

Hamstring muscle injury in the athlete: state of the art

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ABSTRACT

Hamstring injuries (HSI) are the source of significant impairment and disability for both professional and recreational athletes. The incidence and prevalence of HSIs has been well documented in the literature, as they are among the most common soft tissue injuries reported. The significant time loss due to injury and the inherent risk of reinjury pose a significant issue to the athlete, their career longevity and the success of their respective team. This review will deal predominantly with describing the prevalence and incidence of HSI in athletes, discuss risk factors and the mechanisms of injury for HSI, how to properly diagnose, image and prognosticate appropriate return to sport (RTS) for individuals who have sustained an HSI, prescribe treatment and prevention strategies and to discuss relevant options to decrease overall risk of primary and secondary recurrence of HSI.

Current treatments of acute HSI necessitate a thorough understanding of the mechanism of injury, identifying muscle imbalances and/or weakness, inclusion of eccentric and concentric hamstring (HS) and hip extension (HE) exercises, evaluation of pathokinematic movement patterns and use non-surgical methods to promote healing and RTS. This methodology can be used prospectively to mitigate the overall risk of HSI. Injection therapies for HSI, including ultrasound-guided platelet-rich plasma and corticosteroids, may impart some short-term benefit, but the existing literature is largely inconclusive with respect to long-term functional outcomes. Future directions should prioritise injury prevention, early diagnosis and targeted interventions that combine both non-surgical and minimally invasive orthobiological approaches and identifying biomechanical risk factors prospectively to mitigate risk.

INTRODUCTION

Hamstring injury (HSI) is a common musculoskeletal pathology that afflicts active individuals and professional athletes alike. The incidence and prevalence of HSI has been well established, particularly in the sports of soccer (football), American football, Australian rules football, rugby, cricket, Gaelic football, baseball and track and field.^{1–8} They occur more frequently in competitive games versus training.^{9–12} Individuals who have sustained an acute HSI typically present with posterior thigh pain that occurred during high-speed running or an overstretched position.¹³ An athlete that has incurred an HSI may report localised pain and an audible pop at the time of injury, which is more likely indicative of an injury to the proximal tendon.¹⁴ HSIs are typically self-limiting, and athletes tend to

have persistent symptoms and a prolonged period of convalescence.¹⁵ These injuries represent over 39% of all reported sports injuries and may result in prolonged time loss due to injury, ranging from 17 to 90 days, which requires extensive treatment intervention and rehabilitation.^{7 16–19} In addition, 12%–63% of individuals who sustain an HSI are subject to a recurrence.^{1 6 7 16–18 20–24} Approximately one-third of these reinjuries occur within 1 year of the initial injury, and are often more severe.²⁵ The high recurrence rate of HSI may be attributed to insufficient rehabilitation interventions, not addressing the true aetiology of the injury, or not meeting the objective criteria for return to sport (RTS).^{9 15} Prior injury is the most common risk factor reported for a secondary HSI.²⁶

ANATOMY OF THE HAMSTRING

The hamstring (HS) muscle group comprised three individual muscles: the semitendinosus (ST), semimembranosus (SM) and the biceps femoris (BF). It originates at the ischial tuberosity and runs distally along the femur, crossing the femoroacetabular and tibiofemoral joints. The short head of the biceps femoris (BFsh) has a unique origin, the lateral lip of the femoral linea aspera, and does not cross the femoroacetabular joint.²⁷ The proximal long head of the biceps femoris (BFlh) and ST muscles form an aponeurosis which extends distally from the ischial tuberosity, which explains why the BFlh and ST may be injured simultaneously. The proximal tendon occupies approximately 60% of the length of the BFlh, while the musculotendinous junction (MTJ) spans the remainder of the muscle length and terminates in the muscle belly.²⁸ The BFlh is innervated by the tibial portion of the sciatic nerve, while the SM is innervated by a nerve branch descending from the common peroneal nerve. However, there is some evidence that the SM has two nervous system sources: a branch of the sciatic nerve and another nerve emanating from the common peroneal nerve. The ST is innervated by one or two branches of the tibial nerve.²⁹

MECHANISM AND TIME LOSS DUE TO INJURY

The mechanism of injury is an important prognostic factor when determining appropriate rehabilitation treatment protocols and allowing an athlete to ultimately RTS. HS strain injuries occur more commonly in men³⁰ and in sports that require sprinting, hurdling, kicking and high-speed movements with coupled hip flexion and knee extension.^{31 32} They are most likely to occur during late swing and the late stance phase of sprinting, which



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Figure 1 Coronal short tau inversion recovery (STIR: Short-TI Inversion Recovery) MRI of the thigh in a professional soccer athlete incurred during sprinting. There is a grade 2a injury of the semitendinosus muscle (red arrows).

requires anterior pelvic tilt and extensive elongation of the HS muscle group as the limb decelerates in preparation for initial foot contact.^{9 15 33 34} There are two types of HSI: type 1 HSI and type 2 HSI. Type 1 HSI occurs while running and sprinting; while maximum eccentric contraction and muscle elongation occurs in the BFlh.^{35–37} Type 1 usually entails involvement of the BFlh^{31 38–40} (figure 1). Running-related injuries usually occur at the MTJ, the aponeurosis and the fibres adjacent to these structures.¹⁵ Type 2 HSI occurs with excessive lengthening of the HS, with the hip flexed and the knee extended (during dancing, gymnastics, sliding and tackling). Type 2 HSI usually involves the SM and its proximal free tendon.^{15 41}

HS strains account for 50% of muscle injuries incurred in sprinters and are the most commonly reported injury in

hurdlers.^{37 42 43} In American Football National Football League (NFL), most HSIs are sustained during non-contact activities, with sprinting as the primary activity, and tend to occur more often during preseason. HSIs were the most common and the most severe muscle strain in preseason, with an average of 8.3 days lost to injury.³ In the Australian Football League (AFL), the HSI injury rate (IR) in matches is 4.3/1000 player-hours, 2.2/1000 player-hours in training and 0.8/1000 player-hours in preseason with a 34% recurrence rate. The average time loss due to HSI was 21.2 days.⁵ In professional rugby union players, the reported IR of HSI was 5.6 injuries/1000 player-hours in matches and 0.27/1000 player-hours in training, with an average time loss of 17 days per injury.⁴⁴ The players with a history of HSI had a significant fourfold greater risk of subsequent HSI than players without a history of HSI.⁴⁵ In professional baseball, 62% of HSI injuries occur during base running (running to first base) and account for 6% of all injuries reported in one season (0.7/1000 athlete exposures (AE) major league and 0.7/1000 AE minor league). The average time loss in the major league is 27 days and 24 days in the minor league. Two-thirds of reported HSIs resulted in more than 7 days of time loss and 25% of HSIs required 1 month or more to successfully RTS. Of all the HSIs reported during the study period, 20% were recurrences from the previous year in Major League Baseball (MLB) and 8% in Minor League Baseball.² In elite soccer, HSI incidence has been increasing in the last two decades at the rate of 2.3% each year⁴⁶ and accounts for 12% of all injuries in a football squad.¹¹ A team consisting of 25 soccer players can expect approximately seven HS strains each season.¹¹ HSI in soccer usually occurs by virtue of an indirect mechanism ($\approx 80\%$). The incidence of HSI in matches is ninefold higher compared with training, but the incidence rate increase has been more prolific for training injuries.⁴⁶

RISK FACTORS

Risk factors for HSI can be stratified into two categories: modifiable and non-modifiable. Modifiable risk factors include altered muscle length, decreased muscular flexibility, strength imbalance, core weakness/instability, exercise volume, insufficient warm-up, anterior pelvic tilt, lumbar pathology, increased neural tension and fatigue.^{1 31 43 47 48} Age, sex, race and previous HSI are defined as non-modifiable risk factors.^{28 49} Studies have consistently identified that the most significant risk factors for

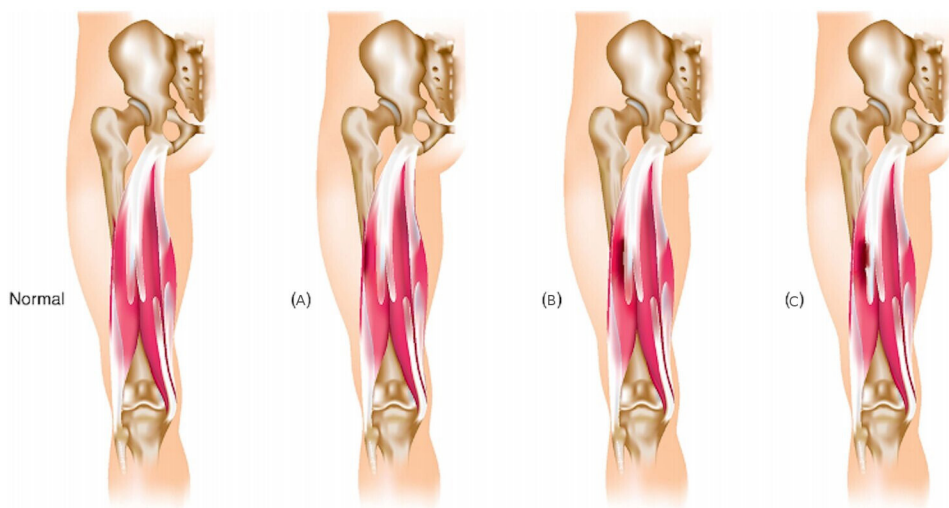


Figure 2 Intratendinous. British Athletics Muscle Injury Classification system: letter classification system based on the anatomical site of muscle injury. (A) Myofascial, (B) musculotendinous, (C) intratendinous. Pollock *et al.* *Br J Sports Med* 2012; 46: p 112–117.¹¹²



Figure 3 Asking's L-protocol for hamstring injury: (A) The Extender, (B) The Diver, and (C) The Glider.

HSI were increasing age and history of ipsilateral HSI.^{50–52} However, the literature supporting the scientific validity of other risk factors is inconsistent.^{31,50} Height, weight, body mass index, hamstring:quadriceps (H:Q) isokinetic ratio, maximal average power, player exposure and HS and quadriceps flexibility were not found to be significant in the regression analysis.^{50,52,53}

Sex, race and previous HSI

Most HSIs occur in male athletes. Dalton *et al*⁹ analysed the National Collegiate Athletic Association Injury Surveillance Program database and found that the HSI IR in males exceeded that of females for soccer, baseball/softball and indoor track. In a study analysing HSI in collegiate soccer players, men were 64% more likely to incur an HSI compared with female soccer players. In addition, 22% of males sustained an HSI recurrence compared with 12% of females.³⁰ In a study involving male and female track and field athletes (aged 13–25 years), high school girls displayed a lower HSI compared with high school boys.⁵⁴ In contrast, in an epidemiological study analysing high school soccer players (aged 13–18 years), males demonstrated a lower IR for thigh muscle strain compared with females.⁵⁵ A study investigating Dutch amateur female soccer players using the Hip

and Groin Outcome Score (HAGOS) determined that 11% of the players had reported a history of HSI.²²

There had been limited evidence to support race as a predictive variable for an HSI recurrence.⁴⁹ Recent epidemiological studies have suggested that professional athletes of Black African, Caribbean and Aboriginal descent participating in Australian rules football, rugby union and soccer may have an increased risk of HSI.^{16,56,57} Anthropometric and physiological differences across ethnicity, including differences in VO₂max, muscle phenotype, percentage of type II fibres and lumbopelvic positioning, have been implicated in the increased risk of HSI in the aforementioned races compared with their Caucasian counterparts. During a soccer-specific aerobic field testing (SAFT 90) protocol, performance, significant overall concentric quadriceps peak torque and eccentric HS peak torque decreased over both halves of a soccer match. There was also a significant decrease in H:Q functional strength ratio (10.1%).⁵⁸ The measurable changes observed in Black African soccer players throughout the soccer match play may have implications for competitive performance and increased risk to HSI compared with other ethnicities. However, these potential variables have not been scientifically substantiated

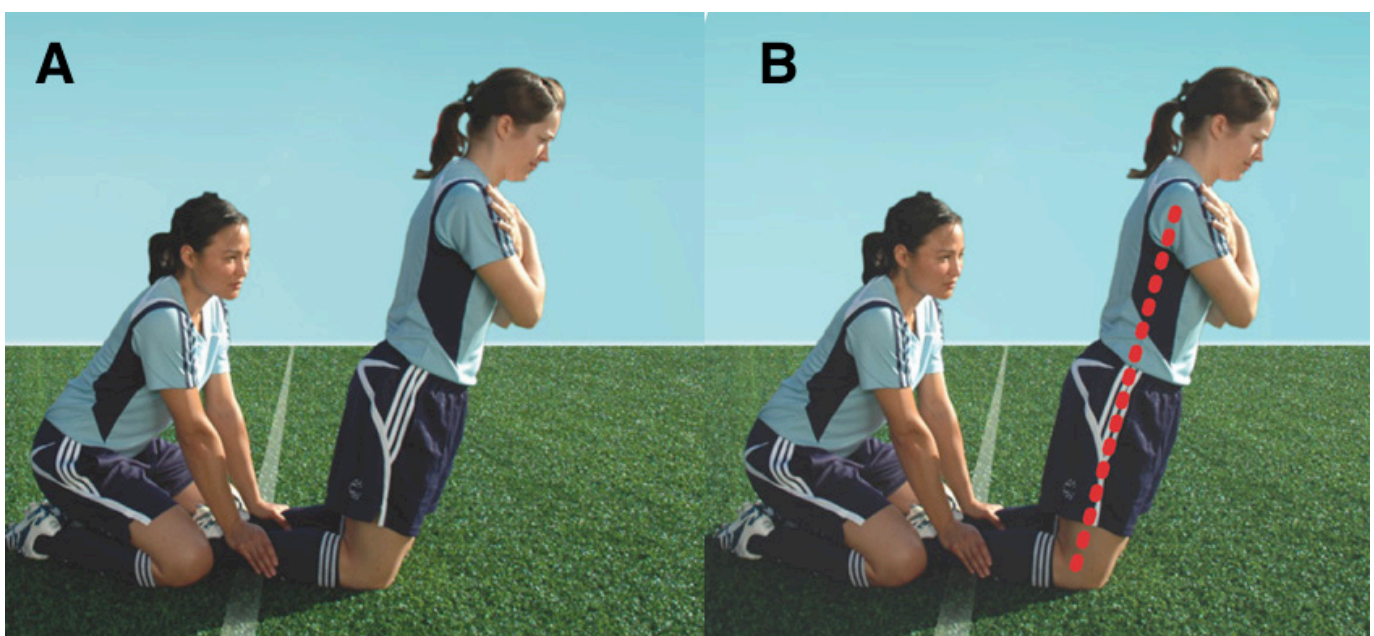


Figure 4 (A) 11+ (Russian) eccentric hamstring exercise and (B) demonstrating proper lumbopelvic control (courtesy of C von Grebel and M Bizzini, Zürich, Switzerland).

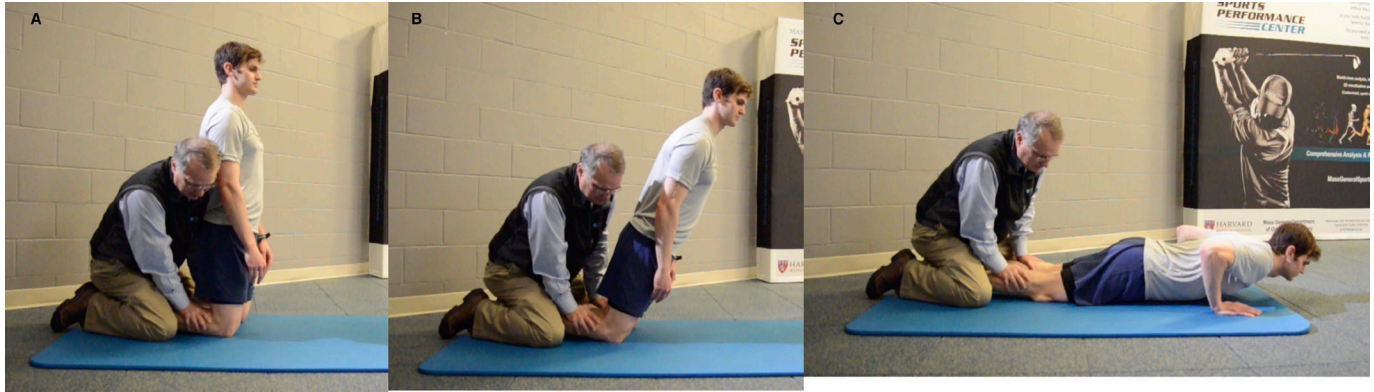


Figure 5 Nordic hamstring eccentric exercise: (A) starting position, (B) eccentrically controlling descent with proper lumbopelvic control, and (C) lowering upper body to the ground.

Box 1 Key articles

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and further evidence is required to determine how race may play a role in HSI risk.

Prior HSI has been identified as a major risk factor for injury recurrence.^{47 50} Recurrent HSIs occur in 14%–63% of athletes in the same playing season or up to 2 years after the primary injury.²⁴ A larger volume size of initial HS trauma, a grade 1 HSI and a previous ipsilateral anterior cruciate ligament (ACL) reconstruction, independent of graft selection, were consistent with increased risk for recurrent HSI, but the evidence is limited. Integrating HS prevention methodology, which emphasises agility and stabilisation, seems to be protective against a secondary HSI.⁵⁹

Muscle imbalance

HS muscle imbalance compared with the contralateral side, or as a discrepancy in H:Q strength, may increase inherent risk of HSI. The risk of injury is increased when the side-to-side strength deficit exceeds 10%–15%, or when the H:Q strength ratio is less than 0.6. Diminished H:Q strength ratios increase the knee extension moment, forcing the HS to elongate and cause eccentric contraction, perhaps past its physiological norms.¹ Crosier *et al*⁶⁰ prospectively performed a concentric and eccentric isokinetic strength assessment in soccer players. The authors determined that the HSI IR was significantly higher in athletes with untreated strength imbalances compared with players demonstrating no imbalance during preseason screening assessment (RR=4.66; 95% CI 2.01 to 10.8). Interestingly, when concentric training was compared with eccentric, increased specificity related to velocity and contraction type changes in strength of only the eccentrically trained legs were measured. However, no major training effects were present in eccentric to concentric ratios of quadriceps or HS activation. Therefore, the muscle action type and speed-specific changes seen in eccentric strength are not due to any effects on neural mechanisms, such as a specific increase in muscle activation during eccentric movements.⁶¹ However, meta-analysis shows that only increased quadriceps peak torque increases the risk of injury, and H:Q isokinetic ratio, HS peak torque and HS weakness during quadriceps concentric contraction did not play a significant role in HSI.⁵⁰ The scientific evidence is limited and further research is required to confirm the role of muscle imbalance in HSI. In addition, the ability of a strength assessment to prospectively detect HSI risk has been debated. Strength assessment should be included in a variety of testing protocols, and not considered in isolation.^{62 63}

Box 2 Validated injury classification systems

Classification systems are useful tools for clinicians and patients to allow for a guided treatment protocol and prognosis to be applied. There are a multitude of classification systems that have been used that incorporate clinical signs and clinical findings in US and MRI imaging tests.^{83 108–111} Currently, there is still no widely accepted classification system. There are several classification systems to consider:

- ▶ American Medical Association (AMA) acute muscle injury scale (O'Donoghue).
- ▶ Ryan classification system.
- ▶ Nirschl Phase Rating Scale (NPRS).
- ▶ Orchard Sports Injury Classification System (OSICS).
- ▶ Peetrons ultrasound classification system.
- ▶ Stoller classification system (MRI).
- ▶ Acute muscle strain injuries classification system.
- ▶ British Athletics Muscle Injury Classification (BAMIC).
- ▶ Munich muscle injury classification (figure 2).

The following self-directed questionnaires used to provide details on the injury history, individual player physical characteristics and physical activities associated with hamstring injury (HSI)^{22 115 116}.

- ▶ Functional Assessment Scale for Acute Hamstring Injuries (FASH).
- ▶ Hip and Groin Outcome Score (HAGOS).
- ▶ Hamstring Outcome Score (HaOS).

These tools may assist clinicians in making more accurate prognoses and identifying high-risk individuals and allowing for HSI prevention intervention to be implemented prior to injury.

Bourne *et al* reported that athletes who have previously endured an HSI display chronic activation deficits compared with uninjured contralateral HS muscles.⁶⁴ Chumanov *et al* analysed HS kinematics during high-speed treadmill running and determined that the HS are significantly loaded during both the stance and swing phases of gait. However, the authors determined that eccentric lengthening contraction of the HS

Box 3 Key issues of hamstring treatment and prevention

- ▶ Preseason and in-season eccentric strength training programmes have shown proven efficacy in reducing the rate of hamstring injury (HSI) in soccer players.^{147 148}
- ▶ Including conventional stretching and concentric strengthening exercises, in addition to eccentric hamstring (HS) exercises, to an injury prevention programme (IPP) may decrease incidence and severity of HSI during training and competition.⁴⁴
- ▶ Both the 11 and the 11+ IPPs have been shown to decrease the rate of acute HSI.^{96 150}
- ▶ Despite the fact on the coaching and player awareness of the effectiveness of these programmes on mitigating overall HSI risk, 83.3% of professional soccer teams were deemed non-compliant to an HSI IPP.⁹⁵
- ▶ As reflected in many studies involving anterior cruciate ligament (ACL) injury prevention,^{152–154} compliance and adherence to an HSI IPP is critical in order to mitigate risk. Decreasing the incidence of HSI is incumbent on proper HS IPP implementation, programme fidelity and athlete compliance.¹³⁴

only occurs during late swing, therefore negative muscle work is performed only in swing phase.¹³ Conversely, Van Hooren and Bosch disputed the notion that eccentric contraction of the HS occurs during swing phase. The authors suggested that the increasing distance between the musculotendinous attachment points during swing phase is an isometric action of the HS, and not eccentric.⁶⁵ This information suggests that including both concentric and eccentric exercises for HSI injured athletes can be exceedingly helpful when prescribing appropriate therapeutic interventions for successful RTS and reducing HSI recurrence.

Pelvic tilt and lumbopelvic stability

Anterior pelvic tilt (static and dynamic) during acceleration, with or without forward trunk leaning, can excessively increase tensile forces on the HS complex, thus increasing injury risk.⁴⁴ Furthermore, iliopsoas weakness and hypomobility, and weakness of the abdominal and lumbar musculature may also exacerbate anterior pelvic tilt, placing the HS group at a mechanical disadvantage by altering the length–tension relationship.⁶⁶

Fatigue

Muscle fatigue has been linked to the high incidence of HSI across sport, but it remains a controversial variable in the discussion of potential risk factors of HSI. Muscle fatigue is defined as a decrease in maximal force or power production in response to contractile activity.⁶⁷ Fatigue originates at two different levels of the motor pathway: central (cortical and motor neuron output) and peripheral (impacting blood flow, oxygen delivery and contraction efficiency of the muscle). Peripheral fatigue is produced by changes at or distal to the neuromuscular junction. Central fatigue originates at the central nervous system and decreases the overall neural drive to the muscle. Muscle fatigue may negatively impact overall athletic performance and other strenuous or prolonged activities.⁶⁸

HSI IRs have been reported to be higher at the end of the first and second halves in soccer.^{49 69 70} Reduced HS muscle force production has been reported in response to soccer-specific agility exercise.^{69 70} Soccer players demonstrated a significant decrease in peak eccentric knee flexor torques at half time and postgame compared with prematch analysis after completing a replicated match activity protocol.⁷⁰ After completing a kinematic analysis of the SAFT 90 fatigue protocol in semiprofessional soccer players, there was a significant increase in measured sprint time and a subsequent decrease in stride length.⁷¹ Recent research identified peripheral muscle fatigue and central motor output reductions 30–40 min after completing a soccer match.^{72 73} Peripheral fatigue was identified by a significant reduction of maximal voluntary contraction in the quadriceps (–11%) and gastrocnemius (–3%) during sprint performance and significantly increased muscle soreness. Marshall *et al* studied eight soccer players during a 90-minute soccer match. Centrally mediated reductions in maximal torque and rate of torque development may provide a partial explanation to the increased IR HS identified in soccer. This reduction was reflected by a decrease in HS rate of torque development during the first half of the match and a subsequent decrease in maximal electromyography of BFLh in the later stages of the second half.⁷⁴ Small *et al*⁷¹ analysed semiprofessional soccer prior to exercise, at half time and postmatch. There were significant reductions in eccentric HS peak torque and in the H:Q ratio as the match progressed. This time-dependent decrease in peak eccentric HS torque and in the functional strength ratio may have critical implications for the increased risk of HSI during match play. Vicens-Bordas

Box 4 Essentials for HSI diagnosis

The following self-directed questionnaires used to provide details on the injury history, individual player physical characteristics and physical activities associated with hamstring injury (HSI)^{22 115 116}:

- ▶ Functional Assessment Scale for Acute Hamstring Injuries (FASH).
- ▶ Hip and Groin Outcome Score (HAGOS).
- ▶ Hamstring Outcome Score (HaOS).

These tools may assist clinicians in making more accurate prognoses and identifying high-risk individuals and allowing for HSI prevention intervention to be implemented prior to injury.

Additionally, the use of the visual analogue scale (VAS), objective strength testing of the quadriceps, gluteals and hamstring (dynamometer or isokinetic testing), palpation, ultrasound, MRI and active hamstring flexibility tests should be used during a clinical examination when determining safe and appropriate return to sport (RTS) after HSI.^{37 156}

et al found a negative association between age and eccentric HS strength. Ageing soccer players and players with HSI history have demonstrated lower preseason eccentric HS strength.²⁸ By carefully monitoring loading and transient strength loss over the course of a player's career, clinicians may be used to offset the risk of HSI in these populations.

In a track and field observational study, there was a significantly higher incidence of HSI during the 4×400 meter (m) relay compared with the IR during the 4×100 m relay.⁵⁴ The authors suggested that the increased demand of high-speed running and the subsequent anaerobic-induced fatigue of completing the 4×400 m relay supersedes that of the 4×100 m, and may impose and increase risk for HSI, accordingly.

Match congestion fatigue has been considered as a potential variable impacting player performance and demonstrating higher injury incidence when playing two matches per week, eliciting a reduction in recovery time.^{75–79} Fixture congestion has shown to increase the

Box 5 Tips and tricks

- ▶ The use of concentric and eccentric hamstring exercises, in addition to hip extension exercises, has been shown to be beneficial at reducing hamstring injury (HSI) in athletes. This should be implemented during warm-ups and part of the strength and conditioning protocols.^{44 137 157}
- ▶ Studies have demonstrated that increases in long head of the biceps femoris (BFlh) fascicle length, cross-sectional area (CSA) and improvements in eccentric knee flexor strength are effective means for reducing hamstring injury and recurrence.¹³³
- ▶ Increased levels of BFlh and semimembranosus (SM) electromyography (EMG) activity have been observed during hip extension strengthening exercises. In contrast, semitendinosus (ST) and biceps femoris short head activation has been reported during hamstring strengthening exercises involving knee flexion.^{133 158} When developing a rehabilitation treatment or an injury prevention protocol, inclusion of both types of exercise should be considered.
- ▶ Both the 11 and the 11+ have been shown to statistically reduce the incidence of HSI when the programme is properly implemented and compliance is adequate.^{96 150}

risk of muscle injuries, especially if matches are played within 5 days.^{75 80} When analysing the IR during congested fixtures of professional soccer players, recovery of 4 days or less after a game demonstrated a fivefold higher IR compared with players who received 6 days of recovery or more.⁷⁶ This risk may be mitigated by decreasing functional output on days following a game/match and using player rotation strategies to dissipate individual load to specific players. However, there is insufficient scientific evidence to directly correlate fatigue with increased HSI IR at this time.

HSI CHARACTERISTICS

Location of injury

Most epidemiological studies corroborate that the most commonly strained component of the HS group is the BFlh, followed by the SM.^{37 39} These two muscles show distinct differences in neuromuscular coordination and synergistic activation, with the BFlh partially compensating for the lack of SM endurance, which may increase the risk of HSI.⁸¹ In elite rugby athletes, the BFlh was the most commonly injured muscle (73%) and the distal myofascial junction was the most common injury site (58% of BFlh injuries).⁸² In professional soccer, of 180 HSIs reported in 23 European clubs, 151 (84%) involved the BF muscle, 20 (11%) to the SM and 9 (5%) occurred to the ST muscles. There was no significant difference in lay-off time for injuries to the three different muscles (BF 21±19, SM 19±11 and ST 17±11 days, respectively¹⁸). Zanon *et al* reported a mean time loss due to HSI in professional soccer players of 36.7±19 days; mean time loss for BFlh injuries was 31.7±14.3 days for grade 2a, 61.3±8.5 days for grade 2b and 49.3±13 days for grade 2c lesions, using Peetrons ultrasound classification system.^{83 84} Although intramuscular injury has been associated with longer time to RTS, it is not associated with HS recurrence.⁸⁵

Muscle architecture

Morphometric data, including the fascicle number, length (cm) and muscular cross-sectional area (CSA) for the BFlh, BFsh, SM and ST, have been analysed and normative values have been established.²⁹ A thorough understanding of the muscle architecture and how it relates to force generation is critical as clinicians strive to intervene to pre-empt primary and secondary HSI. The susceptibility of the BFlh could potentially be related to its biarticular morphological characteristics; as it is subjected to extensive tensile and eccentric forces throughout the forward swing phase during running and kicking.^{13 86} Fascicular length and volume have been shown to decrease with age and with decreased activity.⁸⁷ The stretch distribution of the BFlh aponeurosis and the width of the aponeurosis may play a role in HSI vulnerability.^{88 89} The involvement of the central tendon or an HSI with proximity to the ischial tuberosity has been correlated with prolonged convalescence and delayed RTS.^{90 91} Morphological adaptations of the HS due to training have shown to evoke favourable changes in BFlh fascicle length and HS CSA following 10 weeks of Nordic hamstring eccentric exercise (NHE) and HE exercises. BFlh fascicles were significantly elongated by virtue of using NHE and HE exercises at mid-training and post-training. BFlh volume significantly increases more for the HE than the NHE and the control group. Interestingly, both NHE and HE induced significant increases in ST volume.⁶⁴

Seasonal timing of Injury

In the NFL, Elliott *et al* analysed the injury database of the entire league over a 10-year period. They reported HSI was the second highest reported injury in preseason, with more than half (53.1%; n=912) of the overall HSI occurring during the 7-week

Box 6 Major pitfalls of HSI

- ▶ Hamstring injuries (HSIs) are challenging entities to treat. Prior hamstring history, gender and age have been consistently reported as risk factors for HSI.
- ▶ The recurrence rate of HSI is exceedingly high, ranging from 13% to 33% depending on the age, gender, injury history and sporting activity.³¹
- ▶ The cost associated with HSI can be exceedingly high, including imaging, treatment and revenue loss due to absence from play (in the professional athlete).
- ▶ The utilisation of platelet-rich plasma (PRP) in the treatment of acute HSI has not garnered significant support in the current literature and cannot be deemed medically relevant in the treatment of HSI at this juncture.^{117 118 123 124 126 128 129}
- ▶ The role of the neurological system in the aetiology of HSI has not been thoroughly appreciated.⁵⁶ HSI is a multifactorial issue and it is critical to evaluate and treat these injuries holistically. Incorporate a thorough exam of the lumbar spine and pelvis during your physical examination.

preseason (July to August) compared with the 16-week regular season (45.7%; n=785).³ Feeley *et al* analysed one team in the NFL over 10 years and found a slightly lower HSI IR compared with the league-wide study conducted by Elliott *et al* (0.82/1000 AE vs 1.79/1000 AE for practice and 2.47/1000 AE vs 4.07/1000 AE for games).⁶ A similar phenomenon was reported in baseball. Ahmad *et al*² found that in MLB, there was a statistically higher frequency of HSIs during the month of May compared with any other month in the season. In Minor League Baseball, more than one-third of all reported regular season HSIs occurred in April and May. These months accounted for the highest risk during the season and were significantly higher than the other months combined. Brooks *et al* analysed the epidemiology of injuries in English professional rugby union. Contrary to the NFL findings, there was a significantly lower IR during preseason (August) matches (67) compared with in-season matches (98).⁴⁴

Player position

HSIs have been assessed by player position within sport. Position played has shown to be a significant factor in the incidence of HSI. In the NFL, Feeley *et al* reported that HSIs were most commonly reported in running backs (22%), defensive backs/safeties (14%) and wide receivers (12%), respectively.³ Also in the NFL, Elliott *et al* reported offensive players sustained HSI more frequently (45.1%; n=771) than defensive players (41.7%; n=716), whereas the players on special teams unit

sustained 13.0% of HSI reported (n=222). When groups were stratified by player position, the defensive secondary accounted for 23.1% HSI (IR=1.37 per team season). Offensively, the wide receivers represent 20.8% of the injuries (IR=1.23 per team season).⁶ Dauty and Collon reported the HSI prevalence for soccer players was highest for forwards (22.6%), followed by midfielders (20%), defenders (18.2%) and goalkeepers (7.9%).⁹² Differences in IR by player position have not been reported in the literature for professional rugby union players.^{44 93} However, despite finding no significant differences in the incidence of HSI during training, the incidence of HSI in rugby matches was significantly higher for backs (8.6 injuries/1000 player-hours) than for forwards (3.0 injuries/1000 player-hours).⁴⁴ Zachazewski *et al* reported 23.4% of all surveyed competitive collegiate baseball players had a history of HSI, with infielders reporting a prevalence of 31.9%, followed by outfielders of 25.5%, pitchers of 25.5% and catchers of 17.0%.⁹⁴

Financial liability

For many sports, the rate of HSI has been increasing over the last 15 years, despite the concerted efforts by the sports medicine community to implement HSI prevention and reduction methodology.^{7 16–18 46 66 95 96} There is a distinct financial burden for the athlete and the team/club to endure. In male soccer, teams may endure five to six HSIs per year which financially translates into US\$300 000 in an annual revenue loss to the club.⁹⁷ Similarly, in professional baseball (MLB), teams incur a financial burden of US\$330 000 per HSI, predicated on a league average salary and a 30-day time loss.⁹⁸ In the AFL, the financial cost of a single HSI increased by 56% over the course of 9 years; from \$A25 603 in 2003 to \$A40 021 in 2012 despite little variability in the measurable rate of HSI. This accounted for a 71% increase cost to the club over the 9-year period.⁹⁹ In women's rugby union (New Zealand), the average HSI cost \$705±\$49 per claim, secondary to the lower wages that female athletes are currently remunerated.¹⁰⁰ Male amateur soccer players who used the '11' programme for injury prevention incurred fewer HSIs and less severe injuries. The mean cost of HSI per player who used the '11' as their dynamic warm-up was significantly lower: (€742) compared with the control group (€1271).¹⁰¹

DIAGNOSIS, CLASSIFICATIONS AND VALIDATED OUTCOME MEASURES

Assessing, diagnosing and prognosticating an HSI is challenging. A thorough physical examination is used to identify location and severity of the HSI, pain, weakness and loss of active range of motion (ROM). Active-assisted ROM and resistive testing at various angles will allow the clinician to properly identify the location of the injury. Palpation of the posterior thigh allows the clinician to detect the presence or absence of pain and any defect in the muscle and/or tendon. The proximity of the HSI to the ischial tuberosity is closely related to injury of the proximal tendon, and therefore demanding a longer convalescence period.^{102 103} The injury is graded using a classification system in order to reflect the extent of the muscle and/or tendon damage and to estimate the length of time the athlete will require for healing.¹⁵ Unless a proximal avulsion injury with an apophyseal fracture is in question, plain film radiographs are not particularly useful in the examination of an acute HSI. For intramuscular injury, MRI may be a useful tool in order to properly determine the severity of injury and, in combination with the clinical exam, predict time for rehabilitation and ultimate RTS.^{18 104} MRIs for acute HSI can determine the presence and severity of an injury,

Box 7 Future perspectives

Hamstring injuries (HSIs) are exceedingly common in the athletic population, entail significant impairment and disability and have a high recurrence rate. Administering a thorough physical evaluation, evaluating the athlete's medical history, understanding the mechanism of injury, location of injury and biomechanical risk factors and implementing an appropriate treatment protocol to address the aetiology of the HSI will allow the medical staff to determine a prognosis and an individualised rehabilitation protocol. Future efforts should focus on developing and refining rehabilitation interventions and injury prevention efforts to mitigate the risk of primary HSI.

the extent of the injury (haemorrhage, oedema, length and CSA), and provide an estimate of the rehabilitation period.⁸⁹ However, MRI has not been shown to be a valid method of properly predicting RTS.^{105 106} Ultrasound sonography may be considered as an alternative to MRI for imaging acute HSIs due to its accessibility and lower financial implications.¹⁰⁷

There are several classification systems to consider: the American Medical Association (AMA) acute muscle injury scale (O'Donoghue), Ryan classification system, the Nirschl Phase Rating Scale, the Orchard Sports Injury Classification System, the Peetrons ultrasound classification system, Stoller classification system (MRI), acute muscle strain injuries classification system, British Athletics Muscle Injury Classification and the Munich muscle injury classification^{83 108–113} (figure 2). The early muscle injury classification systems (AMA) were deemed attractive for practitioners and patients, but the grading is based on subjective opinion and is devoid of scientific empirical evidence.¹¹⁴ The utilisation of ultrasound and MRI provided a more objective means for grading muscle injury during clinical evaluation.

The use of validated tools can assist clinicians in more accurately diagnosing and determining appropriateness for RTS. The Functional Assessment Scale for Acute Hamstring Injuries, the HAGOS and the Hamstring Outcome Score are self-directed questionnaires used to provide details on the injury history, individual player physical characteristics and physical activities associated with HSI.^{22 115 116} These tools may assist, prospectively, in identifying high-risk individuals and allowing for HSI prevention intervention to be implemented prior to injury.

TREATMENT AND RTS

A meta-analysis examining conservative management of HSI showed that including eccentric rehabilitation exercises significantly reduced time to RTS, but has no effect on the risk of recurrence.⁵⁹ Platelet-rich plasma (PRP) injections had no effect when compared with control groups for time to RTS and reinjury risk.^{117–119} There was limited evidence that progressive agility and trunk stability training reduces HSI recurrence rates.¹²⁰ A previous systematic review found that there was limited evidence to support the use of stretching, agility and trunk stability exercises, intramuscular actovegin injections or neural slump stretching.¹²¹ The use of non-steroidal anti-inflammatory drugs has poor evidence to support its use for pain management¹²⁰ and may be considered counterproductive, as it may ultimately impair muscle healing.¹²²

Platelet-rich plasma

The use of autologous biological products to expedite muscle healing as a treatment alternative for muscle injury has garnered significant attention over the last two decades.¹²³ PRP injections have been used as a treatment intervention to accelerate muscle injury healing and decrease recovery time.¹²⁴ They are derived from an individual's centrifuged blood, creating a highly concentrated platelet serum, which contains growth factors that promote mitogenesis and angiogenesis in the tissue.^{125 126} The basic premise of PRP is to expedite the development of autologous plasma, platelet-derived proteins and growth factors and adhere to a fibrin scaffold (injection site) that can act as a matrix for cell growth and differentiation to facilitate the repair of injured tissue. However, the use of PRP has been controversial and the effect of PRP on HSIs is currently unsubstantiated.^{117 118 120} The current literature demonstrates conflicting evidence regarding the benefit of PRP injections in the treatment of acute HSI.¹²⁶

The International Olympic Committee authored a consensus paper in 2010 determining that the scientific evidence supporting the use of PRP in the treatment of muscle injuries was not scientifically substantiated to recommend as a therapeutic intervention for HSI.¹²⁷ Since the publication of that paper, Grassi *et al* published a meta-analysis of six PRP studies for the treatment of acute muscle injury and determined that despite the promising biological rationale, the positive preclinical and anecdotal findings, and the successful early clinical experience of PRP injections are not confirmed by the recent high-level randomised controlled trials.¹²⁸ Guillodo *et al* investigated the use of PRP in acute HSIs and found no significant difference in RTS between the PRP and the control group (50.9±10.7 days in the PRP group and 52.8±15.7 days in control group).¹²⁹ Hamilton *et al* investigated the use of PRP, platelet poor plasma (PPP) and no injection in male athletes with acute HSI and found no significant difference between RTS in any of the groups (PRP and PPP –5.7 days (95% CI –10.1 to –1.4); PRP and no injection –2.9 days (95% CI –7.2 to 1.4); and PPP and no injection 2.8 days (95% CI –1.6 to 7.2)).¹¹⁷ Conversely, Hamid *et al* evaluated the use of a single PRP injection and rehabilitation for grade 2 HSIs versus rehabilitation alone. RTS was significantly shorter for the PRP group (26.7±7.0 days) compared with the control group (42.5±20.6 days), but found no significant difference in reported subjective pain scales (visual analogue scale).¹³⁰ When comparing PRP to corticosteroid injection in the treatment of grade 2 HSI, the PRP group reported reduced pain 1 week after injection.¹¹⁹

Research suggests that PRP injections may be slightly more beneficial in younger and professional athletes who have sustained a more severe acute HSI or an HSI recurrence.⁸⁴ However, the current scientific literature does not substantiate the use of PRP in acute HSI at this juncture.^{88 117 118 124 126 128 129 131}

Exercise-based rehabilitation

There is lack of high-level evidence comparing different exercise-based rehabilitation strategies for the treatment of HSI.¹³² The muscle lengthening exercises, popularised by Askling *et al*, are characterised by extensive lengthening of the HS group during eccentric muscle actions (L-protocol and C-protocol). Both protocols consist of three different exercises: one aiming to increase flexibility, other combining strength and trunk/pelvis stabilisation and a third that is a specific strength training exercise.^{102 103 133} The L-protocol ('The Extender', 'The Diver' and 'The Glider') is more demanding, but has shown to significantly shorten the time to RTS¹⁰³ (figure 3). Eccentric knee flexion exercises, such as the Nordic and Russian HS exercises, have also been validated in the literature and should be included in HSI interventions^{134–137} (figures 4 and 5).

The course of treatment should be predicated on an accurate structural diagnosis that includes type, location, severity and history. The treatment plan should be a collaborative effort between the medical team, athlete and the coach in order to ensure rehabilitation compliance. The type of injury has an impact on the tissue healing time frame (myofascial: up to 3 weeks; muscle–tendon junction: 4–8 weeks; and intratendinous: 2–4 months) and thus on rehabilitation progressions.¹³⁸ The location of the injury is critical with respect to exercise selection, as there is heterogeneity of HS activation patterns with different therapeutic exercises.¹³⁹ Macdonald *et al* published clinical guidelines for HSI rehabilitation, running progression and RTS for each type of HSI and defined some useful principles in HSI rehabilitation¹³⁸:

- ▶ Correction of pathokinematics of the hip and pelvis.
- ▶ Progressive sprint loading (running drills).
- ▶ Use goal-based strengthening exercises, including both isometric and eccentric loading.
- ▶ Develop high eccentric strength and fatigue resistance.
- ▶ Work on length–tension relationship (increase fascicle length), improve muscle–tendon unit specificity and overcome selective muscle inhibition.
- ▶ Implement lumbopelvic and hip retraining exercises.
- ▶ Target and eliminate the contributing factor to injury.

The rehabilitation of HSIs should be progressive, goal based, sports specific and tailored to the type of injury and to individual characteristics. In myofascial injuries, there is a focus on early return to functional running and muscular strengthening (but specific HS exercises are typically not prioritised). For muscle–tendon junction injuries, progressive running drills are prioritised (progression on intensity and complexity). Strength training focuses on the injured muscle using isometric and progressing to more challenging eccentric exercises. In intratendinous HSI, secondary to the long tissue healing time frame, the running progressions are delayed in order to avoid the elastic strain on the injury site. The strength training is characterised by prolonged isometric loading and a delayed progression to eccentric exercises.¹³⁸ Specific exercise selection based on HSI location is critical, as it will impact selective activation of the appropriate muscle of the HS group.^{64 140 141} Recurrent HSIs pose a unique clinical challenge to rehabilitate and implore a more holistic and tailored approach in order to mitigate risk to the modifiable risk factors, longitudinally.¹⁴²

CLINICAL OUTCOMES AND RTS

The ability of the medical staff to properly prognosticate return to play for the athlete is a challenging task. HSI poses complexities; include variations in injury presentation type, location, mechanism of injury, severity and size. This poses a challenging conundrum to the medical staff when attempting to provide a chronological time frame for healing. The RTS decision should be a collaborative decision based on objective criteria that comprise the five domains: functional performance, strength, flexibility, pain and player's psychological confidence.¹⁴³ The use of classification systems can be helpful when prognosticating time to RTS.^{109 138} A consensus-based Delphi study, which comprised 58 expert panellists, defined RTS for HSI as 'the moment a player has received criteria-based medical clearance and is mentally ready for full availability for match selection and/or full training'.¹⁴⁴ The criteria to RTS comprised similar HS flexibility (compared with preinjury baseline data and/or uninjured side), performance on field testing, psychological readiness and absence of pain on palpation, strength testing, flexibility testing and/or functional testing. For the field testing, the expert panel agreed on four of the most important tests to assess eligibility to RTS after HSI: including position-specific, global positioning system (GPS) targeted, match-specific rehabilitation; repeated sprint ability test; single leg bridge; and deceleration drills. Despite the added value to assist clinical examination and rehabilitation progression (structural analysis), the role of MRI in RTS is still controversial as it is not currently able to predict the optimal RTS timing, nor risk of reinjury.^{18 85 104 106 144–146}

HSI PREVENTION

Numerous attempts have been made to reduce or prevent HSI from occurring.^{7 16–18 66 95 96} Askling *et al* used a preseason eccentric strength training programme in elite soccer players. Despite

a 47% decrease in HSI IR, no changes in performance measures were identified.¹⁴⁷ An eccentric HS training programme in male soccer players demonstrated a 57% decrease in HSI compared with players performing concentric HS curls and a 58% reduction compared with historical baseline HSI data.¹⁴⁸ An injury prevention programme (IPP) that was implemented in professional rugby union determined that NHE in addition to conventional stretching and strengthening exercises had lower incidences and severities of injury during training and competition.⁴⁴ A meta-analysis of 15 studies, which included various sports and age groups, showed that prevention programmes that include the NHE reduce the IR of HSIs in up to 51%.¹⁴⁹

Although there are differences in the component exercise included, both the '11' and the 11+ IPP were similar in their philosophical design: as a dynamic warm-up to reduce all lower extremity soccer-related injury.^{96 150–152} The '11' was used in male amateur soccer players over two seasons. There was a significant reduction in both HSI and lateral ankle sprains for both defenders and midfielders.⁹⁶ The 11+ IPP was used for one competitive season in male collegiate soccer players (aged 18–25). The 11+ included a partner eccentric HS exercise that requires proper lumbopelvic control (figure 4). At the culmination of the season, there were 55 HSIs reported in the control group (8%; IR 1.244) compared with 16 in the intervention group (IG: 6%; IR 0.454), accounting for a 2.74-fold reduction in HSI.¹⁵⁰ Despite the fact on the coaching and player awareness of the effectiveness of these programmes on mitigating overall HSI risk, 83% of professional soccer teams were deemed non-compliant to an HSI IPP.⁹⁵ As reflected in many studies involving ACL injury prevention,^{152–154} compliance and adherence to an HSI IPP is critical in order to mitigate risk.¹³⁴ Decreasing the incidence of HSI is incumbent on proper HS IPP implementation, programme fidelity and athlete compliance.¹³⁴ In addition, it is critical to implement these philosophies after an acute HSI in order to decrease the risk of secondary HSI.

In order to implement a validated prevention programme for HSI, the clinician should focus on tailoring the prevention programme to the mechanism of injury and the individual player; incorporate specific HS exercises into a more generalised IPP; and ensure compliance from players and coaches.¹⁵⁵ HSI prevention should focus on strengthening the HS muscles, implementation of lumbopelvic exercises; incorporate optimal movement and neuromuscular control; develop player physical fitness, careful player monitoring and optimal recovery strategies.¹⁵⁵

CONCLUSION AND FUTURE DIRECTIONS

The neuromuscular inhibition that persists after incurring an HSI may hinder the efforts of the rehabilitation team to properly prepare an athlete for RTS. This inhibition, if persistent, may lead to maladaptation of HS muscle structure and function, including prolonged concentric and eccentric weakness, atrophy of the involved musculature, persistent biomechanical deficits and alterations in peak knee flexor torque. Proper rehabilitation and treatment interventions must adopt a multifactorial and holistic approach to HSI. This entails addressing muscular strength imbalances, HS flexibility, impairments in neuromuscular control and lumbopelvic stability. On return to competitive play and training, functional load management and game/match scheduling should be highly considered for the athlete returning to sport. An individualised, evidence-based approach to strength training for the prevention of HSI should entail specific exercise selection for appropriate muscle activation based on the mechanism of the HSI and consider how these targeted interventions

can positively impact the HS muscle architecture, morphology and function to mitigate HSI recurrence. Future research should include evaluation of the effectiveness of current rehabilitation programmes, further elucidation of appropriate RTS criteria and the improved development of effective prevention strategies to reduce the occurrence and recurrence of HSI.

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