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Hamstring Strain Injury
Clinical Practice Guidelines
Linked to the International Classification
of Functioning, Disability, and Health
from the Academy of Orthopaedic Physical Therapy and American Academy of Sports Physical Therapy of the
American Physical Therapy Association

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RECOMMENDATIONS SUMMARY

List of Abbreviations

°/s: degrees per second

AKE: active knee extension

AOPT: Academy of Orthopaedic Physical Therapy

APTA: American Physical Therapy Association

BMI: body mass index

CI: confidence interval

CPG: clinical practice guideline

ES: effect size

FASH: Functional Assessment Scale for Acute Hamstring Injuries

HR: hazard ratio

HSI: hamstring strain injury

H:Q: hamstring/quadriceps ratio

JOSPT: Journal of Orthopaedic Sports Physical Therapy

ICC: intraclass correlation coefficient

ICF: International Classification of Functioning, Disability, and Health

IRR: incidence rate ratio

Kg: kilograms

MCID: minimal clinicalimportant difference

MDC: minimal detectable change

MHFAKE: Maximal hip flexion active knee extension

MRI: magnetic resonance imaging

m/s: meters per second

N: Newton(s)

NM: Newton-meters

NCAA: National Collegiate Athletic Association

NFL: National Football League

NHE: Nordic hamstring exercise

n: sample size

OR: odds ratio

PATS: progressive agility and trunk stabilization

PKE: passive knee extension

Q:H: quadriceps to hamstring ratio

RR: relative risk

PSLR: passive straight leg raise

RICE: rest, ice, compression, elevation

ROM: range of motion

RTP: return to play

RTS: return to Sport

SEM: standard error of the measure

SLR: straight leg raise

SR: systematic review

STST: stretching and strengthening

TOST: taking off the shoe test

TTP: tenderness to palpation

US: ultrasound

INTRODUCTION

INTRODUCTION

AIM OF THE GUIDELINES

The Academy of Orthopaedic Physical Therapy of the American Physical Therapy Association (APTA) has an ongoing effort to create evidence-based clinical practice guidelines (CPGs) for orthopaedic physical therapy management of patients with musculoskeletal impairments described in the World Health Organization's International Classification of Functioning, Disability, and Health (ICF).(World Health Organization 2001) The purposes of these clinical guidelines are to:

- Describe evidence-based physical therapy practice including diagnosis, prognosis, intervention, and assessment of outcome for musculoskeletal disorders commonly managed by orthopaedic physical therapists;
- Classify and define common musculoskeletal conditions using the World Health Organization's terminology related to impairments of body function and body structure, activity limitations, and participation restrictions;
- Identify interventions supported by current best evidence to address impairments of body function and structure, activity limitations, and participation restrictions associated with common musculoskeletal conditions;
- Identify appropriate outcome measures to assess changes resulting from physical therapy interventions in body function and structure as well as in activity and participation of these individuals;
- Provide a description to policy makers, using internationally accepted terminology, of the practice of orthopaedic physical therapists;
- Provide information for payers and claims reviewers regarding the practice of orthopaedic physical therapy for common musculoskeletal conditions;
- Create a reference publication for orthopaedic physical therapy clinicians, academic instructors, clinical instructors, students, interns, residents, and fellows regarding the best current practice of orthopaedic physical therapy.

STATEMENT OF INTENT

These guidelines are not intended to be construed or to serve as a standard of medical care. Standards of care are determined on the basis of all clinical data available for an individual patient and are subject to change as scientific knowledge and technology advance and patterns of care evolve. These parameters of practice should be considered guidelines only. Adherence to them will not ensure a successful outcome in every patient, nor should they be construed as including all proper methods of care or excluding other acceptable methods of care aimed at the same results. The ultimate judgment regarding a particular clinical procedure or treatment plan must be made based on clinician experience and expertise in light of the clinical presentation of the patient, the available evidence, available diagnostic and treatment options, and the patient's values, expectations, and preferences. However, we suggest that significant departures from accepted guidelines should be documented in the patient's medical records at the time the relevant clinical decision is made.

SCOPE AND RATIONALE OF THE GUIDELINE

The hamstring muscle group consists of three muscles in the posterior thigh: the semitendinosus, semimembranosus, and biceps femoris. Hamstring strain injuries (HSI) may result in considerable impairment, activity limitation, and participation restriction, including time lost from competitive sports. In professional sports, HSIs may be associated with significant financial costs.[1] HSIs are typically classified by the involved muscle, anatomical location, and severity of damage.[1][2] Classifications may also consider whether there is myofascial, musculotendinous, and/or intratendinous involvement.[1][2] A variety of injury mechanisms for HSIs have been described and typically involve some type of eccentric overloading and/or overstretching in a position of hip flexion and knee extension.[3] Different mechanisms of injury may be associated with unique injury locations and specific structural impairments. For example, overloading injuries typically occur in a lengthened position, as in high speed running, when the hamstring is eccentrically contracting across the hip and knee, late in swing phase/early heel strike.[4] This overload injury usually involves the bicep femoris and surrounding tissue. In contrast, overstretching injuries occur with combined hip flexion and knee extension movements, as in kicking or reaching to pick and lift something off the ground with the knee extended. This overstretching injury typically involves the proximal semimembranosus.[5] This CPG includes sports-related overloading and overstretching injuries to myofascial or musculotendinous structures in any combination of the three hamstring muscles. Injuries exclusive to the proximal or distal hamstring tendons with primarily intratendinous involvement are different from HSIs that involve the myofascial and musculotendinous structures with respect to incidence, mechanism of injury, pathoanatomical features, clinical course, and treatment strategies.[2] Given these differences, this CPG will exclude isolated tendon injuries. While the effect of interventions for those with a HSI can be measured in a variety of ways, including but not limited to strength, range of motion (ROM), and pain levels, the ultimate success of the rehabilitation process is determined by the individual's ability return to sports participation while preventing re-injury. Therefore only studies that directly assessed time to return to play (RTP) and re-injury rates were included when discussing interventions for HSIs.

METHODS

METHODS

Content experts were appointed by the Academy of Orthopaedic Physical Therapy, APTA, to conduct a review of the literature and develop a HSI CPG. The aims of this review were to provide a concise summary of the contemporary evidence and to develop recommendations to support evidence-based practice. The authors of this guideline revision worked with the CPG editors and medical librarians for methodological guidance. The research librarians were chosen for their expertise in systematic review and rehabilitation literature search and to perform systematic searches for concepts associated with classification, examination, and intervention strategies for HSI. Briefly, the following databases were searched from 1967 to June 2021: MEDLINE; CINAHL; Cochrane Library; and PEDro [See **APPENDIX A** for full search strategies and **APPENDIX B** for search dates and results, available at www.orthopt.org].

The authors declared relationships and developed a conflict management plan, which included submitting a Conflict-of-Interest form to the Academy of Orthopaedic Physical Therapy, APTA. Articles that were authored by a reviewer were assigned to an alternate reviewer. Funding was provided to the CPG development team for travel and expenses for CPG development training by the Academy of Orthopaedic Physical Therapy, APTA, The CPG development team maintained editorial independence.

Articles contributing to recommendations were reviewed based on pre-specified inclusion and exclusion criteria with the goal of identifying evidence relevant to physical therapist clinical decision-making for adults with HSI. The title and abstract of each article were reviewed independently by 2 members of the CPG development team for inclusion. [See **APPENDIX C** for Inclusion and Exclusion criteria, available at www.orthopt.org]. Full text review was then similarly conducted to obtain the final set of articles for contribution to the recommendations. The team leader (RLM) provided the final decision for discrepancies that were not resolved by the review team. [See **APPENDIX D** for flow chart of articles [available at www.orthopt.org]. For selected relevant topics that were not appropriate for the development of recommendations, such as incidence and imaging, articles were not subject to the systematic review process and were not included in the flow chart. Evidence tables for this CPG are available on the Clinical Practice Guidelines page of the Academy of Orthopaedic Physical Therapy of the APTA website: www.orthopt.org.

This guideline was issued in 2022 based on the published literature up through June 2021, and will be considered for review in 2026, or sooner if important evidence becomes available. Any updates to the guideline in the interim period will be noted on the Academy of Orthopaedic Physical Therapy of the APTA website: www.orthopt.org.

LEVELS OF EVIDENCE

Individual clinical research articles were graded according to criteria adapted from the Centre for Evidence-Based Medicine, Oxford, United Kingdom for diagnostic, prospective, and therapeutic studies. In teams of 2, each reviewer independently assigned a level of evidence and evaluated the quality of each article using a critical appraisal tool. [See **APPENDIX E** and **F** for Levels of Evidence table and details on procedures used for assigning levels of evidence, available at www.orthopt.org]. The evidence update was organized from highest level of evidence to lowest level. An abbreviated version of the grading system is provided below.

I	Evidence obtained from high quality diagnostic studies, prospective studies, systematic reviews, or randomized controlled trials
II	Evidence obtained from lesser-quality diagnostic studies, systematic reviews, prospective studies, or, randomized controlled trials (eg, weaker diagnostic criteria and reference standards, improper randomization, no blinding, less than 80% follow-up)
III	Case controlled studies or retrospective studies
IV	Case series
V	Expert opinion

STRENGTH OF EVIDENCE AND GRADES OF RECOMMENDATION

The strength of the evidence supporting the recommendations was graded according to the established methods provided below. Each team developed recommendations based on the strength of evidence, including how directly the studies addressed the question relating to HSIs. In developing their recommendations, the authors considered the strengths and limitations of the body of evidence and the health benefits, side effects, and risks of tests and interventions.

GRADES OF RECOMMENDATION		STRENGTH OF EVIDENCE	LEVEL OF OBLIGATION
A	Strong evidence	A preponderance of level I and/or level II studies support the recommendation. This must include at least 1 level I study	Must or should

B	Moderate evidence	A single high-quality randomized controlled trial or a preponderance of level II studies support the recommendation	Should
C	Weak evidence	A single level II study or a preponderance of level III and IV studies, including statements of consensus by content experts, support the recommendation	May
D	Conflicting evidence	Higher-quality studies conducted on this topic disagree with respect to their conclusions. The recommendation is based on these conflicting studies	
E	Theoretical/ foundational evidence	A preponderance of evidence from animal or cadaver studies, from conceptual models/principles, or from basic sciences/bench research support this conclusion	May
F	Expert opinion	Best practice based on the clinical experience of the guidelines development team	May

GUIDELINE REVIEW PROCESS AND VALIDATION

Identified reviewers who are experts in HSI management and rehabilitation reviewed the CPG draft for integrity, accuracy, and to ensure that it fully represented the current evidence for the condition. The guideline draft was also posted for public comment and review on www.orthopt.org and a notification of this posting was sent to the members of the Academy of Orthopaedic Physical Therapy, APTA, Inc. In addition, reviewers were invited from a panel including consumer/patient representatives and external stakeholders, claims reviewers, medical coding experts, academic educators, clinical educators, physician specialists, researchers, and clinical practice guideline methodologists. All comments, suggestions, and feedback from the reviews, were provided to the authors and editors for consideration and revisions. Guideline development methods policies, and implementation processes are reviewed at least yearly by the Academy of Orthopaedic Physical Therapy, APTA's Clinical Practice Guideline Advisory Panel..

DISSEMINATION AND IMPLEMENTATION TOOLS

In addition to publishing this CPG in the Journal of Orthopaedic & Sports Physical Therapy (JOSPT), it will be posted on the CPG website pages of both the JOSPT and the Academy of Orthopaedic Physical Therapy, APTA,, which are free access website areas, and submitted to be made available free access on the ECRI Guidelines Trust® (guidelines.ecri.org) and the Physiotherapy Evidence Database (PEDro.org.au). The planned implementation tools for patients, clinicians, educators, payors, policy makers, and researchers, and the associated implementation strategies are listed in **TABLE 1**.

TABLE 1. Planned strategies and tools to support the dissemination and implementation of this Clinical Practice Guideline

Tool	Strategy
"Perspectives for Patients"	Patient-oriented guideline summary available on jospt.org and orthopt.org
Mobile application of guideline-based exercises for patient/clients and healthcare practitioners	Marketing and distribution of app using orthopt.org

Clinician's Quick-Reference Guide	Summary or guideline recommendations available on orthopt.org
Read-for-credit continuing education units	Continuing education units available for physical therapists and athletic trainers from JOSPT
Webinars educational offering for healthcare practitioners	Guideline-based instruction available for practitioners on orthopt.org
Mobile and web-based app of guideline for training of healthcare practitioners	Marketing and distribution of app using orthopt.org
Non-English versions of the guidelines and guideline implementation tools	Development and distribution of translated guidelines and tools to JOSPT's international partners and global audience via jospt.org
APTA CPG+	Dissemination and implementation aids

ORGANIZATION OF THE GUIDELINE

For in which systematic reviews were conducted to support specific recommendations, summaries of studies with the corresponding evidence levels are followed by a synthesis of the literature and rationale for the recommendation(s), discussion of gaps in the literature if appropriate, and finally the recommendation(s). Topics for which recommendations are provided include: return to play and re-injury risk, examination, injury prevention, and interventions. For other topics, where a systematic review was outside of the scope of this CPG, a summary of the literature is provided. This includes incidence/prevalence, pathoanatomic features, risk factors, clinical course, differential diagnosis, and imaging.

CLASSIFICATION

CLASSIFICATION

The primary ICD-10 Codes associated with a HSI are the following:

1. **S76.01 sprains, strains of the pelvis, hip, and thigh**
2. **S76.302A (312 Left thigh and 311 for the right thigh) unspecified injury of a muscle, fascia, and tendon of the posterior muscle group at the thigh level**
3. **S76.319D includes strain of muscle, fascia , and tendon of the posterior muscle group at thigh level, unspecified thigh, subsequent encounter**

The primary ICF body-function codes associated with hamstring strain are **b7301,7303 movement of a single limb and movement of lower extremity.**

The primary ICF body-structure codes associated with hamstring strain is **S75002 muscles of the thigh.**

The primary ICF activities and participation codes associated with hamstring strain are: **d4101 squatting, d4153 maintaining a sitting position, d4502 walking on different surfaces, d-4552 running, d4551**

climbing, d4553 jumping, d4558 moving around, specified as direction changes while walking or running, and **d9201 sports.**

INCIDENCE/PREVALENCE

INCIDENCE/PREVALENCE

HSIs are common in activities that involve high speed running, jumping, kicking, and/or explosive lower extremity movements with rapid changes in direction, including lifting objects from ground. Therefore, sports such as track, soccer, Australian Rules football, American football, and rugby have the highest frequency of reported injuries.[6] [7] [8] [9] The estimated incidence of HSIs per 1000 hours of exposure is 0.87 in non-contact sports and 0.92-0.96 in contact sports.[8] Incidence rate estimates are 3-4.1/1000 competition hours and 0.4-0.5/1000 training hours for professional male European soccer players.[10] The incidence of HSIs has recently been reported to be increasing in some groups. For example, in professional male European football players between 2001-2014 , there was an increase in HSIs of 2.3% per year (95% CI:0.02, 0.043%) during competition and 4.0% per year (95% CI: 0.011, 0.070%) during training.[11] [10] Dalton et al [12] reported 68.2% of HSIs occur during practice in men's football, men's soccer, and women's soccer. A professional soccer team of 25 players can expect about 7 hamstring injuries per season.[8] Australian Rules football players have a 1.3-fold higher risk of a HSI with each additional year of age, while soccer players have a 1.9-fold higher risk with each increasing year of age.[13] HSIs frequently cause a significant loss of time from competition, generally ranging from 3 to 28 days or more, depending on injury severity.[8] Re-injury rates are high and range between 13.9-63.3% across the Australian Rules football and track and field athletes.[14] [8] Further, those with a history of HSI have a 3.6 times higher risk of sustaining a future HSI.[15] The high incidence of recurrent HSIs may be attributable to inadequate rehabilitation or premature return to participation.[12]

PATHOANATOMICAL FEATURES

PATHOANATOMICAL FEATURES

Skeletal muscle consists of slow (type-I) and fast (type-II) muscle fibers, to a varying degree. It is believed that the hamstring muscle group has a higher percentage of type-II fibers than other thigh muscles, which may make the muscle more susceptible to injury.[16] [13] However, the actual percentage of type-two fibers may vary depending on age and other individual anatomical variations.[13] The biceps femoris muscle is the most commonly involved hamstring muscle in both first time and recurrent injuries, being involved in 79-84% of HSIs.[17] [18] [19] [20] Anatomically, increased anterior pelvic tilt can place the hamstring muscle group in a more lengthened position and potentially increase the likelihood of a HSI.[21] [13]

Tosovic et al.[9], used ultrasound (US) imaging to evaluate the anatomy of the biceps femoris of 20 physically active 18-30 year old males, and found varied muscle architecture throughout the length of the biceps femoris. The distal 90% of the muscle contained an arrangement of shorter fascicles that were more pennated compared to the proximal 30% of the muscle.[9] Although this was a small sample with no women, these findings may suggest that the proximal segment possesses a reduced ability to adjust to length changes and that muscle architecture may contribute to the high rate of HSIs experienced at the proximal muscle tendon junction.[9] Timmins et al.[22] studied 20 recreationally active athletes with no history of HSI and 16 elite athletes with a history of a unilateral HSI. They compared US imaging measures of the biceps femoris muscle architecture (muscle thickness, pennation angle, and fascicle length) during graded isometric contractions at 0, 30, and 60° of knee flexion. The researchers found: 1) significantly shorter fascicle length and fascicle length relative to muscle thickness on the injured side compared to uninjured side at all contraction intensities and 2) significantly greater pennation angle on the injured biceps femoris compared to the uninjured side at all contraction intensities. [22]

Summary

Most HSIs occur in the long head of the biceps femoris and they may be associated with increased in anterior pelvic tilt. There is also evidence to suggest that muscle architecture (higher pennation angle and smaller fascicle length) may contribute to a HSI.

RISK FACTORS

RISK FACTORS

Risk factors for acute HSI are categorized as being non-modifiable or modifiable. Non-modifiable factors describe characteristics of an individual that cannot be changed, such as history of previous HSI and age. Modifiable factors are those that can be altered and include factors such as muscle characteristics, muscle performance, and performance characteristics.[23-25]

Non-modifiable Risk Factors

Previous Injury

Systematic reviews have consistently identified previous injury as a risk factor for a HSI.[26] [27] [23] Studies within these reviews reported a 2 to 6 times higher rate of recurrence following a previous HSI.[28] [29] A prospective study, not included in these reviews found male sprinters with a prior HSI had a significantly higher injury rate than those who had never sustained a HSI (OR=2.85; $P < .05$).[30] A recent HSI (within 8 weeks) was found to place individuals at greater risk for injury when compared to those with a non-recent injury (OR 13.1; 95% CI: 11.5, 14.9 vs OR 3.5; 95% CI: 3.2, 3.9)[31] Also, the meta-analysis by Green et al.[23] the risk of recurrent HSI was found to be greatest during the same season (RR 4.8; 95%CI: 3.5, 6.6). Green et al.[23] also found a history of anterior cruciate ligament injury (RR=1.7; 95%CI 1.2,2.4;) and calf strain (RR=1.5, 95%CI 1.3, 1.7), as well as other knee injuries and ankle ligament sprains, to be risk factors for a HSI. A history of a quadriceps strain and chronic groin pathology were not identified as risk factors.[23]

Physical Characteristics

Systematic reviews have identified increasing age to be a significant risk for HSI.[23] [26] [27] One study included in these reviews found that athletes above the age of 23 were at greater risk than those 23 or below (RR=1.34; 95%CI: 1.14, 1.57).[32] Another study found Australian Rules football athletes above the age of 25 were at greater risk than those 25 or below (RR=4.43; 95%CI: 1.57, 12.52).[29] While systematic reviews have found height [26] [27] and preferred kicking leg [26] not to be risk factors, ethnicity was identified as a risk factor with African-American athletes and Aboriginal Australian Rules footballers being at higher risk. [27]

Modifiable Risk Factors

Weight and Body Mass Index

Weight and BMI were not found to be risk factors for HSIs in systematic reviews.[26] [27]

Muscle Characteristics

Findings from systematic reviews and meta-analyses found no relationship between hamstring flexibility and HSI.[27] [26] [23] In addition, a meta-analysis by Green et al. [23] found no relationship between HSIs and passive knee extension ROM, active knee extension ROM, passive straight leg raise, and slump tests. While flexibility has not been found to play a role, biceps femoris fascicle length and hamstring muscle-tendon unit stiffness were related to HSIs in lower level studies.[23] Green et al [23] also found conflicting evidence regarding the effect of hip flexors tightness and limited ankle dorsiflexion ROM on HSIs.

Muscle Performance

The meta-analysis by Green et al. [23] reported limited evidence for hamstring weakness as a risk factor for a HSI, a finding potentially influenced by the method and timing of measurement. They included a summary of previously published meta-analyses and noted no association between HSI and reduced knee flexor strength measured during Nordic hamstring extension (NHE) or with isokinetic testing.[23] Similar findings were noted by Opar et al.[33] in their meta-analysis. The meta-analysis by Freckleton & Pizzari [26] identified increased peak quadriceps torque as a risk factor for HSIs. When examining strength imbalances between the hamstrings and quadriceps as a risk factor for HSI, conflicting results have been found in systematic reviews.[27] [26] Differences in study findings did not seem to be related to measurement speed and type of muscle contraction.[27] [26] Green et al.[23] found decreased trunk muscle activity during the backswing phase of sprinting and increased gluteus medius activity during running as risk factors in lower level studies. They also identified abnormal motor control of the trunk and hamstring muscles as risk factors for HSI.[23] Conflicting evidence exist regarding increased gluteus maximus activity during running as a risk factor for HSI.[23]

Performance Characteristics

The meta-analysis by Green et al. [23] found that increased positional high speed running demands was a risk factor for HSIs, with moderate to strong evidence in soccer, American football, and rugby, and lower levels of evidence in Gaelic football and cricket. Those with rapid increases in high speed running exposure may be especially at risk. Sprinting characteristics with increased anterior pelvic tilting during the backswing and increased thoracic side bending during the backswing, were associated with HSIs in lower level studies. Within this review, one study found a higher proportion (68%, $P< 0.001$) of HSI were sustained during running activities but more severe injuries were sustained during kicking. [6] Systematic reviews have identified lower levels of evidence for predicting HSI using performance measures such as the single leg hop for distance and jumping percentage difference between non-countermovement and countermovement jumping.[23] [26] Freckleton and Pizzari [26] found that work load with time spent in games versus practice, as well frequency of off season running were not risk factors for HSI when looking at a variety of sports.

Summary

There is evidence that has identified previous HSI, age greater than 23, anterior cruciate ligament injuries, calf strains, and other knee and ankle ligament injuries as non-modifiable risk factors for HSI. While hamstring flexibility has not been identified as a modifiable risk factor, fascicle length and stiffness at the muscle-tendon junction were related to injury risk. There is evidence that supports high speed running demands with increased anterior pelvic tilting and abnormal trunk and pelvic control as risk factors for HSI. However, research is needed to further examine performance characteristics that might be risk factors, including hamstring weakness.

CLINICAL COURSE

CLINICAL COURSE
A HSI can occur anywhere along the length of the muscle, but occur most frequently in the proximal biceps femoris at the musculotendinous junction.[34] At the time of injury an individual experiences sudden, sharp pain in the posterior thigh. This can can be accompanied by an audible or palpable popping sensation[35] and often occurs during an activity that overloads and/or overstretches the hamstring muscle.[3][36] The individual may report being unable to complete the event or activity due to the pain and limited function. The recurrence rate of HSI ranges between 13.9-63.3% when followed over the same and subsequent seasons.[14] Also, injuries with more extensive myofascial damage that extends into the tendon are more prone to re-injury and delayed RTP.[37]

The clinical course of a HSI depends on the extent and nature of the muscle damage. In mild injuries, only the myofibrils are damaged.[36] With greater injury severity, the extreme tensile and shear forces result in additional tearing of fascia along with tearing of the basal lamina and blood vessels.[21] Release of muscle enzymes, creatine kinase, and collagen with proteoglycan degradation and inflammation occurs following the injury. Blood vessel damage results in bleeding and clotting.[21] The most common type of HSI occurs within the biceps femoris, where the myofibers attach to the intramuscular fascia.[38] [39] [40]

The healing process includes three phases: inflammation, proliferation, and remodeling.[21] The inflammation phase occurs immediately after the injury, lasts approximately 3-5 days,[38] and is characterized by vasodilation and increased capillary permeability causing fluid stasis. This can result in anischemic local environment with further muscle damage and edema. Two to four days after injury, phagocytic cells arrive to the damaged area and begin the clean-up process as well as activate local undifferentiated (“stem”) cells to begin rebuilding the collagen and vascular infrastructure (fibroblasts and endothelial cells).[38] Clinically, this phase is typically characterized by pain, swelling, bleeding, and loss of range of motion

The proliferation phase may overlap to varying degrees with the inflammation phase and lasts up to several weeks. During the proliferation phase, satellite cells contribute to repair damaged myofibers [41] as collagen and vascular infrastructures are rebuilt. At this time individuals often experience muscle weakness, stiffness, swelling, and limited function.[42] Suboptimal outcomes occur when these symptoms and signs continue for an extended period of time.[38]

Depending on the extent of the HSI, the remodeling phase can continue for up to two years. This phase is characterized by final collagen formation allowing for support to the site of injury. A properly aligned extracellular matrix is required to maintain optimal myofibril orientation. With an intact or repaired basal lamina acting as a scaffold, myofibrils can regenerate. Early range of motion after injury was associated with less disorganized scar formation (cite) and re-injury (cite). As the remodeling phase progresses, the individual will have minimal complaints and be able to tolerate greater stress to the muscle.[38]

Summary
The normal healing process of HSI is similar to other biological tissues and progresses through stages of inflammation, proliferation, and remodeling. The remodeling phase can last up to 2 years. Early hip and knee range of motion was associated with less disorganized scar formation and lower re-injury rate.

RETURN TO PLAY AND RE-INJURY RISK

RE-INJURY RISK AND RETURN TO PLAY

Overview

The high rate of recurrent HSIs are associated with substantial losses of time in training and competition for athletes and large costs to professional sports organizations. This makes optimizing re-injury risk assessment and RTP decision-making a high priority to all stakeholders. While more severe HSIs may take longer to recover, the importance of determining when the athlete can safely return to play while minimizing risk of re-injury remains high.

I

In a meta-analysis that included 71,324 athletes, a previous HSI was a risk factor for future injury (RR 2.7; 95% CI: 2.4, 3.1).[23] Multiple systematic reviews [43] [44] [26] and additional studies not included in these reviews supported this finding.[45-46] [47] Also, in 1932 Australian Rules football players, those with a recent HSI (within 8 weeks) were at higher risk (OR 13.1; 95% CI: 11.5, 14.9) for re-injury compared to those with a non-recent injury (greater than 8 weeks) (OR 3.5; 95%CI: 3.2, 3.9)[31] The meta-analysis by Green et al.[23] noted a risk of recurrent HSI was greatest during the same season (RR 4.8; 95%CI: 3.5, 6.6).

II

The systematic review by de Visser et al.[14] noted a lower risk of hamstring strain re-injury when individuals performed agility and stabilization exercises after injury as compared to stretching and strengthening exercises (7.7% vs 70%, respectively). In 48 semi-professional soccer players Mendiguchia et al.[48] found a comprehensive impairment-based treatment program to reduce the risk of re-injury compared to a standard NHE program alone (RR = 6; 90% CI: 1, 35).

II

A systematic review by Hickey et al.[49] recommended a combination of clinical assessment (manual muscle testing, ROM, palpation), performance (sprinting, agility, hopping, sport specific movements), and isokinetic dynamometry tests to inform RTP decision-making. Included in this review, four studies used RTP criteria based on a combination of clinical assessment and performance tests and reported mean RTP of 23-45 days and re-injury rates between 9.1-63.3%.[49] Two studies that implemented the Askling H-test as part of the decision-making criteria reported mean RTP times of 36 and 63 days with re-injury rates of 1.3% and 3.6%.[49] The most practical findings were noted in three studies that used isokinetic dynamometry, in addition to clinical assessment, and performance test with a reported mean RTP times of 12-25 days and re-injury rates between 6.25%-13.9%.[49]Schut et al.[50] in their systematic review found limited evidence for initial findings of visible bruising, muscle pain during every day activities, a popping sound at injury, being forced to stop play within 5 min, width of palpation pain, pain on trunk flexion, and pain on active knee flexion in predicting RTP times. This review also found limited evidence that identified no association with RTP times and an individual’s height and weight.[50]

II

At physical therapy initial evaluation, a combination of three demographic and six clinical variables explained 50% of the variance (±19 days) in predicting the time to RTP after grade I/II HSI.[51] However, a combination of clinical and demographic variables obtained on physical therapy assessment 7 days after the initial evaluation explained 97% of the variance (±5 days) in predicting time to RTP. In order of importance the variables most predictive for RTP were change in strength during the first week for the 'mid-range' test, peak isokinetic knee flexion torque of the uninjured leg at day 1, pain level at the time of injury, days to walk pain free, playing soccer, 'inner-range' hamstring strength at day 1, the presence or absence of pain on a single-leg bridge at day 7, delay in starting physical therapy, and percentage of strength in the 'outer-range' test compared to the healthy leg.[51]

II

Cross et al.[52] found no between-sex differences in the RTP time for first-time (median: men7.0 days, women 6.0 days; P=.07) or recurrent (median: men11 days, women5.5 days; P=.06) HSIs. However, the authors reported that male soccer players had a higher rate of re-injuries compared to females (men 22%; women 12%; P=0.003).[52] Similarly, Schut et al.[50] noted no association between RTP times and sex or previous HSI sustained within the last 12 months. Related to characteristics of sport and time to RTP, moderate evidence supports no association between the level of sports activity or the intensity of sport activity performed (three or fewer times per week or three or more times per week).[50] Conflicting evidence was noted for type of sport and time to RTP from injury.[50]

II

Two RCTs with fair evidence were identified in a meta-analysis and found a significant reduction in time to RTP (HR 3.22; 95% CI: 2.17, 4.77) when eccentric exercises were added to a conventional stretching, strengthening, and stabilization program after a HIS.[53]

III

Hamstring injuries categorized by deficits in active knee extension ROM with the hip flexed demonstrated longer bouts of rehabilitation as the ROM deficit increased. Grade I injuries had less than a 15° ROM deficit and required 25.9 days of rehab. Grade II injuries had a 16° to 25° ROM deficit and required 30.7 days of rehab , while grade III injuries had a 26° to 35° ROM deficit and required 75.0 days of rehab.[18] Normalization of isokinetic strength was not required to successfully complete a soccer-specific rehabilitation program.[54]

III

The length of the area of tenderness measured on initial evaluation (r^2=0.58; P< 0.001), area of tenderness (r^2=0.36; P=0.006), and age (r^2=0.27; P=0.024) were significant predictors for RTP, while width of tenderness (r^2=0.006; P=0.75) and location of injury were not (proximal-distal P=0.62, medial-lateral P=0.64).[55] Combining age with length of injury into a multiple regression analysis improved the prediction of RTP (r^2=0.73; P< 0.001).[55]

IV

A systematic review by Fournier-Farley et al.[56] also identified stretching type injuries, recreational-level sports, structural injuries (macroscopic evidence of muscle fiber damage), greater than 20° to 25°of active ROM deficit with knee extension, time to first treatment consultation >1 week, higher maximal pain score (≥5) on the 0-10 VAS, and >1 day to be able to walk pain free after the injury to predict longer recovery times. When specifically looking at criteria for RTP decisions, a systematic review by van der Horst et al.[57] found a wide variety of functional related criteria, none of which have been validated.

Gaps in knowledge

There is a lack of strong evidence for predicting clinical course, factors that predict time to RTP, and factors that predict risk for re-injury. Some of the limitations are associated with the lack of consistency, reliability and validity in the definition of RTP.

Evidence Synthesis and Rationale

The CPG Teams found the the best evidence for the history of a HSI as a risk factor for re-injury and needs to be considered in RTP decisions. There is also evidence that identified the absence an appropriately progressed, comprehensive impairment-based functional exercise program a risk factor for re-injury and programs that do not specifically include eccentric training a risk factor for re-injury as well as delayed RTP. An objective assessment with a criterion-based functional exercise progression may allow injured athletes to effectively RTP in a time sensitive manner, while minimizing the risk of re-injury. The harms of allowing an athlete to RTP before they are ready would be the potential risk of re-injury.

RECOMMENDATIONS

B

Clinicians should consider a previous HSI a risk factor for a future re-injury, with those having sustained a more recent injury being at higher risk.

B

Clinicians should consider the absence of an appropriately progressed, comprehensive impairment-based functional exercise program a risk factor for re-injury and programs that do not specifically include eccentric training a risk factor for re-injury as well as delayed RTP.

B

Clinicians should use hamstring strength, pain level at the time of injury, number of days from injury to pain-free walking, and area of tenderness measured on initial evaluation to estimate time to RTP.

DIAGNOSIS/CLASSIFICATION

DIAGNOSIS/CLASSIFICATION

Overview

Early and accurate clinical diagnosis of a HSI is important for providing appropriate treatment, deciding on RTP, and preventing re-injury. Because HSIs are typically diagnosed and graded based on physical findings, it is important for the clinician to not only recognize the clinical features of a HSI but also the signs and symptoms associated with the different grades of injury.

II

In 83 Australian Rule football athletes with posterior thigh pain, Verrall et al.(19) found the clinical features of a HSI (N=68) were a sudden onset of pain, an injury associated with running/acceleration, posterior thigh tenderness, and pain on resisted hamstring muscle contraction. The report of a sudden onset of pain (91%) was the most useful finding.(19)

II

Schneider-Kolsky et al.(58) found that clinical examination (r=0.69, P< 0.001) and MRI (r=0.58, P< 0.001) were associated with time to RTP in 58 Australian Rules football athletes. Wangensteen et al.(59) found the addition of MRI to clinical examination alone explained only an additional 2.8% of the variance in time to RTP in a prospective cohort of 180 male athletes.

IV

Zeren and Oztekin[60] defined the "taking off the shoe" test (TOST) for grade I and II biceps femoris injuries and found it to be 100% accurate when compared to US diagnosis.

Gaps in knowledge

Although a clinical examination represents the gold standard for diagnosing a HSI, evidence to define the accuracy of this examination is limited. A clinical examination traditionally describes a HSI as grade I, II, or III to represent the severity of injury and ranges from mild muscle damage without loss of structural integrity to complete muscle tearing with fiber disruption. The following criteria are used to identify each grade of injury.[61] [62]

●Grade I (Mild strain): 1) Micro-tearing of a few muscle fibers; 2) Local pain of smaller dimensions;3) Tightness in the posterior thigh, may experience cramping; 4)Slight pain with muscle stretching and activation;5) Stiffness may subside during activity but returns following activity; 6) Minimal loss of strength.

●Grade II (Moderate strain): 1) Moderate tearing of muscle fibers but muscle still intact; 2) Local pain covering larger area than a grade I; 3) More severe pain with muscle stretch and activation; 4) Stiffness, weakness, with possible hemorrhaging and bruising; 5) Limited ability to walk, especially for 24-48 hours after injury.

●Grade III (Severe strain): 1) Complete tear of the muscle; 2) Widespread swelling and bleeding; 3) Palpable mass of muscle tissue at tear site may be evident;.4) Extreme difficulty or inability to walk. The CPG team feels that when clinicians are practicing in a direct access model, grade III injuries should be referred to physicians when identified.

While the above grading criteria are commonly used as part of the clinical examination, research is needed to support its reliability and validity. Also, these criteria do not consider the exact location of the injury that may be able to be identified with MRI and US imaging.

Evidence Synthesis and Rationale

Detailed classification systems using diagnostic imaging have been described, however diagnostic imaging is usually not recommended. Although the evidence for the use of clinical examination to diagnose hamstring injury is limited an individual with an acute HSI typically presents with a sudden onset of well-localized posterior thigh pain, associated with muscle tenderness and loss of function. The mechanism of injury is commonly related to an overloading and/or overstretching of the hamstring muscle group. The injury may be associated with a popping and/or tearing sensation and result in localized ecchymosis. Pain may be reproduced with stretching and activation of the hamstring muscle group. However, these symptoms may be absent in some individuals with complete tears. When the area of maximal tenderness is at either the origin or insertion of the hamstring muscle group, tendon pathology should be considered as part of the differential diagnosis. When direct trauma to the posterior thigh is the mechanism of injury, the clinician should consider a different diagnosis, such as a contusion. Although it can occur on rare occasions in those with a HSI, an insidious onset of vague posterior symptom should raise concerns of referred pain. The benefits of properly diagnosing a HSI would allow for appropriate injury management, including RTP decisions and injury prevention measures. The harms of not appropriately recognizing the clinical features of a HSI could result in further injury or re-injury if the individual is not removed from athletic participation.

RECOMMENDATION
C
Clinicians may make a diagnosis of HSI when an individual presents with a sudden onset of posterior thigh pain during activity, associated with muscle tenderness with palpation, and loss of function, that is reproduced when the hamstring is stretched or activated.

DIFFERENTIAL DIAGNOSIS

Differential Diagnosis
The differential diagnosis for those with primarily proximal or distal posterior thigh symptoms may need to include hip and knee pathologies as well as isolated tendon lesions, apophysitis, and avulsion fractures. Specifically, for those with posterior thigh symptoms the differential diagnosis includes the following :[63]

- Lumbar radiculopathy
- Sacroiliac dysfunction
- Deep gluteal nerve entrapment
- Ischial tunnel syndrome
- Adductor muscle strain
- Contusion
- Compartment syndrome
- Thrombosis

IMAGING

Imaging
Imaging is typically not needed in those diagnosed with a HSI based on clinical examination. This may be especially true in those with less severe injuries as studies have found these less severe injuries may not be identifiable on MRI.[58][64] Detailed systems to classify HSIs based on MRI findings are available, such as the British Athletics Muscle Injury Classification,[65] modified Peetron's ,[17] and the anatomically based system described by Chan et al.[66] However, the role of MRI in helping to determine the clinical course, including RTP and risk of re-injuries, is unclear. Studies have found the addition of MRI does not improve the prediction of RTP beyond clinical examination.[58] [59] However, if there is suspicion of a non-musculoskeletal pain source, such as a thrombosis, imaging may be indicated. While the American College of Radiology Appropriateness Criteria® do not specifically outline guidelines for those with a HSI, the criteria for chronic hip pain notes MRI or US are "usually appropriate" in those with chronic symptoms and suspected extra-articular noninfectious soft-tissue abnormalities.(https://www.acr.org/) Therefore, MRI or US can be useful in decision-making in individuals with an atypical presentation of symptoms or who do not have satisfactory results with non-surgical care. Radiographs are usually not required unless symptoms are proximal and may be useful to rule out avulsion fractures.

EXAMINATION – PHYSICAL IMPAIRMENT MEASURES

Examination Overview

Activities that involve eccentric overloading of the hamstring in a lengthened position are not only associated with a HSI but may also remain impaired after injury. This includes high speed running, jumping, kicking, and/or explosive lower extremity movements. These activities are integral to sports such as track, soccer, Australian Rules football, American football, and rugby. Therefore it is appropriate for a physical examination to not only include measures of hamstring related impairments (strength and muscle length) but also direct and self-reported assessments of sports specific activities. An assessment of potential risk factors that may have contributed to injury may also be appropriate.

Isometric Knee Flexor Muscle Strength	
ICF category:	Measurement of impairment of body function, power of isolated muscles and muscle groups
Description:	Resistive measures of knee flexion strength with an isometric muscle contraction.
Measurement method	While positioned in prone or supine, the individual performs an isometric muscle knee flexion contraction against a hand-held dynamometer (HHD) that is placed on the posterior aspect of the distal tibia. The highest force of three trials is recorded for each position. The hip and knee positions may be altered to affect the length of the hamstring muscle group. Specific testing positions include: Inner-range: Strength is measured with the individual positioned prone with the knee in 90° flexion. The athlete gradually builds-up force to a maximum generated knee flexor force against a HHD that creates a “make” force.(67) Mid-range: Strength is measured prone with the knee extended and dorsum of the foot on the table. The therapist passively lifts the leg off the table equal to the distance of the foot length. The athlete pushes up against the HHD for 3 seconds. The examiner applies a “break” force once peak force is achieved.(67) Outer-range: Strength is measured with the individual supine with the hip and knee in 90° flexion. The athlete pushes against the HHD for 3 seconds. The examiner applies a “break” force once peak force is achieved. (67) 15° of knee flexion: Strength is measured with the individual positioned prone with the knee in 15° flexion. The athlete gradually built-up force to a maximum generated knee flexor force against a HHD that creates a “make” force. (68)
Nature of variable:	Continuous
Unit of measurement:	Kilograms or Newtons
Measurement properties: Reliability	Inner-range Intra-rater reliability:(67) • $ICC_{3,1}$ = 0.87; 95% CI: 0.84,0.89 • SEM = 1.78kg • MDC_{95}=4.9kg Inter-rater reliability:(68) • $ICC_{1,1}$ = 0.71; 95% CI: 0.62, 0.82 • SEM = 26N

	Inter-rater reliability:[67] • $ICC_{2,1}$ = 0.69; 95% CI: 0.45,0.83 • SEM = 2.01kg • MDC_{95}=5.6kg
	Mid-range Intra-rater reliability:[67] • $ICC_{3,1}$ = 0.89; 95% CI: 0.87, 0.90 • SEM = 2.02kg • MDC_{95}=5.6kg Inter-rater reliability:[67] • $ICC_{2,1}$ = 0.83; 95% CI: 0.68, 0.90 • SEM = 1.05kg • MDC_{95}=4.1kg
	Outer-range Intra-rater reliability:[67] • $ICC_{3,1}$ = 0.90; 95% CI: 0.88,0.92 • SEM = 2.19kg • MDC_{95}=6.1kg Inter-rater reliability:[67] • $ICC_{2,1}$ = 0.79; 95% CI: 0.62,0.88 • SEM = 2.17kg • MDC_{95}=6.0kg
	15° of knee flexion Inter-rater reliability:[68] • $ICC_{1,1}$ = 0.83; 95% CI: 0.73,0.90 • SEM = 29N
Measurement Properties: Validity	Isometric strength deficits, when assessed less than 7 days post injury, were found in the injured limbs compared to the non-injured side (ES = -1.72, 95% CI: -3.43, 0.0)[69]
	Deficits in knee flexor strength were noted between the previously injured limb compared to the contralateral non-injured limb for mean force with an isometric contraction (ES: d= -1.06; 90% CI: -1.93, -0.19 at 0°/0°, and at 45°/45°; d=-0.88; 90%CI: -1.74, -0.02).[70]
	Athletes with HSI generated significantly less isometric knee flexor force than those without HSI. Mean difference between groups: peak torque: -44.8N;95% CI: -86.3, -3.; normalized: -22.2Nm; 95%CI: -40.5, -3.7; normalized to body weight: -0.2; 95% CI: -0.4, 0.0.[71]

Isokinetic Knee Extensor and Flexor Muscle Strength	
ICF category:	Measurement of impairment of body function, power of isolated muscles and muscle groups
Description:	Resistive measures of the strength of the knee extensors and flexors using an isokinetic dynamometer.
Measurement method:	The individual is seated with the hip and knee flexed to 90°. The distal tibia is fixed with a cuff attached to a load cell just proximal to the malleoli. Straps are used to secure the thigh just proximal to the knee. After a brief warm-up, the individual exerts a maximal contraction through an arc of motion for both knee extension and flexion at selected speeds.
Nature of variable:	Continuous
Unit of measurement:	Newton-meters, foot-pounds, or Q:H ratio
Measurement Properties: Reliability	Intra-tester reliability (non-injured athletes)[72] • $ICC_{2,1}$ =.82 for eccentric contractions • SEM: 2.84 Nm • MCD: 7.87 Nm
Measurement Properties: Validity	Individuals with a HSI generated significantly less knee flexor force than controls at speeds of 60°/s ($p < .0013$) and 180°/s ($p < .0036$). When comparing knee flexor strength between the uninjured (within the previous 12 months) and injured side, injured side knee flexors were weaker at 60°/s during concentric ($p < .038$) and eccentric ($p < .03$) contractions. They were also weaker with eccentric contractions at 180°/s ($p < .038$).[73]
	A greater than 15%-20% between-limb eccentric knee flexor muscle strength imbalance was associated with an increased risk of HSI by 2.4 times (95% CI: 1.1, 5.5) and 3.4 times (95% CI: 1.5, 7.6), respectively.[74]
	At 60°/sec, athletes with HSI showed eccentric hamstring to concentric quadriceps asymmetry with imbalances of H:Q ratios less than 0.60 being able to best identify those a previous HSI.[75]
	Concentric isokinetic testing at 60°/s showed a difference in injured to non-injured knee flexor strength shown by the area under the curve of Receiver Operating Characteristics = 0.773, $p < 0.05$. No significant differences were noted at 120°/s.[76]
	Isokinetic Q:H strength ratios (concentric and eccentric) were not predictive of HSI.[77]
	At 60°/s individuals with a HSI demonstrated a 9.6% deficit in peak torque and a 6.4% deficit in workcompared to the uninjured side at the time to RTP.[78] Injured individuals also generated significantly less peak torque and work than the contralateral side when tested at 240°/s. The H:Q ratio (30° eccentric and 240°/sec concentric) revealed the injured limb had a lower ratio than the uninjured limb.[78]

	Individuals with prior HSI demonstrated significantly lower eccentric strength (at 25° to 5° of knee flexion: 81.2 Nm/kg vs 75.2 Nm/kg; $p < .025$.[79]
	Greater peak quadriceps concentric torque adjusted for body weight at 300°/s (>1SD above mean, 2.2–3.7Nm/ kg) was identified as a risk factor for injury (HR 2.06; 95% CI: 1.21, 3.51).[80]
	A significant small effect for a lower conventional hamstring:quadriceps (H:Q) ratio was found in previously injured legs compared to the uninjured contralateral legs at 60°:60°/sec; ES = 0.32; 95% CI: -0.54, -0.11) and 240°:240°/sec, ES: -0.43; 95% CI: -0.83, 0.03, but not 180°:180°/s or 300°:300°/s.[69]

Nordic Eccentric Knee Flexor Muscle Strength Test	
ICF category:	Measurement of impairment of body function, power of isolated muscles and muscle groups
Description:	Resistive measure of eccentric knee flexor strength.
Measurement method:	The individual is positioned in a tall kneeling position, arms across the chest, and both ankles firmly secured to a load-cell instrumented device. The athlete performs a Nordic Hamstring Test by slowly lowering the trunk toward the floor keeping the spine and hips in neutral.
Nature of variable:	Continuous
Unit of measurement:	Kilograms or Newtons
Measurement Properties: Reliability	Inter-tester reliability: non-injured athletes:[81] • ICC_{95} = 0.87-0.92 • MDC_{95} = 55.6 N (left and right sides pooled)
	Inter-tester reliability: non-injured athletes (same day)[82] • ICC: 0.60; 95% CI: 0.38,0.75; left leg • ICC: 0.62; 95% CI: 0.41, 0.76; right leg Inter-tester reliability: (1 week apart)[82] • ICC: 0.67; 95% CI: 0.38,0.84; left leg • ICC: 0.76; 95% CI: 0.53, 0.89; right leg

The Knee Extension Test for Hamstring Length (Hip/Knee: 90/90)	
ICF category:	Measurement of impairment of body function, mobility of a single joint
Description:	Measures knee flexor muscles length

Measurement methods	The individual lies supine with the hip and knee flexed to 90°; the knee is then maximally extended, either passively or actively. A goniometer or inclinometer can be used measure the knee extension deficit.
Nature of variable:	Continuous
Unit of measurement:	Degrees
Measurement Properties: Reliability	Inclinometer inter-rater reliability with knee PROM (same day)[83] $ICC_{1,1}$: 0.77; 95% CI: 0.63, 0.86 SEM: 7.6° MDC: 21° Inclinometer inter-rater reliability with knee AROM (same day)[83] $ICC_{1,1;}$ 0.89; 95% CI: 0.81,0.94 SEM: 5.3° MDC: 15°
Measurement Properties:Validity	PROM measures: Athletes with a HSI were categorized into grades based on the lack of full knee extension measured. Athletes with a Grade I injury had less than a 15° deficit and required 25.9 days of rehabilitation. Those with a Grade II injury, exhibited a 16° to 25° deficit and required 30.7 days of rehabilitation. Athletes with a Grade III injury demonstrated a 26° to 35° deficit and required 75.0 days of rehabilitation.[18]
	AROM measures: The active knee extension test in players with an US confirmed diagnosis of HSI had limited hamstring flexibility. The injured limb had a mean deficit of 12.8° (SD 6.8°) when compared to the uninjured side.[18]
Modifications	Maximal Hip Flexion Active Knee Extension Test (MHFAKE) assesses hamstring flexibility with the athlete positioned in maximum hip flexion Intra-rater reliability[67] $ICC_{3,1}$ = 0.83; 95% CI: 0.80, 0.86 SEM = 6.2° MDC = 17.2° Inter-rater reliability[67] $ICC_{2,1}$ = 0.96; 95% CI: 0.92, 0.98 SEM = 3.3° MDC = 9.3°

Straight Leg Raise for Assessing Hamstring Length	
ICF category:	Measurement of impairment of body function, mobility of a single joint

Description:	Measures of knee flexor muscles length
Measurement methods:	The athlete lies supine with the hip and knee extended. The examiner passively flexes the hip, as much as the athlete tolerates, while keeping the knee extended. A modification is to perform the maneuver and stop when the athlete reports pain at a 3 ("moderate") on a pain scale with 0=no pain and 10=maximal pain.
Nature of variable:	Continuous
Unit of measurement:	Degrees
Measurement Properties (Reliability) with an inclinometer:	Intra-rater reliability (athlete tolerance)[67] $ICC_{3,1}$ = 0.88; 95% CI: 0.86, 0.90 SEM: 4.7° MDC: 13.0° Inter-rater reliability (athlete tolerance)[67] $ICC_{2,1}$ = .74; 95% CI: 0.52, 0.86 SEM: 6.54° MDC: 18.1° Intra-rater reliability (stopping point being pain moderate" 3 out of 10)[3] $ICC_{3,1}$ = 0.98; 95% CI: 0.95, 0.99
Modification for determining RTP using an inclinometer (Askling H-test)	The clinician passively flexes the hip, with the knee extended, to athlete tolerance. The athlete then performs 3 SLR as fast and as high as possible to the point of not sustaining re-injury. The examiner records the highest value of the 3 trials.[84] $ICC_{1,1}$ = 0.96; 95% CI: 0.84, 0.99

Muscle Tenderness	
ICF category:	Measurement of impairment of body structure
Description:	Assess the location of peak tenderness and region of tenderness of the knee flexor muscles after a HSI
	The athlete lies prone on a treatment table with the knee fully extended
Nature of variable:	Continuous
Unit of measurement:	Centimeters or inches
Measurement Methods:	The examiner palpates the muscle to identify the location of peak hamstring tenderness and measures the distance from the ischial tuberosity. Next, marks are placed at the most proximal and distal and medial and lateral points of tenderness (at the point that tenderness subsides) to establish the length and width of tenderness. The area is “mapped” by expressing the length and width of tenderness as a percentage of the posterior thigh length and width. [55]

Measurement Properties: Validity	Percentage length of tenderness and age were the best predictors of days to RTP following HSI ($R^2 = 0.73$; $p < 0.001$) with the following predictive equation: number of days before return to sport = (% length of tenderness X 2.1) + (age X 1.5) – 43.4 [55]
	Athletes who report more proximal pain have a longer time to RTP.[5]

Gaps in Knowledge

It is recognized that those with a HSI present with knee flexor weakness, hamstring tightness, and muscle tenderness. However, the best method for assessing hamstring muscle strength, whether isometric, isokinetic, or eccentric, as well as the clinical interpretation of strength deficits remains undetermined. Studies are also needed to examine the reliability of measures other than with the hip flexed to 90° using an inclinometer to asses hamstring muscle length. Mapping hamstring muscle tenderness is felt to be a valuable component of a clinical examination but more evidence is needed to define its usefulness in HSI management. While increased anterior pelvic tilt and abnormal trunk and pelvic control during movements may be risk factors for an initial HSI,[13, 21, 23] further evidence is needed to support the usefulness of assessing these impairments over the course of treatment.

Evidence Synthesis and Rational

There is strong evidence for strength and ROM measures after a HSI. Current evidence suggests good reliability for measures of knee flexor weakness following HSI with isometric, isokinetic, and eccentric contractions with HHD or isokinetic dynamometer as well as hamstring muscle length with the hip flexed to 90° and straight leg raise methods using an inclinometer. The degree of knee extension deficit measured with the hip flexed to 90° has demonstrated potential usefulness grading the severity of injury. Weak evidence was identified for mapping the location and area of muscle tenderness. Percentage length of tenderness combined with age were predictors of days to RTP and those who had more proximal pain had a longer time to RTP. The benefits of properly assessing knee flexor weakness, loss of hamstring flexibility, and muscle tenderness may be used in conjunction with a criterion-based functional activity progression to allow injured athletes effectively RTP in a time-sensitive manner, while minimizing the risk of re-injury. The harms of not properly assessing the injury would be allowing the athlete to RTP before they are ready with risking potential re-injury.

RECOMMENDATION

A

Clinicians should quantify knee flexor strength following HSI by using either a HHD or isokinetic dynamometer.

A

Clinicians should assess hamstring length measuring knee extension deficit with the hip flexed to 90° using an inclinometer.

C

Clinicians may measure the length of muscle tenderness and location from the ischial tuberosity to assist in predicting timing of RTP.

F

Clinicians may asses for increased anterior pelvic tilt and abnormal trunk and pelvic control during function movements.

EXAMINATION: ACTIVITY LIMITATION AND PARTICIPATION RESTRICTION

II
Hickey et al provided general guidelines for assessing activity limitations that include a progression sequence of pain-free walking, pain-free normal jogging, running at 70% perceived maximum speed, pain-free change of direction, and pain-free 100% running speed.[49]
II
The Repeated Sprint Test was found to be reliable with an ICC=0.978 (95% CI 0.96, 0.98), SEM=0.008 s, and MDC_{95}=0.022 s in 75 semi-professional and professional soccer players (19 ± 3 years). Athletes with a previous HSI showed a significant decrease in speed with repeated sprinting (.07 s versus .02 s; P=.007).[85]
III
Ishoi et al.[86] found that 11 soccer players with a prior history of a HSI had a higher mean maximal sprinting velocity when compared to 33 controls. (Mean difference = .45m/s; 95%CI: 0.059, 0.85;).

Gaps in Knowledge
Information is needed to allow clinicians to select and interpret scores from measures of activity and participation in those with a HSI. Because athletes are the population that typically sustain a HSI, evidence to support the validity, reliability, and responsiveness of sport-related functional activities, including high speed running, jumping, kicking, and/or explosive lower extremity movements, would be useful.

Evidence Synthesis and Rational
Limited evidence exists regarding the most appropriate activity and participation measures that should be used to document progress over the course of treatment. Because injuries often occur with high speed running, combined with the fact that gait and running are typically impaired after a HSI, it would seem appropriate that objective measures of activity and participation should include gait and running.

RECOMMENDATION
C
Clinicians may include objective measures of an individual's ability to walk, run, and sprint when documenting changes in activity and participation over the course of treatment.

EXAMINATION: OUTCOME MEASURES

OUTCOME MEASURES
I
The Functional Assessment Scale for Acute Hamstring Injuries (FASH) is a reliable and valid 10-item questionnaire used to assess function after an acute HSI. The FASH exhibited very good test–retest reliability (ICC=0.9), internal consistency (Chronbach's Alpha = 0.98), and responsiveness (3.8 and 5.32 using baseline and pooled standard deviation). The FASH also has established face validity, content validity, and construct validity (eg, its ability to discriminate between those with acute HSI and non-injured hamstrings).[87]
II
The Hamstring Outcome Score (HaOS) is a five-domain questionnaire that assesses an athlete's soreness, symptoms, pain, activities (sports), and quality of life. Questions on the HaOS are scored 0-4, from no complaints to maximum complaints. A score of 100% suggests no complaints in all domains. A score of 80% or more indicates a low risk for HSI, while below 80% indicates a high risk for HSI. The scale has been shown to be a predictor of new HSI with athletes with lower HaOSs having a more recent injury in a study of 365 amateur soccer player ($P < 0.005$).[88] [89]

Evidence Synthesis and Rationale
The FASH and HaOS are the only evidence-based instruments designed to assess athletes with HSI. While other potential instruments, such as the Hip and Groin Outcome Score (HAGOS), are available, no evidence exists for its use in those with HSI. Although the FASH has established reliability and validity, additional work is needed to determine the MDC and MCID to understand its responsiveness and score interpretation. The HaOS has established construct validity for predicting HSI in athletes but does not have established reliability and is used primarily before athletic participation begins to identify athletes who may be susceptible to a HSI.

RECOMMENDATION
B
Clinicians should use the FASH before and after interventions intended to alleviate the impairments of body function and structure, activity limitations, and participation restrictions in those diagnosed with a HSI.

INJURY PREVENTION

Prevention first time injury
Hamstring injuries are common in sports that require high speed running, jumping, kicking, explosive rapid changes in direction, and/or lifting objects from ground. Prevention of a first time HSI is considered important because of the considerable impairment, activity limitation and participation restriction, including time lost from competitive sports that may occur after injury. Prevention may be

particularly important in professional sports, where HSIs can be associated with significant financial costs.[1]

I

Systematic reviews have concluded that exercise prevention programs that included the NHE were effective in reducing the incidence of HSI.[90]; [91] [92][93] Specifically an umbrella review by Raya-GonzAlez,[90] included a systematic review and meta-analysis by van Dyk et al. [94], who noted the NHE reduced hamstring injury by 51% (RR 0.49; 95% CI: 0.32, 0.74) in 15 studies with 8459 athletes. The systematic review by Goode et al., [95] which included 4 studies, found the effectiveness of NHE may be dependent on compliance with the exercise.

I

When specifically looking at female soccer players, a systematic review by Crossley et al.[96] found in 5 studies that exercise-based strategies (single-component and multicomponent) significantly reduced the incidence of HSIs (IRR 0.40, 95%CI 0.17, 0.95). It was concluded that although the evidence was not as robust in female soccer players, exercise-based strategies can reduce HSI by 40-60%, similar to what was found with their male counterparts.[96]

II

A RCT with 259 male high school soccer players found the time-lost to injury was lower in the NHE group (113.7/10,000 hours) compared to the control group (1116.3/10,000 hours) [P< 0.001].[97]

III

Within the umbrella review by Raya-GonzAlez[90], systematic reviews by Rogan et al.[98] reported inconclusive evidence to support the role of hamstring stretching with Hibbert et al.[99] noting weak evidence for eccentric hamstring exercises other than NHE. Not included in the Raya-GonzAlez review, a systematic review by Mcall et al.[100] also found weak evidence in 3 studies to support eccentric hamstring exercises other than NHE. While there is evidence to support NHE in HSI prevention, Elerian et al.[101] did not find a significant difference in HSI rates between seasons where 34 soccer players performed the NHE and a season where the NHE was not performed.

IV

In 613 male collegiate sprinters followed over a period of 24 seasons by the same coach, the incidence of HSI decreased as agility and flexibility were added to strength training.[102] Results from other case series further supported the use of eccentric hamstring (in addition to NHE)[103]) and isokinetic[104] strengthening exercises for reducing HSI rate.

Evidence Synthesis and Rational

Further research is needed to specifically define the most effective warm-up, stretching, balance, strengthening, and function movements and other eccentric hamstring exercises, that should be added to NHE. The International Federation of Association Football (Fédération Internationale de Football Association- FIFA) 11+ and Harmoknee programs, both of which include the NHE, and "New Warm-up Program", which did not include the NHE, are examples of comprehensive injury prevention programs that include components of warm-up, stretching, stability training, strengthening, and functional movements (sport-specific, agility and high-speed running).[91] Additionally, frequency and load progression of all preventive interventions need to be further defined. Recommendations regarding dosing of the NHE can vary with volumes that range from two sets of three repetitions once per week to three sets of 10 repetitions twice a week, with a gradual progression of four repetitions per week. These exercises are generally performed after training and on days before a rest day to allow for adequate recovery.[105] The benefits of a HSI prevention program with NHE and other components of warm-up, stretching, stability training, strengthening, and functional movements (sport-specific, agility and high-speed running) outweigh the potential harms. It should be noted the harms of performing preventative exercises have not been described but could potentially include muscle soreness from exercise.

Recommendation

A
Clinicians should include the NHE as part of a hamstring injury prevention program with other components of warm-up, stretching, stability training, strengthening, and functional movements (sport-specific, agility and high-speed running).

INTERVENTIONS

Intervention after Injury
Only studies of interventions within the scope of physical therapy that directly assessed time to RTP and re-injury rates were included in the review process. While the effect of interventions for those with a HSI can be measured in a variety of ways, including but not limited to strength, ROM, and pain levels, the ultimate success of the rehabilitation process is determined by the individual's ability to return to participation while preventing re-injury.

I
A high quality RCT found RTP following a standardized progressive rehabilitation protocol comprised of hamstring strengthening exercises and running performed within either pain-free (N=21) or pain-threshold limits (N=22) each had 2 re-injuries, with no difference in RTP time. The median time from hamstring injury to RTP was 15 days (95%CI: 13, 17) for the pain-free group and 17 days (95%CI: 11, 24) for the pain-threshold group (P=.37).[106]

II
A systematic review and meta-analysis by Pas et al.[53] identified 2 RCTs with fair evidenceto support a program that added eccentric strengthening exercises to a conventional program of stretching, strengthening, and stabilization after a HSI with significantly reduced time to RTP (HR 3.22; 95%CI: 2.17, 4.77) but did no affect re-injury rate (RR 0.25, 95% CI: 0.03, 2.20).

II
A systematic review that included a total of 5 studies found progressive agility and trunk stabilization (PATS) added to a rehabilitation program focusing on stretching and strengthening (STST) does not seem to improve RTP time but may decrease re-injury rate.[14] Included within this review, Sherry et al.[107] specifically found a significant reduction in re-injury rates in favor of PATS (0/13 re-injuries within 16 days after RTP and 1/13 within 1 year, vs 6/10 and 7/10, respectively in the STST group (P< 0.001).

II
Systematic reviews found insufficient evidence to support the use of stretching as an isolated treatment in the management of HSI.[53] [108] [27] [14] [109]*

II
A RCT found an individualized criteria-based treatment program consisting of comprehensive impairment-based treatments reduced the risk of re-injury compared to a standard NHE program (RR =

6, 90%CI 1, 35) but resulted in no difference in RTP time (25.5days vs 23.2 days; -13.8% 90%CI -34, 3.4%) in a total of 48 male semi-professional soccer players.[48]

II

A systematic review by Hickey et al[49] identified 9 studies (total N=601) looking at individuals diagnosed with an acute HSI and concluded that specific criteria for progression of rehabilitation were not well defined.[49]*

III

In a case control study that compared professional male soccer players (mean age 24.3 years) over 2 seasons, re-injury rate was reduced from 7/35 to 1/34 in the season that NHE was instituted.[101]

IV

A case series found 50 out of 54 athletes (mean age 36 years; 30 male, 20 female) who were compliant with a rehabilitation program emphasizing eccentric hamstring strengthening in a lengthened position reported no re-injuries.[110]

IV

A retrospective case series consisting of 48 consecutive HSIs in intercollegiate athletes found that early mobilization with progressive stretching and sport-related functional exercises was successful in allowing athletes to return to sport after HSI at an average of 11.9 days (range 5-23 days) with 3 re-injuries.[111]

Gaps in Knowledge

While there is evidence to support exercise in the treatment of a HSI, evidence is lacking to support commonly used treatments such as soft-tissue mobilization, nerve glides, and therapeutic modalities. These commonly used treatments are believed to assist in the healing process and shorten the period of disability after a HSI. However, research is needed to support the efficacy of these treatments in reducing time to RTP and decreasing re-injury rates.

Evidence Synthesis and Rational

Evidence supports initiating hamstring strengthening exercises, including eccentrics early in the rehabilitation process guided by patient pain tolerance. Successful interventions included 6-12 repetitions depending on the intensity of the exercise, with both load and ROM increased as tolerated. Exercises were performed 2-3 times per week. The evidence behind eccentric hamstring exercises includes, but is not limited to, NHE. Evidence also supports PATS exercises and a running program, involving acceleration and deceleration phases with a progressive increase in speed and distance, to be included throughout the rehabilitation process as tolerated. The benefits of eccentric training, added to stretching, strengthening, stabilization, and progressive running programs are improved RTP times, while progressive agility and trunk stabilization added to a comprehensive impairment-based treatment are reduced re-injury rates. Although the harms of initiating and progressing exercise and running have not been well described, there a potential to aggravate symptoms if the load of the activity is beyond the individual's tolerance. Potential harms may be mitigated if the clinician recognizes the primary phase of healing (inflammatory, proliferation, or remodeling) and use a logical systematic method to begin, monitor, and progress tissue loading.

Recommendation

B

Clinicians should use eccentric training, added to stretching, strengthening, stabilization, and progressive running programs to improve RTP time after a HSI.

B

Clinicians should use progressive agility and trunk stabilization added to a comprehensive impairment-based treatment program with stretching, strengthening, and functional exercises, to reduce re-injury rate after a HSI.

F

Clinicians may use soft-tissue mobilization, nerve glides, and therapeutic modalities to assist in the healing process and shorten the period of disability after a HSI.

Decision Tree

Component 1: Medical Screening

Component 2: Classify condition and assess re-injury risk

Patient Examination:

- Sudden onset of posterior thigh pain[C]
- Reproduction of pain with hamstring stretching and activation[C]
- Muscle tenderness with palpation[C]
- Loss of function[C]
- Use the following criteria to grade muscle injury:[F]
    - Grade I (mild strain): 1) Micro-tearing of a few muscle fibers; 2) Local pain of smaller dimensions; 3) Tightness in the posterior thigh, may experience cramping; 4) Slight pain with muscle stretching and contraction;5) Stiffness may subside during activity but returns following activity; 6) Minimal loss of strength
    - Grade II (moderate strain): 1) Moderate tearing of muscle fibers but muscle still intact; 2) Local pain covering larger area than a grade I; 3) More severe pain with muscle stretch and activation; 4) Stiffness, weakness, with possible hemorrhaging and bruising; 5) Limited ability to walk, especially for 24-48 hours after injury
    - Grade III (severe strain): 1) Complete tear of the muscle; 2) Widespread swelling and bleeding; 3) Palpable mass of muscle tissue at tear may be evident; 4) Extreme difficulty or inability to walk
- Previous HSI[B]

***Grade III HSIs are referred to a Physician**

Component 3: Irritability

Component 4: Outcome measures to document progress

- Knee flexor strength using either a HHD or isokinetic dynamometer[A]
- Hamstring length measuring knee extension deficit with the hip flexed to 90° using an inclinometer[A]
- Measure the length of muscle tenderness to palpation and location from the ischial tuberosity
- Assess for increased anterior pelvic tilt and abnormal trunk and hip muscle activity during functional movements.[F]
- Objective measures to qualify and grade an individual's ability to walk, run, and sprint[C]
- FASH[B]

Component 5: Measures to estimate time to RTP

- Knee flexor strength using either a HHD or isokinetic dynamometer[B]
- Pain level at the time of injury[B]
- Number of days to walk pain free after injury[B]
- Area of tenderness to palpation measured on initial evaluation[B]

<u>Component 6: Intervention Strategies</u>

- Eccentric training, added to an impairment-based treatment program with stretching, strengthening, stabilization, agility, and progressive running[B]
- Soft-tissue and nerve mobilization[F]
- Therapeutic modalities for symptom management[F]

<u>Component 7: Injury Prevention</u>

- NHE with other components of warm-up, stretching, stability training, strengthening, and functional movements (sport-specific agility and high-speed running).[A]

Prisma

To be furnished at time of publication

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