects of examination or examination tests do you put most weight on for Diagnosis?

please list your top 5 examination tests for diagnosis. (In order of importance)

20. Do you use bracing in the early-stage post injury or surgery?

○ no Bracing

○ hip Brace

○ knee brace

○ used only after surgery

if you use bracing - what ROM? and What time period

21. what are the factors you would consider in precautions?

please list the top 5 factors in decision making for precautions post injury or surgery (in order of importance)

22. what are the key criteria that you use to progress Range of movement and initial loading of the injured hamstring?

Please list your top 5 criteria for progression (in order of importance)

23. What are the key questions that you would like answered regarding the early phase of rehabilitation?

Please list your top 5 questions (in order of importance)

24. what are the most important factors for you when considering choice of hamstring exercise?

Please list your 5 most important factors (in order of importance)

25. what factors do you use to determine - DOSAGE of exercise ( ie frequency duration and intensity)

Dosage factors

26. what factors do you use to determine - when to PROGRESS exercise ( ie frequency duration and intensity)

Progression factors

27. what other muscle groups do you prioritise in the kinetic chain?

☐ Adductors

☐ Gluteals

☐ Quadriceps

☐ Calf

☐ Hip flexors

☐ other

What top 5 questions would you most want answered relating to Hamstring injury and other muscles in kinetic chain? (List them in order of importance

28. what adjuncts do you find useful for strengthening Hamstring muscles in rehabilitation? ( ie adjuncts like - electrical stimulation, Blood Flow restriction training, etc )

adjuncts (please list your top 5 in order of utility)

29. What questions would you most like answered on exercise prescription in Hamstring injury rehabilitation?

    Please list your top 5 questions (in order of importance)

30. What are your criteria for return to running?

    Criteria for return to running. (Please list your top 5 in order of importance)

31. What are your criteria for return to full sprinting?

    Criteria for return to full sprinting? (Please list your top 5 in order of importance)

32. What are your criteria for return to sport (match / competition)?

    Criteria for return to full sport (competition / match)? Please list your top 5 in order of importance.

33. What are the questions you would like answered on return to running and sport after hamstring injury?

    Please list your top 5 questions (in order of importance)

34. What factors would influence your decision making when deciding if surgery would be indicated?

    Please list the top 5 factors (in order of importance)

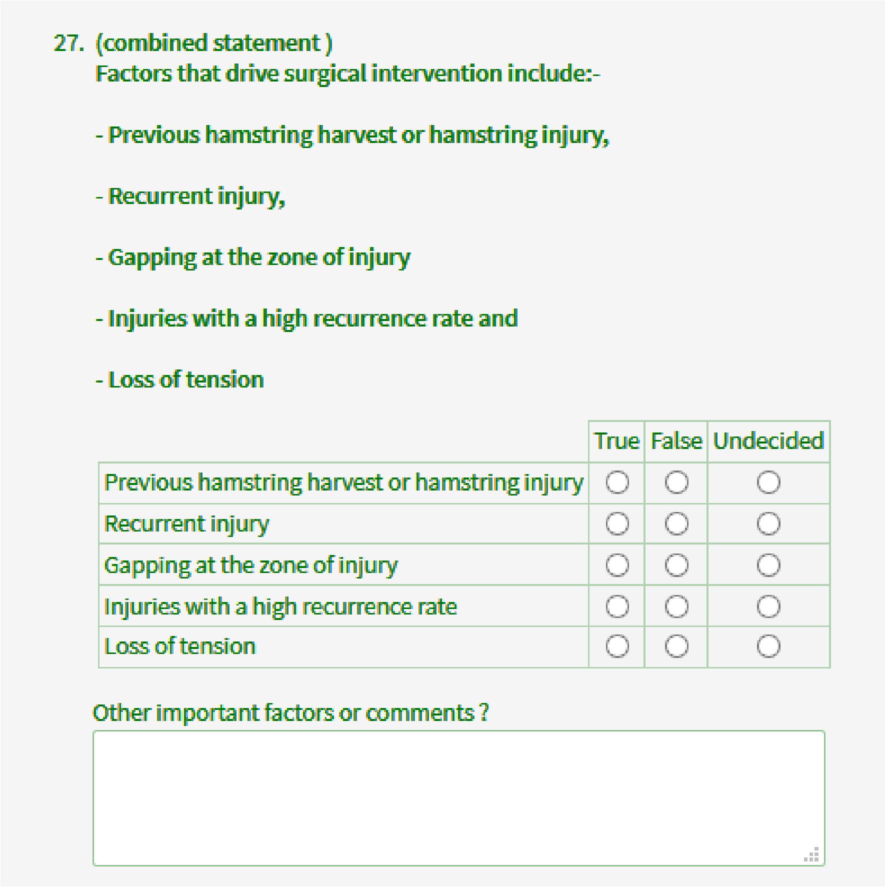
35. What are the questions you would most want answered on surgery for Hamstring injury?

Please list your top 5 questions on surgery (in order of importance)

36. What are the questions you would most want answered regarding rehabilitation after surgery?

List your top 5 questions in order of importance

## Appendix 2 Round 2 Draft Question Examples –matrices responses



27. (combined statement )
Factors that drive surgical intervention include:-

- Previous hamstring harvest or hamstring injury,

- Recurrent injury,

- Gapping at the zone of injury

- Injuries with a high recurrence rate and

- Loss of tension

| | True | False | Undecided |
|---|---|---|---|
| Previous hamstring harvest or hamstring injury | ○ | ○ | ○ |
| Recurrent injury | ○ | ○ | ○ |
| Gapping at the zone of injury | ○ | ○ | ○ |
| Injuries with a high recurrence rate | ○ | ○ | ○ |
| Loss of tension | ○ | ○ | ○ |

Other important factors or comments ?

## Appendix 3 Survey round 1 Questions and typical responses

Nb Questions on classification and imaging are supplied in the classification paper.

*Table 1 What are the key questions that you would like answered regarding the early phase of rehabilitation after HSI?*

| *Domain Area* | *responses* | *Typical Responses* |
|---|---|---|
| **Early interventions (STM / neural mob/ + adjuncts BFR / EM stim)** | *9* | Is there a role for adjunct treatment modalities? At what time point are they safe and to what level of intensity? |
| **Progression criteria (including pain)** | *6* | What outcomes should we be aiming to achieve for criteria-based progression along stages |
| **Optimum exercise/ load types** | *6* | What are the optimal exercises to use in this phase? How early can we safely prescribe eccentric / long length exercises? |
| **Pain importance** | *5* | What are the outcomes of pain monitored/threshold approach to rehabilitation? |
| **Modalities for inflammation / healing (RICE, Meds)** | *5* | Does prolonged use of Ice, Compression or medication positively or negatively affect hamstring healing rates? |
| **Timescales (start and progress load)** | *4* | How early can we safely prescribe eccentric / long length exercises? |
| **Flexibility/ ROM** | *3* | Is there a role for Knee flexibility work? |
| **Immobilisation & Bracing (optimum, effects)** | *3* | Does initial immobilisation positively or negatively affect hamstring healing rates? |
| **Neural factors, inhibition & activation** | *3* | What are the outcomes of return to run process, early vs delayed vs criteria based, vs early introduction of eccentrics - any effect on neuromuscular inhibition? |
| **Optimum dosing (Frequency, Intensity, Duration)** | *2* | What exercise dosages are optimal for loading early phase after HSI? |
| **Safety of early loading** | *1* | Does early mobilization / rehab (including stretching), and activation of the hamstring speed or limit recovery? |
| **Tissue strain load /exercise** | *1* | What is the strain placed on muscle/tendon by different rehab exercises? |
| **Weight bearing** | *1* | When does initial reduction in weightbearing help or hinder healing? |
| **Early strength** | *1* | What are the outcomes of early introduction of eccentric exercises? |
| **Total** | ***50*** | |

*Table 2 What questions would you most like answered on exercise prescription in HSI rehabilitation?*

| ***Domain Area*** | ***responses*** | ***Typical Responses*** |
|---|---|---|
| ***Progression of exercise*** | ***8*** | What is optimum order of progression of exercise? inner to outer? short length to long concentric to eccentric to isometric? OKC vs CKC? knee to hip based? |
| ***Dosage*** | ***5*** | What is the optimum dosage of strength exercise? |
| ***Contraction types*** | ***5*** | What type of contraction should be emphasised during hamstring injury rehabilitation? |
| ***Running /sprinting*** | ***4*** | What is a safe but stimulating dosage of pitch-based running? |
| ***Exercise choice*** | ***4*** | what are the optimal exercises for hamstring injury prevention? |
| ***Importance of symptoms*** | ***3*** | How effective is early introduction of eccentrics and pain threshold training? |
| ***Safety vs effectiveness balance*** | ***3*** | What is a safe but stimulating dosage of strength exercise? |
| ***Tissue healing stage*** | ***2*** | What modes of exercise should be carried out at certain healing stages? |
| ***Timing*** | ***2*** | When should certain exercise types, isometric, concentric, eccentric, SSC be implemented throughout rehabilitation |
| ***Insufficient evidence*** | ***2*** | Can we get more insights to the specific mechanisms of HSI at a contraction mode, neural and structural level to aid prevention and rehabilitation exercise choices? |
| ***Flexibility*** | ***1*** | What are the effects of flexibility exercises? |
| ***Strength*** | ***1*** | What types of strength are crucial? |
| ***Which Muscles*** | ***1*** | How best do we target loading the Biceps femoris long or short head and do we need to? |
| ***Functional exercise*** | ***1*** | More RCTs (analogous to those employing the Nordic) exploring the functional effectiveness of different exercises |
| ***Neural factors*** | ***1*** | Which exercises promote optimal hamstring activation? |
| ***Total*** | ***43*** | |

*Table 3 What are the questions you would like answered on return to running and sport after HSI?*

| ***Domain Area*** | ***responses*** | ***Typical responses*** |
|---|---|---|
| ***running mechanics*** | ***8*** | Does early return to running effect rehab outcomes? |
| ***optimum monitoring*** | ***7*** | What key benchmarks should we be considering before each stage and research about |
| ***recovery*** | ***2*** | How long to leave it between bouts of HSR? |
| ***sport specifics*** | ***3*** | What are the sport-specific match demands that we can replicate towards the end of rehabilitation? |
| ***load tolerance*** | ***1*** | Does early return to running effect rehab outcomes? |
| ***strength*** | ***3*** | What are key strength components and levels to enable safe return |
| ***dosage*** | ***2*** | What dosage of running should be permitted before sprinting is safe |
| ***timing*** | ***4*** | How early is it safe to sprint? |
| ***Total*** | ***30*** | |

*Table 4 What are the questions you would most want answered on Surgery for HSI?*

| ***Domain Area*** | ***responses*** | ***Typical responses*** |
|---|---|---|
| ***Outcomes*** | ***8*** | Does it affect functional outcomes? |
| ***Indications*** | ***9*** | What level of tendon disruption requires surgery? |
| ***Surgery vs Conservative*** | ***7*** | Is it more effective than conservative management? |
| ***Long term effects*** | ***4*** | What are the long-term outcomes for elite athletes having had surgery? |
| ***Surgery & RTS*** | ***3*** | Does it affect time to return preinjury level of sporting activity? |
| ***Recurrence rate*** | ***3*** | Does surgery reduce reinjury? |
| ***Techniques*** | ***3*** | Can surgical drainage of large intramuscular haemorrhage improve recovery without repair of muscle? |
| ***Timing post injury*** | ***3*** | How soon after certain pathologies should surgery be undertaken? |
| ***Rehabilitation post-Surgery*** | ***1*** | Development of an evidence-based rehabilitation protocol. |
| ***Terminology*** | ***1*** | Consistent terminology much-needed |
| ***Injury factors*** | ***1*** | Can we grade injuries needing surgery |
| ***Surgery never required*** | ***1*** | |
| ***Relationship w classification*** | ***1*** | When is surgery indicated for particular hamstring classifications? |
| ***Total*** | ***45*** | |

## Appendix 4 Consensus statements – and voting for Round 2 Survey

*Table 1 - Consensus statements and percentage agreement for round 2 survey – Global expert Panel -* ***Rehabilitation***

| **Statements related to General Rehabilitation** | | **TRUE** | **FALSE** | **Undecided** | **Samples of typical responses - discussion points or areas of disagreement** |
|---|---|---|---|---|---|
| ***Initial and progressive loading of injured hamstring muscles should include exercise with different: - -contraction types, muscle lengths, functional movements, body positions, but the type of exercise will depend on the sports specific adaptation required, symptoms and risks of reinjury*** | | **89.8%** | **8.5%** | **1.7%** | Initial loading about neuromuscular stimulation and improving healing / Muscle tension at length not ideal/ initial loading isometric to minimise stress or shearing on tendon / eccentric contractions should be the focus. |
| ***The ORDER and SPEED of PROGRESSION of exercises - (concentric / isometric / eccentric exercises), hip and knee-based exercises, Inner and outer length exercises and open and closed kinetic chain exercises) - will depend on: -*** | ***adaptation required*** | **96.2%** | **0.0%** | **3.8%** | Level of agreement reflects the importance of the target adaptations required as a criterion for prescription. |
| | ***symptoms*** | **88.9%** | **7.4%** | **3.7%** | Symptoms were the main criterion used by rehabilitation clinicians to make decisions. |
| | ***type of injury*** | **75.0%** | **15.4%** | **9.6%** | Overall, the injury and tissue type were major considerations for clinicians in deciding on exercise. |
| | ***risk of recurrence*** | **60.4%** | **26.4%** | **13.2%** | No comments made -? Possibly reflecting the little literature available on this. |
| | ***stage of tissue healing*** | **90.7%** | **5.6%** | **3.7%** | Tissue and stage of healing showed strong agreement - discussions suggested that it was harder to know at tissue level how healing was progressing, and symptoms were used as a surrogate to this. |
| ***The CRITERIA FOR PROGRESSION of exercise should include: -*** | ***symptoms pain*** | **90.7%** | **1.9%** | **7.4%** | Symptoms were the main criterion used by rehabilitation clinicians to make decisions. |
| | ***strength*** | **92.7%** | **3.6%** | **3.6%** | While strength overall showed good agreement - there was less agreement on which components of strength were thought to be most important. |
| | ***Special tests*** | **62.7%** | **13.7%** | **23.5%** | Lack of agreement on specific tests - but a combination of factors was thought to be more important |
| | ***Functional milestones*** | **87.3%** | **5.5%** | **7.3%** | Function was agreed to be important - but panel could not agree on which functional milestones are most important. |
| | ***Flexibility*** | **67.9%** | **17.0%** | **15.1%** | Flexibility and ROM were thought by the panel to be less important as a criterion- and comments were that strength exercises at longer length were sometimes used to build flexibility concurrently with strength. |
| | ***The severity of the injury*** | **73.1%** | **15.4%** | **11.5%** | After the initial diagnosis and early treatment stage the progressions were led more by the above criteria than the severity of the injury - although many issued cautions with tendon injuries and higher-grade tendon injuries due to risk of re rupture. |
| ***The Dosage of exercise (frequency, intensity, duration) should be based on: -*** | ***The response to previous loading*** | **96.3%** | **1.9%** | **1.9%** | Graded process of loading and assessing response - both during and after exercise - especially in terms of pain - it was felt this gave the optimum speed of rehab |
| | ***Examination findings*** | **88.2%** | **9.8%** | **2.0%** | High agreement that examination was vital prior to progressions in dosage. |
| | ***Stage of Healing*** | **86.5%** | **7.7%** | **5.8%** | Appropriate healing level to tolerate applied loads. |
| | ***Periodisation factors*** | **88.2%** | **3.9%** | **7.8%** | Weekly and seasonal factors affect decisions on dosage and are key considerations in elite sport environments. |
| | ***Sporting level*** | **82.7%** | **15.4%** | **1.9%** | These 3 questions related to knowing the end goal in load capacity for match fitness, which will depend on type and level of sport. |
| | ***Current and previous capacity*** | **88.7%** | **7.5%** | **3.8%** | |
| | ***The target adaptations related to the patient's goals and or sport*** | **92.3%** | **3.8%** | **3.8%** | |
| | ***Strength*** | **92.6%** | **3.7%** | **3.7%** | Training principles of overload - ensuring strength loads are progressed to enable muscle to keep adapting - i.e., avoid accommodation to the equivalent applied loads. |

| | | | | |
|---|---|---|---|---|
| ***Fitness*** | **78.8%** | **13.5%** | **7.7%** | Cardiovascular fitness may not affect dosage in gym-based work but will affect running work. |
| ***Severity of the injury*** | **84.6%** | **11.5%** | **3.8%** | It may not be appropriate to load some injuries too heavily - as they may not have symptoms but still be at risk of retear - it biceps femoris and central tendon involvement. |
| ***The whole rehabilitation process should be agreed within the MDT and have athlete engagement*** | **96.8%** | **1.6%** | **1.6%** | MDT and athlete engagement were key - the discussions were around all the stakeholders' potentially conflicting goals and timeframes. |
| ***The patient's sport and previous level of participation will impact the progression of exercise selection and ultimate return to activity*** | **95.2%** | **3.2%** | **1.6%** | The discussions were like the 3 questions above. |
| ***It is important to consider the possibility of sciatic nerve / neural symptoms when considering a patient's progression through rehabilitation. Neural mobility could be considered in treatment but the protection of the repaired or vulnerable tissue should be maintained.*** | **90.5%** | **0.0%** | **9.5%** | Strong agreement. Neural Tethering / scarring in the healing process was also thought to be one reason for lack of progression with conservative treatment. |
| ***ADJUNCTS to REHABILITATION, such as blood flow restriction, electrical stimulation and hydrotherapy should be considered in the early stages to enhance tissue healing and recovery (Caution should be used with cuff pressures over repairing tissues when using blood flow restriction (BFR) training)*** | **68.9%** | **6.6%** | **24.6%** | There was less uniform global practice when relating to use of adjuncts such as BFR- this reflects small evidence base only in HIS. |
| ***Rehabilitation should be MONITORED with appropriate markers that are progressive with recovery*** | **98.4%** | **0.0%** | **1.6%** | Monitoring was agreed but the most common form of monitoring was very varied!! - most panellists mentioned monitoring with GPS data allowing on field training / match play load data. |
| ***Final stage strengthening should aim to achieve adequate symptom free, outer range, eccentric and isometric strength in injured and uninjured limb.*** | **95.2%** | **1.6%** | **3.2%** | Panel had agreement on the types of strength to be achieved by final stage rehab - with outer length eccentric and isometric strength - in line with evidence on strength. |
| ***It is key during a hamstring rehabilitation to assess, treat and prescribe exercises addressing the whole kinetic chain.*** | **90.5%** | **3.2%** | **6.3%** | Panel agreed that biomechanical kinetic chain was important but there was less agreement on which were the most important components - many panellists suggested that it should be individualised and decided based on thorough subject and objective examination. |

*Table 2 - Consensus statements and percentage agreement for round 2 survey – Global expert Panel -* ***Return to Running***

| Statements related to return to running | TRUE | FALSE | Undecided | Samples of typical responses - discussion points or areas of disagreement |
|---|---|---|---|---|
| ***On pitch/track/field (sport specific) running is a significant part of hamstring rehabilitation.*** | **98.4%** | **1.6%** | **0.0%** | Levels of agreement for these 2 questions reflects the importance of running as part of HSI rehabilitation. |
| ***Running dosages should be gradually increased to ensure return to full sprinting.*** | **100.0%** | **0.0%** | **0.0%** | Hamstring muscle function discussed and difference in function at speed was acknowledged. |
| ***Sprinting dosage loads should approach game level intensities and volumes to reduce risk of recurrence on return to sport*** | **95.2%** | **4.8%** | **0.0%** | Sprinting in games presents injury risk and sprint work is a key component in final phase rehabilitation. |
| ***Further research should investigate the specific actions, bias, roles of individual muscles in function of running and sprinting to aid rehab exercise prescription.*** | **84.7%** | **0.0%** | **15.3%** | Differences in muscle roles were discussed and the panel expressed need for more research into how the differences in muscle function will then impact rehabilitation. |
| ***Further research should investigate types (styles) and dosages of running (quantity, speed) that promote adaptations but reduce risk of recurrence*** | **90.3%** | **1.6%** | **8.1%** | Discussions suggested that running had not been prioritised sufficiently in literature and identified a research need. |
| ***Further research should investigate safe time frames to commence running post Hamstring injury or surgery*** | **90.3%** | **1.6%** | **8.1%** | Risk of reinjury is high when reexposing HSI athletes to running - and the panel wanted safter time frames for return - and more research onto timeframes. |

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| ***Mild pain with running is permissible in rehabilitating certain HSI, but we need to consider the function of the individual, the anatomy, injury, classification and the 24-hour pain pattern (subjective and objective)*** | **83.9%** | **9.7%** | **6.5%** | The panel acknowledged many athletes have pain when restarting running - there was less agreement on how much pain was permissible / deleterious - the stated consideration factors reached agreement but other factors did not. |
| ***In HSI Pain free running is a criterion for return to sprinting.*** | **85.5%** | **8.1%** | **6.5%** | The panel agreed that pain levels should be reduced prior to permitting sprinting - the panel acknowledged that the initial commencement of full sprinting - was a high-risk period for reinjury. |

*Table 3 - Consensus statements and percentage agreement for round 2 survey – Global expert Panel -* ***Return to sport***

| **Statements related to Return to Sport** | **TRUE** | **FALSE** | **Undecided** | **Samples of typical responses - discussion points or areas of disagreement** |
|---|---|---|---|---|
| ***In HSI, Range of motion is a consideration for RTS. If previous data is available, then within 10% of previous scores should be used otherwise within 20% of the other limb*** | **45.0%** | **23.3%** | **31.7%** | Flexibility was not considered a key factor by many clinicians - stretching did not always produce improvements in function or performance and less agreement over acceptable levels. |
| ***Kinetic chain strength/function is a consideration criterion for RTS.*** | **78.3%** | **6.7%** | **15.0%** | All agreed Kinetic chain was important - but panel did not agree on key kinetic chain factors. A clinical reasoning approach was advocated to assess each athlete based on the required sporting demand and key injury risk activities. |
| ***Progression to Peak isometric force in mid and outer range, isotonic strength (eccentric only/eccentric & concentric) are all considerations for RTS*** | **83.3%** | **1.7%** | **15.0%** | Optimal types of exercise were controversial but consistent with literature - eccentric or isometric exercises at length were considered important and reached agreement. |
| ***Benchmarks for strength should reflect the end goal demands of the athlete but should be within 10% of previous data or population means*** | **66.1%** | **10.2%** | **23.7%** | The low agreement for this question reflected differences in opinion on strength benchmarks. |
| ***Athlete subjective apprehension is a consideration for RTS criteria.*** | **98.3%** | **0.0%** | **1.7%** | The strong agreement reflects the importance the panel placed on the athletes leading the RTS / RTR process - and ensuring their opinion was prioritised. |
| ***Athlete self-assessment of their readiness to RTS is a key factor in the return to sport decision making process.*** | **86.7%** | **5.0%** | **8.3%** | |
| ***Askling H-Test is a useful test in the return to sprinting decision process*** | **57.6%** | **18.6%** | **23.7%** | The respondents were divided on use of pain provocation tests.<br>Their usefulness was acknowledged but it was felt that no one specific test could assess readiness to return to sprinting - and the tests should form part of an ongoing assessment and clinical reasoning process. |
| ***Endurance Capacity testing of the hamstrings should be a consideration for RTS*** | **78.3%** | **6.7%** | **15.0%** | Endurance was felt to be important, but it was harder to get agreement on which endurance tests were most important - running endurance was felt to be important but the panel suggested that the level of endurance related to the specific sporting demands. |
| ***Pain free sprinting is a criterion for return to play*** | **96.7%** | **1.7%** | **1.7%** | The importance of sprinting in match play / competition was acknowledged, with high agreement. There was less agreement on the dosage of full sprinting. While some pain was permitted in running, sprinting in RTS - was expected to be pain-free. |
| ***Completing full unrestricted training session should be a criterion for Return to Sport*** | **93.3%** | **6.7%** | **0.0%** | Training sessions reached agreement - particularly as this assessed the athlete with sports specific demands and endurance requirements. |
| ***The use of previous GPS metrics can guide the required dosage of appropriate metrics i.e., volume, sprints, speed, HSR*** | **83.3%** | **3.3%** | **13.3%** | Many in the panel were using GPS to measure running dosage - and their usefulness was thought to be key - with practice expertise moving faster than research evidence base - this was thought be an area requiring greater research. |
| ***Return to sport should be a multidisciplinary process that involves all stakeholders ideally*** | **98.3%** | **0.0%** | **1.7%** | The importance of a whole MDT and coaching athlete stakeholder involvement reached high LOA - but many clinicians acknowledged significant pressure from stakeholder groups to modify their clinical decision-making. |

*Table 4 - Consensus statements and percentage agreement for round 2 survey – Global expert Panel -* ***Classification***

| **Consensus statements related to Classification** | | **TRUE** | **FALSE** | **Undecided** | **Samples of typical responses - discussion points or areas of disagreement** |
|---|---|---|---|---|---|
| ***Anatomical (radiological) classification is essential in the diagnostic process*** | | **62.0%** | **22.0%** | **16.0%** | It is essential in the higher-grade hamstrings to determine the tendon involvement however with smaller strains radiology is non-essential. |
| ***There is a need for One main classification system (agreed terminology and nomenclature).*** | | **84.8%** | **2.0%** | **13.1%** | A 'one size fits all' may not be appropriate. Different sports have different mechanisms of injury, demands and therefore RTP times, and re injury rates.<br>Seems logical that what may work for track and field doesn't necessarily hold true for football. Difficult to fit everything into one main classification anatomy, function, and prognostication. |
| ***Classification needs clear parameters such as (but not limited to) :-*** | ***Anatomical, radiological classification*** | **95.9%** | **0.0%** | **4.1%** | It appears research remains undecided for the influence of anatomical location and free vs central tendon involvement in classification systems. |
| | ***Free Tendon vs Central Tendon*** | **86.9%** | **6.1%** | **7.1%** | Again, the evidence is limited in the classification of tendon vs MTJ injuries (as an example). No evidence suggests central tendon involved injuries are better off with surgical intervention or not.<br>The only evidence we do have is that treating without the MRI and using clinical markers to guide progression is the only consistent approach, whether central tendon is involved or not. |
| | ***Should evolve to include surgical criteria*** | **52.1%** | **19.8%** | **28.1%** | Surgical criteria would be useful for practitioners deciding on prognosis and management. |
| ***Classification systems should have agreed Terminology*** | | **91.8%** | **2.0%** | **6.1%** | Diagnostic classification system should be clear in reports and research. Only for consistency's sake from both a scientific and clinical perspective. |
| ***There is a need for a registry for hamstring injuries*** | | **68.7%** | **10.1%** | **21.2%** | more data is useful, but I fear people will bias their interpretation of it (E.g., all central tendon injuries take longer to rehab than MTJ - but this is because you treated them based on the MRI which showed central tendon and you were conservative as a result). This bias is tough to avoid in these registry datasets and people will misconstrue the data. Would be difficult with so many sports. Maybe intra sport registry. |
| ***Mechanism of injury should be commented alongside the classification (where appropriate / known)*** | | **82.0%** | **11.0%** | **7.0%** | This always allows for a clearer prognosis/ This is more useful than the classification system. /Affects anatomical involvement, prognosis, and rehab decisions. |
| ***We SHOULD differentiate between muscles in the classification?*** | | **88.9%** | **4.0%** | **7.1%** | Obvious/Different muscles have different functions so a classification that guides rehab is desirable<br>hamstrings have different structure and therefore function which needs to be clearly stated to understand if certain muscles are at greater re-injury risk or require longer / Requires a very demanding system that may be too difficult to adhere to. |
| ***Beyond anatomical classification, there is a need to have: -*** | ***functional criteria running beside*** | **90.0%** | **6.0%** | **4.0%** | Time to walk pain free/Confidence to Sprint/ patient expected time to return to sport. |
| | ***PROMS running beside*** | **80.4%** | **10.3%** | **9.3%** | Current PROMs for hamstring injury may not be particularly useful/ PHAT LEFS/ Marx score/ FASH. |

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| ***Imaging is vital in the classification system*** | | **70.5%** | **14.7%** | **14.7%** | To decide between conservative or surgery, not otherwise/ Would prefer that classification would guide us to ask for imaging. Not that imaging is always essential especially in low grade injury/ in professional sport, imaging is more often required than not, however does not always change management. |
| ***Immediate Physical Examination signs like bruising, loss of muscle tension, palpable defects and /*** *or significant* ***weakness and excessive/no response on provoking activities warrant further investigation*** | | **92.6%** | **2.1%** | **5.3%** | In this presentation you are suspecting a free tendon or complete rupture which may require surgery/ Pain level and mechanism (suggesting a complete tear, avulsion, or anything else that might require a surgical opinion. |
| ***MRI is the preferred imaging for diagnosis and classification*** | | **89.5%** | **4.2%** | **6.3%** | If used, I prefer MRI/ Ultrasound imaging can be very useful if conducted by a physician/ sonographer with lots of training. Ultrasound is also very suited to examine the damaged muscle- connective tissue area under movement. Ultrasound can also be a good cheaper alternative. |
| ***MRI side to side comparison is ideal for classification*** | | **49.5%** | **25.3%** | **25.3%** | This does not happen that often due to financial restrictions. Enough information can likely be gained from a unilateral MRI to give an accurate diagnosis. /Contralateral side is not always a 'healthy' side/Should be used together with US/I prefer a correct protocolized MRI only of the affected side. |
| ***When is Ultrasound most useful / relevant as*** | ***primary imaging after injury PRE 48 hours*** | **14.8%** | ***58.0%*** | **27.3%** | Ultrasound is not particularly useful when there is a lot of oedema, in the early post-injury period. |
| | ***primary imaging after injury POST 48 hours*** | **25.8%** | ***42.7%*** | **31.5%** | 4-day deadline is best to see well the hematic collection. |
| | ***in the rehabilitation phase*** | **61.8%** | **16.9%** | **21.3%** | It depends in what aspect. Architecture - yes. Lesion tracking -no. |

*Table 5. Consensus statements and percentage agreement for round 2 survey – Global expert Panel -* ***Surgery***

| **Statements related to domain of Surgery** | | **responses** | **not answered** | **TRUE** | **FALSE** | **Undecided** | **Samples of typical responses - discussion points or areas of disagreement** |
|---|---|---|---|---|---|---|---|
| ***Factors that drive surgical intervention include: -*** | ***Previous hamstring harvest or HSI*** | **83** | **32** | **26.5%** | **38.6%** | **34.9%** | I think all of these are relevant but none of them determine/ drive/ necessarily require surgical intervention. Undecided if any of these factor into surgical intervention unless coupled with poor functional outcomes (e.g., lack of rehab progress etc). The level of athlete and stage of competition are also factors to consider. |
| | ***Recurrent Injury*** | **83** | **32** | **33.7%** | **38.6%** | **27.7%** | All factors should be considered, and the importance of each factor differs depending on type of injury and type of patient. Recurrence: not been proven that surgery will reduce recurrence rate.<br>I am not aware of any convincing, high quality scientific data on the success of surgery following hamstring injuries. |
| | ***Injuries with a high recurrence rate*** | **84** | **31** | **40.5%** | **28.6%** | **31.0%** | |
| | ***Gapping at the zone of injury*** | **86** | **29** | **87.2%** | **2.3%** | **10.5%** | This was felt to be the main driver. Degree of tendon retraction important the main indication for surgery if complete free tendon (BA grade 4) for grade intra tendon injury > 50% of the CSA. High (3b) grade injuries can make a complete return to sport. |
| | ***Loss of tension*** | **82** | **33** | **70.7%** | **13.4%** | **15.9%** | Loss of tension is evident in most injuries, as an acute sign, but improves with healing, it is less important than size of gap and loss of tendon tension more important than myofascial tension |
| ***The indications for surgery in hamstring injuries are dependent on: -<br>the anatomy of the injury<br>the demands on the athlete/patient<br>and the expected functional outcome.*** | | **85** | **30** | **87.1%** | **9.4%** | **3.5%** | I don't know that we have enough information now to be able to say with any confidence who is truly in need of surgery (if anyone), Until we simply have decent outcome studies looking at usual care, and something comes out of the data, we're guessing.<br>Dependent on the anatomy but not the demands of the athlete/ patient or the expected functional outcome.<br>Function, recurrence, and lack of progress are the main ones for me.<br>Failure of conservative care would seem to be the only indication at the moment as near as I can tell.<br>This is true but just in some type of injuries (e.g., those affecting the free tendon). |

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| | | | | | | | Anatomy yes If conjoint tendon full rupture in elite athlete, I would advocate surgery. Semimembranosus full rupture would advocate conservative. Degree of tendon retraction important in ST or BF rupture. If small and healing possible then would trial conservative first. |
| ***Surgical management has the capacity to: -*** | ***Speed up recovery timescales*** | **86** | **29** | **36.0%** | **36.0%** | **27.9%** | Speed up: not supported by literature/surveys. Current protocols are very slow.<br>For Speed up recovery timescales = I would say speeds up and gives more consistent/ predictable recovery which gives us good outcomes. Only for high grade avulsions. |
| | ***Restore Anatomy and function*** | **85** | **30** | **87.1%** | **1.2%** | **11.8%** | We need more research into this, but potentially true as surgery is often undertaken with failed conservative management. |
| | ***Reduce risk of recurrence*** | **85** | **30** | **48.2%** | **17.6%** | **34.1%** | Need more research into this but potentially true as surgery often undertaken with failed conservative management. Reduced recurrence has been the experience in our cohort.<br>Recurrence: not been proven that surgery will reduce recurrence rate.<br>I have seen reinjury at different location following grade 4 injuries and free tendon repair.<br>Reoccurrence will be hugely influenced by post operative rehabilitation and a progressive RTP.<br>Surgery will restore anatomy, but an injury may reoccur due to ineffective rehabilitation.<br>Recurrent injury only relevant if recurrent tendon or previous surgery, or sciatic nerve issue requiring neurolysis.<br>Reduces recurrence we believe but less predictability with conservative treatment in high grade tendon injury. |
| ***Hamstring fixation should be performed endoscopically*** | | **84** | **31** | **9.5%** | **25.0%** | ***65.5%*** | Need better field of view - attachment footprint is too large and sciatic nerve involvement should be checked |
| ***The reporting of hamstring recurrence should be based on the IOC criteria and cover a two-year time frame*** | | **84** | **31** | **53.6%** | **11.9%** | **34.5%** | Long term outcomes certainly would make for a fairer appraisal of benefits.<br>Assume this in reference to the Methodological consensus statement on reporting of injuries? I think as we standardize our approach, this is certainly the most relevant and up to date reference for reporting.<br>Yes, for research purposes but 2 years is a long time. I would prefer 1 season |
| ***Undisplaced bony hamstring avulsions DO NOT require immediate operative intervention*** | | **81** | **34** | **50.6%** | **18.5%** | **30.9%** | There are several factors that contribute to this decision-making process, having a binary approach is too difficult. In addition, there needs clarity of what type of bony avulsion is being referenced.<br>It depends on athlete characteristics. Function during rehab should dictate this.<br>Need to be re-imaged and monitored closely. |
| ***Displaced bony avulsions of the ischium should be managed operatively if symptomatic*** | | **81** | **34** | **72.8%** | **4.9%** | **22.2%** | Depends on function, how much displacement, and athlete level and characteristics. |
| ***Surgical intervention for bony avulsions of the ischium should be: -*** | ***Internal fixation*** | **78** | **37** | **46.2%** | **5.1%** | **48.7%** | It depends on the time frame and the fragment size, bone to bone healing is preferable.<br>If the fragment is too small, non-union may develop with internal fixation and in this scenario resection and soft tissue repair is favoured. |
| | ***Resection of Avulsed bone and Soft Tissue Repair*** | **77** | **38** | **31.2%** | **14.3%** | **54.5%** | |
| ***Undisplaced soft tissue hamstring avulsions can be initially managed non operatively*** | | **80** | **35** | **61.3%** | **7.5%** | **31.3%** | Depends on time frames and upcoming competitions. Maybe able to be managed non-operatively if time frames allow. However, surgery will help give an accurate RTP prediction.<br>This is dependent on several factors such as extent of injury, which hamstring, playing position etc |
| ***Undisplaced proximal hamstring origin tears should be managed operatively in athletes*** | | **79** | **36** | **32.9%** | **27.8%** | **39.2%** | We don't have RCTs, |
| ***Criteria for surgical intervention in the proximal free tendon injuries include*** | ***loss of muscle and tendon tension which results in a gap*** | **79** | **36** | **83.5%** | **1.3%** | **15.2%** | Dependent on size of gap, and the level of athlete? |
| | ***risk of functional loss / performance deficit with non-operative management*** | **79** | **36** | **72.2%** | **7.6%** | **20.3%** | Proven loss of function in a patient who has a thorough understanding of the outcomes of surgical and conservative care and the patient still wishes to undergo surgery.<br>We don't have RCTs, tough one. Dependant on whether elite or recreational athlete. |
| ***The management of free tendon injuries with displacement differs from that of intramuscular tendon injuries where the overall fascial envelope is still intact*** | | **79** | **36** | **69.6%** | **6.3%** | **24.1%** | Intramuscular tendon injuries benefit from the 'scaffold' of surrounding muscular tissue<br>I think free tendon injuries are a different type of injury than a hamstring injury with damage to the intramuscular tendon and require therefore specific treatment.<br>The jury is still out on this. It would be a good topic for a well-coordinated multi-centre RCT. |
| | ***corticosteroid injections*** | **80** | **35** | **2.5%** | **80.0%** | **17.5%** | Evidence conflicting, but panel consensus disagreement on this statement. |

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| ***Undisplaced soft tissue hamstring avulsions is there a role for*** | ***injecting Blood / Platelet Rich Plasma (PRP)?*** | **80** | **33** | **16.3%** | ***50.0%*** | **33.8%** | ? PRP although evidence is weak at best. We have not used PRP but can see why it is worth consideration if you were going to trial conservative management. |
| | ***Other injections*** | **69** | **46** | **1.4%** | ***53.6%*** | **44.9%** | Dry needling. No conclusive evidence that these approaches improve outcomes. |
| ***Does haematoma aspiration have a role in*** | ***avulsions*** | **79** | **36** | **19.0%** | **40.5%** | **40.5%** | Perhaps large haematoma around the sciatic nerve - risk of fibrosis and adhesions. |
| | ***Tendon Injuries*** | **79** | **36** | **19.0%** | **41.8%** | **39.2%** | Injections/aspirations increase infection risk and haematomas often recur after aspiration. However, there may be. Has a role but precaution as the blood product may actually assist healing and fibrosis/ tear bridging. exceptions in case of very large or painful haematomas where the patient is fully informed and decides to take the risk. Only when it gives symptoms (content of haematoma is comparable to PRP). |
| | ***Other types of HSI*** | **78** | **37** | **28.2%** | **33.3%** | **38.5%** | Morel-lavallae lesion<br>Contusions for symptomatic relief |
| ***There is a role for drainage of haematomas without surgery for hamstring muscle injuries and avulsions*** | | **77** | **38** | **29.9%** | **32.5%** | **37.7%** | The haematoma being a space occupying lesion and preventing complete healing makes theoretical sense, but the few times we've tried it, the gap promptly refilled with blood despite firm compression bandaging. Maybe there's a technically better way to do this, but we've not figured it out yet.<br>Hematoma potentially contributes to regeneration. |

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# 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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