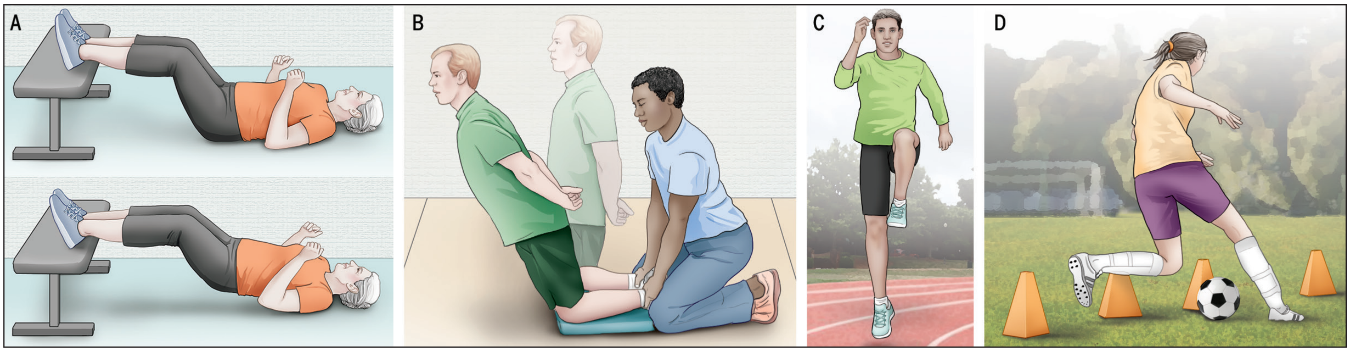
Hamstring Injury: What Is It? What Should I Do About It? When Can I Get Back to My Sport?

J Orthop Sports Phys Ther 2022;52(3):129. doi:10.2519/jospt.2022.0502

How do I know if I have a hamstring injury? Typically, people feel a sudden pain in the back of the thigh. In sports, hamstring injuries often occur when the hamstring muscles are stretched quickly (eg, kicking or sprinting). Walking or other daily activities may reproduce the pain.

How long will my hamstring injury take to recover? The good news is that most hamstring injuries resolve within 6 weeks, and you can get back to doing the sports and recreational activities that you enjoy without lasting problems. You may notice some swelling and pain around the injured part in the hamstring for 1 or 2 weeks. Muscle stiffness and weakness are also common, and you may not be able to do the things you normally do, such as running or playing sports, for a few weeks. The time it takes to recover fully is different for different people.



(A) Start by lying on your back with both knees slightly bent and feet resting on a chair or bench. Lift your buttocks off the floor to straighten your hips. Lower slowly, and repeat. Progress to a single-leg exercise when your hamstring is stronger. (B) Kneel on a soft surface with your hips extended and body upright. Have someone hold your ankles steady. Keep your spine straight while you slowly lower your chest toward the floor. Use your arms to break your fall when you can no longer control the movement of your upper body. Use your arms to push yourself back to the start position. Repeat. (C) A skips and B skips with high knees are part of a return-to-running program; focus on the knee straightening as you kick out with each step. (D) Sport-specific drills are the last step in preparing your hamstring for returning to sport.

WHAT THE GUIDELINES MEAN FOR MANAGING YOUR HAMSTRING INJURY

Early in your recovery (1-2 weeks), focus on reducing pain and swelling; build up to walking and slow jogging without pain. Next, build strength, flexibility and balance with exercises like bridges (A) and Nordic hamstring exercises (B). Finally, focus on preparing your body to return to full activities, including sports with A and B skips (C) and sport-specific movements (D).

When can I play my sport again? A slow and steady progression of your rehabilitation is key to successful return to sport. You should have no pain, full movement, full strength, and completed your sport-specific movements (eg, sprints, direction changes, and kicks) at full speed with no hamstring pain before returning to full participation. Return to sport can take weeks to months. Ask your rehabilitation provider about incorporating the Nordic hamstring exercise (image B) into your normal sport training to help you avoid future hamstring injuries.

This *JOSPT* Perspectives for Patients is based on clinical practice guidelines by Martin et al: "Hamstring Strain Injury in Athletes" (*J Orthop Sports Phys Ther. 2022;52(3):CPG1-CPG44. https://doi.org/10.2519/jospt.2022.0301*). This JOSPT Perspectives for Patients article was produced by Patient and Public Partnerships Editor Joletta Belton and a team of *JOSPT*'s editorial board and staff, led by Editor-in-Chief Clare Ardern, and illustrated by Jeanne Robertson. For this and more topics, visit *JOSPT* Perspectives for Patients online at **www.jospt.org**.

Hamstring Strain Injury in Athletes: A Summary of Clinical Practice Guideline Recommendations

Using the Evidence to Guide Physical Therapist Practice

J Orthop Sports Phys Ther 2022;52(3):127-128. doi:10.2519/jospt.2022.0501

Hamstring strain injuries (HSIs) are common in sports that involve high-speed running, jumping, kicking, explosive lower extremity movements, or lifting objects from the ground. The injury typically involves some type of eccentric overloading or overstretching in a position of hip flexion and knee extension.[1,2] The injured individual typically experiences a sudden, sharp pain in the posterior thigh, with a popping or pulling sensation.[5] For athletes, HSIs frequently cause absence from competition, generally ranging from 3 to 28 days or more, depending on injury severity.[6] Those with a history of HSI have a 3.6-times higher risk of sustaining a future HSI.[7] The long head of the biceps femoris muscle is the most commonly injured hamstring muscle in both first-time and recurrent injuries, being involved in 79% to 84% of HSIs.[4,9-11]

WHAT WE KNEW

Hamstring strain injuries may result in considerable impairment, activity limitation, and participation restriction, including time lost from competitive sports. In professional sports, HSIs may impose substantial financial costs.[3] The high reinjury rate is also a challenge.[7] Improving reinjury risk assessment and decision making for safe return to play is a high priority for all stakeholders.

WHAT WE DID

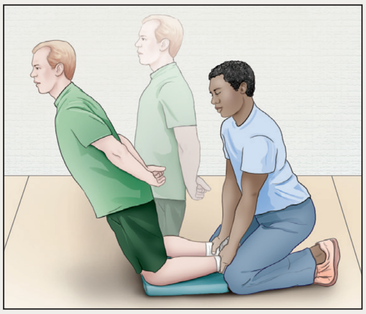
This clinical practice guideline[8] focused on sports-related HSI to myofascial or musculotendinous structures, and excluded isolated proximal and distal tendon injuries. The ultimate success of rehabilitation is reflected by safe return to sport, with no reinjury. Therefore, we focused on studies that directly assessed time to return to play and reinjury rates. We reviewed over 14 000 articles to produce recommendations for return to play and reinjury risk, examination, injury prevention, and interventions.

WHAT WE FOUND

Hamstring muscle architecture (eg, higher pennation angle and smaller fascicle length) and strength, high-speed running exposure, abnormal trunk and pelvic posture, and/or abnormal motor control may contribute to HSI, whereas hamstring flexibility does not. When clinicians suspect HSI, physical examination should include measures of hamstring-related impairments (strength and muscle length) and direct and self-reported assessments of sport-specific activities.

BOTTOM LINE FOR PRACTICE

Injury prevention exercise programs must include the Nordic hamstring exercise, plus other components of warm-up, stretching, stability training, strengthening, and functional movements (sport specific, agility, and high-speed running). Initiate hamstring-strengthening exercises after an HSI, including eccentrics, early in the rehabilitation process, as guided by patient pain tolerance. Effective interventions included 6 to 12 repetitions, depending on the intensity of the exercise, with both load and range of motion increasing as tolerated. Patients should perform the exercises 2 to 3 times per week. The evidence supporting eccentric hamstring exercises after injury includes, but is not limited to, the Nordic hamstring exercise. Introduce progressive agility and trunk stabilization exercises and a running program that involves acceleration and deceleration phases, with progressive increases in speed and distance as tolerated.



This *JOSPT* Perspectives for Practice article is based on the guideline by Martin et al[8] and was written by RobRoy L. Martin, PT, PhD and illustrated by Jeanne Robertson. The flow chart on the next page was produced by Alex Scott, PT, PhD. For this and more topics, visit *JOSPT* Perspectives for Practice online at **www.jospt.org**.

Hamstring Injuries in Athletes: Care Process Model

Diagnosis

Diagnose HSI when an individual presents with the following: sudden onset of posterior thigh pain during activity, pain reproduced when the hamstring is stretched and/or activated, muscle tenderness with palpation, and loss of function – B

Examination

- Quantify knee flexor strength using a handheld or isokinetic dynamometer – A
- Assess hamstring length with the hip flexed to 90°, using an inclinometer – A
- May use the length of muscle tenderness and proximity to the ischial tuberosity to assist in predicting timing of return to play – C
- May assess trunk and pelvic posture and control during functional movements – F

Outcome Measures

- Include objective measures of walking, running, and sprinting when documenting changes during treatment – B
- In acute HSI, use the FASH before and after interventions intended to alleviate impairments of body function and structure, activity limitations, and participation restrictions – B

Interventions

- To reduce time to return to play, use eccentric training to patient tolerance, along with stretching, strengthening, stabilization, and progressive running programs – B
- To reduce the reinjury rate, use progressive agility and trunk stabilization, added to a comprehensive impairment-based treatment program with stretching, strengthening, and functional exercises – B

Prevention

Include the Nordic hamstring exercise as part of an HSI prevention program, along with other components of warm-up, stretching, stability training, strengthening, and functional movements (sport specific, agility, and high-speed running) – B

Based on the guidelines, the grades in this flow chart may be translated as follows: A, strong evidence; B, moderate evidence; C, weak evidence; F, expert opinion.
Abbreviations: FASH, Functional Assessment Scale for Acute Hamstring Injuries; HSI, hamstring strain injury.

REFERENCES

1. Ahmad CS, Redler LH, Ciccotti MG, Maffulli N, Longo UG, Bradley J. Evaluation and management of hamstring injuries. *Am J Sports Med*. 2013;41:2933-2947. https://doi.org/10.1177/0363546513487063
2. Askling C, Saartok T, Thorstensson A. Type of acute hamstring strain affects flexibility, strength, and time to return to pre-injury level. *Br J Sports Med*. 2006;40:40-44. https://doi.org/10.1136/bjsm.2005.018879
3. Danielsson A, Horvath A, Senorski C, et al. The mechanism of hamstring injuries – a systematic review. *BMC Musculoskelet Disord*. 2020;21:641. https://doi.org/10.1186/s12891-020-03658-8
4. Ekstrand J, Healy JC, Waldén M, Lee JC, English B, Hägglund M. Hamstring muscle injuries in professional football: the correlation of MRI findings with return to play. *Br J Sports Med*. 2012;46:112-117. https://doi.org/10.1136/bjsports-2011-090155
5. Hamilton B. Hamstring muscle strain injuries: what can we learn from history? *Br J Sports Med*. 2012;46:900-903. https://doi.org/10.1136/bjsports-2012-090931
6. Kerkhoffs GM, van Es N, Wieldraaijer T, Sierevelt IN, Ekstrand J, van Dijk CN. Diagnosis and prognosis of acute hamstring injuries in athletes. *Knee Surg Sports Traumatol Arthrosc*. 2013;21:500-509. https://doi.org/10.1007/s00167-012-2055-x
7. Lee JWY, Mok KM, Chan HCK, Yung PSH, Chan KM. Eccentric hamstring strength deficit and poor hamstring-to-quadriceps ratio are risk factors for hamstring strain injury in football: a prospective study of 146 professional players. *J Sci Med Sport*. 2018;21:789-793. https://doi.org/10.1016/j.jsams.2017.11.017
8. Martin RL, Cibulka MT, Bolgla LA, et al. Hamstring strain injury in athletes. *J Orthop Sports Phys Ther*. 2022;52:CPG1-CPG44. https://doi.org/10.2519/jospt.2022.0301
9. Smirnova L, Derinov A, Glazkova I. Hamstring structural injury in futsal players: the effect of active range of motion (AROM) deficit on rehabilitation period. *Muscles Ligaments Tendons J*. 2020;10:645-650. https://doi.org/10.32098/mltj.04.2020.12
10. Verrall GM, Slavotinek JP, Barnes PG, Fon GT. Diagnostic and prognostic value of clinical findings in 83 athletes with posterior thigh injury: comparison of clinical findings with magnetic resonance imaging documentation of hamstring muscle strain. *Am J Sports Med*. 2003;31:969-973. https://doi.org/10.1177/03635465030310063701
11. Wangensteen A, Tol JL, Witvrouw E, et al. Hamstring reinjuries occur at the same location and early after return to sport: a descriptive study of MRI-confirmed reinjuries. *Am J Sports Med*. 2016;44:2112-2121. https://doi.org/10.1177/0363546516646086

RAY BREED, AES, MA[1,2] • DAVID OPAR, PhD[1,3] • RYAN TIMMINS, PhD[1,3]
NIRAV MANIAR, PhD[1,3] • HARRY BANYARD, PhD[2] • JACK HICKEY, AEP, PhD[1,3]

Poor Reporting of Exercise Interventions for Hamstring Strain Injury Rehabilitation: A Scoping Review of Reporting Quality and Content in Contemporary Applied Research

Hamstring strain injuries (HSIs) are the main cause of the unavailability of athletes in running-based sports[16,44,57] and have substantial performance and financial consequences for professional teams.[21,41] Sports injury practitioners are regularly required to prescribe HSI rehabilitation interventions that facilitate fast return to sport with minimal risk of reinjury.[15,20,40] Deficits in hamstring structure and function often persist, sometimes long after athletes have completed HSI rehabilitation and returned to sport. These deficits likely contribute to reinjury risk and impaired sporting performance.[9,32,53] Over the past decade, researchers have focused on the efficacy of different HSI rehabilitation interventions for reducing time to return to sport and reinjury risk.[52]

OBJECTIVE: To review the quality of reporting and identify the content of exercise interventions prescribed for hamstring strain injury (HSI) rehabilitation in the scientific literature from 2010 to 2020.

DESIGN: Scoping review.

LITERATURE SEARCH: We searched the bibliometric databases Web of Science, CINAHL, SPORTDiscus, Scopus, Cochrane Library, MEDLINE, and Embase.

STUDY SELECTION CRITERIA: Original research articles (randomized controlled trials and cohort studies) published from 2010 to 2020 that described an exercise rehabilitation intervention for participants with acute HSIs were included. Injuries must have been confirmed within 7 days of occurrence via clinical assessment and/or diagnostic imaging.

DATA SYNTHESIS: The quality of reporting, in terms of completeness of exercise intervention description, was evaluated using the Consensus on Exercise Reporting Template (CERT), and the content of interventions was categorized into exercise types.

RESULTS: Fourteen studies were included; exercise intervention quality of reporting was moderate in 3 studies and low in 11 studies. Using the 19-item CERT, an average of 8.8 items (range, 4-14) were reported across all studies. Two studies reported sufficient exercise content and progression information to allow replication. Exercises categorized as hamstring flexibility, hamstring strength, running related, and non–hamstring specific were prescribed in 13, 11, 10, and 10 studies, respectively. Half of the included studies incorporated all 4 exercise types in their exercise interventions.

CONCLUSION: There is a wide variety of exercise interventions applied in published research that has addressed HSI rehabilitation. Researchers must improve reporting quality to support other professionals in replicating exercise interventions and help practitioners to effectively implement research in practice. *J Orthop Sports Phys Ther 2022;52(3):130-141. Epub 21 Sep 2021. doi:10.2519/jospt.2022.10641*

KEY WORDS: *CERT, exercise interventions, hamstring strain injury, rehabilitation, reporting quality*

Exercise is the most evidence-based HSI rehabilitation intervention and the one demonstrated to be most effective in reducing time to return to sport and reinjury risk.[25] Exercise-based HSI rehabilitation typically focuses on improving hamstring flexibility, strength, running performance, agility, or trunk stability.[24,29,32,48] However, the quality of reporting and specific content of different exercise interventions applied in contemporary HSI rehabilitation research are uncertain.[23,52]

Evaluating the quality of exercise intervention reporting for HSI rehabilita-

[1]School of Behavioural and Health Sciences, Australian Catholic University, Fitzroy, Australia. [2]Department of Health Sciences and Biostatistics, School of Health Sciences, Swinburne University of Technology, Hawthorn, Australia. [3]Sports Performance, Recovery, Injury and New Technologies Research Centre, School of Behavioural and Health Sciences, Australian Catholic University, Fitzroy, Australia. ORCID: Breed, https://orcid.org/0000-0002-9267-8390; Opar, https://orcid.org/0000-0002-8354-6353; Timmins, https://orcid.org/0000-0003-4964-1848. This review was registered with PROSPERO on July 7, 2020 (CRD42020190831). The title of this manuscript was changed from a "systematic" to a "scoping" review, based on editorial feedback as part of the peer-review process, on March 13, 2021. No funding or financial assistance was required for this review. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Ray Breed, Department of Health Sciences and Biostatistics, School of Health Sciences, Swinburne University of Technology, Mail H21, PO Box 218, SPW Health Precinct, Hawthorn, VIC 3122 Australia. E-mail: rbreed@swin.edu.au

tion included in contemporary research is necessary to ensure that professionals who implement evidence-based practice can replicate the interventions in rehabilitation. The Consensus on Exercise Reporting Template (CERT) was developed to improve the quality of reporting in the scientific literature by assessing the completeness of descriptions of exercise interventions.[50] Reviews of exercise interventions for musculoskeletal conditions such as groin pain,[8] Achilles tendon rupture,[10] and osteoarthritis[5] have applied the CERT. Considering the abundant applied research in HSI rehabilitation over the past decade, investigating the quality of reporting and specific content of HSI exercise interventions is warranted.

The primary aim of this scoping review was to assess the quality of reporting of exercise interventions in HSI rehabilitation literature over the past decade, using the CERT. The secondary aim was to describe the specific content of different exercise interventions applied to HSI rehabilitation.

METHODS

Protocol and Registration

This review was registered with the PROSPERO international registry for systematic reviews on July 7, 2020 (CRD42020190831), and the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines were followed.[38] Based on feedback obtained via the peer-review process, we reframed our review as a scoping review (originally registered as a systematic review).[39]

Literature Search

A systematic search of 7 electronic databases (Web of Science, CINAHL, SPORTDiscus, Scopus, Cochrane Library, MEDLINE, and Embase) from 2010 to 2020 was conducted on July 14, 2020. To capture a contemporary approach to implementing exercise interventions in clinical practice, we limited our search to articles published from 2010 to 2020, as HSI knowledge has advanced considerably within the past decade.[52] Key words were grouped in 3 concepts (muscle, injury, and intervention), then variations of key words and controlled vocabulary were searched using each database (**APPENDIX A**, available at www.jospt.org). All references were imported to EndNote X9 (Clarivate Analytics, Philadelphia, PA) and duplicates removed.

Study Eligibility

We included original research written in English that described the implementation of an exercise intervention for participants with an acute HSI. Injury had to be confirmed within 7 days of occurrence, using clinical assessment and/or diagnostic imaging, so that the timing of different exercise interventions in the context of acute HSI rehabilitation could be assessed. We excluded studies in which participants experienced other causes of posterior thigh pain, such as proximal hamstring tendon avulsion, tendinopathy, or contusion injury. Case studies, clinical commentaries, recommendation papers, and consensus statements were also excluded.

Study Selection

Titles and abstracts were initially screened for relevance, followed by a full-text review by 2 authors (R.B. and J.H.), using the predetermined eligibility criteria. Any inconsistencies regarding eligibility were discussed and, if required, resolved in consultation with a third author (D.O.).

Exercise Intervention Reporting Quality

Reporting quality for the exercise interventions applied in each study was assessed with the CERT.[50] The CERT is a 19-item checklist (maximum score, 19 points) that evaluates quality of reporting in terms of completeness of describing an exercise intervention.[50] Two authors (R.B. and J.H.) independently extracted data from each study relevant to each CERT item and evaluated the information based on the CERT elaboration statement.[50] Differences in CERT results were discussed and, if necessary, a third author (D.O.) was consulted to reach consensus.

Exercise Intervention Content

Data related to the content, supervision, and progression of exercise interventions applied in each included study were independently extracted and collated by 2 authors (R.B. and J.H.). Exercises were categorized as (1) hamstring flexibility, (2) hamstring strength, (3) running related, and (4) non–hamstring specific, based on author consensus (R.B. and J.H.) (**APPENDIX B**, available at www.jospt.org). Within each of these categories, exercises were further classified based on the specific mode (eg, stretch type, contraction mode), prescription (eg, sets, repetitions, and intensity), and progression (eg, changes in regimen throughout rehabilitation), and for each exercise the data relevant to these categories were extracted.

Data Synthesis

Overall CERT scores for each study were converted to a percentage, and the quality of reporting for each study was classified as high (greater than 75%), moderate (60%-74%), or low (less than 60%).[8] Based on previous work, exercise interventions were considered reproducible if they met items 8 and 13, related to describing each exercise and the intervention/program in detail, as well as items 7a and 7b, related to the progression of each exercise.[8] The overall methodological quality of each included study was not assessed, as this scoping review was not reporting on a quantitative outcome that could be impacted by issues such as sample size, randomization, or sample type.[56]

RESULTS

The database searches identified 3755 articles once duplicates were removed (**FIGURE**). Following the screening of titles and abstracts, 35 articles were eligible for full-text review, with 12 of these subsequently meeting criteria for inclusion. Two additional eligible articles were identified after screening the reference lists of the included articles, resulting in a total of 14 included studies.[3,4,6,19,22,26-28,33,36,42,43,46,53]

Description of Included Studies

An overview of the design, participants, injury diagnosis, and rehabilitation interventions of the 14 included studies is provided in **TABLE 1**. Across all studies, 559 participants with acute HSIs were included, of whom 89% were male; 7 studies[3,4,6,27,28,43,46] included male and female participants. Eleven studies described a single exercise intervention that was applied across all participants.[6,19,22,26-28,33,42,43,46,53] Three studies compared 2 different exercise interventions after randomizing participants into 1 of 2 groups.[3,4,36] One of these studies[36] compared a multifactorial rehabilitation algorithm (including various exercise types) to hamstring-lengthening exercises.[4] However, as the hamstring-lengthening exercises were not described, only exercises described in the multifactorial rehabilitation algorithm were eligible for data extraction.[36]

Exercise Intervention Reporting Quality

TABLE 2 shows the overall CERT score and percentage for each study, along with the number and percentage of studies meeting each item. The average CERT score was 8.8 of the maximum 19 points across all 14 studies. No study achieved high exercise intervention reporting quality. Exercise intervention reporting quality was moderate in 3 studies[6,22,46] and low in the remaining 11 studies.[3,4,19,26-28,33,36,42,43,53] Four of the 19 CERT items related to the progression of exercise interventions were met by at least 11 of the 14 included studies (greater than 75%), reporting whether exercises were generic or tailored, how exercises were individualized, progression of exercise intervention, and the starting level of the exercise. Three or fewer of the 14 included studies (less than 25%) did not meet 8 of the CERT items: the supervisor's qualifications and experience, reporting whether the exercises were performed individually or in a group, participant adherence, any motivational strategies used, any adverse events that occurred during the program, the setting in which the exercises were performed, the fidelity of the intervention, and whether the intervention was delivered as planned. Exercise interventions were deemed to be reproducible in 2 studies,[22,36] which satisfactorily described each exercise, the overall intervention, and progression of each exercise.

Exercise Intervention Content

An overview of the type, supervision, and progression of exercise interventions described in each study is shown in **TABLE 3**. All 4 exercise types were included in 7 studies.[3,6,26,33,36,43,53] The most common exercise intervention type was hamstring flexibility (13 studies), followed by hamstring strength (11 studies), running related (10 studies), and non–hamstring specific (10 studies). Supervision of exercise interventions varied, with 5 studies not clearly reporting whether the intervention was supervised.[26,28,33,36,42] All exercises were progressed concurrently through stages of rehabilitation in 10 studies, either based on time from injury[6,19,26,27,42] or passing specific criteria (eg, pain-free completion of the previous stage or clinical tests).[28,33,36,43,53]

Hamstring Flexibility Exercises Passive stretching was implemented in 7 studies[3,4,6,27,42,46,53] and active stretching/range-of-motion exercises were prescribed in 10 studies[3,4,19,26,28,33,36,42,43,53] (**TABLE 4**). Hamstring flexibility exercises were introduced within the first 7 days following HSI in 10 studies.[3,4,19,26,27,33,36,42,46,53] The most common hamstring flexibility exercises were a static stretch while standing with the injured leg raised on an object (with variations in heights and forward trunk lean)[3,4,6,27,46] and a supine active knee extension with the hip at approximately 90° of flexion.[3,4,33,36,42,53]

Hamstring Strength Exercises Ten of the 11 studies that included hamstring strength exercises prescribed at least 1 eccentric exercise[3,4,6,22,27,33,36,42,43,53] (**TABLE 5**). Hamstring strength exercises prescribed within the first 7 days following HSI were

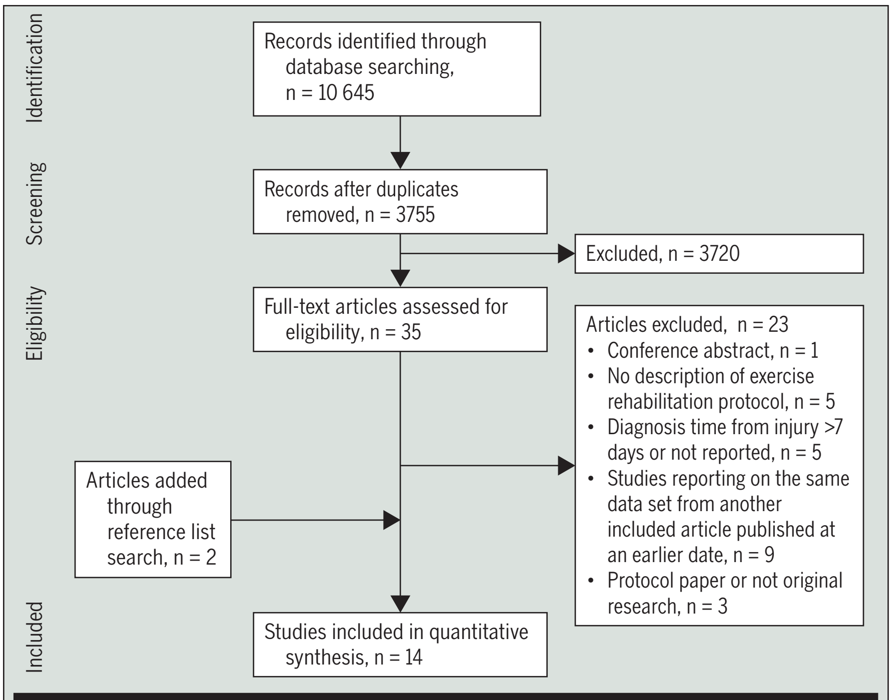


FIGURE. Article selection process.

generally isometric or bilateral conventional exercises that were progressed in load or by an eccentric emphasis. The most common hamstring strength exercises were variations of a hamstring bridge[3,4,22,33,42,53] and the Nordic hamstring exercise.[6,22,33,36,53]

Running-Related Exercises Of the 10 studies that included running-related exercise, 9 reported using some form of running technique or agility drill,[3,6,26-28,33,36,43,53] 8 included progressive straight-line running,[3,22,26,27,33,36,43,53] and 5 incorporated plyometrics[6,27,33,36,53] (**TABLE 6**). Fast foot stepping or high knees,[3,6,28,43] grapevines, sidestepping, and forward and backward sidestepping over a line[27,28,36,43] were the most common running techniques or agility drills. Some form of high-speed running (eg, intensity greater than 90%) or sprinting was prescribed in 7 studies,[3,22,26,27,33,36,53] although description and prescription varied.

Non–Hamstring-Specific Exercises Of the 10 studies that incorporated non–hamstring-specific exercises, 7 prescribed general lower-limb strengthening and flexibility exercises,[6,19,26,33,36,42,53] 4 included lumbopelvic strength and stability exercises,[28,33,36,43] and 5 implemented general conditioning via aquatics[19] and ergometer cycling[3,19,42,43,53] (**APPENDIX C**, available at www.jospt.org).

DISCUSSION

We evaluated the quality of reporting and described the specific content of exercise interventions

TABLE 1 CHARACTERISTICS OF THE INCLUDED STUDIES

Study, Design	Participants	Injury Diagnosis	Rehabilitation Interventions
Askling et al[4] RCT	n = 75 (92% male) elite soccer athletes in Sweden; mean ± SD age, 25 ± 5.5 y	Clinical exam, ≤2 d; MRI, ≤5 d	L-protocol: emphasis on lengthening exercises C-protocol: conventional exercises
Askling et al[3] RCT	n = 56 (68% male) elite track-and-field athletes in Sweden; mean ± SD age, 20 ± 3.5 y	Clinical exam, ≤2 d; MRI, ≤5 d	L-protocol and general exercise program C-protocol and general exercise program
Bayer et al[6] RCT	n = 42 (86% male) amateur athletes participating in various sports in Denmark; mean ± SD age, 33.6 ± 10.1 y	Clinical exam and US, ≤2 d; MRI, ≤7 d	Early exercise program (2 d after injury) Delayed exercise program (9 d after injury)
Gaballah et al[19] RCT	n = 17 (100% male) well-trained soccer athletes in Egypt; mean ± SD age, 22.3 ± 0.4 y	MRI, ≤7 d	PRP injection and exercise program Exercise program
Hickey et al[22] RCT	n = 43 (100% male) amateur athletes participating in various sports in Australia; mean ± SD age, 26.1 ± 5.2 y	Clinical exam, ≤7 d	Pain-free exercise program Pain-threshold exercise program
Jiménez-Rubio et al[26] Prospective cohort	n = 19 (100% male) professional soccer athletes in Spain; mean ± SD age, 24.2 ± 5.4 y	US and MRI, ≤2 d	Off-field and on-field exercise program
Kilcoyne et al[27] Retrospective cohort	n = 48 (83% male) recreational to collegiate-level athletes participating in various sports in the United States; age, 18-25 y	Clinical exam, ≤2 d	Exercise program
Lai et al[28] RCT	n = 10 (70% male) recreational to national-level athletes participating in various sports in Malaysia; mean ± SD age, 23.8 ± 5.2 y	Clinical exam and US, ≤7 d	PRP injection and exercise program Exercise program
Medeiros et al[33] RCT	n = 22 (100% male) amateur athletes participating in various sports in Brazil; mean ± SD age, 29.2 ± 7.2 y	Clinical exam, ≤5 d	LLLT and exercise program Placebo treatment and exercise program
Mendiguchia et al[36] RCT	n = 48 (100% male) semiprofessional to professional soccer athletes in Spain; mean ± SD age, 23.4 ± 5.2 y	Clinical exam and US, ≤4 d	Multifactorial algorithm exercise program L-protocol
Rettig et al[42] Retrospective case-control	n = 10 (100% male) professional American football athletes in the United States; age, 24.5 y (range, 22-28 y)	MRI, ≤2 d	PRP injection and exercise program Exercise program
Reurink et al[43] RCT	n = 80 (95% male) recreational or competitive athletes participating in a range of sports in the Netherlands; mean ± SD age, 29 ± 7.5 y	Clinical exam and MRI, ≤5 d	PRP injection and exercise program Placebo injection and exercise program
Sefiddashti et al[46] RCT	n = 37 (57% male) athletes participating in sport activity for at least 2 y (3 times per week) in Iran; mean ± SD age, 24.7 ± 4 y	Clinical exam, ≤2 d	Cryotherapy Cryotherapy and stretching exercise program
Tol et al[53] Prospective study of a cohort of participants in a larger RCT	n = 52 (100% male) professional soccer athletes in Qatar; age, 24.9 y (range, 18-38 y)	MRI, ≤5 d	PRP injection and exercise program PPP injection and exercise program Exercise program

Abbreviations: LLLT, low-level laser therapy; MRI, magnetic resonance imaging; PPP, platelet-poor plasma; PRP, platelet-rich plasma; RCT, randomized controlled trial; US, ultrasound.

TABLE 2 Results Summary of the Consensus on Exercise Reporting Template, Applied to Each Included Study

Study	Items[a] 1	2	3	4	5	6	7a	7b	8	9	10	11	12	13	14a	14b	15	16a	16b	Total, n (%)	Reporting Quality
Askling et al[4]	✓			✓				✓	✓					✓	✓	✓	✓			8 (42)	L
Askling et al[3]	✓			✓				✓	✓		✓			✓	✓	✓	✓			9 (47)	L
Bayer et al[6]	✓			✓	✓		✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	13 (68)	M
Gaballah et al[19]		✓		✓				✓		✓	✓	✓			✓		✓			8 (42)	L
Hickey et al[22]	✓	✓		✓			✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	14 (74)	M
Jiménez-Rubio et al[26]							✓	✓					✓		✓		✓			5 (26)	L
Kilcoyne et al[27]	✓			✓			✓				✓				✓	✓	✓			7 (37)	L
Lai et al[28]	✓						✓	✓							✓	✓	✓			6 (32)	L
Medeiros et al[33]							✓	✓						✓	✓	✓	✓			6 (32)	L
Mendiguchia et al[36]	✓						✓	✓	✓		✓			✓	✓	✓	✓			9 (47)	L
Rettig et al[42]							✓	✓			✓				✓					4 (21)	L
Reurink et al[43]				✓	✓	✓	✓	✓		✓	✓				✓	✓	✓	✓		11 (58)	L
Sefiddashti et al[46]	✓			✓	✓				✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	13 (68)	M
Tol et al[53]	✓	✓		✓			✓	✓			✓		✓		✓	✓	✓			10 (53)	L
Studies, n (%)	9 (64)	3 (21)	0 (0)	9 (64)	3 (21)	1 (7)	10 (71)	12 (86)	6 (43)	5 (36)	10 (71)	2 (14)	3 (21)	6 (43)	14 (100)	11 (79)	13 (93)	3 (21)	3 (21)		

Abbreviations: ✓, a clear/detailed description was provided; L, low; M, moderate.
[a]Items: 1, Exercise equipment used; 2, Supervisor's background; 3, Group or individual; 4, Supervision; 5, Adherence; 6, Motivational strategies; 7a, Exercise progression rules; 7b, Program progression; 8, Description of each exercise; 9, Home program component; 10, Nonexercise component; 11, Any adverse events; 12, Exercise setting; 13, Exercise intervention; 14a, generic or tailored exercises; 14b, Individualization; 15, Starting level; 16a, Exercise fidelity; 16b, Intervention delivered as planned.

TABLE 3 Overview of Exercise Intervention Type, Supervision, and Progression

Study	Type of Exercise Intervention Included[a] 1	2	3	4	Supervision of Exercise Intervention[b] 1	2	3	Progression of Exercise Intervention[c] 1	2	3	4
Askling et al[4]	✓	✓				✓				✓	
Askling et al[3]	✓	✓	✓	✓		✓				✓	
Bayer et al[6]	✓	✓	✓	✓		✓		✓			
Gaballah et al[19]	✓			✓	✓			✓			
Hickey et al[22]		✓	✓		✓					✓	
Jiménez-Rubio et al[26]	✓	✓	✓	✓			✓	✓			
Kilcoyne et al[27]	✓	✓	✓		✓			✓			
Lai et al[28]	✓		✓	✓			✓		✓		
Medeiros et al[33]	✓	✓	✓	✓			✓		✓		
Mendiguchia et al[36]	✓	✓	✓	✓			✓		✓		
Rettig et al[42]	✓	✓		✓			✓	✓			
Reurink et al[43]	✓	✓	✓	✓		✓			✓		
Sefiddashti et al[46]	✓					✓					✓
Tol et al[53]	✓	✓	✓	✓	✓				✓		
Studies, n (%)	13 (93)	11 (79)	10 (71)	10 (71)	4 (29)	5 (36)	5 (36)	5 (36)	5 (36)	3 (21)	1 (7)

Abbreviation: ✓, the category reported.
[a]Nonexclusive category: 1, Hamstring flexibility; 2, Hamstring strength; 3, Running related; 4, Non–hamstring specific.
[b]Category: 1, All sessions supervised; 2, Some sessions supervised; 3, Not clearly reported.
[c]Category: 1, All exercises concurrently progressed in stages based on time from injury; 2, All exercises progressed concurrently in stages based on pain-free completion of previous stage or clinical criteria; 3, Each exercise progressed individually based on performance within limits of pain; 4, No progression described.

applied in HSI rehabilitation in contemporary research. Overall, complete exercise interventions were reported to a low to moderate degree. Most studies included a range of exercise types, with details related to prescription and progression varying widely, limiting the scope for replication.

Quality of Exercise Intervention Reporting

The low to moderate quality of reporting of exercise interventions included in contemporary HSI literature is consistent with previous reviews that have applied the CERT to other musculoskeletal conditions.[5,8,10,30] For example, exercise interventions for managing groin injury were reported to a moderate quality in only 1 of 14 studies,[8] with the remaining 13 studies of low reporting quality. The most important CERT item is the description of exercises to a level that allows replication, which was met by only 6 of 14 (43%) studies included in our scoping review. This CERT item was also poorly reported in interventions targeting osteoarthritis (26%), groin injuries (14%), rotator cuff disorders (29%), and Achilles tendon ruptures (26%).[5,8,10,30] Therefore, poor quality of reporting is not unique to the HSI field, and researchers across all areas of musculoskeletal rehabilitation should consider using tools such as the CERT to help future researchers and practitioners replicate and apply evidence-based exercise interventions.[5,51]

Practitioners require the following information to replicate an exercise intervention: description of each exercise to include intensity and load, sets, repetitions, and frequency; and progression of exercises and interventions.[8] Only 2 studies reported exercise intervention content with sufficiently detailed descriptions and key prescription principles of sets, repetitions, frequency, and progression

TABLE 4 Hamstring Flexibility Exercises for HSI Rehabilitation, Categorized as Passive Stretching or Active Stretching/ROM

Study	Passive Stretching	Active Stretching/ROM
Askling et al[4]	C-protocol (2 times per day from 5 d after HSI): standing hamstring stretch, leg raised (3 × 4 reps; 10 s contracted/10 s relaxed; 20-s hold)	L-protocol (2 times per day from 5 d after HSI): "extender" active knee extension in supine, with 90° of hip flexion (3 × 12 reps)
Askling et al[3]	C-protocol (2 times per day from 5 d after HSI): standing hamstring stretch, leg raised (3 × 4 reps; 10 s contracted/10 s relaxed; 20-s hold)	L-protocol (2 times per day from 5 d after HSI): "extender" active knee extension in supine, with 90° of hip flexion (3 × 12 reps)
Bayer et al[6]	Phase 1 (3 times per day from week 1 of rehabilitation, starting 2 or 9 d after HSI): standing hamstring stretch with (*a*) bent knee and (*b*) straight knee (3 × 30-s hold)	
Gaballah et al[19]		From 0 to 7 d after HSI: active light hamstring stretching
Jiménez-Rubio et al[26]		Day 3 after HSI: controlled mobilizations to achieve full hip and knee ROM
Kilcoyne et al[27]	Daily from 2 d after HSI: standing hamstring stretch, leg raised (60- to 90-s hold)	
Lai et al[28]		Stage 2 (daily): single-leg standing windmill touch (4 × 20 s)
Medeiros et al[33]		Phase 1 (3 times per week from 5 d after HSI): extender Phase 2 (3 times per week): high kicks Phase 3 (3 times per week): swing (2 × 15 reps)
Mendiguchia et al[36]		Algorithm phase 1 (daily from 5 d after HSI): • Hamstring dynamic mobility with FitBALL (2 × 8 reps) • Hamstring dynamic mobility in supine (2 × 8 reps) Algorithm phase 2 (twice per day for 3 d): • Hamstring dynamic mobility and contralateral psoas flexibility (2 × 5 reps) • Hamstring ballistic stretching (2 × 6 reps) • Hamstring wall flexibility push/pull (3 × 3 reps)
Rettig et al[42]	Days 4 to 7 after HSI: light passive hamstring stretch Days 7 to 14 after HSI: passive stretch	Days 1 to 4 after HSI: active hamstring stretch in supine 90°/90° position Days 4 to 7 after HSI: active hamstring stretch
Reurink et al[43]		Phase 2 (daily): single-leg standing windmill touch (4 × 20 s)
Sefiddashti et al[46]	Cryotherapy and stretching (4-5 times daily, starting within 5 d of HSI): standing hamstring stretch, leg raised (3 × 30-s holds)	
Tol et al[53]	Stage 2 (5 times per week): hamstring stretching (supine, 90° of hip flexion, knee extension) Straight leg raise (supine to onset of discomfort, adding ankle dorsiflexion)	Stage 1 (5 times per week, starting within 5 d of HSI): supine active knee flexion and extension, then prone active flexion and extension

Abbreviations: HSI, hamstring strain injury; reps, repetitions; ROM, range of motion.

to enable the content to be reproduced in HSI rehabilitation.[22,36] There is a clear need for studies of exercise interventions to incorporate standardized reporting of exercise prescription.

Content of Exercise Interventions

Most of the studies in our scoping review included a variety of exercise types (eg, hamstring flexibility, hamstring strengthening, running-related, and non–hamstring-specific exercises). A range of exercise types could be considered a strength of these rehabilitation interventions, as it increases the likelihood that the numerous factors associated

TABLE 5 HAMSTRING STRENGTH EXERCISES FOR HSI REHABILITATION, CATEGORIZED AS ISOMETRIC, CONVENTIONAL, OR ECCENTRIC

Study	Isometric	Conventional	Eccentric
Askling et al[4]		C-protocol (from 5 d after HSI): • Standing cable hip extension (3 × 6 reps every second day) • Hamstring bridge (3 × 8 reps every third day, bilateral to unilateral)	L-protocol (from 5 d after HSI): • Diver (3 × 6 reps every second day, slow to fast) • Glider (3 × 4 reps every third day, restricted ROM to full ROM)
Askling et al[3]		C-protocol (from 5 d after HSI): • Standing cable hip extension (3 × 6 reps every second day) • Hamstring bridge (3 × 8 reps every third day, bilateral to unilateral)	L-protocol (from 5 d after HSI): • Diver (3 × 6 reps every second day, slow to fast) • Glider (3 × 4 reps every third day, restricted ROM to full ROM)
Bayer et al[6]	Phase 2 (daily from weeks 2 to 4): • Prone isometric at 90° of knee flexion (light to heavy elastic band) • Isometric pelvic lift (bilateral to unilateral)	Phase 3 (3 times per week from weeks 5 to 8): bilateral prone machine leg curl (15RM to 10RM)	Phase 4 (3 times per week from weeks 9 to 12): • Supine slider (bilateral to unilateral) • Nordic hamstring exercise (low to high repetitions)
Hickey et al[22]		2 times per week, starting within 7 d of HSI: • Hamstring bridge: bilateral (3 × 10-12 reps) to unilateral (3 × 8-10 reps) • 45° hip extension: bilateral (3 × 8-10 reps) to unilateral (3 × 6-8 reps)	2 times per week, starting within 7 d of HSI: • Supine slider: bilateral (3 × 6-8 reps) to unilateral (3 × 4-6 reps) • Nordic hamstring exercise (3 × 4-6 reps)
Jiménez-Rubio et al[26]		Days 6 and 7 after HSI: deadlift from a height Days 8 to 17 after HSI: unilateral deadlift	
Kilcoyne et al[27]			3 times per week from 7 d after HSI: prone eccentric (2 × 10 reps)
Medeiros et al[33]	Phase 1 (3 times per week from 5 d after HSI): isometric contractions (15 reps of 6-s holds at 15°, 45°, and 90° of knee flexion)	Phase 2 (3 times per week): • Seated hamstring curl (2 × 10-15 reps) • Unilateral hamstring bridge (2 × 10-15 reps) Phase 3 (3 times per week): unilateral hamstring bridge (3 × 15 reps)	Phase 2 (3 times per week): Nordic hamstring exercise (2 × 8-10 reps) Phase 3 (3 times per week): Nordic hamstring exercise (3 × 8-12 reps)
Mendiguchia et al[36]	Algorithm phase 1 (daily from 5 d after HSI): • Prone isometric (2 × 5 reps of 5-s hold) • Standing long length (2 × 5 reps of 5-s hold) • Supine isometric (2 × 5 reps of 3-s hold)	Algorithm phase 2 (once daily for 3 d): • Bilateral slide curl (2 × 6 reps) • Bilateral deadlift with a 4-kg medicine ball (2 × 8 reps) • Unilateral deadlift with a 15-kg weight and step-up (2 × 6 reps)	Algorithm phase 1 (daily from 5 d after HSI): submaximal eccentric in prone (2 × 8 reps) Algorithm phase 2 (once daily for 3 d): • Nordic hamstring exercise (2 × 4 reps) • Sprinter eccentric leg curl (2 × 6 reps)
Rettig et al[42]		Days 1 to 4 after HSI: standing leg curl, prone hip extension Days 4 to 7 after HSI: hip extension with band Days 7 to 14 after HSI: unilateral Romanian deadlift and bridge with FitBALL leg curls	Days 4 to 7 after HSI: eccentric tubing hamstring curls Days 7 to 14 after HSI: eccentric weighted leg curls
Reurink et al[43]			Phase 2 (2 times per week): submaximal eccentric exercises near mid length Phase 3 (2 times per week): eccentric exercises near end ROM
Tol et al[53]	Stage 1 (5 times per week, starting within 5 d of HSI): • Supine heel dig through range of angles • Prone manual resisted at varying knee angles	Stage 2 (5 times per week): resisted hamstring (4 × 15 reps) Stage 3 (5 times per week): unilateral bridge foot on a Swiss ball (4 × 8 reps)	Stage 3 (5 times per week): Nordic hamstring exercise, manual-resisted eccentric exercise, prone catches, arabesque

Abbreviations: HSI, hamstring strain injury; reps, repetitions; RM, repetition maximum; ROM, range of motion.

with HSI are addressed.[18,40] However, it is difficult to assess the efficacy of specific exercises for improving HSI rehabilitation outcomes.[48] Practitioners must also consider the time required to implement an intervention with various types of exercises in the clinical practice setting. Prescribing an excessive number of exercises may affect adherence, particularly for recreational or subelite athletes, who may perform rehabilitation unsupervised.[14,34] Only 3 studies in our review reported adherence and fidelity of exercise interventions, which highlights the need to focus on implementation issues from research to practice.[2,6]

The high prevalence of hamstring flexibility exercises is consistent with general rehabilitation guidelines for acute muscle injury.[20,54] There is some evidence that more frequent hamstring stretching can accelerate recovery of active knee extension range of motion and reduce overall rehabilitation time following HSI.[31] However, it is unclear whether hamstring flexibility exercises are essential for restoring range of motion following HSI, and evidence for flexibility as a risk factor for HSI is conflicting.[15,18,32] Hamstring flexibility exercises seem to be a logical inclusion in an HSI rehabilitation protocol, but future research should focus on clarifying the necessity and timing of this intervention.

Unlike flexibility, hamstring strength has a clear link with HSI risk, particularly

TABLE 6 Running-Related Exercises for HSI Rehabilitation, Categorized as Progressive Running, Running Technique and Agility Drills, or Plyometrics

Study	Progressive Running	Running Technique and Agility Drills	Plyometrics
Askling et al[3]	General program stage 2 (3 times per week): high-speed running (6 × 20 m, 4 × 40 m, 2 × 60 m)	General program stage 1 (3 times per week from 5 d after HSI): • Fast feet in place (10 × 20 s) • Jogging with short strides (10 × 40 m) • Forward/backward accelerations (10 × 10 m)	
Bayer et al[6]		Phase 4 (3 times per week from weeks 9 to 12): sprints with high knees (stationary to moving)	Phase 4 (3 times per week from weeks 9 to 12): jumps
Hickey et al[22]	2 times per week, starting within 7 d of HSI: accelerate/hold/decelerate over 50 m, progressing intensity from jog (50% maximum) to run (70% maximum) to sprint (100% maximum)		
Jiménez-Rubio et al[26]	On-field program (days 8 to 17 after HSI): • Running <14 km/h (6 × 10 s) • Fartlek run: 15 s at >14 km/h, 10 s at <14 km/h (3 × 70-90 s) • Run at 100%-120% maximum aerobic velocity (3 × 80 s, 40-s rest) • Repeated sprints over 40 m, with varying rest periods • Soccer-specific running and ball skills	Day 5 after HSI: sled pushes and forward/backward running On-field program (days 8 to 17 after HSI): • Various soccer-specific agility and coordination drills • Planned change of direction (4 × 8-14 m with 15-s rest) • Sled tow (10 kg; 4 × 20 m, with 8-s rest)	
Kilcoyne et al[27]	Day 2 after HSI: jog until fatigued (approximately 1 mi) From 1 to 2 wk after HSI: rolling sprints (4-6 reps at 90%-95% maximum)	From day 3 after HSI: • Butt kicks and carioca run over 50 yd • Forward/backward/lateral drills between cones, 10-50 yd apart • Stair-bounding drills on the affected leg only, single steps	From day 3 after HSI: • Tuck jumps (2 × 8 reps) • Kangaroo hops (2 × 15 reps) • Bounding (8-15 reps)
Lai et al[28]		Stages 1 and 2 (daily, starting within 7 d of HSI): side-step, grapevines, forward/backward step sideways (2-3 × 1 min each at low/moderate to moderate/high intensity) Stage 2 (daily after passing criteria): fast feet in place (4 × 20 s)	
Medeiros et al[33]	Phase 3 (3 times per week): 10-m sprint	Phase 1 (3 times per week from 5 d after HSI): ladder drills Phase 2 (3 times per week): ladder drills and resistance-band running (moderate intensity) Phase 3 (3 times per week): "X" drill, "W" drill, and resistance-band running (high intensity)	Phase 1 (3 times per week from 5 d after HSI): box jump (30 cm, up/down) Phase 2 (3 times per week): squat jumps with support Phase 3 (3 times per week): squat jumps

Table continues on page 138.

TABLE 6 Running-Related Exercises for HSI Rehabilitation, Categorized as Progressive Running, Running Technique and Agility Drills, or Plyometrics (continued)

Study	Progressive Running	Running Technique and Agility Drills	Plyometrics
Mendiguchia et al[36]	Algorithm phase 1 (daily from 5 d after HSI): running (4 × 5 m, 3 × 10 m, 2 × 15 m, all with 5-m deceleration) Algorithm phase 2 (once daily for 3 d): sprinting (3 × 5 m, 3 × 10 m, 4 × 15 m, 3 × 20 m, 2 × 30 m, 1 × 40 m, with 15 s of rest for every 1 s of sprinting)	Algorithm phase 1 (daily from 5 d after HSI): • Sidestep, grapevines, forward/backward step sideways (5 × 10 m each) • Various sagittal plane running drills in place and over 8 m • Bilateral and unilateral hamstring/gastrocnemius dissociation drills (2-3 × 6 reps) • Step bounding from side to side (25% BW, 2 × 10 reps) Algorithm phase 2 (once daily for 3 d): • Static "B" drill with resistance band (2 × 5 reps) • Hurdle drills, military march (2 × 15 m) • Skip to run (4 × 20 m) • Sled push (30% BW, 3 × 5 m/2 × 10 m) • Ankle drills 1 and 2 (10% BW, 4 × 10 m)	Algorithm phase 2 (once daily for 3 d): • Bilateral hurdle hop (2 × 4 reps) • Bilateral broad jump (5 kg; 2 × 4 reps) • Scissor jump (3 × 2 reps) • Unilateral horizontal jump (2 × 3 reps)
Reurink et al[43]	Phase 2 (2 times per week): run <50% maximum	Phase 1 (daily from 5 d after HSI): sidestep, grapevines, forward/backward step sideways (2-3 × 1 min each at low to moderate intensity) Phase 2 (daily): • Fast feet in place (4 × 20 s) • Sidestep, grapevines, forward/backward step sideways (2-3 × 1 min each at moderate to high intensity) Phase 3 (2 times per week): agility and sport-specific drills involving quick direction changes	
Tol et al[53]	Stage 2 (5 times per week): walk/jog at 25%-70% maximum speed Stage 3 (5 times per week): high-intensity running intervals (20-m jog/30-m run at 70%-95% maximum speed)	Stage 2 (5 times per week): triple extension walk, "A" drill with knee extension Stage 3 (5 times per week): "T" drill (70%-95% maximum effort) Soccer-specific stage: change of direction with/without ball (40 min)	Soccer-specific stage: jumping drills (10-15 min)

Abbreviations: BW, body weight; HSI, hamstring strain injury; reps, repetitions.

during eccentric contractions.[12,40,44,57] Therefore, it is not surprising that most studies that prescribed hamstring strength exercises included at least 1 with an eccentric emphasis. Though it is a matter of contention among researchers and practitioners,[37] the Nordic hamstring exercise was one of the most common strength interventions. Several studies have shown the exercise to reduce the risk of HSI in uninjured populations.[1,55,57] Of the conventional hamstring strength exercises prescribed, variations of the hamstring bridge were most common. Compared to the Nordic hamstring exercise, hamstring bridge variations have a lower metabolic and mechanical exercise intensity[7] and require minimal equipment, making it an easy exercise to implement and modify during the initial stages of HSI rehabilitation.

One of the key principles in return-to-play decision making is whether the athlete is ready or prepared to meet the demands of the sport activity, such as high-speed running (a common mechanism of HSI).[11,13] However, only half of the studies explicitly prescribed any high-speed running and/or sprinting drills during rehabilitation. There were variations in the definitions of high-speed running or sprinting, and only 3 studies[22,27,53] clearly reported prescription of high-speed running intensity as a percentage of maximum velocity (eg, 90%-95% maximum speed). Exposure to progressive high-speed running and sprinting is advisable during rehabilitation, as sprint exposure may be a protective mechanism for reducing the risk of HSI.[35]

Most studies included exercises that were not hamstring specific or running related. Exercises targeting muscles of the lumbopelvic region were common (eg, the gluteus maximus and gluteus medius), including those originally described in the progressive agility and trunk stability (PATS) protocol by Sherry and Best[47] in 2004. When applied to HSI rehabilitation, the PATS protocol can reduce reinjury risk compared to relatively conservative exercises[47] and has outcomes equal to those of progressive running and eccentric exercise.[49] There is emerging evidence of a link between lumbopelvic kinematics during running and HSI risk.[17,45] However, there is no direct evidence that these variables can be altered by implementing lumbopelvic exercises like the PATS protocol during HSI rehabilitation, and the possibility to accurately and reliably measure these outcomes is limited to the laboratory environment.[36,47-49]

Limitations

The CERT was developed in 2016, so it is possible that included articles published after this date may have a greater chance of reporting their exercise interventions with a higher standard. However, a manual search of the reference lists of all included articles revealed that none cited the CERT, which further emphasizes the need for improved awareness of reporting quality. When the level of detail about the intervention was insufficient, we classified the exercises based on our interpretation of the exercise purpose, which might not have been the original intent of the researchers. Exercises were only included in an intervention if they were explicitly reported. Therefore, the potential inclusion of studies with inadequate reporting of methodological approaches and study outcomes might have limited and biased our findings. Four authors of this scoping review (J.H., R.T., N.M., and D.O.) were authors of 1 study included in this review.[22] Risk of bias was minimized by using a pre-established method of data extraction and the validated CERT tool, which were applied by 2 authors (R.B. and J.H.), 1 of whom (R.B.) was not involved in the aforementioned study.

Clinical Implications

We recommend a standard and structured approach to reporting exercise interventions so that researchers and practitioners can implement evidence-based programs. At a minimum, authors should describe each exercise, including the sets, repetitions, intensity, frequency, and progression, to a level of detail that allows replication in clinical and research settings. In many exercise rehabilitation programs, a variety of exercises are used without supporting evidence of the types and modes that are contributing to the restoration of full hamstring function. Therefore, practitioners should carefully consider the intervention duration, adherence, motivation, and the competitive level of the athlete when selecting each exercise.

CONCLUSION

EXERCISE INTERVENTIONS IN CONtemporary HSI rehabilitation research are poorly reported. Use of exercise prescription and reporting guidelines, such as sets, repetitions, load, and frequency, must improve to ensure a minimum standard of reporting and to support implementing exercise interventions in research or practice. ◉

KEY POINTS

FINDINGS: Exercise interventions applied in contemporary hamstring strain injury (HSI) rehabilitation research are poorly reported. Most HSI rehabilitation protocols use multiple exercise intervention types; however, the rationale for the different stimuli is not always clear.

IMPLICATIONS: Authors must improve reporting quality and should include key prescription variables, such as sets, repetitions, frequency, and intensity, to a standard that enables replication of exercise interventions for HSI rehabilitation. When designing HSI rehabilitation programs, carefully consider and prioritize exercise types within the constraints of clinical practice.

CAUTION: We did not examine the effect of each exercise intervention, so we are unable to draw conclusions regarding the effectiveness of the HSI rehabilitation protocols. The lack of quality reporting of exercise interventions limited the extraction and classification of exercises to aid our interpretation of the information provided.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: Ray Breed and Dr Hickey designed the study and also performed the study selection and data extraction. Any issues that could not be resolved were discussed and agreed via a majority with Dr Opar. All authors made significant contributions to the scientific knowledge and development of the review, including approval of the final manuscript.

DATA SHARING: All data relevant to the study are included in the article or are available as online appendices.

PATIENT AND PUBLIC INVOLVEMENT: There was no patient or partner involvement in any part of this research.

REFERENCES

1. Al Attar WSA, Soomro N, Sinclair PJ, Pappas E, Sanders RH. Effect of injury prevention programs that include the Nordic hamstring exercise on hamstring injury rates in soccer players: a systematic review and meta-analysis. *Sports Med*. 2017;47:907-916. https://doi.org/10.1007/s40279-016-0638-2
2. Andrew N, Gabbe BJ, Cook J, et al. Could targeted exercise programmes prevent lower limb injury in community Australian football? *Sports Med*. 2013;43:751-763. https://doi.org/10.1007/s40279-013-0056-7
3. Askling CM, Tengvar M, Tarassova O, Thorstensson A. Acute hamstring injuries in Swedish elite sprinters and jumpers: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. *Br J Sports Med*. 2014;48:532-539. https://doi.org/10.1136/bjsports-2013-093214
4. Askling CM, Tengvar M, Thorstensson A. Acute hamstring injuries in Swedish elite football: a prospective randomised controlled clinical trial comparing two rehabilitation protocols. *Br J Sports Med*. 2013;47:953-959. https://doi.org/10.1136/bjsports-2013-092165
5. Bartholdy C, Nielsen SM, Warming S, Hunter DJ, Christensen R, Henriksen M. Poor replicability of recommended exercise interventions for knee osteoarthritis: a descriptive analysis of evidence informing current guidelines and recommendations. *Osteoarthritis Cartilage*. 2019;27:3-22. https://doi.org/10.1016/j.joca.2018.06.018
6. Bayer ML, Magnusson SP, Kjaer M, Tendon Research Group Bispebjerg. Early versus delayed rehabilitation after acute muscle injury [letter]. *N Engl J Med*. 2017;377:1300-1301. https://doi.org/10.1056/NEJMc1708134
7. Bourne MN, Williams MD, Opar DA, Al Najjar A, Kerr GK, Shield AJ. Impact of exercise selection on hamstring muscle activation. *Br J Sports Med*. 2017;51:1021-1028. https://doi.org/10.1136/bjsports-2015-095739

8. Charlton PC, Drew MK, Mentiplay BF, Grimaldi A, Clark RA. Exercise interventions for the prevention and treatment of groin pain and injury in athletes: a critical and systematic review. *Sports Med*. 2017;47:2011-2026. https://doi.org/10.1007/s40279-017-0742-y
9. Charlton PC, Raysmith B, Wollin M, et al. Knee flexion not hip extension strength is persistently reduced following hamstring strain injury in Australian Football athletes: implications for Periodic Health Examinations. *J Sci Med Sport*. 2018;21:999-1003. https://doi.org/10.1016/j.jsams.2018.03.014
10. Christensen M, Zellers JA, Kjaer IL, Silbernagel KG, Rathleff MS. Resistance exercises in early functional rehabilitation for Achilles tendon ruptures are poorly described: a scoping review. *J Orthop Sports Phys Ther*. 2020;50:681-690. https://doi.org/10.2519/jospt.2020.9463
11. Chumanov ES, Schache AG, Heiderscheit BC, Thelen DG. Hamstrings are most susceptible to injury during the late swing phase of sprinting. *Br J Sports Med*. 2012;46:90. https://doi.org/10.1136/bjsports-2011-090176
12. de Visser HM, Reijman M, Heijboer MP, Bos PK. Risk factors of recurrent hamstring injuries: a systematic review. *Br J Sports Med*. 2012;46:124-130. https://doi.org/10.1136/bjsports-2011-090317
13. Duhig S, Shield AJ, Opar D, Gabbett TJ, Ferguson C, Williams M. Effect of high-speed running on hamstring strain injury risk. *Br J Sports Med*. 2016;50:1536-1540. https://doi.org/10.1136/bjsports-2015-095679
14. Eckard T, Lopez J, Kaus A, Aden J. Home exercise program compliance of service members in the deployed environment: an observational cohort study. *Mil Med*. 2015;180:186-191. https://doi.org/10.7205/MILMED-D-14-00306
15. Erickson LN, Sherry MA. Rehabilitation and return to sport after hamstring strain injury. *J Sport Health Sci*. 2017;6:262-270. https://doi.org/10.1016/j.jshs.2017.04.001
16. Fournier-Farley C, Lamontagne M, Gendron P, Gagnon DH. Determinants of return to play after the nonoperative management of hamstring injuries in athletes: a systematic review. *Am J Sports Med*. 2016;44:2166-2172. https://doi.org/10.1177/0363546515617472
17. Franettovich Smith MM, Bonacci J, Mendis MD, Christie C, Rotstein A, Hides JA. Gluteus medius activation during running is a risk factor for season hamstring injuries in elite footballers. *J Sci Med Sport*. 2017;20:159-163. https://doi.org/10.1016/j.jsams.2016.07.004
18. Freckleton G, Pizzari T. Risk factors for hamstring muscle strain injury in sport: a systematic review and meta-analysis. *Br J Sports Med*. 2013;47:351-358. https://doi.org/10.1136/bjsports-2011-090664
19. Gaballah A, Elgeidi A, Bressel E, Shakrah N, Abd-Alghany A. Rehabilitation of hamstring strains: does a single injection of platelet-rich plasma improve outcomes? (Clinical study). *Sport Sci Health*. 2018;14:439-447. https://doi.org/10.1007/s11332-018-0474-x
20. Heiderscheit BC, Sherry MA, Silder A, Chumanov ES, Thelen DG. Hamstring strain injuries: recommendations for diagnosis, rehabilitation, and injury prevention. *J Orthop Sports Phys Ther*. 2010;40:67-81. https://doi.org/10.2519/jospt.2010.3047
21. Hickey J, Shield AJ, Williams MD, Opar DA. The financial cost of hamstring strain injuries in the Australian Football League. *Br J Sports Med*. 2014;48:729-730. https://doi.org/10.1136/bjsports-2013-092884
22. Hickey JT, Timmins RG, Maniar N, et al. Pain-free versus pain-threshold rehabilitation following acute hamstring strain injury: a randomized controlled trial. *J Orthop Sports Phys Ther*. 2020;50:91-103. https://doi.org/10.2519/jospt.2020.8895
23. Hickey JT, Timmins RG, Maniar N, Williams MD, Opar DA. Criteria for progressing rehabilitation and determining return-to-play clearance following hamstring strain injury: a systematic review. *Sports Med*. 2017;47:1375-1387. https://doi.org/10.1007/s40279-016-0667-x
24. Ishøi L, Hölmich P, Aagaard P, Thorborg K, Bandholm T, Serner A. Effects of the Nordic hamstring exercise on sprint capacity in male football players: a randomized controlled trial. *J Sports Sci*. 2018;36:1663-1672. https://doi.org/10.1080/02640414.2017.1409609
25. Ishøi L, Krommes K, Husted RS, Juhl CB, Thorborg K. Diagnosis, prevention and treatment of common lower extremity muscle injuries in sport – grading the evidence: a statement paper commissioned by the Danish Society of Sports Physical Therapy (DSSF). *Br J Sports Med*. 2020;54:528-537. https://doi.org/10.1136/bjsports-2019-101228
26. Jiménez-Rubio S, Navandar A, Rivilla-García J, Paredes-Hernández V. Validity of an on-field readaptation program following a hamstring injury in professional soccer. *J Sport Rehabil*. 2019;28:0203. https://doi.org/10.1123/jsr.2018-0203
27. Kilcoyne KG, Dickens JF, Keblish D, Rue JP, Chronister R. Outcome of grade I and II hamstring injuries in intercollegiate athletes: a novel rehabilitation protocol. *Sports Health*. 2011;3:528-533. https://doi.org/10.1177/1941738111422044
28. Lai L, Mohamed MNA, Ali MRM, Teng-Keen K, Yusof A. Effect of platelet-rich plasma treatment on antioxidant enzymes' activity following hamstring injury among Malaysian athletes. *Sains Malaysiana*. 2016;45:769-775.
29. Macdonald B, McAleer S, Kelly S, Chakraverty R, Johnston M, Pollock N. Hamstring rehabilitation in elite track and field athletes: applying the British Athletics Muscle Injury Classification in clinical practice. *Br J Sports Med*. 2019;53:1464-1473. https://doi.org/10.1136/bjsports-2017-098971
30. Major DH, Røe Y, Grotle M, et al. Content reporting of exercise interventions in rotator cuff disease trials: results from application of the Consensus on Exercise Reporting Template (CERT). *BMJ Open Sport Exerc Med*. 2019;5:e000656. https://doi.org/10.1136/bmjsem-2019-000656
31. Malliaropoulos N, Papalexandris S, Papalada A, Papacostas E. The role of stretching in rehabilitation of hamstring injuries: 80 athletes follow-up. *Med Sci Sports Exerc*. 2004;36:756-759. https://doi.org/10.1249/01.mss.0000126393.20025.5e
32. Maniar N, Shield AJ, Williams MD, Timmins RG, Opar DA. Hamstring strength and flexibility after hamstring strain injury: a systematic review and meta-analysis. *Br J Sports Med*. 2016;50:909-920. https://doi.org/10.1136/bjsports-2015-095311
33. Medeiros DM, Aimi M, Vaz MA, Baroni BM. Effects of low-level laser therapy on hamstring strain injury rehabilitation: a randomized controlled trial. *Phys Ther Sport*. 2020;42:124-130. https://doi.org/10.1016/j.ptsp.2020.01.006
34. Medina-Mirapeix F, Escolar-Reina P, Gascón-Cánovas JJ, Montilla-Herrador J, Jimeno-Serrano FJ, Collins SM. Predictive factors of adherence to frequency and duration components in home exercise programs for neck and low back pain: an observational study. *BMC Musculoskelet Disord*. 2009;10:155. https://doi.org/10.1186/1471-2474-10-155
35. Mendiguchia J, Conceição F, Edouard P, et al. Sprint versus isolated eccentric training: comparative effects on hamstring architecture and performance in soccer players. *PLoS One*. 2020;15:e0228283. https://doi.org/10.1371/journal.pone.0228283
36. Mendiguchia J, Martinez-Ruiz E, Edouard P, et al. A multifactorial, criteria-based progressive algorithm for hamstring injury treatment. *Med Sci Sports Exerc*. 2017;49:1482-1492. https://doi.org/10.1249/MSS.0000000000001241
37. Milanese S, Eston R. Hamstring injuries and Australian Rules football: over-reliance on Nordic hamstring exercises as a preventive measure? *Open Access J Sports Med*. 2019;10:99-105. https://doi.org/10.2147/OAJSM.S212008
38. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred Reporting Items for Systematic reviews and Meta-Analyses: the PRISMA statement. *J Clin Epidemiol*. 2009;62:1006-1012. https://doi.org/10.1016/j.jclinepi.2009.06.005
39. Munn Z, Peters MDJ, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Med Res Methodol*. 2018;18:143. https://doi.org/10.1186/s12874-018-0611-x
40. Opar DA, Williams MD, Shield AJ. Hamstring strain injuries: factors that lead to injury and re-injury. *Sports Med*. 2012;42:209-226. https://doi.org/10.2165/11594800-000000000-00000
41. Pickering C, Kiely J. Hamstring injury prevention: a role for genetic information? *Med Hypotheses*.

2018;119:58-62. https://doi.org/10.1016/j.mehy.2018.07.011
42. Rettig AC, Meyer S, Bhadra AK. Platelet-rich plasma in addition to rehabilitation for acute hamstring injuries in NFL players: clinical effects and time to return to play. *Orthop J Sports Med*. 2013;1:2325967113494354. https://doi.org/10.1177/2325967113494354
43. Reurink G, Goudswaard GJ, Moen MH, et al. Platelet-rich plasma injections in acute muscle injury [letter]. *N Engl J Med*. 2014;370:2546-2547. https://doi.org/10.1056/NEJMc1402340
44. Ruddy JD, Shield AJ, Maniar N, et al. Predictive modeling of hamstring strain injuries in elite Australian footballers. *Med Sci Sports Exerc*. 2018;50:906-914. https://doi.org/10.1249/MSS.0000000000001527
45. Schuermans J, Van Tiggelen D, Palmans T, Danneels L, Witvrouw E. Deviating running kinematics and hamstring injury susceptibility in male soccer players: cause or consequence? *Gait Posture*. 2017;57:270-277. https://doi.org/10.1016/j.gaitpost.2017.06.268
46. Sefiddashti L, Ghotbi N, Salavati M, Farhadi A, Mazaheri M. The effects of cryotherapy versus cryostretching on clinical and functional outcomes in athletes with acute hamstring strain. *J Bodyw Mov Ther*. 2018;22:805-809. https://doi.org/10.1016/j.jbmt.2017.08.007
47. Sherry MA, Best TM. A comparison of 2 rehabilitation programs in the treatment of acute hamstring strains. *J Orthop Sports Phys Ther*. 2004;34:116-125. https://doi.org/10.2519/jospt.2004.34.3.116
48. Shield AJ, Bourne MN. Hamstring injury prevention practices in elite sport: evidence for eccentric strength vs. lumbo-pelvic training. *Sports Med*. 2018;48:513-524. https://doi.org/10.1007/s40279-017-0819-7
49. Silder A, Sherry MA, Sanfilippo J, Tuite MJ, Hetzel SJ, Heiderscheit BC. Clinical and morphological changes following 2 rehabilitation programs for acute hamstring strain injuries: a randomized clinical trial. *J Orthop Sports Phys Ther*. 2013;43:284-299. https://doi.org/10.2519/jospt.2013.4452
50. Slade SC, Dionne CE, Underwood M, Buchbinder R. Consensus on Exercise Reporting Template (CERT): explanation and elaboration statement. *Br J Sports Med*. 2016;50:1428-1437. https://doi.org/10.1136/bjsports-2016-096651
51. Slade SC, Finnegan S, Dionne CE, Underwood M, Buchbinder R. The Consensus on Exercise Reporting Template (CERT) applied to exercise interventions in musculoskeletal trials demonstrated good rater agreement and incomplete reporting. *J Clin Epidemiol*. 2018;103:120-130. https://doi.org/10.1016/j.jclinepi.2018.07.009
52. Thorborg K, Ishøi L, Krommes K. Strong and stringent hamstring strain science: trials and error! *Br J Sports Med*. 2020;54:1069-1070. https://doi.org/10.1136/bjsports-2020-102213
53. Tol JL, Hamilton B, Eirale C, Muxart P, Jacobsen P, Whiteley R. At return to play following hamstring injury the majority of professional football players have residual isokinetic deficits. *Br J Sports Med*. 2014;48:1364-1369. https://doi.org/10.1136/bjsports-2013-093016
54. Valle X, Tol JL, Hamilton B, et al. Hamstring muscle injuries, a rehabilitation protocol purpose. *Asian J Sports Med*. 2015;6:e25411. https://doi.org/10.5812/asjsm.25411
55. van der Horst N, Smits DW, Petersen J, Goedhart EA, Backx FJ. The preventive effect of the Nordic hamstring exercise on hamstring injuries in amateur soccer players: a randomized controlled trial. *Am J Sports Med*. 2015;43:1316-1323. https://doi.org/10.1177/0363546515574057
56. van der Horst N, van de Hoef S, Reurink G, Huisstede B, Backx F. Return to play after hamstring injuries: a qualitative systematic review of definitions and criteria. *Sports Med*. 2016;46:899-912. https://doi.org/10.1007/s40279-015-0468-7
57. van Dyk N, Behan FP, Whiteley R. Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: a systematic review and meta-analysis of 8459 athletes. *Br J Sports Med*. 2019;53:1362-1370. https://doi.org/10.1136/bjsports-2018-100045

APPENDIX A

SEARCH STRATEGY, APPLIED TO THE SCIENTIFIC LITERATURE FROM 2010 ONWARD

Database	Muscle AND	Injury Type AND	Intervention Type
Web of Science CINAHL SPORTDiscus Scopus Cochrane Library	Hamstring* "Posterior Thigh" "Biceps Femoris" Semimembranosus Semitendinosus	Strain* Injur* Tear* Torn	Intervention* Rehab* Therap* Manag* Treat* Exercis* Prescri* Program* Progress* Physiotherap*
Ovid Embase (Emtree/mp)	Hamstring muscle/ or hamstring.mp. Posterior thigh.mp.	Strain.mp. Injury/ or Injury.mp.	Intervention*.mp. Rehabilitation/ Therapy/ Management/ Exercise/ Prescription/ Program*.mp. Progress*.mp. Physiotherapy/
Ovid MEDLINE (MeSH/mp)	Hamstring muscles/ or hamstring.mp. Posterior thigh.mp.	Strain.mp. or "Sprains and Strains"/ Injury.mp. or "Wounds and Injuries"/	Intervention*.mp. Rehabilitation/ Therapeutics/ Management/ Exercise/ Prescriptions/ Program*.mp. Progress*.mp. Physical Therapy Modalities/

Abbreviation: MeSH, Medical Subject Headings.

APPENDIX B

DEFINITIONS FOR CLASSIFYING EACH EXERCISE INTO 4 BROAD CATEGORY TYPES[a]

Category of Exercise	Definition of Category
Hamstring flexibility	Exercise aimed at improving flexibility of the hamstring muscles, directly via stretching or with active range-of-motion interventions
Hamstring strength	Exercise aimed at improving strength of the hamstring muscles, directly via interventions emphasizing either hip extension or knee flexion as the primary movement. Exercises involving simultaneous hip and knee extension (eg, leg press, lunges) were not considered to be hamstring specific
Running related	Exercise that was running related, such as straight-line acceleration, sprinting, technique or agility drills, and lower-limb plyometrics
Non–hamstring specific	Exercise not specifically targeting the hamstring muscles, but rather other lower-limb or trunk muscles, via strength, flexibility, coordination, or general conditioning interventions

[a]*Exercises were classified based on the perception of 2 authors (R.B. and J.H.) who were responsible for study data extraction: R.B. has over 20 years' experience working in exercise prescription and delivery of training programs for adolescent and high-performance athletes in sport, and J.H. has 10 years' experience working in exercise prescription and delivery for musculoskeletal and sports injury prevention and rehabilitation.*

APPENDIX C

INTERVENTION MODE AND PRESCRIPTION DETAILS FROM STUDIES INCLUDING NON–HAMSTRING-SPECIFIC EXERCISES DURING REHABILITATION

Study	Lower-Limb Exercises	Lumbopelvic Exercises	General Conditioning
Askling et al[3]			General program, stage 2 (3 times per week): stationary cycling (10 min)
Bayer et al[6]	Phase 3 (3 times per week from weeks 5 to 8): bilateral leg press, high-foot position (15RM to 4RM) Phase 4 (3 times per week from weeks 9 to 12): unilateral leg press, high-foot position (15RM to 4RM)		
Gaballah et al[19]	From 0 to 7 d after HSI: bilateral bridge exercise		From 0 to 7 d after HSI: stationary cycling Phase 1 (5 times per week from weeks 2 to 6): aquatic exercises
Jiménez-Rubio et al[26]	Day 3 after HSI: lower-limb isometrics, focusing on the gluteus maximus Days 6 and 7 after HSI: unilateral and Bulgarian squats, pelvis slide and elevation		
Lai et al[28]		Stage 1 (daily, starting within 7 d of HSI): prone bridge, supine bridge, and side bridge (all, 4 × 20 s) Stage 2 (daily): push-up/trunk rotation and PNF trunk pull-downs (both, 2 × 15 reps)	
Medeiros et al[33]	Phase 1 (3 times per week from 5 d after HSI): wall squat (2 × 10-15 reps), monster walk (1 × 10-15 reps), wall sit (1 × 30-45 s) Phase 2 (3 times per week): kettlebell front squat (2 × 15 reps), lunge (2 × 10-15 reps), monster walk (2 × 10-15 reps), wall sit (1 × 30-60 s) Phase 3 (3 times per week): monster walk (2 × 10-15 reps), wall sit (1 × 30-60 s)	Phase 1 (3 times per week from 5 d after HSI): front plank (1 × 30-45 s), side plank (1 × 30-45 s), supine bridge (1 × 10-15 reps), bird dog (1 × 10-15 reps) Phase 2 (3 times per week): front plank (1 × 45-60 s), side plank (1 × 45-60 s), supine bridge (2 × 15 reps), isometric supine bridge (2 × 60 s), bird dog (2 × 15 reps) Phase 3 (3 times per week): front plank (1 × 45-60 s), side plank (1 × 45-60 s), supine bridge (2 × 15 reps), isometric supine bridge (2 × 60 s)	
Mendiguchia et al[36]	Algorithm phase 1 (daily from 5 d after HSI): • Flexibility: psoas static flexibility with pelvic retroversion (4 × 15 s), quadriceps dynamic mobility (2 × 8 reps) • Gluteus maximus A: prone hip extension (2 × 10 reps × 3 s), unilateral bridge and kick (2 × 5 reps × 3 s), bilateral bridge (50% BW; 3 × 6 reps × 3 s) • Gluteus maximus B: hip thrust (40% BW; 3 × 6 reps × 3 s), unilateral bridge and kick (10% BW; 2 × 4 reps × 3 s), unilateral hip thrust and kick (10% BW; 2 × 4 reps × 3 s) • Gluteus medius: clam with band, side hip abduction with band (both, 3 × 6 reps × 3 s) Algorithm phase 2 (once for 3 d): • Lunge (15% BW; 2 × 6 reps) • Gluteus maximus A: unilateral hip thrust (10% BW; 3 × 4 reps × 3 s), bilateral hip thrust (60% BW; 3 × 8 reps × 3 s), walking sled push (75% BW; 2 × 15 m) • Gluteus maximus B: elevated hip thrust: unilateral with kick (2 × 4 reps × 3 s), unilateral back extension with perturbation (2 × 4 reps), swing-leg hip extension (2 × 3 reps) • Gluteus medius: sidestep with band, monster run with band (5 × 5 m)	Algorithm phase 1 (daily from 5 d after HSI): • Side bridge with perturbation (2 × 5 reps × 5 s), bird dog (2 × 5 reps × 5 s), supine plank (2 × 4 reps × 5 s), leg scissors (2 × 5 reps × 5 s) Algorithm phase 2 (twice for 3 d): • Stir the pot with FitBALL (3 × 2 reps), leg scissors (2 × 5 reps × 5 s), single-leg rotating reach (4 kg; 2 × 6 reps), TRX helicopter (2 × 4 reps), sprinter push/pull with pulley (2 × 6 reps)	

Table continues on page A4.

APPENDIX C

Study	Lower-Limb Exercises	Lumbopelvic Exercises	General Conditioning
Rettig et al[42]	Days 1 to 4 after HSI: clams Days 7 to 14 after HSI: slide-board lunges		Days 4 to 7 after HSI: stationary cycling Days 7 to 14 after HSI: elliptical/stepper, progressing to treadmill
Reurink et al[43]		Phase 1 (daily): isometric exercises for lumbopelvic musculature, prone bridge, supine bridge, side bridge (all, 4 × 20 s) Phase 2 (daily): trunk rotation/push-up position, PNF trunk pull-downs (2 × 15 reps)	Phase 1 (daily): stationary cycling
Tol et al[53]	Stage 1 (5 times per week, starting within 5 d of HSI): bilateral bridge (4 × 15 reps) Stage 2 (5 times per week): unilateral bridge (4 × 15 reps, then 4 × 8 reps)		Stage 1 (5 times per week, starting within 5 d of HSI): stationary cycling

Abbreviations: BW, body weight; HSI, hamstring strain injury; PNF, proprioceptive neuromuscular facilitation; reps, repetitions; RM, repetition maximum.

[EDITORIAL]

MORTEN HOEGH, PhD[1] • MICHAEL SKOVDAL RATHLEFF, PhD[1]

Pain Science in Practice: Linking Basic Pain Science to the Clinic and Quality Musculoskeletal Rehabilitation Care

Pain is a subjective experience: patients are experts on their own experience of pain. Nociception, the ideal trigger for acute pain, can be studied only through complex methods: basic scientists are experts on nociception and its relation to pain-related phenomena (eg, allodynia). Health care providers need the knowledge and skills to serve as experts who synthesize information from patients and science (clinical and basic) to deliver evidence-based practice.[5] What are the principles from the neurosciences that inform health care providers about the pain that patients experience? The answer is not static.

In this series, we highlight core principles from basic neuroscience and discuss how clinicians can harness neuroscience to deliver high-quality musculoskeletal rehabilitation in their daily clinical practice.

While the idea of pain neuroscience education (PNE) has only been around for 2 decades, the concept of using basic science to inform clinical reasoning has been integrated into the management of musculoskeletal pain for many years,[7] albeit the scientific basis used to be anatomy and biomechanics.[3] Metaphors are essential in PNE. However, there are dissenting views about the value of PNE, suggesting that it is important for clinicians to understand scientific principles and their clinical relevance rather than metaphorical concepts of pain.[1,9] One common misconception attributable to the widespread use of metaphors about pain-related neuroscience has been the attempt to diagnose "central sensitization (syndrome),"[6] which continues to lack scientific support.[2]

There is a dire need for more education on pain and related sciences.[4,8] So, as a supplement to PNE, this editorial series aims to provide basic neuroscience to (1) support clinical reasoning, (2) help clinicians generate useful narratives to validate the pain that is felt and reported by patients (also in the absence of pathologies), and (3) explicitly state the limitations of applying neuroscience to clinical practice.

SYNOPSIS: To understand pain, professionals need a basic understanding of neuroscience. The "pain science in practice" series is aimed at clinicians and explains key elements of pain-related sciences and the role they play in clinical practice, from clinical reasoning to management. *J Orthop Sports Phys Ther 2022;52(3):125-126. doi:10.2519/jospt.2022.10992*

KEY WORDS: *neuroscience, pain education, pain neuroscience education*

The "pain science in practice" series will help current and future clinicians who are working with patients with musculoskeletal pain to describe and discuss pain from the standpoint of neuroscience. The first editorials will focus on explaining essential concepts, such as what transduction is and how receptors work. Subsequent editorials will build on these concepts to explain 3 scientific discoveries and their relation to musculoskeletal pain: (1) peripheral sensitization, (2) central sensitization, and (3) descending modulation. These principles are essential for understanding not only primary and secondary hyperalgesia (eg, pain induced by palpation), but also which cellular and molecular mechanisms are likely to explain clinical pain management.

We envision this series to be a resource for clinicians, students, and educators that will illuminate the role of basic science and how it informs clinical practice, clinical research, and education. We acknowledge the fact that our series is not a complete guide to the neuroscience of pain and invite the JOSPT community to interact with us directly in developing its format and content. Please follow and use #JOSPTScienceInPractice to connect. We welcome the JOSPT community to share in the experiences, codevelop resources, and shape opportunities that arise as we embrace neuroscience.

[1]Department of Health Science and Technology, Faculty of Medicine, Aalborg University, Aalborg, Denmark. ORCID: Hoegh, https://orcid.org/0000-0002-9724-767X. Dr Hoegh has received support from nonindustry professional, private, and scientific bodies (reimbursement of travel costs and speaker fees) for lectures on pain, and he receives book royalties from the publishers Gyldendal, Munksgaard Denmark, FADL, and Muusmann. Dr Rathleff certifies that he has no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Morten Hoegh, Faculty of Medicine, Department of Health Science and Technology, Aalborg University, Fredrik Bajers Vej 7, Aalborg Øst, 9220 Denmark. E-mail: msh@hst.aau.dk

STUDY DETAILS

AUTHOR CONTRIBUTIONS: Both authors contributed equally. There was no funding.
DATA SHARING: There are no data in this editorial to share.
PATIENT AND PUBLIC INVOLVEMENT: No patients or members of the public were involved in this editorial.

REFERENCES

1. Cayrol T, Draper-Rodi J, Fabre L, Pitance L, van den Broeke EN. Stuck in the middle with you: why a broad-brush approach to defining central sensitization does not help clinicians and patients. *J Orthop Sports Phys Ther*. 2021;51:204-206. https://doi.org/10.2519/jospt.2021.10340
2. Curatolo M. Central sensitization: nice to know? *Eur J Pain*. 2018;22:214-215. https://doi.org/10.1002/ejp.1154
3. Hunt A, Adamson B, Higgs J, Harris L. University education and the physiotherapy professional. *Physiotherapy*. 1998;84:264-273. https://doi.org/10.1016/S0031-9406(05)65527-7
4. Hush JM, Nicholas M, Dean CM. Embedding the IASP pain curriculum into a 3-year pre-licensure physical therapy program: redesigning pain education for future clinicians. *Pain Rep*. 2018;3:e645. https://doi.org/10.1097/PR9.0000000000000645
5. Kamper SJ. Evidence in practice: a new series for clinicians. *J Orthop Sports Phys Ther*. 2018;48:429. https://doi.org/10.2519/jospt.2018.0105
6. Nijs J, Goubert D, Ickmans K. Recognition and treatment of central sensitization in chronic pain patients: not limited to specialized care. *J Orthop Sports Phys Ther*. 2016;46:1024-1028. https://doi.org/10.2519/jospt.2016.0612
7. Tegner H, Frederiksen P, Esbensen BA, Juhl C. Neurophysiological pain education for patients with chronic low back pain: a systematic review and meta-analysis. *Clin J Pain*. 2018;34:778-786. https://doi.org/10.1097/AJP.0000000000000594
8. Thompson K, Johnson MI, Milligan J, Briggs M. Twenty-five years of pain education research—what have we learned? Findings from a comprehensive scoping review of research into pre-registration pain education for health professionals. *Pain*. 2018;159:2146-2158. https://doi.org/10.1097/j.pain.0000000000001352
9. van Griensven H, Schmid A, Trendafilova T, Low M. Central sensitization in musculoskeletal pain: lost in translation? *J Orthop Sports Phys Ther*. 2020;50:592-596. https://doi.org/10.2519/jospt.2020.0610

ROBROY L. MARTIN, PT, PhD • **MICHAEL T. CIBULKA,** PT, DPT, OCS • **LORI A. BOLGLA,** PT, PhD
THOMAS A. KOC, JR., PT, DPT, PhD, OCS • **JANICE K. LOUDON,** PT, PhD • **ROBERT C. MANSKE,** PT, DPT
LEIGH WEISS, PT, DPT, ATC, OCS, SCS • **JOHN J. CHRISTOFORETTI,** MD, FAAOS • **BRYAN C. HEIDERSCHEIT,** PT, PhD, FAPTA

Hamstring Strain Injury in Athletes

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

J Orthop Sports Phys Ther. 2022;52(3):CPG1-CPG44. doi:10.2519/jospt.2022.0301

REVIEWERS: Mike Voight, PT, DHSc, OCS, SCS, ATC, FAPTA • John DeWitt, PT, DPT, AT • Brian Young, PT, DSc • Liran Lifshitz, PT, MSc
Douglas White, PT, DPT, OCS, RMSK • David Killoran, PhD • Sandra Kaplan, PT, DPT, PhD, FAPTA
Steve Paulseth, PT, DPT, SCS, ATC • James A. Dauber, DPT, DSc

Summary of Recommendations

REINJURY RISK AND RETURN TO PLAY

B Clinicians should use the history of a hamstring strain injury (HSI) in return-to-play (RTP) progression, as a previous HSI is a risk factor for a future reinjury.

B Clinicians should use caution in RTP decisions for individuals who did not complete an appropriately progressed, comprehensive impairment-based functional exercise program that specifically included eccentric training.

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

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

EXAMINATION: PHYSICAL IMPAIRMENT MEASURES

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

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

C Clinicians may use the length of muscle tenderness and proximity to the ischial tuberosity to assist in predicting timing of RTP.

F Clinicians may assess for abnormal trunk and pelvic posture and control during functional movements.

EXAMINATION: ACTIVITY LIMITATION AND PARTICIPATION RESTRICTION

B Clinicians should 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

B Clinicians should use the Functional Assessment Scale for Acute Hamstring Injuries before and after interventions, intended to alleviate the impairments of body function and structure, activity limitations, and participation restrictions in those diagnosed with an acute HSI.

INTERVENTIONS: INJURY PREVENTION

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

INTERVENTIONS: AFTER INJURY

B Clinicians should use eccentric training to the patient's tolerance, added to stretching, strengthening, stabilization, and progressive running programs, to improve RTP time after an individual sustains an HSI.

B Clinicians should use progressive agility and trunk stabilization, added to a comprehensive impairment-based treatment program of stretching, strengthening, and functional exercises, to reduce reinjury rate after an individual sustains an HSI.

F Clinicians may perform neural tissue mobilization after injury to reduce adhesions to surrounding tissue and therapeutic modalities to control pain and swelling early in the healing process.

List of Abbreviations

AASPT: American Academy of Sports Physical Therapy
AKE: active knee extension
AOPT: Academy of Orthopaedic Physical Therapy
APTA: American Physical Therapy Association
CI: confidence interval
CPG: clinical practice guideline
FASH : Functional Assessment Scale for Acute Hamstring Injuries
FIFA: International Federation of Association Football (Fédération Internationale de Football Association)
HaOS: hamstring outcome score
HHD: handheld dynamometer

H/Q: hamstring-quadriceps
HR: hazard ratio
HSI: hamstring strain injury
ICC: intraclass correlation coefficient
ICF: International Classification of Functioning, Disability and Health
***JOSPT*:** *Journal of Orthopaedic & Sports Physical Therapy*
MDC: minimal detectable change
MRI: magnetic resonance imaging
NHE: Nordic hamstring exercise
OR: odds ratio
RCT: randomized controlled trial
ROM: range of motion
RR: relative risk
RTP: return to play
SEM: standard error of measurement
SLR: straight leg raise
US: ultrasound

Introduction

AIM OF THE GUIDELINES

The Academy of Orthopaedic Physical Therapy (AOPT) and the American Academy of Sports Physical Therapy (AASPT) of the American Physical Therapy Association (APTA) has an ongoing effort to create evidence-based clinical practice guidelines (CPGs) for orthopaedic and sports physical therapist management of patients with musculoskeletal impairments described in the World Health Organization's International Classification of Functioning, Disability and Health (ICF).[108] The purposes of these CPGs are as follows:

- Describe evidence-based physical therapist 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 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 therapist 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 based on 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, considering 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 3 muscles in the posterior thigh: the semitendinosus, semimembranosus, and biceps femoris. Hamstring strain injury (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.[18] The high reinjury rate is also an important issue.[55] Typically, HSIs are classified by the involved muscle, anatomical location, and severity of damage.[3,18] Classifications also may consider whether there is myofascial, musculotendinous, and/or intratendinous involvement.[3,18] 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.[4] 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, and late in swing phase/early heel strike.[11] This overload injury usually involves the biceps femoris and surrounding tissue. In contrast, overstretching injuries occur with combined hip flexion and knee extension movements, as in kicking or reaching to pick up and lift something off the ground with the knee extended. This overstretching injury typically involves the proximal semimembranosus.[6] This CPG includes sports-related overloading and overstretching injuries to myofascial or musculotendinous structures in any combination of the 3 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.[3] Given these differences, this CPG will exclude isolated tendon injuries. While the effect of interventions for those with an 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 to return to sports participation while preventing reinjury. Therefore, only studies that directly assessed time to return to play (RTP) and reinjury rates were included when discussing interventions for HSIs.

Methods

The AOPT and AASPT appointed content experts to conduct a review of the literature and develop an 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 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 searching and to perform systematic searches for concepts associated with classification, examination, and intervention strategies for HSI. Briefly, the following databases were searched from database inception to June 2021: PubMed, Embase, CINAHL, Cochrane Library, Ovid, and SPORTDiscus (see **APPENDIX A** for full search strategies, dates, and results, available at www.jospt.org).

The authors declared relationships and developed a conflict management plan, which included submitting a conflict-of-interest form to the AOPT. Articles authored by a reviewer were assigned to an alternate reviewer. The CPG authors did not draft recommendations when their research was included in that topic area. The AOPT and AASPT funded the CPG development team for travel and CPG development training. The CPG development team maintained editorial independence.

Articles used to support recommendations were reviewed based on prespecified inclusion and exclusion criteria, with the goal of identifying evidence relevant to clinical decision making for managing adults with HSI. Two members of the CPG development team independently reviewed the title and abstract of each article for inclusion (see **APPENDIX B** for inclusion and exclusion criteria, available at www.jospt.org). Full-text review was then similarly conducted to obtain the final set of articles used to make the recommendations. The team leader (R.L.M.) provided the final decision for discrepancies that were not resolved by the review team (see **APPENDIX C** for flow charts of articles, available at www.jospt.org). Articles for selected relevant topics that were not sufficient for developing recommendations (eg, incidence and imaging) 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 CPG page of the AOPT and AASPT of the APTA websites (www.orthopt.org and www.aaspt.org).

This guideline was issued in 2022, based on the published literature 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 AOPT and AASPT of the APTA websites (www.orthopt.org and www.aaspt.org).

LEVELS OF EVIDENCE

Individual clinical research articles were graded according to criteria adapted from the Centre for Evidence-Based Medicine (Oxford, UK) 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 **APPENDICES D** and **E** for the levels-of-evidence table and details on procedures used for assigning levels of evidence, available at www.jospt.org). The evidence update was organized from the highest level of evidence to the lowest level of evidence. An abbreviated version of the grading system is provided in **TABLE 1**.

TABLE 1 Levels of Evidence

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-control 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 (**TABLE 2**). 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.

TABLE 2 Grades of Recommendation

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 study results	
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 supports this conclusion	May

GUIDELINE REVIEW PROCESS AND VALIDATION

Identified reviewers who are experts in HSI management and rehabilitation reviewed the CPG draft for integrity and accuracy, and to ensure that it fully represented the current evidence for the condition. The guideline draft was also posted for open review on www.orthopt.org, and a notification of this posting was sent to the members of the AOPT. 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 CPG methodologists. All comments, suggestions, and feedback from the reviews were provided to the authors and editors for consideration and revision. The AOPT Clinical Practice Guideline Advisory Panel reviews guideline development methods, policies, and implementation processes on a yearly basis.

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 pages of the *JOSPT, AASPT,* and AOPT websites, which are free-access website areas, and submitted for free access on the ECRI Guidelines Trust (guidelines.ecri.org) and the Physiotherapy Evidence Database (www.PEDro.org.au). The planned implementation tools for patients, clinicians, educators, payers, policy makers, and researchers, and the associated implementation strategies, are listed in **TABLE 3**.

ORGANIZATION OF THE GUIDELINE

When 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 when appropriate, and the recommendation(s). Topics for which a systematic review was conducted and recommendations provided include RTP and reinjury risk, examination, injury prevention, and interventions. For other topics where a systematic review was outside the scope of this CPG, a summary of the literature is provided. This includes incidence/prevalence, pathoanatomical features, risk factors, clinical course, differential diagnosis, and imaging.

CLASSIFICATION

The primary International Classification of Diseases-10th Revision codes associated with an HSI are as follows:

1. **S76.01** Strain of muscle, fascia and tendon of hip

2. **S76.302A** Unspecified injury of muscle, fascia and tendon of the posterior muscle group at thigh level, left thigh, initial encounter
   a. **S76.312** Strain of muscle, fascia and tendon of the posterior muscle group at thigh level, left thigh
   b. **S76.311** Strain of muscle, fascia and tendon of the posterior muscle group at thigh level, right thigh
3. **S76.319D** 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 HSI are **b28015** Pain in lower limb and **b7301** Power of muscles of one limb.

The primary ICF body structure code associated with HSI is **S75002** Muscles of thigh.

The primary ICF activities and participation codes associated with HSI are **d4105** Bending, **d4153** Maintaining a sitting position, **d4351** Kicking, **d4509** Walking, unspecified, **d4551** Climbing, **d4552** Running, **d4553** Jumping, and **d9201** Sports.

TABLE 3 Planned Strategies and Tools to Support the Dissemination and Implementation of This CPG

Tool	Strategy
JOSPT's "Perspectives for Patients" and "Perspectives for Practice" articles	Patient- and clinician-oriented guideline summaries available at www.jospt.org
Mobile app of guideline-based exercises for patients/clients and health care practitioners	Marketing and distribution of app via www.orthopt.org and www.aaspt.org
Clinician's Quick-Reference Guide	Summary of guideline recommendations available at www.orthopt.org and www.aaspt.org
JOSPT's Read for Credit℠ continuing education units	Continuing education units available for physical therapists and athletic trainers at www.jospt.org
Webinars and educational offerings for health care practitioners	Guideline-based instruction available for practitioners at www.orthopt.org
Mobile and web-based app of guideline for training of health care practitioners	Marketing and distribution of app via www.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 www.jospt.org
APTA CPG+	Dissemination and implementation aids

CLINICAL PRACTICE GUIDELINES

Incidence/Prevalence

Hamstring strain injuries 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 the ground. Therefore, sports such as track and field, soccer, Australian rules football, American football, and rugby have the highest frequency of reported injuries.[8,50,89,93] The estimated incidence of HSIs per 1000 hours of exposure is 0.87 in noncontact sports and 0.92 to 0.96 in contact sports.[50] Incidence rate estimates are 3 to 4.1 per 1000 competition hours and 0.4 to 0.5 per 1000 training hours for professional male European soccer players.[29] Some groups have reported an increasing incidence of HSIs. For example, in professional male European soccer players between 2001 and 2014, there was an increase in HSIs per year of 2.3% (95% confidence interval [CI]: 0.6%, 4.1%) during competition and 4.0% (95% CI: 1.1%, 7.0%) during training.[25] Dalton et al[17] reported that 68.2% of HSIs occurred during practice in men's football, men's soccer, and women's soccer. A professional soccer team of 25 players can expect about 7 HSIs per season.[50] Australian rules football players have a 1.3-fold higher risk of HSI with each additional year of age, while soccer players have a 1.9-fold higher risk with each increasing year of age.[64] Hamstring strain injuries frequently cause a significant loss of time from competition, generally ranging from 3 to 28 days or more, depending on injury severity.[50] Reinjury rates are high and range between 13.9% and 63.3% across Australian rules football and track and field athletes.[21,50] Furthermore, those with a history of HSI have a 3.6-times higher risk of sustaining a future HSI.[55] The high incidence of recurrent HSIs may be attributable to inadequate rehabilitation or premature RTP.[17]

Pathoanatomical Features

Skeletal muscle consists of slow (type I) and fast (type II) muscle fibers. It is believed that the hamstring muscle group has a higher percentage of type II fibers than other thigh muscles, making the muscle more susceptible to injury.[30,64] However, the actual percentage of type II fibers may vary, depending on age and other individual anatomical variations.[64] The long head of the biceps femoris muscle is the most commonly involved hamstring muscle in both first-time and recurrent injuries, being involved in 79% to 84% of HSIs.[23,86,103,106] Anatomically, an increased anterior pelvic tilt may place the hamstring muscle group in a more lengthened position and potentially increase the likelihood of an HSI.[49,64] Timmins et al[90] studied 20 recreationally active athletes with no history of HSI and 16 elite athletes with a history of a unilateral HSI and compared ultrasound (US) imaging measures of the biceps femoris muscle architecture (eg, 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 the 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.[90]

SUMMARY

Most HSIs occur in the long head of the biceps femoris. Evidence suggests that muscle architecture (eg, higher pennation angle and shorter fascicle length) may contribute to an HSI.

Risk Factors

Risk factors for acute HSI are categorized as being nonmodifiable or modifiable. Nonmodifiable factors describe characteristics of an individual that cannot be changed, such as history of previous HSI and age. Modifiable factors are factors that can be altered, such as muscle characteristics, muscle performance, and performance characteristics.[38,98,100]

NONMODIFIABLE RISK FACTORS

Previous Injury

Systematic reviews have consistently identified previous injury as a risk factor for a subsequent HSI.[34,38,73] Studies within these reviews reported a 2- to 6-times higher rate of recurrence following a previous HSI.[27,35] A prospective study not included in these reviews found that male sprinters with a prior HSI had a significantly higher injury rate than those who had never sustained an HSI (odds ratio [OR] = 2.85, $P<.05$).[91] A recent HSI (within 8 weeks) was found to place individuals at greater risk for injury when compared to those with a nonrecent injury (OR = 13.1; 95% CI: 11.5, 14.9 versus OR = 3.5; 95% CI: 3.2, 3.9).[69] Also, Green et al[38] reported the risk of recurrent HSI to be greatest during the same season (relative risk [RR] = 4.8; 95% CI: 3.5, 6.6). Green et al[38] also reported 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 an HSI. A history of a quadriceps strain and chronic groin pathology were not identified as risk factors.[38]

Physical Characteristics

Systematic reviews have identified increasing age to be a significant risk factor for HSI.[34,38,73] One study included in these reviews found that athletes older than 23 years of age were at greater risk than those 23 years of age or younger (RR = 1.34; 95% CI: 1.14, 1.57).[68] Another study found that Australian rules football athletes older than 25 years of age were at greater risk than those 25 years of age or younger (RR = 4.43; 95% CI: 1.57, 12.52).[35] While systematic reviews have found height[34,73] and preferred kicking leg[34] not to be risk factors, ethnicity represented a risk factor in African-American athletes and Aboriginal Australian rules footballers.[73]

MODIFIABLE RISK FACTORS

Weight and Body Mass Index

Findings from systematic reviews do not support weight or body mass index as risk factors for HSIs.[34,73]

Muscle Characteristics

Findings from systematic reviews and meta-analyses found no relationship between hamstring flexibility and HSI.[34,38,73] In addition, Green et al[38] found no relationship between HSIs and passive knee extension ROM, active knee extension (AKE) ROM, passive straight leg raise (SLR), and slump tests. While flexibility does not play a role, lower-level studies suggest that biceps femoris fascicle length and hamstring muscle-tendon unit stiffness are related to HSIs.[38] Green et al[38] also found conflicting evidence regarding the effect of hip flexor tightness and limited ankle dorsiflexion ROM on HSIs.

Muscle Performance

Green et al[38] reported limited evidence for hamstring weakness as a risk factor for 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 the Nordic hamstring exercise (NHE) or with isokinetic testing.[38] Similar findings were noted by Opar et al[63] in their meta-analysis. The meta-analysis by Freckleton and Pizzari[34] identified increased peak quadriceps torque as a risk factor for HSIs. Conflicting results from systematic reviews existed when examining hamstring-to-quadriceps strength imbalances as a risk factor for HSI.[34,73] Study findings did not seem to be related to measurement, speed, or type of muscle contraction.[34,73] Based on lower-level studies, Green et al[38] found altered trunk and gluteus muscle activity and abnormal motor control to be potential risk factors for HSI.[38]

Performance Characteristics

The meta-analysis by Green et al[38] found that increased positional high-speed running demands were 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. Athletes with rapid increases in high-speed running exposure may be especially at risk. Findings from lower-level studies showed that sprinting characteristics, with increased anterior pelvic tilting and thoracic spine sidebending during the backswing, were also associated with HSIs. Within this meta-analysis, 1 study found a higher proportion (68%, $P<.001$) of HSIs sustained during running activities and more severe injuries during kicking.[8] Systematic reviews have included lower levels of evidence for predicting HSI using performance measures, such as the single-leg hop for distance and the jumping percentage difference between noncountermovement and countermovement jumping.[34,38] Freckleton and Pizzari[34] examined a variety of sports and found that workload, with time spent in games versus practice, as well as frequency of off-season running were not risk factors for HSI.

SUMMARY

Previous HSI, age greater than 23 years, anterior cruciate ligament injuries, calf strains, and other knee and ankle ligament injuries represent nonmodifiable risk factors for HSI. Hamstring fascicle length and stiffness, but not flexibility, are modifiable risk factors. High-speed running demands with abnormal trunk and pelvic posture and motor control may be risk factors for HSI. However, further research is needed to better define performance characteristics, such as hamstring weakness, that might be risk factors.

Clinical Course

An HSI can occur anywhere along the length of the muscle, but occurs most frequently in the proximal biceps femoris at the musculotendinous junction.[14] At the time of injury, an individual experiences a sudden, sharp pain in the posterior thigh. Additionally, an audible or palpable popping sensation[39] often occurs during an activity that overloads and/or overstretches the hamstring muscle.[2,4] The individual may stop the event or activity due to the pain and limited function. The recurrence rate of HSI ranges between 13.9% and 63.3% when followed over the same and subsequent seasons.[21] Also, injuries with more extensive myofascial damage extending into the tendon are more prone to reinjury and delayed RTP.[72]

The clinical course of an HSI depends on the extent and nature of the muscle damage. In mild injuries, only the myofibrils are damaged.[2] With greater injury severity, the extreme tensile and shear forces result in additional fascia, basal lamina, and blood vessel tearing.[49] 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.[49] The most common type of HSI occurs within the biceps femoris, where the myofibers attach to the intramuscular fascia.[13,53,102]

The healing process includes 3 phases: inflammation, proliferation, and remodeling.[49] The inflammation phase occurs immediately after HSI and lasts approximately 3 to 5 days.[53] Vasodilation and increased capillary permeability during this phase cause fluid stasis, resulting in an ischemic local environment, causing further muscle damage and edema. Two to 4 days after injury, phagocytic cells enter the damaged area to activate local undifferentiated ("stem") cells that begin rebuilding the collagen and vascular infrastructure (eg, fibroblasts and endothelial cells).[53] Clinically, pain, swelling, bleeding, and loss of ROM typically characterize this phase.

The proliferation phase may overlap to varying degrees with the inflammation phase and last up to several weeks. During this phase, satellite cells contribute to repair damaged myofibers[61] as collagen and vascular infrastructures are rebuilt. At this time, individuals often experience muscle weakness, stiffness, swelling, and limited function.[109] Suboptimal outcomes occur when these symptoms and signs continue for an extended period.[53]

Depending on the extent of the HSI, the remodeling phase can continue for up to 2 years. This phase is characterized by final collagen formation, allowing for support to the injury site. 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 ROM and soft tissue mobilization after injury may help promote more organized scar formation, with fewer adhesions to surrounding tissue. As the remodeling phase progresses, the individual will have minimal complaints and can tolerate greater stress to the muscle.[53]

SUMMARY

The normal healing process of an 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 ROM may contribute to less disorganized scar formation and a lower reinjury rate.

Return to Play and Reinjury Risk

OVERVIEW

The high rates of recurrent HSIs are associated with substantial losses of time in training and competition for athletes and large costs to professional sports organizations. Optimizing reinjury risk assessment and RTP decision making is a high priority for all stakeholders. The importance of determining when the athlete can safely RTP while minimizing risk of reinjury remains high, especially following severe HSI that usually requires a longer recovery.

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).[38] Multiple systematic reviews[31,34,95] and additional studies not included in these reviews supported this finding.[12,66] In Australian rules football players (n = 1932), those with a recent HSI (within 8 weeks) were at higher risk (OR = 13.1; 95% CI: 11.5, 14.9) for reinjury compared to those with a nonrecent injury (greater than 8 weeks) (OR = 3.5; 95% CI: 3.2, 3.9).[69] Green et al[38] noted that the 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[21] noted a lower risk of hamstring strain reinjury when individuals performed agility and stabilization exercises after injury, compared to only stretching and strengthening exercises (7.7% versus 70%, respectively). In 48 semiprofessional soccer players, Mendiguchia et al[60] found that a comprehensive impairment-based treatment program reduced the risk of reinjury compared to a standard NHE program (RR = 6; 90% CI: 1, 35).

II A systematic review by Hickey et al[45] 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. Four studies included in the Hickey et al[45] review used RTP criteria, based on a combination of clinical assessment and performance tests, and reported mean RTP times of 23 to 45 days and reinjury rates between 9.1% and 63.3%.[45] 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 reinjury rates of 1.3% and 3.6%.[45] The most practical findings were noted in 3 studies that used isokinetic dynamometry, in addition to clinical assessment and performance tests, with reported mean RTP times of 12 to 25 days and reinjury rates between 6.25% and 13.9%.[45] In their systematic review, Schut et al[84] found limited evidence for initial findings of visible bruising, muscle pain during everyday activities, a popping sound at injury, being forced to stop play within 5 minutes, width of palpation pain, pain on trunk flexion, and pain on active knee flexion in predicting RTP times. They also found limited evidence to support an association between RTP times and an individual's height and weight.[84]

II At the time of physical therapist initial evaluation, a combination of 3 demographic and 6 clinical variables explained 50% of the variance (±19 days) in predicting the time to RTP after grade I or II HSI.[48] 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 following variables were most predictive for RTP: (1) change in strength during the first week for the "mid-range" test, (2) peak isokinetic knee flexion torque of the uninjured leg at day 1, (3) pain level at the time of injury, (4) days to walk pain free, (5) playing soccer, (6) "inner-range" hamstring strength at day 1, (7) the presence or absence of pain on a single-leg bridge at day 7, (8) delay in starting physical therapy, and (9) percentage of strength in the "outer-range" test compared to the healthy leg.[48]

II Cross et al[15] found no between-sex differences in the RTP time for first-time (median: men, 7.0 days; women, 6.0 days; P = .07) or recurrent (median: men, 11 days; women, 5.5 days; P = .06) HSIs. However, they reported that male soccer players had higher rates of reinjury compared to female players (men, 22%; women, 12%; P = .003).[15] Similarly, Schut et al[84] 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 showed no association between the level of sport activity or the intensity of sport activity performed (3 or fewer times per week or more than 3 times per week).[84] Conflicting evidence existed for type of sport and time to RTP from injury.[84]

II Two lesser-quality randomized controlled trials (RCTs) identified in a meta-analysis found a significant reduction in time to RTP (hazard ratio [HR] = 3.22; 95% CI: 2.17, 4.77) when eccentric exercises were added to a conventional stretching, strengthening, and stabilization program after HSI.[70]

II Hamstring strain injuries categorized by deficits in AKE 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 rehabilitation. Grade II injuries had a 16° to 25° ROM deficit and required 30.7 days of rehabilitation, while grade III injuries had a 26° to 35° ROM deficit and required 75.0 days of rehabilitation.[86] Normalization of isokinetic strength was not required to successfully complete a soccer-specific rehabilitation program.[92]

IV The length of the area of tenderness measured on initial evaluation (R^2 = 0.58, P<.001), area of tenderness (R^2 = 0.36, P = .006), and age (R^2 = 0.27, P = .024) were significant predictors for RTP, while width of tenderness (R^2 = 0.006, P = .75) and location of injury were not (proximal/distal P = .62, medial/lateral P = .64).[82] Combining the individual's age with length of injury into a multiple regression analysis improved the prediction of RTP (R^2 = 0.73, P<.001).[82]

IV A systematic review by Fournier-Farley et al[32] identified lower levels of evidence for the following risk factors: (1) stretching-type injuries, (2) recreational-level sport participant, (3) structural injuries (macroscopic muscle fiber damage), (4) a greater than 20° to 25° deficit of AKE, (5) a greater than 1-week time to first treatment consultation, (6) higher maximal pain score on a 0-to-10 visual analog scale, and (7) greater than 1 day to walk pain free after HSI. When specifically looking at criteria for RTP decisions, a systematic review by van der Horst et al[97] found a wide variety of function-related criteria, none of which have been validated.

GAPS IN KNOWLEDGE

Despite some evidence, additional studies are needed to accurately predict the clinical course as well as identify factors that predict time to RTP and risk for reinjury. An important limitation in this area is lack of consistency, reliability, and validity in defining RTP.

EVIDENCE SYNTHESIS AND RATIONALE

The CPG teams found the best evidence of a risk factor for reinjury to be the history of HSI, with those having sustained a more recent injury being at higher risk. Therefore, RTP decisions should consider a previous HSI. Moderate evidence supports the absence of an appropriately progressed, comprehensive impairment-based functional exercise program as a risk factor for reinjury. Moderate evidence also identifies rehabilitation programs that do not specifically include eccentric training as a risk factor for reinjury and 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 reinjury. Allowing athletes to RTP before they are ready increases the risk of reinjury.

RECOMMENDATIONS

B Clinicians should use the history of an HSI when implementing RTP progression, as a previous HSI is a risk factor for a future reinjury.

B Clinicians should use caution in RTP decisions for individuals who did not complete an appropriately progressed, comprehensive impairment-based functional exercise program that specifically included eccentric training.

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 at initial evaluation to estimate time to RTP.

Diagnosis/Classification

OVERVIEW

Early and accurate clinical diagnosis of an HSI is important for providing appropriate treatment, deciding on RTP, and preventing reinjury. Because HSIs are typically diagnosed and graded based on physical findings, clinicians should recognize both the clinical features and signs and symptoms associated with the different injury grades of HSI. It should be noted that detailed classification systems using diagnostic imaging have been described but are outside the scope of this CPG.

II In 83 Australian rules football athletes with posterior thigh pain, Verrall et al[103] found the clinical features of an HSI (n = 68) to be 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.[103]

II In a prospective cohort of 180 male athletes, Schneider-Kolsky et al[83] found that clinical examination (r = 0.69, P<.001) and magnetic resonance imaging (MRI) (r = 0.58, P<.001) were associated with time to RTP in 58 Australian rules football athletes. Wangensteen et al[104,105] found that the addition of MRI to clinical examination alone explained only an additional 2.8% of the variance in time to RTP.

IV Zeren and Oztekin[111] defined the taking-off-the-shoe test for grade I and II biceps femoris injuries (n = 140) and found it to be 100% accurate compared to US diagnosis.

GAPS IN KNOWLEDGE

Although a clinical examination represents the gold standard for diagnosing an HSI, evidence to define the accuracy of this examination is limited. A clinical examination traditionally describes an HSI as grade I, II, or III, representing severity ranging 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.[1,86,110]

Grade I (Mild Strain)

1. Microtearing of a few muscle fibers
2. Local pain of smaller dimensions
3. Tightness and possible cramping in the posterior thigh
4. Slight pain with muscle stretching and/or activation
5. Stiffness that may subside during activity but returns following activity
6. Minimal strength loss
7. Less than a 15° deficit with the AKE test

Grade II (Moderate Strain)

1. Moderate tearing of muscle fibers, but the muscle is still intact
2. Local pain covering a larger area than in a grade I strain
3. Greater pain with muscle stretching and/or activation
4. Stiffness, weakness, and possible hemorrhaging and bruising
5. Limited ability to walk, especially for 24 to 48 hours after injury
6. A 16° to 25° deficit with the AKE test

Grade III (Severe Strain)

1. Complete tear of the muscle
2. Diffuse swelling and bleeding
3. A possible palpable mass of muscle tissue at the tear site
4. Extreme difficulty or inability to walk
5. A 26° to 35° deficit with the AKE test

The CPG team believes that clinicians practicing in a direct-access model should refer individuals with suspected grade III injuries to a physician.

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

EVIDENCE SYNTHESIS AND RATIONALE

Although evidence for the use of clinical examination to diagnose an HSI is limited, an individual with an acute injury typically presents with a sudden onset of well-localized posterior thigh pain, 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. Hamstring group stretching and/or activation may reproduce the pain. 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 an HSI, an insidious onset of vague posterior symptoms should raise concerns for referred pain from the lumbar spine. The benefits of properly diagnosing an HSI would allow for appropriate injury management, including RTP decisions and injury prevention measures. The harms of not appropriately recognizing the clinical features of an HSI could result in further injury or reinjury if the individual is not removed from athletic participation.

RECOMMENDATION

B Clinicians should make a diagnosis of HSI when an individual presents with a sudden onset of posterior thigh pain during activity, pain reproduced with hamstring stretching and/or activation, muscle tenderness with palpation, and loss of function.

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, differential diagnosis includes the following[52]:

- Lumbar radiculopathy

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

Imaging

Imaging is typically not needed in those diagnosed with a grade I or II HSI, based on clinical examination. This may be especially true in those with less severe injuries, as studies have found that they may not be identifiable on MRI.[24,83] Magnetic resonance imaging assessment is recommended in those with a suspected grade III HSI.[67] Detailed systems to classify HSIs based on MRI findings are available, such as the British Athletics Muscle Injury Classification,[71] the modified Peetrons classification,[23] and the anatomically based system described by Chan et al.[9] However, the role of MRI in helping to determine the clinical course, including RTP and risk of reinjuries, is unclear. Evidence suggests that the addition of MRI does not improve the prediction of RTP beyond clinical examination.[83,105] However, with suspicion of a nonmusculoskeletal 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 an HSI, the criteria for chronic hip pain note that MRI and US are "usually appropriate" in those with chronic symptoms and suspected extra-articular noninfectious soft tissue abnormalities (www.acr.org/). Therefore, MRI or US imaging can be useful in decision making in individuals with an atypical presentation of symptoms or who do not have satisfactory results with nonsurgical care. Radiographs are usually not required, unless the symptoms are proximal and radiographs may be useful to rule out avulsion fractures.

Examination

PHYSICAL IMPAIRMENT MEASURES

Overview

Activities that involve eccentric overloading of the hamstring muscles in a lengthened position are not only associated with HSI, but may also remain impaired after injury. Examples include high-speed running, jumping, kicking, and/or other explosive lower extremity movements. These activities are integral to sports such as track and field, soccer, Australian rules football, American football, and rugby. Therefore, a physical examination should include measures of hamstring-related impairments (strength and muscle length) and direct and self-reported assessments of sport-specific activities. An assessment of potential risk factors that may have contributed to injury also may be appropriate (**TABLES 4** though **10**).

Gaps in Knowledge

Individuals with an HSI present with knee flexor weakness, hamstring tightness, and muscle tenderness. However, the best method for assessing hamstring muscle strength (eg, isometric, eccentric, or isokinetic) and the clinical interpretation of strength deficits remain undetermined. Future studies also should examine the reliability of measures other than using an inclinometer to assess hamstring muscle length with the hip flexed to 90°. Mapping hamstring muscle tenderness is a valuable component of a clinical examination, but more evidence is needed to define its usefulness in HSI management. While abnormal trunk and pelvic posture and control during movements may be risk factors for an initial HSI,[38,49,64] further evidence is needed to support the usefulness of assessing these impairments over the course of treatment.

Evidence Synthesis and Rationale

There is strong evidence for strength and ROM measures after HSI. Current evidence suggests good reliability for measures of knee flexor weakness following HSI with isometric, isokinetic, and eccentric contractions, using a handheld dynamometer (HHD) or isokinetic dynamometer, as well as for hamstring muscle length (hip flexed to 90° and SLR methods) using an inclinometer. The degree of knee extension deficit measured with the hip flexed to 90° is potentially useful for grading the severity of injury. Weak evidence exists for mapping the location and area of muscle tenderness. Percentage length of tenderness and age are predictors of days to RTP; athletes with more proximal pain had a longer time to RTP. Proper assessment of knee flexor strength, hamstring flexibility, and muscle tenderness may be used in conjunction with a criterion-based functional activity progression. This approach allows injured athletes to effectively RTP in a time-sensitive manner, while minimizing the risk of reinjury. A harm of inadequate injury assessment is allowing the athlete to return to sport, which may put the athlete at risk for reinjury.

TABLE 4 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 knee flexion contraction against an HHD that is placed on the posterior aspect of the distal tibia. The highest force of 3 trials is recorded for each position. Pain level during the test can be recorded using a visual analog scale. 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 in prone, with the knee in 90° of flexion. The athlete gradually builds up force to a maximum generated knee flexor force, against an HHD, that creates a "make" force[107] • Midrange: strength is measured in prone, with the knee extended and the dorsum of the foot on the table. The therapist passively lifts the leg off the table to a height equal to the distance of the foot length. The individual pushes up against the HHD for 3 seconds. The examiner applies a "break" force once peak force is achieved[107] • Outer range: strength is measured with the individual supine, with the hip and knee in 90° of flexion. The individual pushes against the HHD for 3 seconds. The examiner applies a "break" force once peak force is achieved[107] • 15° of knee flexion: strength is measured with the individual positioned in prone, with the knee in 15° of flexion. The individual gradually builds up force to a maximum generated knee flexor force, against an HHD, that creates a "make" force[75]
Nature of variable	Continuous
Unit of measurement	Kilograms or Newtons
Measurement properties (reliability)	
Inner range	Intrarater[107] • $ICC_{3,1}$ = 0.87; 95% CI: 0.84, 0.89; SEM, 1.78 kg; MDC_{95}, 4.9 kg Interrater • $ICC_{1,1}$ = 0.71; 95% CI: 0.62, 0.82; SEM, 26 N[75] • $ICC_{2,1}$ = 0.69; 95% CI: 0.45, 0.83; SEM, 2.01 kg; MDC_{95}, 5.6 kg[107]
Midrange	Intrarater[107] • $ICC_{3,1}$ = 0.89; 95% CI: 0.87, 0.90; SEM, 2.02 kg; MDC_{95}, 5.6 kg Interrater[107] • $ICC_{2,1}$ = 0.83; 95% CI: 0.68, 0.90; SEM, 1.05 kg; MDC_{95}, 4.1 kg
Outer range	Intrarater[107] • $ICC_{3,1}$ = 0.90; 95% CI: 0.88, 0.92; SEM, 2.19 kg; MDC_{95}, 6.1 kg Interrater[107] • $ICC_{2,1}$ = 0.79; 95% CI: 0.62, 0.88; SEM, 2.17 kg; MDC_{95}, 6.0 kg
15° of knee flexion	Interrater[75] • $ICC_{1,1}$ = 0.83; 95% CI: 0.73, 0.90; SEM, 29 N
Measurement properties (validity)	Isometric strength deficits, when assessed less than 7 days post injury, were found in the injured limbs compared to the noninjured side (effect size, –1.72; 95% CI: –3.43, 0.00)[57] Deficits in knee flexor strength were noted between the previously injured limb and the contralateral noninjured limb for mean force with an isometric contraction (effect size at 0°/0°, *d* = –1.06; 90% CI: –1.93, –0.19 and at 45°/45°, *d* = –0.88; 90% CI: –1.74, –0.02)[43] Individuals with HSI generated significantly less isometric knee flexor force than those without HSI. Mean difference between groups: peak torque, –44.8 N; 95% CI: –86.3, –3 N; normalized, –22.2 Nm; 95% CI: –40.5, –3.7 Nm; normalized to body weight, –0.2; 95% CI: –0.4, 0.0[10]

Abbreviations: CI, confidence interval; HHD, handheld dynamometer; HSI, hamstring strain injury; ICC, intraclass correlation coefficient; ICF, International Classification of Functioning, Disability and Health; MDC, minimal detectable change; SEM, standard error of measurement.

Recommendations

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

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

C Clinicians may use the length of muscle tenderness and proximity to the ischial tuberosity to assist in predicting timing of RTP.

F Clinicians may assess for abnormal trunk and pelvic posture and control during functional movements.

TABLE 5 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 the H/Q ratio
Measurement properties (reliability)	Intratester (noninjured individuals)[54] • $ICC_{2,1}$ = 0.82 for eccentric contractions; SEM, 2.84 Nm; MDC, 7.87 Nm
Measurement properties (validity)	Individuals with an 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 sides, 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)[65] A between-limb eccentric knee flexor muscle strength imbalance of greater than 15% to 20% 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[7] At 60°/s, individuals 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 with a previous HSI[20] Concentric isokinetic testing at 60°/s showed a difference in injured versus noninjured knee flexor strength, with an area under the receiver operating characteristic curve of 0.773 (*P*<.05). No significant differences were noted at 120°/s[46] Isokinetic quadriceps-hamstring strength ratios (concentric and eccentric) were not predictive of HSI[19] At 60°/s, individuals with an HSI demonstrated a 9.6% deficit in peak torque and a 6.4% deficit in work, compared to the uninjured side, at the time of RTP[81] Injured individuals also generated significantly less peak torque and work than the contralateral side when tested at 240°/s. The H/Q ratio (eccentric, 30°/s and concentric, 240°/s) revealed that the injured limb had a lower ratio than the uninjured limb[81] Individuals with prior HSI demonstrated significantly lower eccentric strength (at 25° to 5° of knee flexion, 81.2 Nm/kg versus 75.2 Nm/kg; *P*<.025)[87] Greater peak quadriceps concentric torque, adjusted for body weight, at 300°/s (greater than 1 SD above the mean, 2.2-3.7 Nm/kg) was identified as a risk factor for injury (HR = 2.06; 95% CI: 1.21, 3.51)[99] A significant small effect for a lower conventional H/Q ratio was found in previously injured legs compared to the uninjured contralateral legs at 60°/s:60°/s (effect size, −0.32; 95% CI: −0.54, −0.11) and 240°/s:240°/s (effect size, −0.43; 95% CI: −0.83, 0.03), but not 180°/s:180°/s or 300°/s:300°/s[57]

Abbreviations: CI, confidence interval; H/Q, hamstring-quadriceps; HR, hazard ratio; HSI, hamstring strain injury; ICC, intraclass correlation coefficient; ICF, International Classification of Functioning, Disability and Health; MDC, minimal detectable change; RTP, return to play; SEM, standard error of measurement.

ACTIVITY LIMITATION AND PARTICIPATION RESTRICTION

II Hickey et al[45] 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.

II Røksund et al[79] established excellent reliability (intraclass correlation coefficient [ICC] = 0.978; 95% CI: 0.96, 0.98; standard error of measurement [SEM], 0.008 seconds; minimal detectable change $[MDC]_{95}$, 0.022 seconds) for the repeated sprint test in 75 semiprofessional and professional soccer players (19 ± 3 years of age). Athletes with a previous HSI showed a significant decrease in speed with repeated sprinting (0.07 seconds versus 0.02 seconds, *P* = .007).[79]

III Ishøi et al[47] found that 11 soccer players with a prior history of an HSI had a higher mean maximal sprinting velocity when compared to 33 controls (mean difference, 0.45 m/s; 95% CI: 0.06, 0.85 m/s).

Gaps in Knowledge

Information is needed to allow clinicians to select and interpret scores from measures of activity and participation in those with HSI. Because athletes make up the population that typically sustains an 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 Rationale

Limited evidence exists regarding the most appropriate activity and participation measures that should be used to docu-

TABLE 6 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, with the 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)	
Intertester (noninjured individuals)	Left and right sides pooled[62] • ICC_{95} = 0.87-0.92; MDC_{95}, 55.6 N Same day[22] • ICC = 0.60; 95% CI: 0.38, 0.75 (left leg) • ICC = 0.62; 95% CI: 0.41, 0.76 (right leg) 1 wk apart[22] • ICC = 0.67; 95% CI: 0.38, 0.84 (left leg) • ICC = 0.76; 95% CI: 0.53, 0.89 (right leg)

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; ICF, International Classification of Functioning, Disability and Health; MDC, minimal detectable change.

TABLE 7 Knee Flexor Muscle Strength: Single-Leg Bridge Test

ICF category	Measurement of impairment of body function, power of isolated muscles and muscle groups
Description	Resistive measure of concentric knee flexor strength
Measurement method	The individual lies down on the ground, with one heel on a box measuring 60 cm high. The test leg is positioned in 20° of flexion. The individual crosses the arms over the chest and pushes down through the heel to lift the buttocks off the ground, with as many repetitions as possible until failure
Nature of variable	Continuous
Unit of measurement	Number of repetitions fully completed
Measurement properties (validity)	In 482 athletes tested prospectively, 28 developed an HSI. Those with a right HSI had a significantly lower mean right single-leg bridge test score (*P* = .029)[33]

Abbreviations: HSI, hamstring strain injury; ICF, International Classification of Functioning, Disability and Health.

ment progress over the course of treatment. Because injuries often occur with high-speed running, combined with the fact that gait, running, and change in direction/cutting movements are typically impaired after an HSI, it would seem appropriate that objective measures of activity and participation should include these activities in sport-specific task analysis.

Recommendation

B Clinicians should 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.

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 has excellent test-retest reliability (ICC = 0.9), internal consistency (Cronbach's α = .98), and responsiveness (3.8 and 5.32 using baseline and pooled SDs). The FASH also has established face validity, content validity, and construct validity (eg, its ability to discriminate between acute HSI and noninjured hamstrings).[56]

II The hamstring outcome score (HaOS) is a 5-domain questionnaire that assesses an athlete's soreness, symptoms, pain, activities (sports), and quality of life. Questions on the HaOS are scored 0 to 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. Based on a study of 365 amateur soccer players, the scale is a predictor of new HSI in athletes with lower HaOS scores (*P*<.005).[28,96]

TABLE 8 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 muscle length
Measurement method	The individual lies supine, with the hip and knee flexed to 90°; the knee is then maximally extended, either passively or actively, with the ankle in an open pack position. A goniometer or inclinometer can be used to measure the knee extension deficit. Comparisons are made with the uninjured side
Nature of variable	Continuous
Unit of measurement	Degrees
Measurement properties (reliability)	
Inclinometer interrater (same day)	With knee passive ROM[76] • $ICC_{1,1}$ = 0.77; 95% CI: 0.63, 0.86; SEM, 7.6°; MDC, 21° With knee active ROM[76] • $ICC_{1,1}$ = 0.89; 95% CI: 0.81, 0.94; SEM, 5.3°; MDC, 15°
Measurement properties (validity)	AKE test: individuals with an HSI were categorized into grades based on the lack of full AKE compared to the uninjured side. Individuals 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[86] In those with a US-confirmed diagnosis of HSI, the AKE test found the injured limb to have a mean ± SD deficit of 12.8° ± 6.8° when compared to the uninjured side[86]
Modifications	Maximum hip flexion AKE assesses hamstring flexibility with the athlete positioned in maximum hip flexion Intrarater reliability[107] • $ICC_{3,1}$ = 0.83; 95% CI: 0.80, 0.86; SEM, 6.2°; MDC, 17.2° Interrater reliability[107] • $ICC_{2,1}$ = 0.96; 95% CI: 0.92, 0.98; SEM, 3.3°; MDC, 9.3°

Abbreviations: AKE, active knee extension; CI, confidence interval; HSI, hamstring strain injury; ICC, intraclass correlation coefficient; ICF, International Classification of Functioning, Disability and Health; MDC, minimal detectable change; ROM, range of motion; SEM, standard error of measurement; US, ultrasound.

TABLE 9 SLR for Assessing Hamstring Length

ICF category	Measurement of impairment of body function, mobility of a single joint
Description	Measures of knee flexor muscle length
Measurement method	The individual lies supine, with the hip and knee extended. The examiner passively flexes the hip to the individual's pain tolerance, while keeping the knee extended. A modification is to perform the maneuver and stop when the individual reports pain in the posterior thigh of 3/10 ("moderate") on a pain scale, with 0 as no pain and 10 as maximal pain
Nature of variable	Continuous
Unit of measurement	Degrees
Measurement properties (reliability)	
Inclinometer (to pain tolerance)	Intrarater[107] • $ICC_{3,1}$ = 0.88; 95% CI: 0.86, 0.90; SEM, 4.7°; MDC, 13.0° Interrater[107] • $ICC_{2,1}$ = 0.74; 95% CI: 0.52, 0.86; SEM, 6.54°; MDC, 18.1°
Inclinometer (stopping point of pain rated at 3/10)	Intrarater[4] • $ICC_{3,1}$ = 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 the individual's tolerance. The individual then performs 3 SLRs as fast and as high as possible to the point of not sustaining reinjury. The examiner records the highest value of the 3 trials[5] • $ICC_{1,1}$ = 0.96; 95% CI: 0.84, 0.99

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; ICF, International Classification of Functioning, Disability and Health; MDC, minimal detectable change; RTP, return to play; SEM, standard error of measurement; SLR, straight leg raise.

TABLE 10 Muscle Tenderness

ICF category	Measurement of impairment of body structure
Description	Assess the location of peak tenderness and the region of tenderness of the knee flexor muscles after an HSI The individual lies prone on a treatment table, with the knee fully extended
Measurement method	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[82]
Nature of variable	Continuous
Unit of measurement	Centimeters or inches
Measurement properties (validity)	Percentage length of tenderness and age were the best predictors of days to RTP following HSI (R^2 = 0.73, P<.001), with the following predictive equation: [number of days before return to sport = (% length of tenderness × 2.1) + (age × 1.5) − 43.4][82] Athletes who report more proximal pain have a longer time to RTP[6]

Abbreviations: HSI, hamstring strain injury; ICF, International Classification of Functioning, Disability and Health; RTP, return to play.

Evidence Synthesis and Rationale

The FASH and HaOS are the only evidence-based instruments designed to assess athletes with an HSI. While other potential instruments (eg, the Copenhagen Hip and Groin Outcome Score) are available, no evidence exists for their use in those with an HSI. Although the FASH has established reliability and validity, future works should determine the MDC and minimal clinically important difference for improved score interpretation and responsiveness. The HaOS has established construct validity for predicting HSI in athletes but does not have established reliability and is used primarily before athletic sport participation begins to identify athletes who may be susceptible to an HSI.

Recommendation

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

INJURY PREVENTION

Prevention of 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 the ground. Prevention of a first-time HSI is 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.[18]

I An umbrella review by Raya-Gonzalez et al[74] identified 8 systematic reviews and concluded that exercise prevention programs that included the NHE were effective in reducing the incidence of HSI. This included a systematic review and meta-analysis by van Dyk et al,[101] who noted that the NHE reduced HSI by 51% (RR = 0.49; 95% CI: 0.32, 0.74) in 15 studies with 8459 athletes. Also included was a systematic review by Goode et al[37] that found that the effectiveness of the NHE may be dependent on exercise compliance. A systematic review not in the umbrella review also concluded that the NHE may be effective in reducing the incidence of HSI.[80]

I When specifically looking at female soccer players, a systematic review by Crossley et al[16] found, in 5 studies, that exercise-based (single-component and multicomponent) strategies significantly reduced the incidence of HSIs (incidence rate ratio = 0.40; 95% CI: 0.17, 0.95). They concluded that although the evidence was not as robust in female soccer players, exercise-based strategies can reduce HSI by 40% to 60%, similar to the rate found in their male counterparts.[16]

II An RCT with 259 male high school soccer players found the time lost to injury to be lower in the NHE group (113.7/10000 hours) compared to the control group (1116.3/10000 hours) (P<.001).[40]

III Within the umbrella review by Raya-Gonzalez et al,[74] the systematic review by Rogan et al[78] reported inconclusive evidence in low-level studies to support the role of hamstring stretching. Hibbert et al[42] noted weak evidence for eccentric hamstring exercises other than the NHE in HSI prevention. Not included in the Raya-Gonzalez et al[74] review, a systematic review by McCall et al[59] also found weak evidence in 3 studies to support eccentric hamstring exercises other than the NHE. While evidence supports the NHE in HSI prevention, Elerian et al[26] did not find a significant difference in HSI rates between seasons when

34 soccer players performed the NHE and a season when they did not perform the NHE.

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.[88] Results from a case series further supported the use of isokinetic strengthening exercises for reducing HSI rate.[41]

Gaps in Knowledge

Further research is needed to specifically define the most effective prevention programs with warm-up, stretching, balance, strengthening, and functional movements, as well as potentially other eccentric hamstring exercises, that should be added to the NHE. 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 2 sets of 3 repetitions once per week to 3 sets of 10 repetitions twice a week and a gradual progression to 4 sessions per week. These exercises are generally performed after training and on days before a rest day to allow for adequate recovery.[36]

Evidence Synthesis and Rationale

Evidence supports injury prevention exercise programs that include the NHE and other components of warm-up, stretching, stability training, strengthening, and functional movements (sport specific, agility, and high-speed running). The International Federation of Association Football (Fédération Internationale de Football Association [FIFA]) 11+, HarmoKnee, and "New Warm-up Program" are examples of specific injury prevention programs.[80] The FIFA 11+ and HarmoKnee programs include the NHE, as well as components of warm-up, stretching, stability training, strengthening, and functional movements (sport specific, agility, and high-speed running).

Recommendation

A Clinicians should include the NHE as part of an HSI prevention program, along 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 reinjury rates were included in the review process. While clinicians measure intervention effectiveness in many ways (eg, strength, ROM, and pain levels), the ultimate success of the rehabilitation process is determined by the athlete's ability to RTP while preventing reinjury.

I A high-quality RCT found that individuals returning to play following a standardized progressive rehabilitation protocol, comprising hamstring-strengthening exercises and running performed within either pain-free (n = 21) or pain-threshold limits (n = 22), reported 2 reinjuries per group, with no difference in RTP time. The median time from HSI 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).[44]

II A systematic review and meta-analysis by Pas et al[70] identified 2 RCTs with fair evidence to support a program that added eccentric strengthening exercises to a conventional program of stretching, strengthening, and stabilization after an HSI. Participating in these programs resulted in a significantly reduced time to RTP (HR = 3.22; 95% CI: 2.17, 4.77) but had no effect on reinjury rate (RR = 0.25; 95% CI: 0.03, 2.20).

II A systematic review of 5 studies found that progressive agility and trunk stabilization, added to a rehabilitation program focusing on stretching and strengthening, did not improve RTP time but may decrease reinjury rate.[21] Included within this systematic review, Sherry and Best[85] specifically found a significant reduction in reinjury rates in favor of progressive agility and trunk stabilization exercises, as they found no reinjuries in 13 participants within 16 days after RTP and 1 reinjury within 1 year, versus 6 reinjuries in 11 athletes and 7 reinjuries in 10 athletes, respectively, in the static stretching, isolated progressive hamstring resistance exercise, and icing group (P<.001).

II Systematic reviews found insufficient evidence to support the use of stretching as an isolated treatment in the management of HSI.[21,58,70,73,77]

II An RCT (n = 48 male semiprofessional soccer players) found that an individualized criterion-based treatment program consisting of comprehensive impairment-based treatments reduced the risk of reinjury compared to a standard NHE program (RR = 6; 90% CI: 1, 35). However, there was no difference in RTP time (25.5 days versus 23.2 days, –13.8%; 90% CI: –34%, 3.4%).[60]

II A systematic review by Hickey et al[45] identified 9 studies (n = 601) that examined individuals diagnosed with an acute HSI and concluded that specific criteria for progression of rehabilitation were not well defined.

III In a case-control study that compared professional male soccer players (mean age, 24.3 years) over 2 seasons, reinjury rate was reduced from 7 of 35 to 1 of 34 in the season that the NHE was instituted.[26]

IV A study found that 50 of 54 athletes (mean age, 36 years; 30 male, 20 female) who were compliant with a rehabilitation program that emphasized eccentric hamstring strengthening in a lengthened position reported no reinjuries.[94]

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 were successful in allowing athletes to return to sport after HSI at an average of 11.9 days (range, 5-23 days), with 3 reinjuries.[51]

V It is the opinion of the CPG team that clinicians should incorporate neural tissue mobilization after injury to reduce adhesions to surrounding tissue and therapeutic modalities to control pain and swelling early in the healing process.

Gaps in Knowledge

While evidence supports exercise in the treatment of HSI, future works should examine the benefits of other commonly used treatments, such as soft tissue mobilization, nerve glides, and therapeutic modalities. These commonly used treatments may assist in the healing process and shorten the period of disability after an HSI. Research is needed to determine the efficacy of these treatments in reducing time to RTP and decreasing reinjury rates.

Evidence Synthesis and Rationale

Evidence supports initiating hamstring-strengthening exercises, including eccentrics, early in the rehabilitation process, guided by patient pain tolerance. Successful interventions included 6 to 12 repetitions, depending on the intensity of the exercise, with both load and ROM increased as tolerated. Patients should perform the exercises 2 to 3 times per week. The evidence behind eccentric hamstring exercises includes, but is not limited to, the NHE. Evidence also supports progressive agility and trunk stabilization exercises and a running program involving acceleration and deceleration phases, with a progressive increase in speed and distance, throughout the rehabilitation process as tolerated. The benefits of eccentric training, added to stretching, strengthening, stabilization, and progressive running programs, are improved RTP times and reduced reinjury rates. Although the harms of initiating and progressing exercise and running are poorly described, there is 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 uses a logical systematic method to begin, monitor, and progress tissue loading.

Recommendations

B Clinicians should use eccentric training to patient tolerance, added to stretching, strengthening, stabilization, and progressive running programs, to improve RTP time after an individual sustains an 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 reinjury rate after an individual sustains an HSI.

F Clinicians may perform neural tissue mobilization after injury to reduce adhesions to surrounding tissue and use therapeutic modalities to control pain and swelling early in the healing process.

Decision Tree

MEDICAL SCREENING (CLASSIFY CONDITION AND ASSESS REINJURY RISK)

Patient Examination

- Sudden onset of posterior thigh pain – B
- Reproduction of pain with hamstring stretching and activation – B
- Muscle tenderness with palpation – B
- Loss of function – B
- Use the following criteria to grade muscle injury – F
  - Grade I (mild strain): (1) microtearing of a few muscle fibers, (2) local pain of smaller dimensions, (3) tightness and possible cramping in the posterior thigh, (4) slight pain with muscle stretching and/or activation, (5) stiffness that may subside during activity but returns following activity, (6) minimal strength loss, and (7) less than a 15° deficit with the AKE test
  - Grade II (moderate strain): (1) moderate tearing of muscle fibers, but the muscle is still intact, (2) local pain covering a larger area than in grade I, (3) greater pain with muscle stretch and/or activation, (4) stiffness, weakness, and possible hemorrhaging and bruising, (5) limited ability to walk, especially for 24 to 48 hours after injury, and (6) a 16° to 25° deficit with the AKE test
  - Grade III (severe strain): (1) complete tear of the muscle, (2) diffuse swelling and bleeding, (3) possible palpable mass of muscle tissue at the tear site, (4) extreme difficulty or inability to walk, and (5) a 26° to 35° deficit with the AKE test
- Previous HSI – B
- Grade III HSIs are referred to a physician – F

OUTCOME MEASURES TO DOCUMENT PROGRESS

- Knee flexor strength using either an HHD or isokinetic dynamometer – A
- Hamstring length and measuring knee extension deficit with the hip flexed to 90° using an inclinometer – A
- Measure the length of muscle tenderness to palpation and the location relative to the ischial tuberosity
- Clinicians may assess for abnormal trunk and pelvic posture and control during functional movements – F
- Objective measures to quantify and grade an individual's ability to walk, run, and sprint – B
- FASH – B

MEASURES TO ESTIMATE TIME TO RTP

- Knee flexor strength using either an 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 at initial evaluation – B

INTERVENTION STRATEGIES

- Eccentric training to patient tolerance, added to an impairment-based treatment program with stretching, strengthening, stabilization, agility, and progressive running – B
- Nerve mobilization – F
- Therapeutic modalities for symptom management – F

INJURY PREVENTION

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

AFFILIATIONS AND CONTACTS

AUTHORS

RobRoy L. Martin, PT, PhD
Editor
ICF-Based Clinical Practice Guidelines
AOPT, APTA, Inc
La Crosse, WI
and
Professor
Department of Physical Therapy
Rangos School of Health Science
Duquesne University
and
Staff Physical Therapist
UPMC Center for Sports Medicine
Pittsburgh, PA
martinr280@duq.edu

Michael T. Cibulka, PT, DPT, OCS
Catherine Worthingham Fellow, APTA
and
Associate Professor, Physical Therapy
Myrtle E. and Earl E. Walker College of Health Professions
Maryville University
St Louis, MO
mcibulka@maryville.edu

Lori A. Bolgla, PT, PhD
Professor and Kellett Chair in Allied Health Sciences
Department of Physical Therapy in the College of Allied Health Sciences
Department of Orthopaedic Surgery at the Medical College of Georgia
The Graduate School
Augusta University
Augusta, GA
LBOLGLA@augusta.edu

Thomas A. Koc, Jr., PT, DPT
Assistant Professor
School of Physical Therapy
Kean University
Union, NJ
tkoc@kean.edu

Janice K. Loudon, PT, PhD
Professor
Saint Luke's College of Nursing and Health Sciences
Rockhurst University
Kansas City, MO
janice.loudon@rockhurst.edu

Robert C. Manske, PT, DPT
Professor
Department of Physical Therapy
Wichita State University
Wichita, KS
Robert.Manske@wichita.edu

Leigh Weiss, PT, DPT, ATC, OCS, SCS
Director of Rehabilitation/Physical Therapist
New York Football Giants
East Rutherford, NJ
Leigh.Weiss@Giants.NFL.net

John J. Christoforetti, MD, FAAOS
Sports Medicine and Arthroscopic Surgery
Texas Health Sports Medicine
Allen, TX
johnchristoforetti@texashealth.org

Bryan C. Heiderscheit, PT, PhD, FAPTA
Fredrick Gaenslen Professor
Vice-Chair of Research, Department of Orthopedics and Rehabilitation
University of Wisconsin-Madison
Madison, WI
Heiderscheit@ortho.wisc.edu

REVIEWERS

Mike Voight, PT, DHSc, OCS, SCS, ATC, FAPTA
Professor
Belmont University School of Physical Therapy
Nashville, TN
and
Editor-in-Chief
International Journal of Sports Physical Therapy
Mike.voight@belmont.edu

John DeWitt, PT, DPT, AT
Associate Director, Education and Professional Development
Wexner Medical Center, Jameson Crane Sports Medicine Institute
and
Assistant Clinical Professor
School of Health and Rehabilitation Sciences, Physical Therapy Division
The Ohio State University
Columbus, OH
John.dewitt@osumc.edu

Brian Young, PT, DSc
Clinical Associate Professor
Assistant Program Director, Doctor of Physical Therapy Program
Graduate Program Director, Physical Therapy Department
Baylor University
Waco, TX
Brian_A_Young@baylor.edu

Liran Lifshitz, PT, MSc
Lecturer and Sport Clinic Manager
Physio & More
Tel Aviv, Israel
and
Chairman of the Sports Interest Group of the Israeli Physiotherapy Society
ptliran@gmail.com

Douglas White, PT, DPT, OCS, RMSK
Milton Orthopaedic & Sports Physical Therapy, PC
Milton, MA
Dr.white@miltonortho.com

David Killoran, PhD
Professor Emeritus
Loyola Marymount University
Los Angeles, CA
David.Killoran@lmu.edu

Sandra Kaplan, PT, DPT, PhD, FAPTA
Professor
Department of Rehabilitation and Movement Services
and
Vice-Chair, Curriculum and Accreditation
Stuart D. Cook, M.D. Master Educators' Guild
Rutgers, The State University of New Jersey
New Brunswick, NJ
kaplansa@shp.rutgers.edu

Steve Paulseth, PT, DPT, SCS, ATC
Clinical Specialist
Paulseth & Associates Physical Therapy, Inc
Los Angeles, CA
Paulsethpt@yahoo.com

James A. Dauber, DPT, DSc
Associate Professor
School of Physical Therapy
Marshall University
Huntington, WV
dauber@marshall.edu

GUIDELINES EDITORS

Christine M. McDonough, PT, PhD, CEEAA
Editor
ICF-Based Clinical Practice Guidelines
AOPT, APTA, Inc
La Crosse, WI
and
Assistant Professor of Physical Therapy
School of Health and Rehabilitation Sciences
University of Pittsburgh
Pittsburgh, PA
cmm295@pitt.edu

Christopher Carcia, PT, PhD
Physical Therapy Program Director and Associate Professor
Department of Kinesiology
Colorado Mesa University
Grand Junction, CO
ccarcia@coloaradomesa.edu

Guy Simoneau, PT, PhD, FAPTA
Editor
ICF-Based Clinical Practice Guidelines
AOPT, APTA, Inc
La Crosse, WI
and
Professor
Physical Therapy
Marquette University
Marquette, WI
guy.simoneau@marquette.edu

ACKNOWLEDGMENTS: *We thank the medical librarians at Augusta University for their assistance in researching the articles included in these guidelines.*

REFERENCES

1. Agre JC. Hamstring injuries. Proposed aetiological factors, prevention, and treatment. *Sports Med*. 1985;2:21-33. https://doi.org/10.2165/00007256-198502010-00003
2. Ahmad CS, Redler LH, Ciccotti MG, Maffulli N, Longo UG, Bradley J. Evaluation and management of hamstring injuries. *Am J Sports Med*. 2013;41:2933-2947. https://doi.org/10.1177/0363546513487063
3. Arner JW, McClincy MP, Bradley JP. Hamstring injuries in athletes: evidence-based treatment. *J Am Acad Orthop Surg*. 2019;27:868-877. https://doi.org/10.5435/JAAOS-D-18-00741
4. Askling C, Saartok T, Thorstensson A. Type of acute hamstring strain affects flexibility, strength, and time to return to pre-injury level. *Br J Sports Med*. 2006;40:40-44. https://doi.org/10.1136/bjsm.2005.018879
5. Askling CM, Nilsson J, Thorstensson A. A new hamstring test to complement the common clinical examination before return to sport after injury. *Knee Surg Sports Traumatol Arthrosc*. 2010;18:1798-1803. https://doi.org/10.1007/s00167-010-1265-3
6. Askling CM, Tengvar M, Saartok T, Thorstensson A. Acute first-time hamstring strains during high-speed running: a longitudinal study including clinical and magnetic resonance imaging findings. *Am J Sports Med*. 2007;35:197-206. https://doi.org/10.1177/0363546506294679
7. Bourne MN, Opar DA, Williams MD, Shield AJ. Eccentric knee flexor strength and risk of hamstring injuries in rugby union: a prospective study. *Am J Sports Med*. 2015;43:2663-2670. https://doi.org/10.1177/0363546515599633
8. Brooks JH, Fuller CW, Kemp SP, Reddin DB. Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. *Am J Sports Med*. 2006;34:1297-1306. https://doi.org/10.1177/0363546505286022
9. Chan O, Del Buono A, Best TM, Maffulli N. Acute muscle strain injuries: a proposed new classification system. *Knee Surg Sports Traumatol Arthrosc*. 2012;20:2356-2362. https://doi.org/10.1007/s00167-012-2118-z
10. Charlton PC, Raysmith B, Wollin M, et al. Knee flexion not hip extension strength is persistently reduced following hamstring strain injury in Australian Football athletes: implications for Periodic Health Examinations. *J Sci Med Sport*. 2018;21:999-1003. https://doi.org/10.1016/j.jsams.2018.03.014
11. Chumanov ES, Schache AG, Heiderscheit BC, Thelen DG. Hamstrings are most susceptible to injury during the late swing phase of sprinting. *Br J Sports Med*. 2012;46:90. https://doi.org/10.1136/bjsports-2011-090176
12. Cloke D, Moore O, Shah T, Rushton S, Shirley MD, Deehan DJ. Thigh muscle injuries in youth soccer: predictors of recovery. *Am J Sports Med*. 2012;40:433-439. https://doi.org/10.1177/0363546511428800
13. Comin J, Malliaras P, Baquie P, Barbour T, Connell D. Return to competitive play after hamstring injuries involving disruption of the central tendon. *Am J Sports Med*. 2013;41:111-115. https://doi.org/10.1177/0363546512463679
14. Connell DA, Schneider-Kolsky ME, Hoving JL, et al. Longitudinal study comparing sonographic and MRI assessments of acute and healing hamstring injuries. *AJR Am J Roentgenol*. 2004;183:975-984. https://doi.org/10.2214/ajr.183.4.1830975
15. Cross KM, Saliba SA, Conaway M, Gurka KK, Hertel J. Days to return to participation after a hamstrings strain among American collegiate soccer players. *J Athl Train*. 2015;50:733-741. https://doi.org/10.4085/1052-6050-50.2.12
16. Crossley KM, Patterson BE, Culvenor AG, Bruder AM, Mosler AB, Mentiplay BF. Making football safer for women: a systematic review and meta-analysis of injury prevention programmes in 11 773 female football (soccer) players. *Br J Sports Med*. 2020;54:1089-1098. https://doi.org/10.1136/bjsports-2019-101587
17. Dalton SL, Kerr ZY, Dompier TP. Epidemiology of hamstring strains in 25 NCAA sports in the 2009-2010 to 2013-2014 academic years. *Am J Sports Med*. 2015;43:2671-2679. https://doi.org/10.1177/0363546515599631
18. Danielsson A, Horvath A, Senorski C, et al. The mechanism of hamstring injuries – a systematic review. *BMC Musculoskelet Disord*. 2020;21:641. https://doi.org/10.1186/s12891-020-03658-8
19. Dauty M, Menu P, Fouasson-Chailloux A. Cutoffs of isokinetic strength ratio and hamstring strain prediction in professional soccer players. *Scand J Med Sci Sports*. 2018;28:276-281. https://doi.org/10.1111/sms.12890
20. Dauty M, Potiron-Josse M, Rochcongar P. Identification of previous hamstring muscle injury by isokinetic concentric and eccentric torque measurement in elite soccer player. *Isokinet Exerc Sci*. 2003;11:139-144. https://doi.org/10.3233/IES-2003-0140
21. de Visser HM, Reijman M, Heijboer MP, Bos PK. Risk factors of recurrent hamstring injuries: a systematic review. *Br J Sports Med*. 2012;46:124-130. https://doi.org/10.1136/bjsports-2011-090317
22. dos Santos Oliveira G, de Araujo Ribeiro-Alvares JB, de Lima-e-Silva FX, Rodrigues R, Vaz MA, Baroni BM. Reliability of a clinical test for measuring eccentric knee flexor strength using a handheld dynamometer. *J Sport Rehabil*. 2022;31:115-119. https://doi.org/10.1123/jsr.2020-0014
23. Ekstrand J, Healy JC, Waldén M, Lee JC, English B, Hägglund M. Hamstring muscle injuries in professional football: the correlation of MRI findings with return to play. *Br J Sports Med*. 2012;46:112-117. https://doi.org/10.1136/bjsports-2011-090155
24. Ekstrand J, Lee JC, Healy JC. MRI findings and return to play in football: a prospective analysis of 255 hamstring injuries in the UEFA Elite Club injury study. *Br J Sports Med*. 2016;50:738-743. https://doi.org/10.1136/bjsports-2016-095974
25. Ekstrand J, Waldén M, Hägglund M. Hamstring injuries have increased by 4% annually in men's professional football, since 2001: a 13-year longitudinal analysis of the UEFA Elite Club injury study. *Br J Sports Med*. 2016;50:731-737. https://doi.org/10.1136/bjsports-2015-095359
26. Elerian AE, El-Sayyad MM, Dorgham HAA. Effect of pre-training and post-training Nordic exercise on hamstring injury prevention, recurrence, and severity in soccer players. *Ann Rehabil Med*. 2019;43:465-473. https://doi.org/10.5535/arm.2019.43.4.465
27. Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Intrinsic risk factors for hamstring injuries among male soccer players: a prospective cohort study. *Am J Sports Med*. 2010;38:1147-1153. https://doi.org/10.1177/0363546509358381
28. Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Prevention of injuries among male soccer players: a prospective, randomized intervention study targeting players with previous injuries or reduced function. *Am J Sports Med*. 2008;36:1052-1060. https://doi.org/10.1177/0363546508314432
29. Ernlund L, de Almeida Vieira L. Hamstring injuries: update article. *Rev Bras Ortop*. 2017;52:373-382. https://doi.org/10.1016/j.rboe.2017.05.005
30. Evangelidis PE, Massey GJ, Ferguson RA, Wheeler PC, Pain MTG, Folland JP. The functional significance of hamstrings composition: is it really a "fast" muscle group? *Scand J Med Sci Sports*. 2017;27:1181-1189. https://doi.org/10.1111/sms.12786
31. Foreman T, Addy T, Baker S, Burns J, Hill N, Madden T. Prospective studies into the causation of hamstring injuries in sport: a systematic review. *Phys Ther Sport*. 2006;7:101-109. https://doi.org/10.1016/j.ptsp.2006.02.001
32. Fournier-Farley C, Lamontagne M, Gendron P, Gagnon DH. Determinants of return to play after the nonoperative management of hamstring injuries in athletes: a systematic review. *Am J Sports Med*. 2016;44:2166-2172. https://doi.org/10.1177/0363546515617472
33. Freckleton G, Cook J, Pizzari T. The predictive validity of a single leg bridge

test for hamstring injuries in Australian Rules Football players. *Br J Sports Med*. 2014;48:713-717. https://doi.org/10.1136/bjsports-2013-092356

34. Freckleton G, Pizzari T. Risk factors for hamstring muscle strain injury in sport: a systematic review and meta-analysis. *Br J Sports Med*. 2013;47:351-358. https://doi.org/10.1136/bjsports-2011-090664

35. Gabbe BJ, Bennell KL, Finch CF, Wajswelner H, Orchard JW. Predictors of hamstring injury at the elite level of Australian football. *Scand J Med Sci Sports*. 2006;16:7-13. https://doi.org/10.1111/j.1600-0838.2005.00441.x

36. Gentilcore DR. The minimal effective dose of Nordic hamstring exercise for reducing hamstring strain injuries in football (soccer). *J Aust Strength Cond*. 2018;26:8.

37. Goode AP, Reiman MP, Harris L, et al. Eccentric training for prevention of hamstring injuries may depend on intervention compliance: a systematic review and meta-analysis. *Br J Sports Med*. 2015;49:349-356. https://doi.org/10.1136/bjsports-2014-093466

38. Green B, Bourne MN, van Dyk N, Pizzari T. Recalibrating the risk of hamstring strain injury (HSI): a 2020 systematic review and meta-analysis of risk factors for index and recurrent hamstring strain injury in sport. *Br J Sports Med*. 2020;54:1081-1088. https://doi.org/10.1136/bjsports-2019-100983

39. Hamilton B. Hamstring muscle strain injuries: what can we learn from history? *Br J Sports Med*. 2012;46:900-903. https://doi.org/10.1136/bjsports-2012-090931

40. Hasebe Y, Akasaka K, Otsudo T, Tachibana Y, Hall T, Yamamoto M. Effects of Nordic hamstring exercise on hamstring injuries in high school soccer players: a randomized controlled trial. *Int J Sports Med*. 2020;41:154-160. https://doi.org/10.1055/a-1034-7854

41. Heiser TM, Weber J, Sullivan G, Clare P, Jacobs RR. Prophylaxis and management of hamstring muscle injuries in intercollegiate football players. *Am J Sports Med*. 1984;12:368-370. https://doi.org/10.1177/036354658401200506

42. Hibbert O, Cheong K, Grant A, Beers A, Moizumi T. A systematic review of the effectiveness of eccentric strength training in the prevention of hamstring muscle strains in otherwise healthy individuals. *N Am J Sports Phys Ther*. 2008;3:67-81.

43. Hickey JT, Hickey PF, Maniar N, et al. A novel apparatus to measure knee flexor strength during various hamstring exercises: a reliability and retrospective injury study. *J Orthop Sports Phys Ther*. 2018;48:72-80. https://doi.org/10.2519/jospt.2018.7634

44. Hickey JT, Timmins RG, Maniar N, et al. Pain-free versus pain-threshold rehabilitation following acute hamstring strain injury: a randomized controlled trial. *J Orthop Sports Phys Ther*. 2020;50:91-103. https://doi.org/10.2519/jospt.2020.8895

45. Hickey JT, Timmins RG, Maniar N, Williams MD, Opar DA. Criteria for progressing rehabilitation and determining return-to-play clearance following hamstring strain injury: a systematic review. *Sports Med*. 2017;47:1375-1387. https://doi.org/10.1007/s40279-016-0667-x

46. Houweling TAW, Head A, Hamzeh MA. Validity of isokinetic testing for previous hamstring injury detection in soccer players. *Isokinet Exerc Sci*. 2009;17:213-220. https://doi.org/10.3233/IES-2009-0356

47. Ishøi L, Thorborg K, Hölmich P, Krommes K. Sprint performance in football (soccer) players with and without a previous hamstring strain injury: an explorative cross-sectional study. *Int J Sports Phys Ther*. 2020;15:947-957.

48. Jacobsen P, Witvrouw E, Muxart P, Tol JL, Whiteley R. A combination of initial and follow-up physiotherapist examination predicts physician-determined time to return to play after hamstring injury, with no added value of MRI. *Br J Sports Med*. 2016;50:431-439. https://doi.org/10.1136/bjsports-2015-095073

49. Järvinen TA, Järvinen M, Kalimo H. Regeneration of injured skeletal muscle after the injury. *Muscles Ligaments Tendons J*. 2013;3:337-345.

50. Kerkhoffs GM, van Es N, Wieldraaijer T, Sierevelt IN, Ekstrand J, van Dijk CN. Diagnosis and prognosis of acute hamstring injuries in athletes. *Knee Surg Sports Traumatol Arthrosc*. 2013;21:500-509. https://doi.org/10.1007/s00167-012-2055-x

51. Kilcoyne KG, Dickens JF, Keblish D, Rue JP, Chronister R. Outcome of grade I and II hamstring injuries in intercollegiate athletes: a novel rehabilitation protocol. *Sports Health*. 2011;3:528-533. https://doi.org/10.1177/1941738111422044

52. Kornberg C, Lew P. The effect of stretching neural structures on grade one hamstring injuries. *J Orthop Sports Phys Ther*. 1989;10:481-487. https://doi.org/10.2519/jospt.1989.10.12.481

53. Laumonier T, Menetrey J. Muscle injuries and strategies for improving their repair. *J Exp Orthop*. 2016;3:15. https://doi.org/10.1186/s40634-016-0051-7

54. Lee JWY, Li C, Yung PSH, Chan KM. The reliability and validity of a video-based method for assessing hamstring strength in football players. *J Exerc Sci Fit*. 2017;15:18-21. https://doi.org/10.1016/j.jesf.2017.04.001

55. Lee JWY, Mok KM, Chan HCK, Yung PSH, Chan KM. Eccentric hamstring strength deficit and poor hamstring-to-quadriceps ratio are risk factors for hamstring strain injury in football: a prospective study of 146 professional players. *J Sci Med Sport*. 2018;21:789-793. https://doi.org/10.1016/j.jsams.2017.11.017

56. Malliaropoulos N, Korakakis V, Christodoulou D, et al. Development and validation of a questionnaire (FASH—Functional Assessment Scale for Acute Hamstring Injuries): to measure the severity and impact of symptoms on function and sports ability in patients with acute hamstring injuries. *Br J Sports Med*. 2014;48:1607-1612. https://doi.org/10.1136/bjsports-2014-094021

57. Maniar N, Shield AJ, Williams MD, Timmins RG, Opar DA. Hamstring strength and flexibility after hamstring strain injury: a systematic review and meta-analysis. *Br J Sports Med*. 2016;50:909-920. https://doi.org/10.1136/bjsports-2015-095311

58. Mason D, Dickens V, Vail A. Rehabilitation for hamstring injuries. *Scand J Med Sci Sports*. 2007;17:191-192. https://doi.org/10.1111/j.1600-0838.2007.00650_2.x

59. McCall A, Carling C, Davison M, et al. Injury risk factors, screening tests and preventative strategies: a systematic review of the evidence that underpins the perceptions and practices of 44 football (soccer) teams from various premier leagues. *Br J Sports Med*. 2015;49:583-589. https://doi.org/10.1136/bjsports-2014-094104

60. Mendiguchia J, Martinez-Ruiz E, Edouard P, et al. A multifactorial, criteria-based progressive algorithm for hamstring injury treatment. *Med Sci Sports Exerc*. 2017;49:1482-1492. https://doi.org/10.1249/MSS.0000000000001241

61. Murach KA, Fry CS, Dupont-Versteegden EE, McCarthy JJ, Peterson CA. Fusion and beyond: satellite cell contributions to loading-induced skeletal muscle adaptation. *FASEB J*. 2021;35:e21893. https://doi.org/10.1096/fj.202101096R

62. Opar DA, Piatkowski T, Williams MD, Shield AJ. A novel device using the Nordic hamstring exercise to assess eccentric knee flexor strength: a reliability and retrospective injury study. *J Orthop Sports Phys Ther*. 2013;43:636-640. https://doi.org/10.2519/jospt.2013.4837

63. Opar DA, Timmins RG, Behan FP, et al. Is pre-season eccentric strength testing during the Nordic hamstring exercise associated with future hamstring strain injury? A systematic review and meta-analysis. *Sports Med*. 2021;51:1935-1945. https://doi.org/10.1007/s40279-021-01474-1

64. Opar DA, Williams MD, Shield AJ. Hamstring strain injuries: factors that lead to injury and re-injury. *Sports Med*. 2012;42:209-226. https://doi.

org/10.2165/11594800-000000000-00000

65. Opar DA, Williams MD, Timmins RG, Dear NM, Shield AJ. Knee flexor strength and bicep femoris electromyographical activity is lower in previously strained hamstrings. *J Electromyogr Kinesiol*. 2013;23:696-703. https://doi.org/10.1016/j.jelekin.2012.11.004

66. Opar DA, Williams MD, Timmins RG, Hickey J, Duhig SJ, Shield AJ. Eccentric hamstring strength and hamstring injury risk in Australian footballers. *Med Sci Sports Exerc*. 2015;47:857-865. https://doi.org/10.1249/MSS.0000000000000465

67. Orchard J, Best TM, Verrall GM. Return to play following muscle strains. *Clin J Sport Med*. 2005;15:436-441. https://doi.org/10.1097/01.jsm.0000188206.54984.65

68. Orchard JW. Intrinsic and extrinsic risk factors for muscle strains in Australian football. *Am J Sports Med*. 2001;29:300-303. https://doi.org/10.1177/03635465010290030801

69. Orchard JW, Chaker Jomaa M, Orchard JJ, et al. Fifteen-week window for recurrent muscle strains in football: a prospective cohort of 3600 muscle strains over 23 years in professional Australian rules football. *Br J Sports Med*. 2020;54:1103-1107. https://doi.org/10.1136/bjsports-2019-100755

70. Pas HI, Reurink G, Tol JL, Weir A, Winters M, Moen MH. Efficacy of rehabilitation (lengthening) exercises, platelet-rich plasma injections, and other conservative interventions in acute hamstring injuries: an updated systematic review and meta-analysis. *Br J Sports Med*. 2015;49:1197-1205. https://doi.org/10.1136/bjsports-2015-094879

71. Pollock N, James SL, Lee JC, Chakraverty R. British Athletics Muscle Injury Classification: a new grading system. *Br J Sports Med*. 2014;48:1347-1351. https://doi.org/10.1136/bjsports-2013-093302

72. Pollock N, Patel A, Chakraverty J, Suokas A, James SL, Chakraverty R. Time to return to full training is delayed and recurrence rate is higher in intratendinous ('c') acute hamstring injury in elite track and field athletes: clinical application of the British Athletics Muscle Injury Classification. *Br J Sports Med*. 2016;50:305-310. https://doi.org/10.1136/bjsports-2015-094657

73. Prior M, Guerin M, Grimmer K. An evidence-based approach to hamstring strain injury: a systematic review of the literature. *Sports Health*. 2009;1:154-164. https://doi.org/10.1177/1941738108324962

74. Raya-Gonzalez J, Castillo D, Clemente FM. Injury prevention of hamstring injuries through exercise interventions. *J Sports Med Phys Fitness*. 2021;61:1242-1251. https://doi.org/10.23736/S0022-4707.21.11670-6

75. Reurink G, Goudswaard GJ, Moen MH, Tol JL, Verhaar JA, Weir A. Strength measurements in acute hamstring injuries: intertester reliability and prognostic value of handheld dynamometry. *J Orthop Sports Phys Ther*. 2016;46:689-696. https://doi.org/10.2519/jospt.2016.6363

76. Reurink G, Goudswaard GJ, Oomen HG, et al. Reliability of the active and passive knee extension test in acute hamstring injuries. *Am J Sports Med*. 2013;41:1757-1761. https://doi.org/10.1177/0363546513490650

77. Reurink G, Goudswaard GJ, Tol JL, Verhaar JA, Weir A, Moen MH. Therapeutic interventions for acute hamstring injuries: a systematic review. *Br J Sports Med*. 2012;46:103-109. https://doi.org/10.1136/bjsports-2011-090447

78. Rogan S, Wüst D, Schwitter T, Schmidtbleicher D. Static stretching of the hamstring muscle for injury prevention in football codes: a systematic review. *Asian J Sports Med*. 2013;4:1-9. https://doi.org/10.5812/ASJSM.34519

79. Røksund OD, Kristoffersen M, Bogen BE, et al. Higher drop in speed during a repeated sprint test in soccer players reporting former hamstring strain injury. *Front Physiol*. 2017;8:25. https://doi.org/10.3389/fphys.2017.00025

80. Rosado-Portillo A, Chamorro-Moriana G, Gonzalez-Medina G, Perez-Cabezas V. Acute hamstring injury prevention programs in eleven-a-side football players based on physical exercises: systematic review. *J Clin Med*. 2021;10:2029. https://doi.org/10.3390/jcm10092029

81. Sanfilippo JL, Silder A, Sherry MA, Tuite MJ, Heiderscheit BC. Hamstring strength and morphology progression after return to sport from injury. *Med Sci Sports Exerc*. 2013;45:448-454. https://doi.org/10.1249/MSS.0b013e3182776eff

82. Schmitt BM, Tyler TF, Kwiecien SY, Fox MB, McHugh MP. Mapping tenderness to palpation predicts return to play following acute hamstring strain. *Int J Sports Phys Ther*. 2020;15:421-428.

83. Schneider-Kolsky ME, Hoving JL, Warren P, Connell DA. A comparison between clinical assessment and magnetic resonance imaging of acute hamstring injuries. *Am J Sports Med*. 2006;34:1008-1015. https://doi.org/10.1177/0363546505283835

84. Schut L, Wangensteen A, Maaskant J, Tol JL, Bahr R, Moen M. Can clinical evaluation predict return to sport after acute hamstring injuries? A systematic review. *Sports Med*. 2017;47:1123-1144. https://doi.org/10.1007/s40279-016-0639-1

85. Sherry MA, Best TM. A comparison of 2 rehabilitation programs in the treatment of acute hamstring strains. *J Orthop Sports Phys Ther*. 2004;34:116-125. https://doi.org/10.2519/jospt.2004.34.3.116

86. Smirnova L, Derinov A, Glazkova I. Hamstring structural injury in futsal players: the effect of active range of motion (AROM) deficit on rehabilitation period. *Muscles Ligaments Tendons J*. 2020;10:645-650. https://doi.org/10.32098/mltj.04.2020.12

87. Sole G, Milosavljevic S, Nicholson HD, Sullivan SJ. Selective strength loss and decreased muscle activity in hamstring injury. *J Orthop Sports Phys Ther*. 2011;41:354-363. https://doi.org/10.2519/jospt.2011.3268

88. Sugiura Y, Sakuma K, Sakuraba K, Sato Y. Prevention of hamstring injuries in collegiate sprinters. *Orthop J Sports Med*. 2017;5:2325967116681524. https://doi.org/10.1177/2325967116681524

89. Timmins RG, Shield AJ, Williams MD, Lorenzen C, Opar DA. Biceps femoris long head architecture: a reliability and retrospective injury study. *Med Sci Sports Exerc*. 2015;47:905-913. https://doi.org/10.1249/MSS.0000000000000507

90. Timmins RG, Shield AJ, Williams MD, Opar DA. Is there evidence to support the use of the angle of peak torque as a marker of hamstring injury and re-injury risk? *Sports Med*. 2016;46:7-13. https://doi.org/10.1007/s40279-015-0378-8

91. Tokutake G, Kuramochi R, Murata Y, Enoki S, Koto Y, Shimizu T. The risk factors of hamstring strain injury induced by high-speed running. *J Sports Sci Med*. 2018;17:650-655.

92. Tol JL, Hamilton B, Eirale C, Muxart P, Jacobsen P, Whiteley R. At return to play following hamstring injury the majority of professional football players have residual isokinetic deficits. *Br J Sports Med*. 2014;48:1364-1369. https://doi.org/10.1136/bjsports-2013-093016

93. Tosovic D, Muirhead JC, Brown JM, Woodley SJ. Anatomy of the long head of biceps femoris: an ultrasound study. *Clin Anat*. 2016;29:738-745. https://doi.org/10.1002/ca.22718

94. Tyler TF, Schmitt BM, Nicholas SJ, McHugh MP. Rehabilitation after hamstring-strain injury emphasizing eccentric strengthening at long muscle lengths: results of long-term follow-up. *J Sport Rehabil*. 2017;26:131-140. https://doi.org/10.1123/jsr.2015-0099

95. van Beijsterveldt AM, van de Port IG, Vereijken AJ, Backx FJ. Risk factors for hamstring injuries in male soccer players: a systematic review of prospective studies. *Scand J Med Sci Sports*. 2013;23:253-262. https://doi.org/10.1111/j.1600-0838.2012.01487.x

96. van de Hoef PA, Brink MS, van der Horst N, van Smeden M, Backx FJG. The prognostic value of the hamstring outcome score to predict the risk of hamstring injuries. *J Sci Med Sport*. 2021;24:641-646. https://doi.

org/10.1016/j.jsams.2021.01.001

97. van der Horst N, van de Hoef S, Reurink G, Huisstede B, Backx F. Return to play after hamstring injuries: a qualitative systematic review of definitions and criteria. *Sports Med*. 2016;46:899-912. https://doi.org/10.1007/s40279-015-0468-7

98. van Doormaal MC, van der Horst N, Backx FJ, Smits DW, Huisstede BM. No relationship between hamstring flexibility and hamstring injuries in male amateur soccer players: a prospective study. *Am J Sports Med*. 2017;45:121-126. https://doi.org/10.1177/0363546516664162

99. van Dyk N, Bahr R, Burnett AF, et al. A comprehensive strength testing protocol offers no clinical value in predicting risk of hamstring injury: a prospective cohort study of 413 professional football players. *Br J Sports Med*. 2017;51:1695-1702. https://doi.org/10.1136/bjsports-2017-097754

100. van Dyk N, Bahr R, Whiteley R, et al. Hamstring and quadriceps isokinetic strength deficits are weak risk factors for hamstring strain injuries: a 4-year cohort study. *Am J Sports Med*. 2016;44:1789-1795. https://doi.org/10.1177/0363546516632526

101. van Dyk N, Behan FP, Whiteley R. Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: a systematic review and meta-analysis of 8459 athletes. *Br J Sports Med*. 2019;53:1362-1370. https://doi.org/10.1136/bjsports-2018-100045

102. Verrall GM, Kalairajah Y, Slavotinek JP, Spriggins AJ. Assessment of player performance following return to sport after hamstring muscle strain injury. *J Sci Med Sport*. 2006;9:87-90. https://doi.org/10.1016/j.jsams.2006.03.007

103. Verrall GM, Slavotinek JP, Barnes PG, Fon GT. Diagnostic and prognostic value of clinical findings in 83 athletes with posterior thigh injury: comparison of clinical findings with magnetic resonance imaging documentation of hamstring muscle strain. *Am J Sports Med*. 2003;31:969-973. https://doi.org/10.1177/03635465030310063701

104. Wangensteen A, Almusa E, Boukarroum S, et al. MRI does not add value over and above patient history and clinical examination in predicting time to return to sport after acute hamstring injuries: a prospective cohort of 180 male athletes. *Br J Sports Med*. 2015;49:1579-1587. https://doi.org/10.1136/bjsports-2015-094892

105. Wangensteen A, Guermazi A, Tol JL, et al. New MRI muscle classification systems and associations with return to sport after acute hamstring injuries: a prospective study. *Eur Radiol*. 2018;28:3532-3541. https://doi.org/10.1007/s00330-017-5125-0

106. Wangensteen A, Tol JL, Witvrouw E, et al. Hamstring reinjuries occur at the same location and early after return to sport: a descriptive study of MRI-confirmed reinjuries. *Am J Sports Med*. 2016;44:2112-2121. https://doi.org/10.1177/0363546516646086

107. Whiteley R, van Dyk N, Wangensteen A, Hansen C. Clinical implications from daily physiotherapy examination of 131 acute hamstring injuries and their association with running speed and rehabilitation progression. *Br J Sports Med*. 2018;52:303-310. https://doi.org/10.1136/bjsports-2017-097616

108. World Health Organization. *International Classification of Functioning, Disability and Health: ICF*. Geneva, Switzerland: World Health Organization; 2001.

109. Worrell TW. Factors associated with hamstring injuries. An approach to treatment and preventative measures. *Sports Med*. 1994;17:338-345. https://doi.org/10.2165/00007256-199417050-00006

110. Zarins B, Ciullo JV. Acute muscle and tendon injuries in athletes. *Clin Sports Med*. 1983;2:167-182. https://doi.org/10.1016/S0278-5919(20)31445-9

111. Zeren B, Oztekin HH. A new self-diagnostic test for biceps femoris muscle strains. *Clin J Sport Med*. 2006;16:166-169. https://doi.org/10.1097/00042752-200603000-00014

APPENDIX A

SEARCH STRATEGIES AND RESULTS

Physical Impairment Measures

All search results, n = 3610; original citations, n = 2686

Patient-Reported Outcome Measures

All search results, n = 1433; original citations, n = 1112

PubMed (June 7, 2020)

	Search Term	Result
1	"Hamstring Tendons"[Mesh] OR Biceps Femoris[tw] OR hamstring[tw] OR hamstrings[tw] OR Semimembranosus[tw] OR Semitendinosus[tw] OR thigh[tw]	45670
2	Myofascial pain syndromes[mh:noexp] OR soft tissue injuries[mh:noexp] OR strains[mh] OR myositis ossificans[mh] OR leg injuries[mh:noexp] OR Pain[mesh:noexp] OR Acute Pain[mesh] OR Chronic Pain[mesh] OR Musculoskeletal Pain[mesh:noexp] OR Pain[tiab] OR Painful[tw] OR Ache[tw] OR Injury[tw] OR Injuries[tw]	1796745
3	1 AND 2	13942
4	Hamstring strain[mesh] OR Hamstring strain[tw] OR Hamstring tear[tw] OR Torn Hamstring[tw] OR Hamstring injury[tw] OR Hamstring injuries[tw] OR Hamstring pain[tw] OR Hamstring ache[tw] OR Hamstring Myositis Ossificans[tw]	829
5	3 OR 4	13956
6	"Sensitivity and Specificity"[Mesh] OR sensitivity[tw] OR specificity[tw] OR "Evaluation Studies as Topic"[Mesh] OR evaluation indexes[tw] OR evaluation report[tw] OR evaluation reports[tw] OR evaluation research[tw] OR use-effectiveness[tw] OR use effectiveness[tw] OR preposttests[tw] OR pre post test[tw] OR preposttest[tw] OR pre post test[tw] OR qualitative evaluation[tw] OR qualitative evaluations[tw] OR quantitative evaluation[tw] OR quantitative evaluations[tw] OR theoretical effectiveness[tw] OR critique[tw] OR critiques[tw] OR evaluation methodology[tw] OR evaluation methodologies[tw] OR "Validation Studies as Topic"[Mesh] OR "Reproducibility of Results"[Mesh] OR reproducibility[tw] OR validity[tw] OR validation[tw] OR reliability[tw] OR "Data Accuracy"[Mesh] OR data accuracy[tw] OR data accuracies[tw] OR data quality[tw] OR data qualities[tw] OR precision[tw] OR responsiveness[tw] OR consistency[tw] OR consistencies[tw] OR consistent[tw] OR log-likelihood ratio[tw] OR likelihood-ratio[tw] OR likelihood ratio[tw] OR LR test[tiab] OR "Epidemiologic Research Design"[Mesh] OR "Research Design"[Mesh] OR research design[tw] OR research designs[tw] OR research strategy[tw] OR research strategies[tw] OR research techniques[tw] OR research technique[tw] OR research methodology[tw] OR research methodologies[tw] OR experimental design[tw] OR experimental designs[tw]	4199739
7	"Gait"[Mesh] OR "Gait Analysis"[Mesh] OR gait[tw] OR "strength test"[tw] OR isokinetic[tw] OR "range of motion"[tw] OR flexibility[tw] OR full movement[tw] OR "lower extremity alignment"[tw] OR "posture"[tw] OR movement pattern[tw] OR movement patterns[tw] OR "straight leg raise"[tw] OR "McConnell test"[tw] OR "dynamic horizontal side support"[tw] OR "dynamic valgus"[tw] OR "single leg bride" [tw] OR "Active hamstring test"[tw] OR "Hamstring 90/90 Test"[tw] OR "endurance test"[tw] OR "single leg squat"[tw] OR "single-leg stance"[tw] OR "single leg balance"[tw] OR "step down"[tw] OR Agility testing[tw] OR sprinting[tw] OR jumping[tw] OR "Timed hop for distance"[tw] OR "Star Excursion balance test"[tw] OR "step-down test"[tw] OR "cross-over"[tw] OR "Copenhagen five second squeeze test"[tw] OR "Double straight leg lower test"[tw] OR "Rehabilitation"[Mesh] OR rehabilitation[tw] OR physical function[tw] OR physical functions[tw] OR physical functioning[tw] OR performance status[tw] OR "Return to Sport"[Mesh] OR "back-to-sport"[tw] OR "return-to-sport"[tw] OR "back to sport"[tw] OR "return to sport"[tw] OR "back-to-sports"[tw] OR "return-to-sports"[tw] OR "back to sports"[tw] OR "return to sports"[tw] OR "sporting activity resumption"[tw] OR "recreational activities resumption"[tw] OR "return to recreation"[tw] OR "return to recreational"[tw] OR "return to play"[tw]	874126
8	"Pain"[Majr] OR pain rating[tw] OR pain scale[tw] OR visual analogue scale[tw] OR visual analog scale[tw] OR numerical rating scale[tw] OR number rating scale[tw] OR Perth Hamstring Assessment Tool[tw] OR "Copenhagen Hip and Groin Outcome Score"[tw] OR "Hip and Groin Outcome Score"[tw] OR NAHS[tiab] OR lower extremity functional scale[tw] OR LEFS[tiab] OR short form health survey[tw] OR short-form health survey[tw] OR SF36[tw] OR SF-36[tw] OR "SF 36"[tw] OR "short form 36"[tw] OR "shortform 36"[tw] OR shortform36[tw] OR "36 item short form"[tw] OR "36-item short form"[tw] OR SF12[tw] OR SF-12[tw] OR "SF 12"[tw] OR "short form 12"[tw] OR "shortform 12"[tw] OR shortform12[tw] OR "12 item short form"[tw] OR "12-item short form"[tw] OR tegner activity level scale[tw] OR hip sports activity scale[tw] OR HSAS[tiab]	329938
9	5 AND 6 AND 7 AND English[language]	681
10	5 AND 6 AND 8 AND English[language]	323

APPENDIX A

Embase (June 7, 2020)

	Search Term	Result
1	'Hamstring Tendon'/exp OR 'biceps femoris tendon'/exp OR "Biceps Femoris": ti,ab,de,tn OR hamstring:ti,ab,de,tn OR hamstrings:ti,ab,de,tn OR 'semimembranosus tendon'/exp OR Semimembranosus:ti,ab,de,tn OR Semitendinosus:ti,ab,de,tn OR thigh:ti,ab,de,tn	60500
2	'Myofascial pain'/de OR 'soft tissue injury'/de OR 'ossifying myositis'/exp OR 'leg injury'/de OR 'Pain'/de OR 'Chronic Pain'/exp OR 'Musculoskeletal Pain'/de OR Pain:ti,ab OR Painful:ti,ab,de,tn OR Ache:ti,ab,de,tn OR Injury:ti,ab,de,tn OR Injuries:ti,ab,de,tn	2610373
3	1 AND 2	19523
4	"Hamstring strain":ti,ab,de,tn OR "Hamstring strains":ti,ab,de,tn OR "Hamstring tear":ti,ab,de,tn OR "Torn Hamstring":ti,ab,de,tn OR "Hamstring injury":ti,ab,de,tn OR "Hamstring injuries":ti,ab,de,tn OR "Hamstring pain":ti,ab,de,tn OR "Hamstring ache":ti,ab,de,tn OR "Hamstring Myositis Ossificans":ti,ab,de,tn	850
5	3 OR 4	19539
6	'sensitivity'/exp OR sensitivity:ti,ab,de OR 'specificity'/exp OR specificity:ti,ab,de OR 'evaluation indexes'/exp OR 'evaluation indexes':ti,ab,de OR 'evaluation report'/exp OR 'evaluation report':ti,ab,de OR 'evaluation reports':ti,ab,de OR 'evaluation research'/exp OR 'evaluation research':ti,ab,de OR 'use effectiveness'/exp OR 'use effectiveness':ti,ab,de OR 'pre post tests'/exp OR 'pre post tests':ti,ab,de OR 'prepost test':ti,ab,de OR 'qualitative evaluation'/exp OR 'qualitative evaluation':ti,ab,de OR 'qualitative evaluations':ti,ab,de OR 'quantitative evaluation'/exp OR 'quantitative evaluation':ti,ab,de OR 'quantitative evaluations':ti,ab,de OR 'theoretical effectiveness'/exp OR 'theoretical effectiveness':ti,ab,de OR 'critique'/exp OR critique:ti,ab,de OR critiques:ti,ab,de OR 'evaluation methodology'/exp OR 'evaluation methodology':ti,ab,de OR 'evaluation methodologies':ti,ab,de OR 'reproducibility'/exp OR reproducibility:ti,ab,de OR 'validity'/exp OR validity:ti,ab,de OR 'reliability'/exp OR reliability:ti,ab,de OR 'data accuracy'/exp OR 'data accuracy':ti,ab,de OR 'data accuracies':ti,ab,de OR 'data quality'/exp OR 'data quality':ti,ab,de OR 'data qualities':ti,ab,de OR 'precision'/exp OR precision:ti,ab,de OR 'responsiveness'/exp OR responsiveness:ti,ab,de OR 'consistency'/exp OR consistency:ti,ab,de OR consistencies:ti,ab,de OR consistent:ti,ab,de OR 'log-likelihood ratio' OR 'likelihood-ratio':ti,ab,de OR 'likelihood ratio'/exp OR 'likelihood ratio':ti,ab,de OR 'research design'/exp OR 'research design':ti,ab,de OR 'research designs':ti,ab,de OR 'research strategy':ti,ab,de OR 'research strategies':ti,ab,de OR 'research techniques':ti,ab,de OR 'research technique':ti,ab,de OR 'research methodology'/exp OR 'research methodology':ti,ab,de OR 'research methodologies':ti,ab,de OR 'experimental design'/exp OR 'experimental design':ti,ab,de OR 'experimental designs':ti,ab,de	8608226
7	'Gait'/exp OR gait:ti,ab,de,tn OR "strength test":ti,ab,de,tn OR isokinetic:ti,ab,de,tn OR "range of motion":ti,ab,de,tn OR flexibility:ti,ab,de,tn OR "full movement":ti,ab,de,tn OR "lower extremity alignment":ti,ab,de,tn OR posture:ti,ab,de,tn OR "movement pattern":ti,ab,de,tn OR "movement patterns":ti,ab,de,tn OR "straight leg raise":ti,ab,de,tn OR "McConnell test":ti,ab,de,tn OR "dynamic horizontal side support":ti,ab,de,tn OR "dynamic valgus":ti,ab,de,tn OR "single leg bride":ti,ab,de,tn OR "Active hamstring test":ti,ab,de,tn OR "Hamstring 90/90 Test":ti,ab,de,tn OR "endurance test":ti,ab,de,tn OR "single leg squat":ti,ab,de,tn OR "single-leg stance":ti,ab,de,tn OR "single leg balance":ti,ab,de,tn OR "step down":ti,ab,de,tn OR "Agility testing":ti,ab,de,tn OR sprinting:ti,ab,de,tn OR jumping:ti,ab,de,tn OR "Timed hop for distance":ti,ab,de,tn OR "Star Excursion balance test":ti,ab,de,tn OR "step-down test":ti,ab,de,tn OR cross-over:ti,ab,de,tn OR "Copenhagen five second squeeze test":ti,ab,de,tn OR "Double straight leg lower test":ti,ab,de,tn OR 'Rehabilitation'/de OR rehabilitation:ti,ab,de,tn OR "physical function":ti,ab,de,tn OR "physical functions":ti,ab,de,tn OR "physical functioning":ti,ab,de,tn OR "performance status":ti,ab,de,tn OR 'Return to Sport'/exp OR back-to-sport:ti,ab,de,tn OR return-to-sport:ti,ab,de,tn OR "back to sport":ti,ab,de,tn OR "return to sport":ti,ab,de,tn OR back-to-sports:ti,ab,de,tn OR return-to-sports:ti,ab,de,tn OR "back to sports":ti,ab,de,tn OR "return to sports":ti,ab,de,tn OR "sporting activity resumption":ti,ab,de,tn OR "recreational activities resumption":ti,ab,de,tn OR "return to recreation":ti,ab,de,tn OR "return to recreational":ti,ab,de,tn OR "return to play":ti,ab,de,tn	675912
8	'Pain'/exp/mj OR "pain rating":ti,ab,de,tn OR "pain scale":ti,ab,de,tn OR "visual analogue scale":ti,ab,de,tn OR "visual analog scale":ti,ab,de,tn OR "numerical rating scale":ti,ab,de,tn OR "number rating scale":ti,ab,de,tn OR "Perth Hamstring Assessment Tool":ti,ab,de,tn OR "Copenhagen Hip and Groin Outcome Score":ti,ab,de,tn OR "Hip and Groin Outcome Score":ti,ab,de,tn OR NAHS:ti,ab OR "lower extremity functional scale":ti,ab,de,tn OR LEFS:ti,ab OR "short form health survey":ti,ab,de,tn OR "short-form health survey":ti,ab,de,tn OR SF36:ti,ab,de,tn OR SF-36:ti,ab,de,tn OR "SF 36":ti,ab,de,tn OR "short form 36":ti,ab,de,tn OR "shortform 36":ti,ab,de,tn OR shortform36:ti,ab,de,tn OR "36 item short form":ti,ab,de,tn OR "36-item short form":ti,ab,de,tn OR SF12:ti,ab,de,tn OR SF-12:ti,ab,de,tn OR "SF 12":ti,ab,de,tn OR "short form 12":ti,ab,de,tn OR "shortform 12":ti,ab,de,tn OR shortform12:ti,ab,de,tn OR "12 item short form":ti,ab,de,tn OR "12-item short form":ti,ab,de,tn OR "tegner activity level scale":ti,ab,de,tn OR "hip sports activity scale":ti,ab,de,tn OR HSAS:ti,ab	558290
9	5 AND 6 AND 7 AND [english]/lim AND [embase]/lim NOT 'conference abstract'/it	887
10	5 AND 6 AND 8 AND [english]/lim AND [embase]/lim NOT 'conference abstract'/it	619

APPENDIX A

CINAHL (June 7, 2020)

	Search Term	Result
1	"Biceps Femoris" OR hamstring OR hamstrings OR Semimembranosus OR Semitendinosus OR thigh	14767
2	(MH "Myofascial pain syndromes") OR (MH "soft tissue injuries") OR (MH "Sprains and Strains") OR (MH "Myositis Ossificans") OR (MH "Leg Injuries") OR (MH "Pain") OR (MH "Chronic Pain") OR Pain OR Painful OR Ache OR Injury OR Injuries	628076
3	1 AND 2	6892
4	"Hamstring strain" OR "Hamstring tear" OR "Hamstring injury" OR "Hamstring injuries" OR "Hamstring pain" OR "Hamstring ache" OR "Hamstring Myositis Ossificans"	633
5	3 OR 4	6896
6	((MH "Sensitivity and Specificity+") OR sensitivity OR specificity OR "evaluation indexes" OR "evaluation report" OR "evaluation reports" OR "evaluation research" OR use-effectiveness OR "use effectiveness" OR preposttests OR "pre post test" OR preposttest OR "pre post test" OR "qualitative evaluation" OR "qualitative evaluations" OR "quantitative evaluation" OR "quantitative evaluations" OR "theoretical effectiveness" OR critique OR critiques OR "evaluation methodology" OR "evaluation methodologies" OR reproducibility OR validity OR validation OR reliability OR "data accuracy" OR "data accuracies" OR "data quality" OR "data qualities" OR precision OR responsiveness OR consistency OR consistencies OR consistent OR "log-likelihood ratio" OR likelihood-ratio OR "likelihood ratio" OR TI "LR test" OR AB "LR test" OR (MH "Study Design+") OR "research design" OR "research designs" OR "research strategy" OR "research strategies" OR "research techniques" OR "research technique" OR "research methodology" OR "research methodologies" OR "experimental design" OR "experimental designs")	1943500
7	(MH "Gait+") OR (MH "Gait Analysis+") OR gait OR "strength test" OR isokinetic OR "range of motion" OR flexibility OR "full movement" OR "lower extremity alignment" OR posture OR "movement pattern" OR "movement patterns" OR "straight leg raise" OR "McConnell test" OR "dynamic horizontal side support" OR "dynamic valgus" OR "single leg bride" OR "Active hamstring test" OR "Hamstring 90/90 Test" OR "endurance test" OR "single leg squat" OR "single-leg stance" OR "single leg balance" OR "step down" OR "Agility testing" OR sprinting OR jumping OR "Timed hop for distance" OR "Star Excursion balance test" OR "step-down test" OR cross-over OR "Copenhagen five second squeeze test" OR "Double straight leg lower test" OR (MH "Rehabilitation+") OR rehabilitation OR "physical function" OR "physical functions" OR "physical functioning" OR "performance status" OR (MH "Sports Re-Entry+") OR back-to-sport OR return-to-sport OR "back to sport" OR "return to sport" OR back-to-sports OR return-to-sports OR "back to sports" OR "return to sports" OR "sporting activity resumption" OR "recreational activities resumption" OR "return to recreation" OR "return to recreational" OR "return to play"	512742
8	(MM "Pain") OR "pain rating" OR "pain scale" OR "visual analogue scale" OR "visual analog scale" OR "numerical rating scale" OR "number rating scale" OR "Perth Hamstring Assessment Tool" OR "Copenhagen Hip and Groin Outcome Score" OR "Hip and Groin Outcome Score" OR TI NAHS OR AB NAHS OR "lower extremity functional scale" OR TI LEFS OR AB LEFS OR "short form health survey" OR "short-form health survey" OR SF36 OR SF-36 OR "SF 36" OR "short form 36" OR "shortform 36" OR shortform36 OR "36 item short form" OR "36-item short form" OR SF12 OR SF-12 OR "SF 12" OR "short form 12" OR "shortform 12" OR shortform12 OR "12 item short form" OR "12-item short form" OR "tegner activity level scale" OR "hip sports activity scale" OR TI HSAS OR AB HSAS	96485
9	5 AND 6 AND 7 AND Language: English	1709
10	5 AND 6 AND 8 AND Language: English	317

APPENDIX A

Cochrane Library (June 7, 2020)

	Search Term	Result
1	"Hamstring Tendons" OR "Biceps Femoris" OR hamstring OR hamstrings OR Semimembranosus OR Semitendinosus OR thigh	6171
2	"Myofascial pain syndromes" OR "soft tissue injuries" OR strains OR "myositis ossificans" OR "leg injuries" OR "Acute Pain" OR "Chronic Pain" OR "Musculoskeletal Pain" OR Pain OR Painful OR Ache OR Injury OR Injuries	232755
3	1 AND 2	2858
4	"Hamstring strain" OR "Hamstring tear" OR "Hamstring injury" OR "Hamstring injuries" OR "Hamstring pain" OR "Hamstring ache" OR "Hamstring Myositis Ossificans"	128
5	3 OR 4	2861
6	(sensitivity OR specificity OR "evaluation indexes" OR "evaluation report" OR "evaluation reports" OR "evaluation research" OR use-effectiveness OR "use effectiveness" OR preposttests OR "pre post test" OR preposttest OR "pre post test" OR "qualitative evaluation" OR "qualitative evaluations" OR "quantitative evaluation" OR "quantitative evaluations" OR "theoretical effectiveness" OR critique OR critiques OR "evaluation methodology" OR "evaluation methodologies" OR reproducibility OR validity OR validation OR reliability OR "data accuracy" OR "data accuracies" OR "data quality" OR "data qualities" OR precision OR responsiveness OR consistency OR consistencies OR consistent OR "log-likelihood ratio" OR likelihood-ratio OR "likelihood ratio" OR "LR test" OR "research design" OR "research designs" OR "research strategy" OR "research strategies" OR "research techniques" OR "research technique" OR "research methodology" OR "research methodologies" OR "experimental design" OR "experimental designs")	159592
7	Gait OR "strength test" OR isokinetic OR "range of motion" OR flexibility OR "full movement" OR "lower extremity alignment" OR posture OR "movement pattern" OR "movement patterns" OR "straight leg raise" OR "McConnell test" OR "dynamic horizontal side support" OR "dynamic valgus" OR "single leg bride" OR "Active hamstring test" OR "Hamstring 90/90 Test" OR "endurance test" OR "single leg squat" OR "single-leg stance" OR "single leg balance" OR "step down" OR "Agility testing" OR sprinting OR jumping OR "Timed hop for distance" OR "Star Excursion balance test" OR "step-down test" OR cross-over OR "Copenhagen five second squeeze test" OR "Double straight leg lower test" OR rehabilitation OR "physical function" OR "physical functions" OR "physical functioning" OR "performance status" OR back-to-sport OR return-to-sport OR "back to sport" OR "return to sport" OR back-to-sports OR return-to-sports OR "back to sports" OR "return to sports" OR "sporting activity resumption" OR "recreational activities resumption" OR "return to recreation" OR "return to recreational" OR "return to play"	167411
8	"pain rating" OR "pain scale" OR "visual analogue scale" OR "visual analog scale" OR "numerical rating scale" OR "number rating scale" OR "Perth Hamstring Assessment Tool" OR "Copenhagen Hip and Groin Outcome Score" OR "Hip and Groin Outcome Score" OR NAHS OR "lower extremity functional scale" OR LEFS OR "short form health survey" OR "short-form health survey" OR SF36 OR SF-36 OR "SF 36" OR "short form 36" OR "shortform 36" OR shortform36 OR "36 item short form" OR "36-item short form" OR SF12 OR SF-12 OR "SF 12" OR "short form 12" OR "shortform 12" OR shortform12 OR "12 item short form" OR "12-item short form" OR "tegner activity level scale" OR "hip sports activity scale" OR HSAS	65171
9	5 AND 6 AND 7	333
10	5 AND 6 AND 8	174

Reinjury Risk

April 6, 2021: total results before duplicate removal, n = 1485; unique results after duplicate removal, n = 969. Updated on June 28, 2021: total results before duplicate removal, n = 1526; new unique results after duplicate removal, n = 33

PubMed

	Search Term	Result
1	"Hamstring Tendons"[Mesh] OR Biceps Femoris[tw] OR hamstring[tw] OR hamstrings[tw] OR Semimembranosus[tw] OR Semitendinosus[tw] OR thigh[tw]	48808
2	Myofascial pain syndromes[mh:noexp] OR soft tissue injuries[mh:noexp] OR strains[mh] OR myositis ossificans[mh] OR leg injuries[mh:noexp] OR Pain[mesh:noexp] OR Acute Pain[mesh] OR Chronic Pain[mesh] OR Musculoskeletal Pain[mesh:noexp] OR Pain[tiab] OR Painful[tw] OR Ache[tw] OR Injury[tw] OR Injuries[tw]	1918350
3	1 AND 2	15217
4	Hamstring strain[mesh] OR Hamstring strain[tw] OR Hamstring tear[tw] OR Torn Hamstring[tw] OR Hamstring injury[tw] OR Hamstring injuries[tw] OR Hamstring pain[tw] OR Hamstring ache[tw] OR Hamstring Myositis Ossificans[tw]	939
5	3 OR 4	15230
6	("Recurrence"[Mesh] OR recur*[tw] OR reoccur*[tw] OR re-occur*[tw] OR re-injur*[tw] OR reinjur*[tw] OR "secondary injury"[tw] OR "secondary injuries"[tw] OR "secondary prevention"[tw] OR "preventing secondary"[tw] OR recidiv*[tw] OR relaps*[tw]) AND (Risk Assessment[Mesh] OR "Risk Adjustment"[Mesh] OR "Health Risk Behaviors"[Mesh] OR "Odds Ratio"[Mesh]OR risk[tw] OR risks[tw] OR prospective[tw] OR longitudinal[tw] OR long-term[tw] OR longterm[tw] OR predict*[tw] OR prognostic[tw] OR prognosis[tw] OR epidemiolog*[tw] OR "multivariate analysis"[tw] OR prevent*[tw] OR "odds ratio"[tw])	515934
7	5 AND 6 AND English[language] NOT ("comment"[Publication Type] OR "editorial"[Publication Type] OR "letter"[Publication Type] OR "news"[Publication Type] OR "retracted publication"[Publication Type] OR "retraction of publication"[Publication Type] OR "Case Reports"[Publication Type])	513

APPENDIX A

Embase

	Search Term	Result
1	'Hamstring Tendon'/exp OR 'biceps femoris tendon'/exp OR "Biceps Femoris":ti,ab,de,tn OR hamstring:ti,ab,de,tn OR hamstrings:ti,ab,de,tn OR 'semimembranosus tendon'/exp OR Semimembranosus:ti,ab,de,tn OR Semitendinosus:ti,ab,de,tn OR thigh:ti,ab,de,tn	65504
2	'Myofascial pain'/de OR 'soft tissue injury'/de OR 'ossifying myositis'/exp OR 'leg injury'/de OR 'Pain'/de OR 'Chronic Pain'/exp OR 'Musculoskeletal Pain'/de OR Pain:ti,ab OR Painful:ti,ab,de,tn OR Ache:ti,ab,de,tn OR Injury:ti,ab,de,tn OR Injuries:ti,ab,de,tn	2801563
3	1 AND 2	21512
4	"Hamstring strain":ti,ab,de,tn OR "Hamstring strains":ti,ab,de,tn OR "Hamstring tear":ti,ab,de,tn OR "Torn Hamstring":ti,ab,de,tn OR "Hamstring injury":ti,ab,de,tn OR "Hamstring injuries":ti,ab,de,tn OR "Hamstring pain":ti,ab,de,tn OR "Hamstring ache":ti,ab,de,tn OR "Hamstring Myositis Ossificans":ti,ab,de,tn	963
5	3 OR 4	21530
6	('recurrence risk'/exp OR recur*:ti,ab,de,tn OR reoccur*:ti,ab,de,tn OR re-occur*:ti,ab,de,tn OR re-injur*:ti,ab,de,tn OR reinjur*:ti,ab,de,tn OR "secondary injury":ti,ab,de,tn OR "secondary injuries":ti,ab,de,tn OR "secondary prevention":ti,ab,de,tn OR "preventing secondary":ti,ab,de,tn OR recidiv*:ti,ab,de,tn OR relaps*:ti,ab,de,tn) AND ('recurrence risk'/exp OR 'risk assessment'/exp OR 'risk behavior'/exp OR 'odds ratio'/exp OR risk:ti,ab,de,tn OR risks:ti,ab,de,tn OR prospective:ti,ab,de,tn OR longitudinal:ti,ab,de,tn OR long-term:ti,ab,de,tn OR longterm:ti,ab,de,tn OR predict*:ti,ab,de,tn OR prognostic:ti,ab,de,tn OR prognosis:ti,ab,de,tn OR epidemiolog*:ti,ab,de,tn OR "multivariate analysis":ti,ab,de,tn OR prevent*:ti,ab,de,tn OR "odds ratio":ti,ab,de,tn)	796351
7	5 AND 6 AND [english]/lim AND [embase]/lim NOT ('conference abstract'/it OR 'editorial'/it OR 'letter'/it OR 'note'/it)	420

CINAHL

	Search Term	Result
1	"Biceps Femoris" OR hamstring OR hamstrings OR Semimembranosus OR Semitendinosus OR thigh	14880
2	(MH "Myofascial pain syndromes") OR (MH "soft tissue injuries") OR (MH "Sprains and Strains") OR (MH "Myositis Ossificans") OR (MH "Leg Injuries") OR (MH "Pain") OR (MH "Chronic Pain") OR Pain OR Painful OR Ache OR Injury OR Injuries	632767
3	1 AND 2	6936
4	"Hamstring strain" OR "Hamstring tear" OR "Hamstring injury" OR "Hamstring injuries" OR "Hamstring pain" OR "Hamstring ache" OR "Hamstring Myositis Ossificans"	634
5	3 OR 4	6941
6	((MH "Recurrence+") OR recur* OR reoccur* OR re-occur* OR re-injur* OR reinjur* OR "secondary injury" OR "secondary injuries" OR "secondary prevention" OR "preventing secondary" OR recidiv* OR relaps*) AND ((MH "Risk Assessment+") OR (MH "Risk Taking Behavior+") OR (MH "Odds Ratio+") OR risk OR risks OR prospective OR longitudinal OR long-term OR longterm OR predict* OR prognostic OR prognosis OR epidemiolog* OR "multivariate analysis" OR prevent* OR "odds ratio")	131078
7	5 AND 6 AND Language: English and Source Type: Academic Journals	402

Cochrane Library

	Search Term	Result
1	"Hamstring Tendons" OR "Biceps Femoris" OR hamstring OR hamstrings OR Semimembranosus OR Semitendinosus OR thigh	6171
2	"Myofascial pain syndromes" OR "soft tissue injuries" OR strains OR "myositis ossificans" OR "leg injuries" OR "Acute Pain" OR "Chronic Pain" OR "Musculoskeletal Pain" OR Pain OR Painful OR Ache OR Injury OR Injuries	232755
3	1 AND 2	2858
4	"Hamstring strain" OR "Hamstring tear" OR "Hamstring injury" OR "Hamstring injuries" OR "Hamstring pain" OR "Hamstring ache" OR "Hamstring Myositis Ossificans"	128
5	3 OR 4	2861
6	(recur* OR reoccur* OR re-occur* OR re-injur* OR reinjur* OR "secondary injury" OR "secondary injuries" OR "secondary prevention" OR "preventing secondary" OR recidiv* OR relaps*) AND (risk OR risks OR prospective OR longitudinal OR long-term OR longterm OR predict* OR prognostic OR prognosis OR epidemiolog* OR "multivariate analysis" OR prevent* OR "odds ratio")	74768
7	5 AND 6	191

APPENDIX A

Return to Play

April 6, 2021: total results before duplicate removal, n = 1690; unique results after duplicate removal, n = 1103. Updated June 28, 2021: total results before duplicate removal, n = 1765; new unique results after duplicate removal, n = 53

PubMed

	Search Term	Result
1	"Hamstring Tendons"[Mesh] OR Biceps Femoris[tw] OR hamstring[tw] OR hamstrings[tw] OR Semimembranosus[tw] OR Semitendinosus[tw] OR thigh[tw]	48808
2	Myofascial pain syndromes[mh:noexp] OR soft tissue injuries[mh:noexp] OR strains[mh] OR myositis ossificans[mh] OR leg injuries[mh:noexp] OR Pain[mesh:noexp] OR Acute Pain[mesh] OR Chronic Pain[mesh] OR Musculoskeletal Pain[mesh:noexp] OR Pain[tiab] OR Painful[tw] OR Ache[tw] OR Injury[tw] OR Injuries[tw]	1918350
3	1 AND 2	15217
4	Hamstring strain[mesh] OR Hamstring strain[tw] OR Hamstring tear[tw] OR Torn Hamstring[tw] OR Hamstring injury[tw] OR Hamstring injuries[tw] OR Hamstring pain[tw] OR Hamstring ache[tw] OR Hamstring Myositis Ossificans[tw]	939
5	3 OR 4	15230
6	"Return to Sport"[Mesh] OR "Athletic Performance"[Mesh] OR "back-to-sport"[tw] OR "return-to-sport"[tw] OR "back to sport"[tw] OR "return to sport"[tw] OR "back-to-sports"[tw] OR "return-to-sports"[tw] OR "back to sports"[tw] OR "return to sports"[tw] OR "return to recreation"[tw] OR "return to recreational"[tw] OR "return to play"[tw] OR "return to activity"[tw] OR "return to competition"[tw] OR "competition return"[tw] OR "resume competition"[tw] OR "resume play"[tw] OR "resume sport"[tw] OR "resume sports"[tw] OR "resume activity"[tw] OR "resume activities"[tw] OR "return to performance"[tw] OR "sport resumption"[tw] OR "sports resumption"[tw] OR "sporting activity resumption"[tw] OR "play resumption"[tw] OR "competition resumption"[tw] OR "activity resumption"[tw] OR "activities resumption"[tw] OR "unrestricted sport"[tw] OR "unrestricted sports"[tw] OR "unrestricted activity"[tw] OR "unrestricted play"[tw] OR "full recovery"[tw] OR "level of play"[tw] OR "athletic performance"[tw] OR "sports performance"[tw] OR "sports re-entry"[tw]	75457
7	5 AND 6 AND English[language] NOT ("comment"[Publication Type] OR "editorial"[Publication Type] OR "letter"[Publication Type] OR "news"[Publication Type] OR "retracted publication"[Publication Type] OR "retraction of publication"[Publication Type] OR "Case Reports"[Publication Type])	673

Embase

	Search Term	Result
1	'Hamstring Tendon'/exp OR 'biceps femoris tendon'/exp OR "Biceps Femoris":ti,ab,de,tn OR hamstring:ti,ab,de,tn OR hamstrings:ti,ab,de,tn OR 'semimembranosus tendon'/exp OR Semimembranosus:ti,ab,de,tn OR Semitendinosus:ti,ab,de,tn OR thigh:ti,ab,de,tn	65504
2	'Myofascial pain'/de OR 'soft tissue injury'/de OR 'ossifying myositis'/exp OR 'leg injury'/de OR 'Pain'/de OR 'Chronic Pain'/exp OR 'Musculoskeletal Pain'/de OR Pain:ti,ab OR Painful:ti,ab,de,tn OR Ache:ti,ab,de,tn OR Injury:ti,ab,de,tn OR Injuries:ti,ab,de,tn	2801563
3	1 AND 2	21512
4	"Hamstring strain":ti,ab,de,tn OR "Hamstring strains":ti,ab,de,tn OR "Hamstring tear":ti,ab,de,tn OR "Torn Hamstring":ti,ab,de,tn OR "Hamstring injury":ti,ab,de,tn OR "Hamstring injuries":ti,ab,de,tn OR "Hamstring pain":ti,ab,de,tn OR "Hamstring ache":ti,ab,de,tn OR "Hamstring Myositis Ossificans":ti,ab,de,tn	963
5	3 OR 4	21530
6	'return to sport'/exp OR 'athletic performance'/exp OR back-to-sport:ti,ab,de,tn OR return-to-sport:ti,ab,de,tn OR "back to sport":ti,ab,de,tn OR "return to sport":ti,ab,de,tn OR back-to-sports:ti,ab,de,tn OR return-to-sports:ti,ab,de,tn OR "back to sports":ti,ab,de,tn OR "return to sports":ti,ab,de,tn OR "return to recreation":ti,ab,de,tn OR "return to recreational":ti,ab,de,tn OR "return to play":ti,ab,de,tn OR "return to activity":ti,ab,de,tn OR "return to competition":ti,ab,de,tn OR "competition return":ti,ab,de,tn OR "resume competition":ti,ab,de,tn OR "resume play":ti,ab,de,tn OR "resume sport":ti,ab,de,tn OR "resume sports":ti,ab,de,tn OR "resume activity":ti,ab,de,tn OR "resume activities":ti,ab,de,tn OR "return to performance":ti,ab,de,tn OR "sport resumption":ti,ab,de,tn OR "sports resumption":ti,ab,de,tn OR "sporting activity resumption":ti,ab,de,tn OR "play resumption":ti,ab,de,tn OR "competition resumption":ti,ab,de,tn OR "activity resumption":ti,ab,de,tn OR "activities resumption":ti,ab,de,tn OR "unrestricted sport":ti,ab,de,tn OR "unrestricted sports":ti,ab,de,tn OR "unrestricted activity":ti,ab,de,tn OR "unrestricted play":ti,ab,de,tn OR "full recovery":ti,ab,de,tn OR "level of play":ti,ab,de,tn OR "athletic performance":ti,ab,de,tn OR "sports performance":ti,ab,de,tn OR 'sports re-entry':ti,ab,de,tn	36409
7	5 AND 6 AND [english]/lim AND [embase]/lim NOT ('conference abstract'/it OR 'editorial'/it OR 'letter'/it OR 'note'/it)	382

APPENDIX A

CINAHL

	Search Term	Result
1	"Biceps Femoris" OR hamstring OR hamstrings OR Semimembranosus OR Semitendinosus OR thigh	14880
2	(MH "Myofascial pain syndromes") OR (MH "soft tissue injuries") OR (MH "Sprains and Strains") OR (MH "Myositis Ossificans") OR (MH "Leg Injuries") OR (MH "Pain") OR (MH "Chronic Pain") OR Pain OR Painful OR Ache OR Injury OR Injuries	632767
3	1 AND 2	6936
4	"Hamstring strain" OR "Hamstring tear" OR "Hamstring injury" OR "Hamstring injuries" OR "Hamstring pain" OR "Hamstring ache" OR "Hamstring Myositis Ossificans"	634
5	3 OR 4	6941
6	(MH "Sports Re-Entry") OR (MH "Athletic Performance") OR back-to-sport OR return-to-sport OR "back to sport" OR "return to sport" OR back-to-sports OR return-to-sports OR "back to sports" OR "return to sports" OR "return to recreation" OR "return to recreational" OR "return to play" OR "return to activity" OR "return to competition" OR "competition return" OR "resume competition" OR "resume play" OR "resume sport" OR "resume sports" OR "resume activity" OR "resume activities" OR "return to performance" OR "sport resumption" OR "sports resumption" OR "sporting activity resumption" OR "play resumption" OR "competition resumption" OR "activity resumption" OR "activities resumption" OR "unrestricted sport" OR "unrestricted sports" OR "unrestricted activity" OR "unrestricted play" OR "full recovery" OR "level of play" OR "athletic performance" OR "sports performance" OR "sports re-entry"	20789
7	5 AND 6 AND Language: English and Source Type: Academic Journals	562

Cochrane Library

	Search Term	Result
1	"Hamstring Tendons" OR "Biceps Femoris" OR hamstring OR hamstrings OR Semimembranosus OR Semitendinosus OR thigh	6171
2	"Myofascial pain syndromes" OR "soft tissue injuries" OR strains OR "myositis ossificans" OR "leg injuries" OR "Acute Pain" OR "Chronic Pain" OR "Musculoskeletal Pain" OR Pain OR Painful OR Ache OR Injury OR Injuries	232755
3	1 AND 2	2858
4	"Hamstring strain" OR "Hamstring tear" OR "Hamstring injury" OR "Hamstring injuries" OR "Hamstring pain" OR "Hamstring ache" OR "Hamstring Myositis Ossificans"	128
5	3 OR 4	2861
6	back-to-sport OR return-to-sport OR "back to sport" OR "return to sport" OR back-to-sports OR return-to-sports OR "back to sports" OR "return to sports" OR "return to recreation" OR "return to recreational" OR "return to play" OR "return to activity" OR "return to competition" OR "competition return" OR "resume competition" OR "resume play" OR "resume sport" OR "resume sports" OR "resume activity" OR "resume activities" OR "return to performance" OR "sport resumption" OR "sports resumption" OR "sporting activity resumption" OR "play resumption" OR "competition resumption" OR "activity resumption" OR "activities resumption" OR "unrestricted sport" OR "unrestricted sports" OR "unrestricted activity" OR "unrestricted play" OR "full recovery" OR "level of play" OR "athletic performance" OR "sports performance" OR "sports re-entry"	4041
7	5 AND 6	148

APPENDIX A

Intervention

September 6, 2019: all search results, n = 11 432; original citations, n = 9624. Updated on June 30, 2021: all search results, n = 6017; new original citations, n = 1825

2019 Search

PubMed

	Search Term	Result
1	(((thigh [mh] OR quadriceps muscle [mh] OR lower extremity [mh:noexp] OR hamstring tendons [mh] OR hamstring muscles [mh] OR gracilis muscle [mh]) OR ("Adductor" [tiab] OR "Biceps Femoris" [tiab] OR "Gracilis" [tiab] OR "hamstring" [tiab] OR "Iliotibial Band" [tiab] OR "Ischial" [tiab] OR "Quadriceps" [tiab] OR "Quadriceps Femoris" [tiab] OR "Rectus Femoris" [tiab] OR "Semimembranosus" [tiab] OR "Semitendinosis" [tiab] OR "Tensor fascia lata" [tiab] OR "thigh" [tiab] OR "Vastus" [tiab])) AND ((myofascial pain syndromes [mh:noexp] OR soft tissue injuries [mh:noexp] OR tendon injuries [mh:noexp] OR tendinopathy [mh:noexp] OR sprains and strains [mh] OR myositis ossificans [mh] OR leg injuries [mh:noexp]) OR ("Avulsion" [tiab] OR "Ischiofemoral impingement" [tiab] OR "Muscle Strain" [tiab] OR "Muscle Tear" [tiab] OR "Myositis Ossificans" [tiab] OR soft tissue injuries [tiab] OR "injury" [tiab] OR "sprains and strains" [tiab] OR sprain* [tiab] OR "strains" [tiab])) AND ((Acupuncture Therapy [mh:noexp] OR Chiropractic [mh] OR Combined Modality Therapy [mh] OR Cryotherapy [mh] OR Diathermy [mh] OR Iontophoresis [mh] OR Muscle Contraction [mh] OR Orthotic Devices [mh] OR Patient Education as Topic [mh:noexp] OR Physical Therapy Modalities [mh] OR Rehabilitation [mh:noexp] OR Self Care [mh] OR Telerehabilitation [mh] OR Ultrasonography [mh]) OR ("Astym Treatment" [tiab] OR "Augmented Soft-Tissue" [tiab] OR "Mobilization" [tiab] OR "Mobilisation" [tiab] OR Brace* [tiab] OR Chiropract* [tiab] OR "Compression" [tiab] OR "Contract-relax stretching" [tiab] OR "Cross-Friction Massage" [tiab] OR Dry needl* [tiab] OR "Dynamic stretching" [tiab] OR "Exercise" [tiab] OR "Graston" [tiab] OR "Joint Mobilization" [tiab] OR " Kinesio tape" [tiab] OR "Manipulation" [tiab] OR Manual Therapy* [tiab] OR "Massage" [tiab] OR cryotherap* [Tiab] OR thermotherap* [Tiab] OR "Moist Heat" [tiab] OR "Ice" [tiab] OR "diathermy" [tiab] OR ultrasound* [Tiab] OR electrical* [Tiab] OR muscle stimul* [Tiab] OR neuromuscular stimulat* [Tiab] OR "electric muscle stimulation" [tiab] OR "functional electrical stimulation" [tiab] OR "neuromuscular electrical stimulation" [tiab] OR "transcutaneous electrical nerve stimulation" [tiab] OR "laser" [tiab] OR "iontophoresis" [tiab] OR "cryo-cuff" [tiab] OR "therapeutic modalities" [tiab] OR "physical agents" [tiab] OR "physical modalities" [tiab] OR "physical interventions" [tiab] OR Physical therap* [tiab] OR Physiotherap* [tiab] OR "passive modalities" [tiab] OR muscleso* [Tiab] OR "Nerve Mobilization" [tiab] OR "osteopathic manipulative treatment" [tiab] OR "orthotherapy" [Tiab] OR orthoti* [Tiab] OR "proprioceptive neuromuscular facilitation" [tiab] OR "stretching" [tiab] OR "Resistance Training" [tiab] OR "Soft-Tissue Therapy" [tiab] OR "Spray and stretch" [tiab] OR strength* [Tiab] OR stretch* [Tiab] OR "tape" [tiab] OR "taping" [tiab] OR trigger point* [Tiab] OR "Yoga" [tiab] OR "Platelet rich plasma injection" [tiab] OR "Shock wave therapy" [tiab] OR "Antiinflammatory medicine" [tiab] OR "Injection" [tiab] OR "Cortisone" [tiab] OR "repair" [tiab]) NOT ("animals"[MeSH Terms] NOT "humans"[MeSH Terms]))	4095

Ovid: Journals@Ovid

	Search Term	Result
1	((exp thigh / OR muscle, skeletal / OR exp quadriceps muscle / OR lower extremity / OR exp hamstring tendons / OR exp hamstring muscles / OR exp gracilis muscle /) OR (Adductor.ti,ab. OR Biceps Femoris.ti,ab. OR Gracilis.ti,ab. OR hamstring.ti,ab. OR Iliotibial Band.ti,ab. OR Ischial.ti,ab. OR Quadriceps.ti,ab. OR Quadriceps Femoris.ti,ab. OR Rectus Femoris.ti,ab. OR Semimembranosus.ti,ab. OR Semitendinosis.ti,ab. OR Tensor fascia lata.ti,ab. OR thigh.ti,ab. OR Vastus.ti,ab.)) AND ((myofascial pain syndromes / OR soft tissue injuries / OR tendon injuries / OR tendinopathy / OR sprains AND exp strains / OR exp myositis ossificans / OR myofascial pain syndromes / OR leg injuries /) OR (Avulsion.ti,ab. OR Ischiofemoral impingement.ti,ab. OR Muscle Strain.ti,ab. OR Muscle Tear.ti,ab. OR Myositis Ossificans.ti,ab. OR soft tissue injuries.ti,ab. OR injury.ti,ab. OR sprains and strains.ti,ab. OR sprain*.ti,ab. OR strains.ti,ab.)) AND ((Acupuncture Therapy / OR exp Chiropractic / OR exp Combined Modality Therapy / OR exp Cryotherapy / OR exp Diathermy / OR exp Iontophoresis / OR exp Muscle Contraction / OR exp Orthotic Devices / OR Patient Education as Topic / OR exp Physical Therapy Modalities / OR Rehabilitation / OR exp Self Care / OR exp Telerehabilitation / OR exp Ultrasonography /) OR (Astym Treatment.ti,ab. OR Augmented Soft-Tissue.ti,ab. OR Mobilization.ti,ab. OR Mobilisation.ti,ab. OR Brace*.ti,ab. OR Chiropract*.ti,ab. OR Compression.ti,ab. OR Contract-relax stretching.ti,ab. OR Cross-Friction Massage.ti,ab. OR Dry needl*.ti,ab. OR Dynamic stretching.ti,ab. OR Exercise.ti,ab. OR Graston.ti,ab. OR Joint Mobilization.ti,ab. OR Kinesio tape.ti,ab. OR Manipulation.ti,ab. OR Manual Therapy*.ti,ab. OR Massage.ti,ab. OR cryotherap*.ti,ab. OR thermotherap*.ti,ab. OR Moist Heat.ti,ab. OR Ice.ti,ab. OR diathermy.ti,ab. OR ultrasound*.ti,ab. OR electrical*.ti,ab. OR muscle stimul*.ti,ab. OR neuromuscular stimulat*.ti,ab. OR EMS.ti,ab. OR FES.ti,ab. OR NMES.ti,ab. OR TENS.ti,ab. OR laser.ti,ab. OR iontophoresis.ti,ab. OR cryo-cuff.ti,ab. OR therapeutic modalities.ti,ab. OR physical agents.ti,ab. OR physical modalities.ti,ab. OR physical interventions.ti,ab. OR Physical therap*.ti,ab. OR Physiotherap*.ti,ab. OR passive modalities.ti,ab. OR muscleso*.ti,ab. OR Nerve Mobilization.ti,ab. OR OMT.ti,ab. OR orthotherapy.ti,ab. OR orthoti*.ti,ab. OR PNF.ti,ab. OR proprioceptive neuromuscular facilitation.ti,ab. OR stretching.ti,ab. OR Resistance Training.ti,ab. OR Soft-Tissue Therapy.ti,ab. OR Spray and stretch.ti,ab. OR strength*.ti,ab. OR stretch*.ti,ab. OR tape.ti,ab. OR taping.ti,ab. OR trigger point*.ti,ab. OR Yoga.ti,ab. OR Platelet rich plasma injection.ti,ab. OR RPP.ti,ab. OR Shock wave therapy.ti,ab. OR Antiinflammatory medicine.ti,ab. OR Injection.ti,ab. OR Cortisone.ti,ab. OR repair.ti,ab.))	19

APPENDIX A

CINAHL

	Search Term	Result
1	(((MH "thigh +") OR (MH "quadriceps muscle +") OR (MH "lower extremity ") OR (MH "hamstring tendons +") OR (MH "hamstring muscles +") OR (MH "gracilis muscle +")) OR (TI Adductor OR AB Adductor OR TI "Biceps Femoris" OR AB "Biceps Femoris" OR TI Gracilis OR AB Gracilis OR TI hamstring OR AB hamstring OR TI "Iliotibial Band" OR AB "Iliotibial Band" OR TI Ischial OR AB Ischial OR TI Quadriceps OR AB Quadriceps OR TI "Quadriceps Femoris" OR AB "Quadriceps Femoris" OR TI "Rectus Femoris" OR AB "Rectus Femoris" OR TI Semimembranosus OR AB Semimembranosus OR TI Semitendinosis OR AB Semitendinosis OR TI "Tensor fascia lata" OR AB "Tensor fascia lata" OR TI thigh OR AB thigh OR TI Vastus OR AB Vastus)) AND (((MH "myofascial pain syndromes ") OR (MH "soft tissue injuries ") OR (MH "tendon injuries ") OR (MH "tendinopathy ") OR sprains AND (MH "strains +") OR (MH "myositis ossificans +") OR (MH "myofascial pain syndromes ") OR (MH "leg injuries ")) OR (TI Avulsion OR AB Avulsion OR TI "Ischiofemoral impingement" OR AB "Ischiofemoral impingement" OR TI "Muscle Strain" OR AB "Muscle Strain" OR TI "Muscle Tear" OR AB "Muscle Tear" OR TI "Myositis Ossificans" OR AB "Myositis Ossificans" OR TI "soft tissue injuries" OR AB "soft tissue injuries" OR TI injury OR AB injury OR TI "sprains and strains" OR AB "sprains and strains" OR TI sprain* OR AB sprain* OR TI strains OR AB strains)) AND (((MH "Acupuncture Therapy ") OR (MH "Chiropractic +") OR (MH "Combined Modality Therapy +") OR (MH "Cryotherapy +") OR (MH "Diathermy +") OR (MH "Iontophoresis +") OR (MH "Muscle Contraction +") OR (MH "Orthotic Devices +") OR (MH "Patient Education as Topic ") OR (MH "Physical Therapy Modalities +") OR (MH "Rehabilitation ") OR (MH "Self Care +") OR (MH "Telerehabilitation +") OR (MH "Ultrasonography +")) OR (TI "Astym Treatment" OR AB "Astym Treatment" OR TI "Augmented Soft-Tissue" OR AB "Augmented Soft-Tissue" OR TI Mobilization OR AB Mobilization OR TI Mobilisation OR AB Mobilisation OR TI Brace* OR AB Brace* OR TI Chiropract* OR AB Chiropract* OR TI Compression OR AB Compression OR TI "Contract-relax stretching" OR AB "Contract-relax stretching" OR TI "Cross-Friction Massage" OR AB "Cross-Friction Massage" OR TI "Dry needl*" OR AB "Dry needl*" OR TI "Dynamic stretching" OR AB "Dynamic stretching" OR TI Exercise OR AB Exercise OR TI Graston OR AB Graston OR TI "Joint Mobilization" OR AB "Joint Mobilization" OR TI " Kinesio tape" OR AB " Kinesio tape" OR TI Manipulation OR AB Manipulation OR TI "Manual Therapy*" OR AB "Manual Therapy*" OR TI Massage OR AB Massage OR TI cryotherap* OR AB cryotherap* OR TI thermotherap* OR AB thermotherap* OR TI "Moist Heat" OR AB "Moist Heat" OR TI Ice OR AB Ice OR TI diathermy OR AB diathermy OR TI ultrasound* OR AB ultrasound* OR TI electrical* OR AB electrical* OR TI "muscle stimul*" OR AB "muscle stimul*" OR TI "neuromuscular stimulat*" OR AB "neuromuscular stimulat*" OR TI "electric muscle stimulation" OR AB "electric muscle stimulation" OR TI "functional electrical stimulation" OR AB "functional electrical stimulation" OR TI "neuromuscular electrical stimulation" OR AB "neuromuscular stimulation" OR TI "transcutaneous electrical nerve stimulation" OR AB "transcutaneous electrical nerve stimulation" OR TI laser OR AB laser OR TI iontophoresis OR AB iontophoresis OR TI cryo-cuff OR AB cryo-cuff OR TI "therapeutic modalities" OR AB "therapeutic modalities" OR TI "physical agents" OR AB "physical agents" OR TI "physical modalities" OR AB "physical modalities" OR TI "physical interventions" OR AB "physical interventions" OR TI "Physical therap*" OR AB "Physical therap*" OR TI Physiotherap* OR AB Physiotherap* OR TI "passive modalities" OR AB "passive modalities" OR TI muscleso* OR AB muscleso* OR TI "Nerve Mobilization" OR AB "Nerve Mobilization" OR TI "osteopathic manipulative treatment" OR AB "osteopathic manipulative treatment" OR TI orthotherapy OR AB orthotherapy OR TI orthoti* OR AB orthoti* OR TI "proprioceptive neuromuscular facilitation" OR AB "proprioceptive neuromuscular facilitation" OR TI stretching OR AB stretching OR TI "Resistance Training" OR AB "Resistance Training" OR TI "Soft-Tissue Therapy" OR AB "Soft-Tissue Therapy" OR TI "Spray and stretch" OR AB "Spray and stretch" OR TI strength* OR AB strength* OR TI stretch* OR AB stretch* OR TI tape OR AB tape OR TI taping OR AB taping OR TI "trigger point*" OR AB "trigger point*" OR TI Yoga OR AB Yoga OR TI "Platelet rich plasma injection" OR AB "Platelet rich plasma injection" OR TI "Shock wave therapy" OR AB "Shock wave therapy" OR TI "Antiinflammatory medicine" OR AB "Antiinflammatory medicine" OR TI Injection OR AB Injection OR TI Cortisone OR AB Cortisone OR TI repair OR AB repair))	385

Cochrane Library

	Search Term	Result
1	(([mh thigh] OR [mh ^"muscle, skeletal"] OR [mh "quadriceps muscle"] OR [mh ^"lower extremity"] OR [mh "hamstring tendons"] OR [mh "hamstring muscles"] OR [mh "gracilis muscle"] OR Adductor:ti,ab OR "Biceps Femoris":ti,ab OR Gracilis:ti,ab OR hamstring:ti,ab OR "Iliotibial Band":ti,ab OR Ischial:ti,ab OR Quadriceps:ti,ab OR "Quadriceps Femoris":ti,ab OR "Rectus Femoris":ti,ab OR Semimembranosus:ti,ab OR Semitendinosis:ti,ab OR "Tensor fascia lata":ti,ab OR thigh:ti,ab OR Vastus:ti,ab)) AND (([mh ^"myofascial pain syndromes"] OR [mh ^"soft tissue injuries"] OR [mh ^"tendon injuries"] OR [mh ^tendinopathy] OR sprains AND [mh strains] OR [mh "myositis ossificans"] OR [mh ^"myofascial pain syndromes"] OR [mh ^"leg injuries"]) OR (Avulsion:ti,ab OR "Ischiofemoral impingement":ti,ab OR "Muscle Strain":ti,ab OR "Muscle Tear":ti,ab OR "Myositis Ossificans":ti,ab OR "soft tissue injuries":ti,ab OR injury:ti,ab OR "sprains and strains":ti,ab OR sprain*:ti,ab OR strains:ti,ab)) AND (([mh ^"Acupuncture Therapy"] OR [mh Chiropractic] OR [mh "Combined Modality Therapy"] OR [mh Cryotherapy] OR [mh Diathermy] OR [mh Iontophoresis] OR [mh "Muscle Contraction"] OR [mh "Orthotic Devices"] OR [mh ^"Patient Education as Topic"] OR [mh "Physical Therapy Modalities"] OR [mh ^Rehabilitation] OR [mh "Self Care"] OR [mh Telerehabilitation] OR [mh Ultrasonography]) OR ("Astym Treatment":ti,ab OR "Augmented Soft-Tissue":ti,ab OR Mobilization:ti,ab OR Mobilisation:ti,ab OR Brace*:ti,ab OR Chiropract*:ti,ab OR Compression:ti,ab OR "Contract-relax stretching":ti,ab OR "Cross-Friction Massage":ti,ab OR "Dry needl*":ti,ab OR "Dynamic stretching":ti,ab OR Exercise:ti,ab OR Graston:ti,ab OR "Joint Mobilization":ti,ab OR " Kinesio tape":ti,ab OR Manipulation:ti,ab OR "Manual Therapy*":ti,ab OR Massage:ti,ab OR cryotherap*:ti,ab OR thermotherap*:ti,ab OR "Moist Heat":ti,ab OR Ice:ti,ab OR diathermy:ti,ab OR ultrasound*:ti,ab OR electrical*:ti,ab OR "muscle stimul*":ti,ab OR "neuromuscular stimulat*":ti,ab OR "electric muscle stimulation":ti,ab OR "functional electric stimulation":ti,ab OR "neuromuscular electric stimulation":ti,ab OR "transcutaneous electrical nerve stimulation":ti,ab OR laser:ti,ab OR iontophoresis:ti,ab OR cryo-cuff:ti,ab OR "therapeutic modalities":ti,ab OR "physical agents":ti,ab OR "physical modalities":ti,ab OR "physical interventions":ti,ab OR "Physical therap*":ti,ab OR Physiotherap*:ti,ab OR "passive modalities":ti,ab OR muscleso*:ti,ab OR "Nerve Mobilization":ti,ab OR "osteopathic manipulative treatment":ti,ab OR orthotherapy:ti,ab OR orthoti*:ti,ab OR "proprioceptive neuromuscular facilitation":ti,ab OR stretching:ti,ab OR "Resistance Training":ti,ab OR "Soft-Tissue Therapy":ti,ab OR "Spray and stretch":ti,ab OR strength*:ti,ab OR stretch*:ti,ab OR tape:ti,ab OR taping:ti,ab OR "trigger point*":ti,ab OR Yoga:ti,ab OR "Platelet rich plasma injection":ti,ab OR "Shock wave therapy":ti,ab OR "Antiinflammatory medicine":ti,ab OR Injection:ti,ab OR Cortisone:ti,ab OR repair:ti,ab))	658

APPENDIX A

SPORTDiscus

	Search Term	Result
1	(((MH "thigh +") OR (MH "muscle, skeletal ") OR (MH "quadriceps muscle +") OR (MH "lower extremity ") OR (MH "hamstring tendons +") OR (MH "hamstring muscles +") OR (MH "gracilis muscle +")) OR (TI Adductor OR AB Adductor OR TI "Biceps Femoris" OR AB "Biceps Femoris" OR TI Gracilis OR AB Gracilis OR TI hamstring OR AB hamstring OR TI "Iliotibial Band" OR AB "Iliotibial Band" OR TI Ischial OR AB Ischial OR TI Quadriceps OR AB Quadriceps OR TI "Quadriceps Femoris" OR AB "Quadriceps Femoris" OR TI "Rectus Femoris" OR AB "Rectus Femoris" OR TI Semimembranosus OR AB Semimembranosus OR TI Semitendinosis OR AB Semitendinosis OR TI "Tensor fascia lata" OR AB "Tensor fascia lata" OR TI thigh OR AB thigh OR TI Vastus OR AB Vastus)) AND (((MH "myofascial pain syndromes ") OR (MH "soft tissue injuries ") OR (MH "tendon injuries ") OR (MH "tendinopathy ") OR sprains AND (MH "strains +") OR (MH "myositis ossificans +") OR (MH "myofascial pain syndromes ") OR (MH "leg injuries ")) OR (TI Avulsion OR AB Avulsion OR TI "Ischiofemoral impingement" OR AB "Ischiofemoral impingement" OR TI "Muscle Strain" OR AB "Muscle Strain" OR TI "Muscle Tear" OR AB "Muscle Tear" OR TI "Myositis Ossificans" OR AB "Myositis Ossificans" OR TI "soft tissue injuries" OR AB "soft tissue injuries" OR TI injury OR AB injury OR TI "sprains and strains" OR AB "sprains and strains" OR TI sprain* OR AB sprain* OR TI strains OR AB strains)) AND (((MH "Acupuncture Therapy ") OR (MH "Chiropractic +") OR (MH "Combined Modality Therapy +") OR (MH "Cryotherapy +") OR (MH "Diathermy +") OR (MH "Iontophoresis +") OR (MH "Muscle Contraction +") OR (MH "Orthotic Devices +") OR (MH "Patient Education as Topic ") OR (MH "Physical Therapy Modalities +") OR (MH "Rehabilitation ") OR (MH "Self Care +") OR (MH "Telerehabilitation +") OR (MH "Ultrasonography +")) OR (TI "Astym Treatment" OR AB "Astym Treatment" OR TI "Augmented Soft-Tissue" OR AB "Augmented Soft-Tissue" OR TI Mobilization OR AB Mobilization OR TI Mobilisation OR AB Mobilisation OR TI Brace* OR AB Brace* OR TI Chiropract* OR AB Chiropract* OR TI Compression OR AB Compression OR TI "Contract-relax stretching" OR AB "Contract-relax stretching" OR TI "Cross-Friction Massage" OR AB "Cross-Friction Massage" OR TI "Dry needl*" OR AB "Dry needl*" OR TI "Dynamic stretching" OR AB "Dynamic stretching" OR TI Exercise OR AB Exercise OR TI Graston OR AB Graston OR TI "Joint Mobilization" OR AB "Joint Mobilization" OR TI " Kinesio tape" OR AB " Kinesio tape" OR TI Manipulation OR AB Manipulation OR TI "Manual Therapy*" OR AB "Manual Therapy*" OR TI Massage OR AB Massage OR TI cryotherap* OR AB cryotherap* OR TI thermotherap* OR AB thermotherap* OR TI "Moist Heat" OR AB "Moist Heat" OR TI Ice OR AB Ice OR TI diathermy OR AB diathermy OR TI ultrasound* OR AB ultrasound* OR TI electrical* OR AB electrical* OR TI "muscle stimul*" OR AB "muscle stimul*" OR TI "neuromuscular stimulat*" OR AB "neuromuscular stimulat*" OR TI "electric muscle stimulation" OR AB "electric muscle stimulation" OR TI "functional electrical stimulation" OR AB "functional electrical stimulation" OR TI "neuromuscular electrical stimulation" OR AB "neuromuscular electrical stimulation" OR TI "transcutaneous electrical nerve stimulation" OR AB "transcutaneous electrical nerve stimulation" OR TI laser OR AB laser OR TI iontophoresis OR AB iontophoresis OR TI cryo-cuff OR AB cryo-cuff OR TI "therapeutic modalities" OR AB "therapeutic modalities" OR TI "physical agents" OR AB "physical agents" OR TI "physical modalities" OR AB "physical modalities" OR TI "physical interventions" OR AB "physical interventions" OR TI "Physical therap*" OR AB "Physical therap*" OR TI Physiotherap* OR AB Physiotherap* OR TI "passive modalities" OR AB "passive modalities" OR TI muscleso* OR AB muscleso* OR TI "Nerve Mobilization" OR AB "Nerve Mobilization" OR TI "osteopathic manipulative treatment" OR AB "osteopathic manipulative treatment" OR TI orthotherapy OR AB orthotherapy OR TI orthoti* OR AB orthoti* OR TI "proprioceptive neuromuscular facilitation" OR AB "proprioceptive neuromuscular facilitation" OR TI stretching OR AB stretching OR TI "Resistance Training" OR AB "Resistance Training" OR TI "Soft-Tissue Therapy" OR AB "Soft-Tissue Therapy" OR TI "Spray and stretch" OR AB "Spray and stretch" OR TI strength* OR AB strength* OR TI stretch* OR AB stretch* OR TI tape OR AB tape OR TI taping OR AB taping OR TI "trigger point*" OR AB "trigger point*" OR TI Yoga OR AB Yoga OR TI "Platelet rich plasma injection" OR AB "Platelet rich plasma injection" OR TI "Shock wave therapy" OR AB "Shock wave therapy" OR TI "Antiinflammatory medicine" OR AB "Antiinflammatory medicine" OR TI Injection OR AB Injection OR TI Cortisone OR AB Cortisone OR TI repair OR AB repair))	741

2021 Search Update

PubMed

	Search Term	Result
1	("Hamstring Tendons"[Mesh] OR "Biceps Femoris"[tw] OR hamstring[tw] OR hamstrings[tw] OR Semimembranosus[tw] OR Semitendinosus[tw] OR thigh[tw])	48828
2	("Myofascial pain syndromes" [mh:noexp] OR "soft tissue injuries" [mh:noexp] OR strains[mh] OR "myositis ossificans"[mh] OR "leg injuries"[mh:noexp] OR Pain[mesh:noexp] OR "Acute Pain" [mesh] OR "Chronic Pain" [mesh] OR "Musculoskeletal Pain"[mesh:noexp] OR Pain[tiab] OR Painful[tw] OR Ache[tw] OR Injury[tw] OR Injuries[tw])	1918733
3	1 AND 2	15225
4	("Hamstring strain"[mesh] OR Hamstring strain[tw] OR Hamstring tear[tw] OR Torn Hamstring[tw] OR Hamstring injury[tw] OR Hamstring injuries[tw] OR Hamstring pain[tw] OR Hamstring ache[tw] OR Hamstring Myositis Ossificans[tw])	846
5	3 OR 4	15244

Table continues on page CPG37.

APPENDIX A

	Search Term	Result
6	("Combined Modality Therapy"[Mesh:NoExp] OR Cryotherapy[mh] OR Diathermy[mh] OR Iontophoresis[mh] OR "Orthotic Devices"[mh] OR "Physical Therapy Modalities"[mh] OR Rehabilitation[mh:noexp]) OR ("Astym Treatment"[tiab] OR "Augmented Soft-Tissue"[tiab] OR "Mobilization"[tiab] OR "Mobilisation"[tiab] OR Brace[tiab] OR Braces[tiab] OR "Compression"[tiab] OR "Contract-relax stretching"[tiab] OR "Cross-Friction Massage"[tiab] OR "Dry needle"[tiab] OR "Dry needles"[tiab] OR "Dry needling"[tiab] OR "Dynamic stretching"[tiab] OR "Exercise"[tiab] OR "Graston"[tiab] OR "Joint Mobilization"[tiab] OR "Manipulation"[tiab] OR "Manual Therapy*"[tiab] OR "Massage"[tiab] OR cryotherapy[tiab] OR cryotherapies[tiab] OR thermotherapeutic[tiab] OR thermotherapy[tiab] OR thermotherapies[tiab] OR "Moist Heat"[tiab] OR "Ice"[tiab] OR "diathermy"[tiab] OR "muscle stimulation"[tiab] OR "neuromuscular stimulation"[tiab] OR "electric muscle stimulation"[tiab] OR "neuromuscular electrical stimulation"[tiab] OR "transcutaneous electrical nerve stimulation"[tiab] OR "laser therapy"[tiab] OR "laser therapies"[tiab] OR "iontophoresis"[tiab] OR "cryo-cuff"[tiab] OR "therapeutic modalities"[tiab] OR "physical agents"[tiab] OR "physical modalities"[tiab] OR "physical interventions"[tiab] OR "Physical therapeutic*"[tiab] OR "Physical therapy"[tiab] OR "Physical therapies"[tiab] OR Physiotherapy[tiab] OR Physiotherapies[tiab] OR Physiotherapeutic[tiab] OR "passive modalities"[tiab] OR "Nerve Mobilization"[tiab] OR "osteopathic manipulative treatment"[tiab] OR "orthotherapy"[tiab] OR orthotic*[tiab] OR "proprioceptive neuromuscular facilitation"[tiab] OR "stretching"[tiab] OR "Resistance Training"[tiab] OR "Strength Training"[tiab] OR "Soft-Tissue Therapy"[tiab] OR "Spray and stretch"[tiab] OR "strengthen"[tiab] OR "strengthens"[tiab] OR "strengthening"[tiab] OR stretch[tiab] OR stretches[tiab] OR stretching[tiab] OR "kinesiology tape"[tiab] OR "kinesiology taping"[tiab] OR "kinesio tape"[tiab] OR "kinesio taping"[tiab] OR "therapeutic tape"[tiab] OR "therapeutic taping"[tiab] OR "trigger point*"[tiab] OR "Yoga"[tiab])	1142488
7	5 AND 6 AND English[language] NOT ("animals"[MeSH Terms] NOT "humans"[MeSH Terms])	2801

CINAHL

	Search Term	Result
1	("Biceps Femoris" OR hamstring OR hamstrings OR Semimembranosus OR Semitendinosus OR thigh)	14889
2	(MH "Myofascial pain syndromes") OR (MH "soft tissue injuries") OR (MH "Sprains and Strains") OR (MH "Myositis Ossificans") OR (MH "Leg Injuries") OR (MH "Pain") OR (MH "Chronic Pain") OR Pain OR Painful OR Ache OR Injury OR Injuries	632844
3	1 AND 2	6942
4	"Hamstring strain" OR "Hamstring tear" OR "Hamstring injury" OR "Hamstring injuries" OR "Hamstring pain" OR "Hamstring ache" OR "Hamstring Myositis Ossificans"	634
5	3 OR 4	6947
6	(MH "Combined Modality Therapy +") OR (MH "Cryotherapy +") OR (MH "Diathermy +") OR (MH "Iontophoresis +") OR (MH "Muscle Contraction +") OR (MH "Orthotic Devices +") OR (MH "Physical Therapy Modalities +") OR (MH "Rehabilitation ") OR ((TI "Astym Treatment" OR AB "Astym Treatment") OR (TI "Augmented Soft-Tissue" OR AB "Augmented Soft-Tissue") OR (TI Mobilization OR AB Mobilization) OR (TI Mobilisation OR AB Mobilisation) OR (TI Brace OR AB Brace) OR (TI Braces OR AB Braces) OR (TI Compression OR AB Compression) OR (TI "Contract-relax stretching" OR AB "Contract-relax stretching") OR (TI "Cross-Friction Massage" OR AB "Cross-Friction Massage") OR (TI "Dry needle" OR AB "Dry needle") OR (TI "Dry needles" OR AB "Dry needles") OR (TI "Dry needling" OR AB "Dry needling") OR (TI "Dynamic stretching" OR AB "Dynamic stretching") OR (TI Exercise OR AB Exercise) OR (TI Graston OR AB Graston) OR (TI "Joint Mobilization" OR AB "Joint Mobilization") OR (TI Manipulation OR AB Manipulation) OR (TI "Manual Therapy*" OR AB "Manual Therapy*") OR (TI Massage OR AB Massage) OR (TI cryotherapy OR AB cryotherapy) OR (TI cryotherapies OR AB cryotherapies) OR (TI thermotherapeutic OR AB thermotherapeutic) OR (TI thermotherapy OR AB thermotherapy) OR (TI thermotherapies OR AB thermotherapies) OR (TI "Moist Heat" OR AB "Moist Heat") OR (TI Ice OR AB Ice) OR (TI diathermy OR AB diathermy) OR (TI "muscle stimulation" OR AB "muscle stimulation") OR (TI "neuromuscular stimulation" OR AB "neuromuscular stimulation") OR (TI "electric muscle stimulation" OR AB "electric muscle stimulation") OR (TI "neuromuscular electrical stimulation" OR AB "neuromuscular electrical stimulation") OR (TI "transcutaneous electrical nerve stimulation" OR AB "transcutaneous electrical nerve stimulation") OR (TI "laser therapy" OR AB "laser therapy") OR (TI "laser therapies" OR AB "laser therapies") OR (TI iontophoresis OR AB iontophoresis) OR (TI cryo-cuff OR AB cryo-cuff) OR (TI "therapeutic modalities" OR AB "therapeutic modalities") OR (TI "physical agents" OR AB "physical agents") OR (TI "physical modalities" OR AB "physical modalities") OR (TI "physical interventions" OR AB "physical interventions") OR (TI "Physical therapeutic*" OR AB "Physical therapeutic*") OR (TI "Physical therapy" OR AB "Physical therapy") OR (TI "Physical therapies" OR AB "Physical therapies") OR (TI Physiotherapy OR AB Physiotherapy) OR (TI Physiotherapies OR AB Physiotherapies) OR (TI Physiotherapeutic OR AB Physiotherapeutic) OR (TI "passive modalities" OR AB "passive modalities") OR (TI "Nerve Mobilization" OR AB "Nerve Mobilization") OR (TI "osteopathic manipulative treatment" OR AB "osteopathic manipulative treatment") OR (TI orthotherapy OR AB orthotherapy) OR (TI orthotic* OR AB orthotic*) OR (TI "proprioceptive neuromuscular facilitation" OR AB "proprioceptive neuromuscular facilitation") OR (TI stretching OR AB stretching) OR (TI "Resistance Training" OR AB "Resistance Training") OR (TI "Strength Training" OR AB "Strength Training") OR (TI "Soft-Tissue Therapy" OR AB "Soft-Tissue Therapy") OR (TI "Spray and stretch" OR AB "Spray and stretch") OR (TI strengthen OR AB strengthen) OR (TI strengthens OR AB strengthens) OR (TI strengthening OR AB strengthening) OR (TI stretch OR AB stretch) OR (TI stretches OR AB stretches) OR (TI stretching OR AB stretching) OR (TI "kinesiology tape" OR AB "kinesiology tape") OR (TI "kinesiology taping" OR AB "kinesiology taping") OR (TI "kinesio tape" OR AB "kinesio tape") OR (TI "kinesio taping" OR AB "kinesio taping") OR (TI "therapeutic tape" OR AB "therapeutic tape") OR (TI "therapeutic taping" OR AB "therapeutic taping") OR (TI "trigger point*" OR AB "trigger point*") OR (TI Yoga OR AB Yoga))	282834
7	5 AND 6 AND Language: English	1676

APPENDIX A

Cochrane Library

	Search Term	Result
1	"Hamstring Tendons" OR "Biceps Femoris" OR hamstring OR hamstrings OR Semimembranosus OR Semitendinosus OR thigh	7072
2	"Myofascial pain syndromes" OR "soft tissue injuries" OR strains OR "myositis ossificans" OR "leg injuries" OR "Acute Pain" OR "Chronic Pain" OR "Musculoskeletal Pain" OR Pain OR Painful OR Ache OR Injury OR Injuries	257943
3	1 AND 2	3275
4	"Hamstring strain" OR "Hamstring tear" OR "Hamstring injury" OR "Hamstring injuries" OR "Hamstring pain" OR "Hamstring ache" OR "Hamstring Myositis Ossificans"	151
5	3 OR 4	3278
6	([mh ^"Combined Modality Therapy"] OR [mh Cryotherapy] OR [mh Diathermy] OR [mh Iontophoresis] OR [mh "Orthotic Devices"] OR [mh "Physical Therapy Modalities"] OR [mh ^Rehabilitation]) OR ("Astym Treatment":ti,ab OR "Augmented Soft-Tissue":ti,ab OR Mobilization:ti,ab OR Mobilisation:ti,ab OR Brace:ti,ab OR Braces:ti,ab OR Compression:ti,ab OR "Contract-relax stretching":ti,ab OR "Cross-Friction Massage":ti,ab OR "Dry needle":ti,ab OR "Dry needles":ti,ab OR "Dry needling":ti,ab OR "Dynamic stretching":ti,ab OR Exercise:ti,ab OR Graston:ti,ab OR "Joint Mobilization":ti,ab OR Manipulation:ti,ab OR "Manual Therapy":ti,ab OR Massage:ti,ab OR cryotherapy:ti,ab OR cryotherapies:ti,ab OR thermotherapeutic:ti,ab OR thermotherapy:ti,ab OR thermotherapies:ti,ab OR "Moist Heat":ti,ab OR Ice:ti,ab OR diathermy:ti,ab OR "muscle stimulation":ti,ab OR "neuromuscular stimulation":ti,ab OR "electric muscle stimulation":ti,ab OR "neuromuscular electrical stimulation":ti,ab OR "transcutaneous electrical nerve stimulation":ti,ab OR "laser therapy":ti,ab OR "laser therapies":ti,ab OR iontophoresis:ti,ab OR cryo-cuff:ti,ab OR "therapeutic modalities":ti,ab OR "physical agents":ti,ab OR "physical modalities":ti,ab OR "physical interventions":ti,ab OR "Physical therapeutic":ti,ab OR "Physical therapy":ti,ab OR "Physical therapies":ti,ab OR Physiotherapy:ti,ab OR Physiotherapies:ti,ab OR Physiotherapeutic:ti,ab OR "passive modalities":ti,ab OR "Nerve Mobilization":ti,ab OR "osteopathic manipulative treatment":ti,ab OR orthotherapy:ti,ab OR orthotic*:ti,ab OR "proprioceptive neuromuscular facilitation":ti,ab OR stretching:ti,ab OR "Resistance Training":ti,ab OR "Strength Training":ti,ab OR "Soft-Tissue Therapy":ti,ab OR "Spray and stretch":ti,ab OR strengthen:ti,ab OR strengthens:ti,ab OR strengthening:ti,ab OR stretch:ti,ab OR stretches:ti,ab OR stretching:ti,ab OR "kinesiology tape":ti,ab OR "kinesiology taping":ti,ab OR "kinesio tape":ti,ab OR "kinesio taping":ti,ab OR "therapeutic tape":ti,ab OR "therapeutic taping":ti,ab OR "trigger point":ti,ab OR Yoga:ti,ab)	170452
7	5 AND 6	1540

APPENDIX B

ARTICLE INCLUSION AND EXCLUSION CRITERIA

Return to Play

Inclusion	Exclusion
• Strain injury of 1 or more of the hamstring muscles • 10 or more participants • Primarily adult and adolescent (12 years old or older) participants • Studies reporting on persons younger than 12 years old if the proportion in the sample is small (less than 5%) or if separate data are available for adults • Includes the outcome of return to play, defined by any of the following terms: return/resume: play, sport, recreation, activity, competition • Studies that follow participants from onset of injury to return to play	• Studies not published in English • Fewer than 10 participants • Primarily infant and child (younger than 12 years old) participants • Surgical management of hamstring strain injury • Any condition other than hamstring muscle strain injury, such as - Adductor or quadriceps strain - Contusions - Tendinosis and tendinopathy, including of the hamstring muscles - Fractures (including stress fracture and avulsion) - Postoperative thigh pain from hip/knee surgery - Compartment syndrome - Nonmusculoskeletal thigh pain - Primary peripheral nerve entrapment - Peripheral vascular disease - Tumors

Reinjury Risk

Inclusion	Exclusion
• Strain injury of 1 or more of the hamstring muscles • 10 or more participants • Primarily adult and adolescent (12 years old or older) participants • Studies reporting on persons younger than 12 years old if the proportion in the sample is small (less than 5%) or if separate data are available for adults • Longitudinal studies that follow participants from onset of injury to reinjury	• Studies not published in English • Fewer than 10 participants • Primarily infant and child (younger than 12 years old) participants • Surgical management of hamstring strain injury • Any condition other than hamstring muscle strain injury, such as - Adductor or quadriceps strain - Contusions - Tendinosis and tendinopathy, including of the hamstring muscles - Fractures (including stress fracture and avulsion) - Postoperative thigh pain from hip/knee surgery - Compartment syndrome - Nonmusculoskeletal thigh pain - Primary peripheral nerve entrapment - Peripheral vascular disease - Tumors

Evaluation

Inclusion	Exclusion
• Individuals with a hamstring strain injury of 1 or more of the hamstring muscles • Studies that assess hamstring strain, including diagnosis (likelihood ratios, sensitivity and specificity, positive and negative predictive values, all pertinent evaluations, and patient-reported outcome measures in those with a hamstring strain) • Outcome must include injury risk or occurrence • 10 or more participants • Primarily adult and adolescent (12 years old or older) participants • Studies reporting on persons younger than 12 years old if the proportion in the sample is small (less than 5%) or if separate data are available for adults • Diagnostic imaging (ultrasound, MRI, etc) for hamstring muscle strains • Interventions within the scope of physical therapy practice	• Outcome that does not include injury risk or occurrence • Fewer than 10 participants • Primarily infant and child (younger than 12 years old) participants • Diagnostic imaging (ultrasound, MRI, etc) for hamstring muscle tendon injuries • Studies that include surgical management of hamstring strain injury • Adductor or quadriceps strain, contusions • Tendinosis and tendinopathy, including of the hamstring muscles • Fractures (including stress fractures) • Postoperative thigh pain from hip/knee surgery • Compartment syndrome, nonmusculoskeletal thigh pain • Primary peripheral nerve entrapment, peripheral vascular disease, tumors

Abbreviation: MRI, magnetic resonance imaging.

APPENDIX B

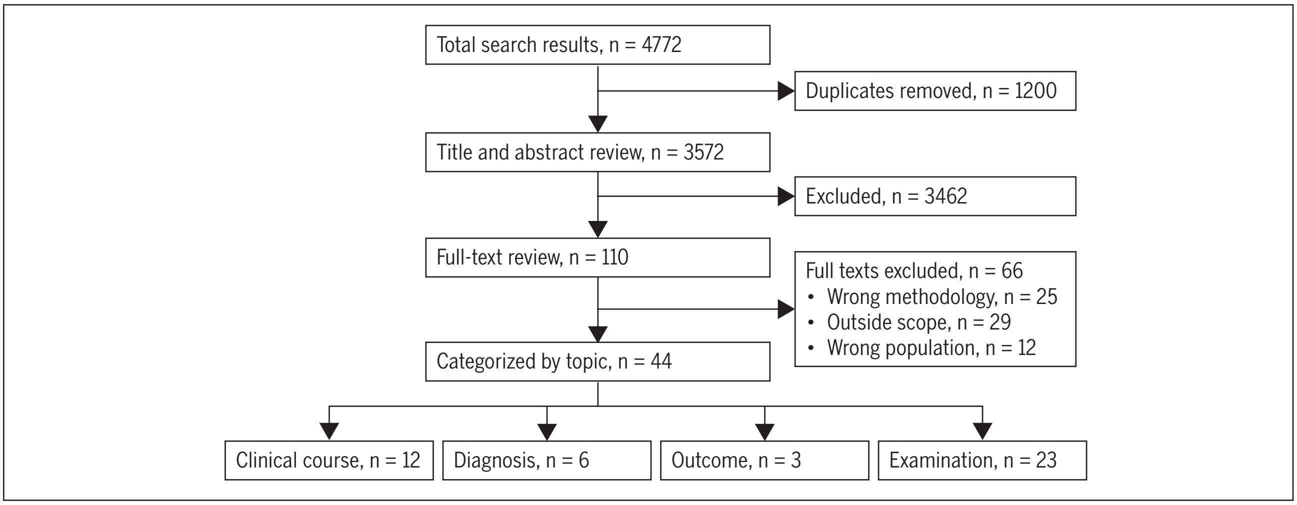
Intervention

Inclusion	Exclusion
Prevention • Healthy individuals; a history of hamstring strain injury is acceptable • Interventions within the scope of physical therapy practice • Outcome must include injury risk or occurrence (longitudinal prospective) • 10 or more participants • Primarily adult and adolescent (12 years old or older) participants • Studies reporting on persons younger than 12 years old if the proportion in the sample is small (less than 5%) or if separate data are available for adults Rehabilitation • Strain injury of 1 or more of the hamstring muscles • Interventions within the scope of physical therapy practice • 10 or more participants • Primarily adult and adolescent (12 years old or older) participants • Studies reporting on persons younger than 12 years old if the proportion in the sample is small (less than 5%) or if separate data are available for adults	Prevention • Interventions not specifically targeting hamstring strain injury prevention • Interventions outside the scope of physical therapy practice • Outcome that does not include injury risk or occurrence • Fewer than 10 participants • Primarily infant and child (younger than 12 years old) participants Interventions • Interventions outside the scope of physical therapy practice • Fewer than 10 participants • Primarily infant and child (younger than 12 years old) participants • Surgical management of hamstring strain injury • Any condition other than hamstring muscle strain injury, such as - Adductor or quadriceps strain - Contusions - Tendinosis and tendinopathy, including of the hamstring muscles - Fractures (including stress fractures) - Postoperative thigh pain from hip/knee surgery - Compartment syndrome - Nonmusculoskeletal thigh pain - Primary peripheral nerve entrapment - Peripheral vascular disease - Tumors

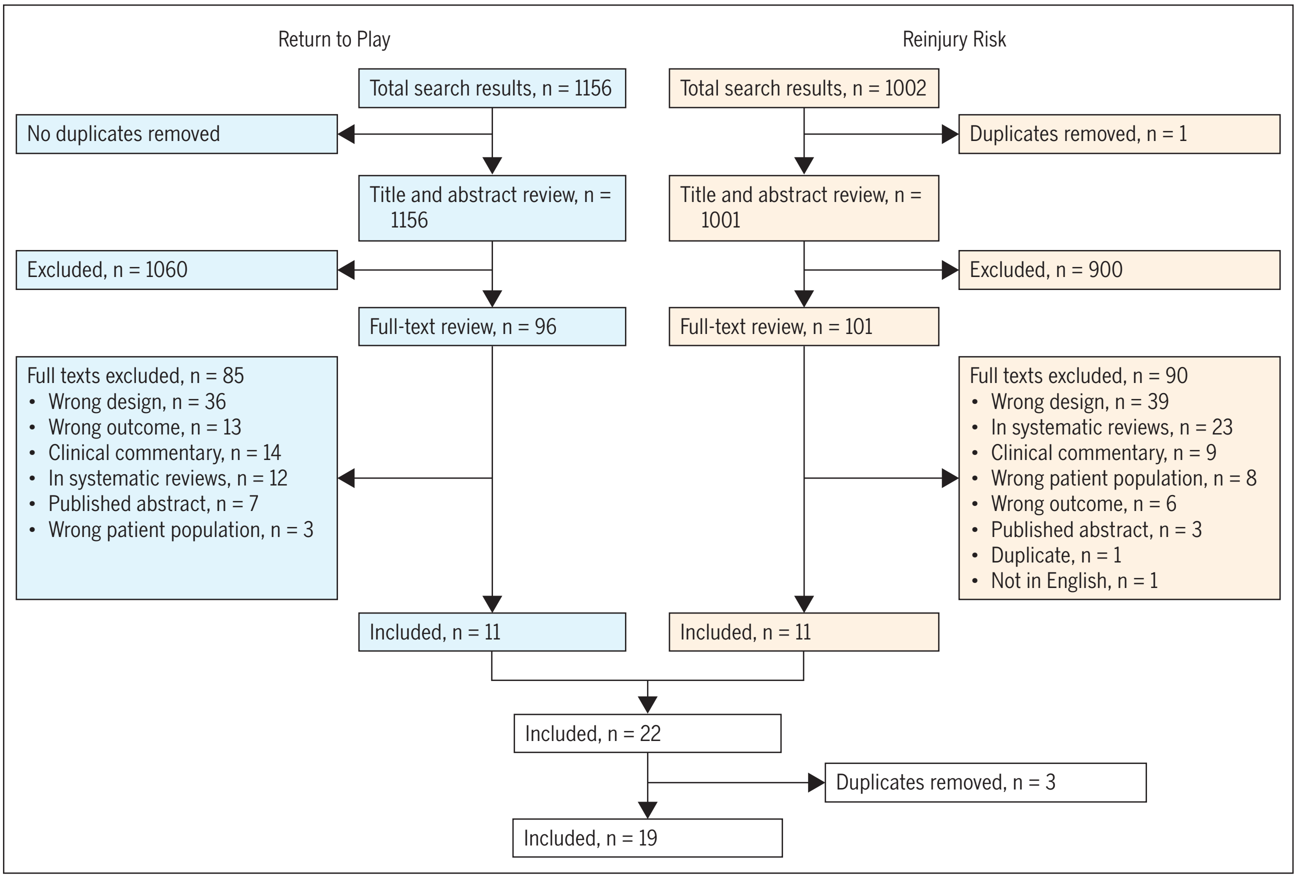
APPENDIX C

FLOW CHARTS OF ARTICLES

Evaluation

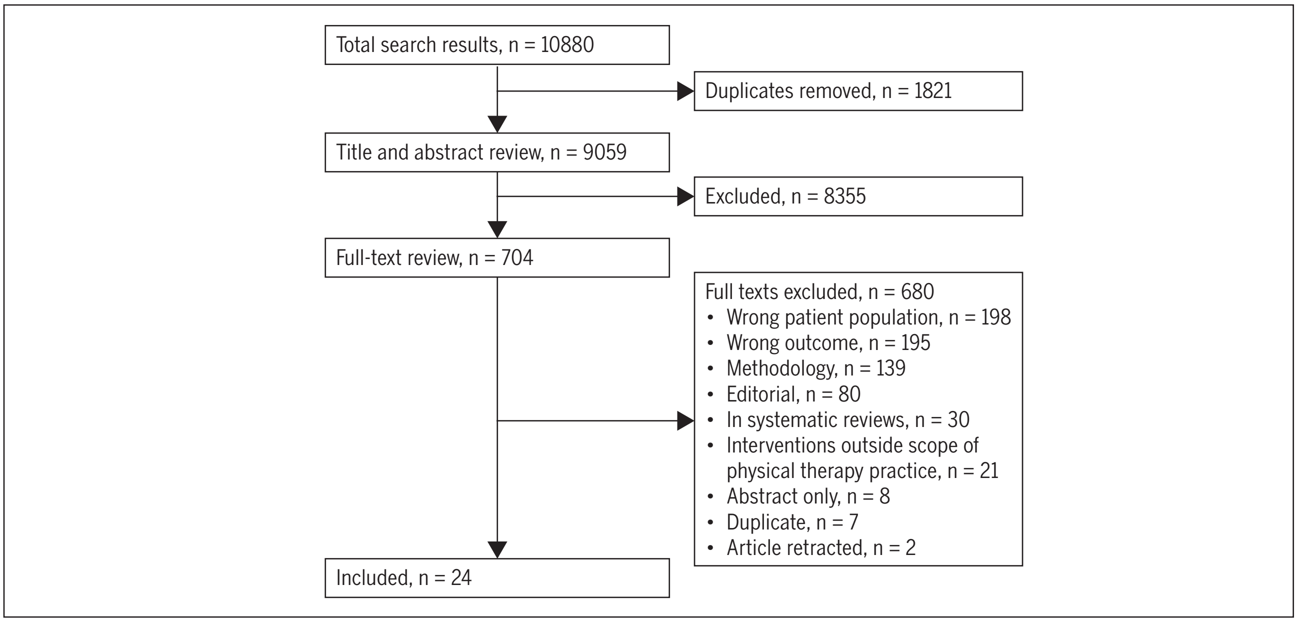


Return to Play and Reinjury Risk



APPENDIX C

Injury Prevention and Intervention



APPENDIX D

LEVEL-OF-EVIDENCE TABLE[a]

Level	Intervention/Prevention	Pathoanatomic/Risk/Clinical Course/Prognosis/Differential Diagnosis	Diagnosis/Diagnostic Accuracy	Prevalence of Condition/ Disorder	Exam/Outcomes
I	Systematic review of high-quality RCTs High-quality RCT[b]	Systematic review of prospective cohort studies High-quality prospective cohort study[c]	Systematic review of high-quality diagnostic studies High-quality diagnostic study[d] with validation	Systematic review, high-quality cross-sectional studies High-quality cross-sectional study[e]	Systematic review of prospective cohort studies High-quality prospective cohort study
II	Systematic review of high-quality cohort studies High-quality cohort study[c] Outcomes study or ecological study Lower-quality RCT[f]	Systematic review of retrospective cohort study Lower-quality prospective cohort study High-quality retrospective cohort study Consecutive cohort Outcomes study or ecological study	Systematic review of exploratory diagnostic studies or consecutive cohort studies High-quality exploratory diagnostic studies Consecutive retrospective cohort	Systematic review of studies that allows relevant estimate Lower-quality cross-sectional study	Systematic review of lower-quality prospective cohort studies Lower-quality prospective cohort study
III	Systematic reviews of case-control studies High-quality case-control study Lower-quality cohort study	Lower-quality retrospective cohort study High-quality cross-sectional study Case-control study	Lower-quality exploratory diagnostic studies Nonconsecutive retrospective cohort	Local nonrandom study	High-quality cross-sectional study
IV	Case series	Case series	Case-control study		Lower-quality cross-sectional study
V	Expert opinion	Expert opinion	Expert opinion	Expert opinion	Expert opinion

Abbreviation: RCT, randomized clinical trial.
[a]*Adapted from Phillips B, Ball C, Sackett D, et al. Oxford Centre for Evidence-Based Medicine: levels of evidence (March 2009). Available at: https://www.cebm.ox.ac.uk/resources/levels-of-evidence/oxford-centre-for-evidence-based-medicine-levels-of-evidence-march-2009. Accessed January 26, 2021. See also* **APPENDIX E.**
[b]*High quality includes RCTs with greater than 80% follow-up, blinding, and appropriate randomization procedures.*
[c]*High-quality cohort study includes greater than 80% follow-up.*
[d]*High-quality diagnostic study includes consistently applied reference standard and blinding.*
[e]*High-quality prevalence study is a cross-sectional study that uses a local and current random sample or censuses.*
[f]*Weaker diagnostic criteria and reference standards, improper randomization, no blinding, and less than 80% follow-up may add bias and threats to validity.*

APPENDIX E

PROCEDURES FOR ASSIGNING LEVELS OF EVIDENCE

- Level of evidence is assigned based on the study design, using the levels-of-evidence table (**APPENDIX D**), assuming high quality (eg, for intervention, randomized clinical trial starts at level I)
- Study quality is assessed using the critical appraisal tool, and the study is assigned 1 of 4 overall quality ratings, based on the critical appraisal results
- Level of evidence assignment is adjusted based on the overall quality rating
  - High quality (high confidence in the estimate/results): the study remains at its assigned level of evidence (eg, if the randomized clinical trial is rated high quality, then its final assignment is level I). High quality should include
    - Randomized clinical trial with greater than 80% follow-up, blinding, and appropriate randomization procedures
    - Cohort study includes greater than 80% follow-up
    - Diagnostic study includes a consistently applied reference standard and blinding
    - Prevalence study is a cross-sectional study that uses a local and current random sample or censuses
  - Acceptable quality (the study does not meet requirements for high quality and weaknesses limit the confidence in the accuracy of the estimate): downgrade 1 level
    - Based on critical appraisal results
  - Low quality: the study has significant limitations that substantially limit confidence in the estimate: downgrade 2 levels
    - Based on critical appraisal results
  - Unacceptable quality: serious limitations—exclude from consideration in the guideline
    - Based on critical appraisal results

NICKY VAN MELICK, PT, PhD[1] • WALTER VAN DER WEEGEN, PhD[1] • NICK VAN DER HORST, PT, PhD[2]

Quadriceps and Hamstrings Strength Reference Values for Athletes With and Without Anterior Cruciate Ligament Reconstruction Who Play Popular Pivoting Sports, Including Soccer, Basketball, and Handball: A Scoping Review

Quadriceps and hamstrings strength tests are important when evaluating rehabilitation progression and making return-to-sport (RTS) decisions after anterior cruciate ligament reconstruction (ACLR).[7,43,53] Athletes who play pivoting sports and who pass strength tests as part of an RTS testing protocol are at lower risk for a second anterior cruciate ligament (ACL) injury, underscoring the importance of these tests.[18,19,30]

OBJECTIVE: To synthesize and present reference values for quadriceps and hamstrings strength tests in healthy athletes who play pivoting sports and in athletes with anterior cruciate ligament reconstruction (ACLR) who play pivoting sports.

DESIGN: Scoping review.

LITERATURE SEARCH: We searched PubMed, the Cochrane Library, MEDLINE, Embase, and Web of Science up to January 26, 2021.

STUDY SELECTION CRITERIA: We included reference values in 2 different categories: (1) quadriceps and hamstrings strength test outcomes in healthy pivoting-sport athletes, and (2) quadriceps and hamstrings strength test outcomes in pivoting-sport athletes with ACLR at a specific time point during rehabilitation.

DATA SYNTHESIS: We performed a qualitative synthesis for reference values from isokinetic (at 60°/s, 180°/s, and 300°/s) and isometric quadriceps and hamstrings strength tests. We summarized the data for type of sport, sex, sport participation level, and age group.

RESULTS: Of the 42 included studies, 26 reported reference values from healthy soccer players, 4 from healthy basketball players, 4 from healthy handball players, and 11 from other healthy pivoting-sport athletes. The limb symmetry index dominant/nondominant limb (LSI-D/ND) ranged from 98% to 114% for healthy athletes. Six studies reported reference values in pivoting-sport athletes with ACLR at a specific time point during rehabilitation. After 7 months, strength values for athletes with ACLR were comparable to those of healthy pivoting-sport athletes.

CONCLUSION: This scoping review summarizes quadriceps and hamstrings strength reference values for athletes who play the most common pivoting sports, including soccer, basketball, and handball. *J Orthop Sports Phys Ther 2022;52(3):142-155. Epub 31 Dec 2021. doi:10.2519/jospt.2022.10693*

KEY WORDS: *anterior cruciate ligament reconstruction, muscle strength, reference values*

The limb symmetry index (LSI)—a comparison between the operated and nonoperated limbs—is often used to guide RTS decisions. However, clinicians and researchers have long raised concerns about using the nonoperated limb as a reference, as the nonoperated limb also detrains and loses strength after injury and surgery.[57] As a result, the LSI may overestimate operated-knee function and may not be sensitive enough to alert clinicians and athletes to a high risk of second ACL injury.[57]

The use of both LSI and preinjury strength values to guide rehabilitation progression could be a solution, but preinjury data are often unavailable in everyday practice. Strength test reference values derived from healthy athletes who play pivoting sports could solve this problem, but a comprehensive overview of reference values for different sports is currently lacking.

We aimed to synthesize and present reference values for quadriceps and hamstrings strength tests in athletes with and without ACLR who play pivoting sports. The goal of our scoping review was to present information to help clinicians

[1]Sports and Orthopaedics Research Center, Anna Hospital, Geldrop, the Netherlands. [2]PSV Eindhoven, Eindhoven, the Netherlands. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Nicky van Melick, Sports and Orthopaedics Research Center, Anna Hospital, Bogardeind 2, 5664 EH Geldrop, the Netherlands. E-mail: n.van.melick@st-anna.nl

understand what "normal" quadriceps and hamstrings strength is for the athletes they work with: what to expect from healthy players without ACLR, and what to expect during rehabilitation and RTS progressions after ACLR. We present reference values for different pivoting sports, sexes, sport participation levels (elite and nonelite), and age groups.

METHODS

THIS SCOPING REVIEW WAS CONDUCTED and reported according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR).[49]

Eligibility Criteria

Inclusion and exclusion criteria were specified for 2 different categories of reference values: (1) quadriceps and hamstrings strength test outcomes in pivoting-sport athletes with ACLR at a specific time point during rehabilitation, from 3 months to RTS, and (2) quadriceps and hamstrings strength test outcomes in healthy pivoting-sport athletes, which can be used as RTS criteria (**TABLE 1**).

Search Strategy

On January 26, 2021, a systematic literature search was performed by an academic librarian. PubMed, the Cochrane Library, MEDLINE, Embase, and Web of Science were searched from database inception to identify relevant articles, using key words specified for the database (supplemental file 1). In addition, a hand search of the reference lists of meta-analyses and systematic reviews was conducted to identify additional studies not found in the primary search.

All database records were exported to the Rayyan application[40] in separate files for quadriceps and hamstrings strength. Duplicates were removed from each file.

Study Selection

Two authors (N.v.M. and W.v.d.W.) independently screened titles and abstracts for eligibility. For all potentially eligible studies, a full-text version was reviewed by 2 authors (W.v.d.W. and N.v.d.H.). Any disagreements in both steps were resolved by consensus. After this, both quadriceps and hamstrings strength Rayyan[40] files were combined, and duplicates were removed.

Data Synthesis

One author (N.v.M.) extracted all relevant study characteristics and reference value data. Study characteristics included author and year of publication, population characteristics, test details, and test outcome variables. Reference values were categorized as pivoting-sport athlete with or without ACLR, type of sport, sex, sport level (elite or nonelite), and age group (adolescent [16-19 years of age] or young adult [20-35 years of age]).[60]

Test outcome variables were reported as the following reference values: peak torque; peak torque normalized to body weight (BW); total work (only reported for an endurance test with at least 10 repetitions and when a test range was described); LSI, calculated as [(operated leg/nonoperated leg) × 100%] for athletes with ACLR LSI-D/ND calculated as [(dominant leg)/(nondominant leg) × 100%] for healthy athletes[54]; concentric hamstrings-to-quadriceps ratio; dynamic control ratio (eccentric hamstrings-to-concentric quadriceps); and maximum voluntary isometric contraction (MVIC). Limb symmetry indexes and ratios were extracted or calculated from the individual studies. When LSIs based on both peak torque and peak torque normalized to BW were available, only the LSI based on peak torque normalized to BW was reported.

When 3 or more studies reported on the same sport, we created a reference value table for the sport. We grouped data from all other sports (reported in

TABLE 1 Inclusion and Exclusion Criteria for Reference Values Derived From Healthy and ACL-Reconstructed Pivoting-Sport Athletes

	Inclusion	Exclusion
Population	• Adolescents (mean age, 16-19 y) or young adults (mean age, 20-35 y) • Athletes performing pivoting sports (clear sports description, Tegner score ≥6, or level 1 or 2 sports[a]) • Athletes with ACLR - Potential concomitant MCL or LCL injuries - Potential concomitant meniscal or cartilage injuries • Male or female athletes • Elite or recreational athletes	• Healthy athletes: history of ACL injury or surgery in the past, or other lower extremity or lower back injury when tested • Athletes with ACLR - ACL revision surgery or contralateral ACL injury in the past - Concomitant PCL injuries
Outcome	• Strength tests for quadriceps or hamstrings with an isokinetic dynamometer (isometric or concentric/eccentric at 60°/s-180°/s-300°/s[50]) or a handheld dynamometer • Absolute values or limb symmetry indexes reported as an outcome • Athletes with ACLR: tests performed at a specific time point during rehabilitation, from 3 mo until the moment of return to sport	• No separate results for male and female athletes • No separate results for elite or recreational athletes • Athletes with ACLR: tests performed more than 1 y after ACLR
Publication type	• All original research types • Language: English, Dutch, or German	• Meta-analyses, systematic or narrative reviews, conference abstracts, posters

Abbreviations: ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; LCL, lateral collateral ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament.
[a]Level 1 sports are sports with frequent pivoting movements (eg, soccer, handball, basketball); level 2 sports are sports with lateral movements and less pivoting than level 1 sports (eg, racket sports, alpine skiing).[22]

2 or fewer studies) in 1 extra reference value table.

All outcome variables reported in 2 or more studies were presented as a weighted mean with a weighted standard deviation. The weighted mean was calculated as the sum of (study mean × study sample size), divided by the sum of all study sample sizes.

The weighted standard deviation was calculated as the sum of (study variance × study sample size), divided by the sum of all study sample sizes. Study variance was calculated as study mean minus weighted mean.

Outcome variables reported in a single study were displayed as mean ± SD. Standard deviation was not available if we calculated the LSI or ratio from data extracted from a specific study.

RESULTS

Study Selection

After removing duplicates, the systematic literature search yielded 712 articles for quadriceps strength and 246 articles for hamstrings strength. After screening titles, abstracts, and full texts for eligibility, 926 articles were excluded, leaving 32 articles for quadriceps and hamstrings strength combined. Hand searching reference lists of meta-analyses and systematic reviews provided 10 additional articles; 42 articles were included for data synthesis (**FIGURE**).

Overview of Strength Testing Protocols

Data on study characteristics are described in supplemental file 2. All included studies performed strength measurements using an isokinetic dynamometer, with a Biodex (Biodex Medical Systems, Shirley, NY) or Cybex (Life Fitness, Rosemont, IL) being used most often (55% and 33%, respectively). Thirty-nine studies measured isokinetic strength only, 2 measured isometric strength only, and 1 measured isokinetic and isometric strength.

Isokinetic Strength Testing Protocols

Two studies measured concentric quadriceps strength only, 28 studies measured concentric quadriceps and hamstrings strength, 6 studies measured concentric quadriceps and concentric plus eccentric hamstrings strength, and 4 studies measured concentric plus eccentric quadriceps and hamstrings strength.

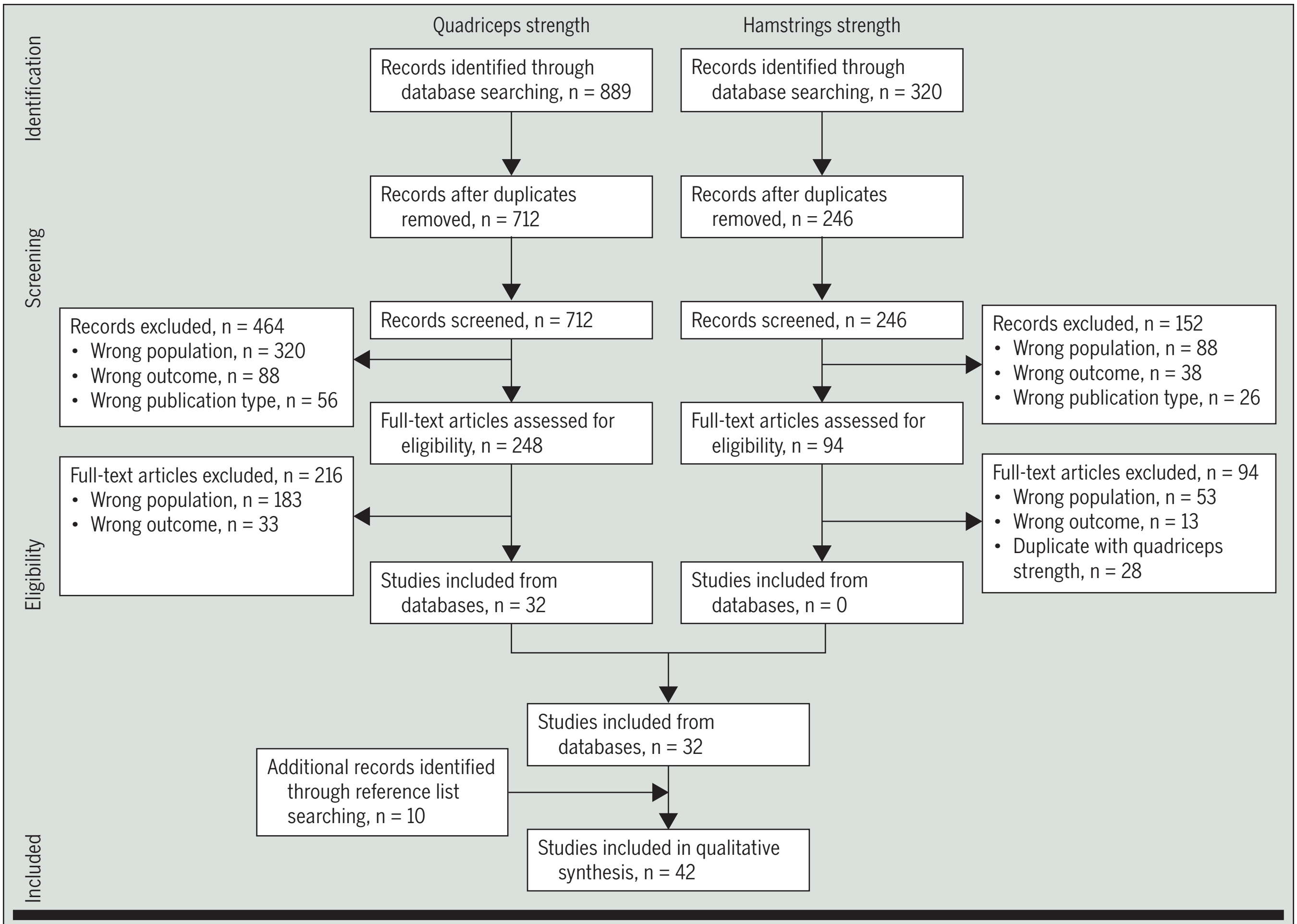


FIGURE. PRISMA flow chart of the study inclusion process.

Thirty-six studies performed concentric strength measurements at 60°/s, usually with 3 or 5 repetitions (39% and 42%, respectively). Seventeen studies reported strength measurements at 180°/s and/or 300°/s, typically with 3 or 5 repetitions (29% and 35%, respectively). One study that reported total work as an outcome parameter performed more than 10 repetitions at these higher speeds.[63] Eccentric strength was typically measured over 5 repetitions (70%). Range of motion was not specified in 33% of all isokinetic studies. In those that reported range of motion, 100° to 0° of flexion and 90° to 0° of flexion were mentioned in 15% and 33%, respectively. Rest between sets and whether gravity correction was performed were usually not described.

Isometric Strength Testing Protocols

Isometric strength measurements were all performed at different knee angles (45°, 70°, or 90° of flexion) and with different durations (2, 3, or 4 seconds).

Quadriceps and Hamstrings Strength Test Results

Soccer Strength results from healthy soccer players were reported in 26 studies.[2,6,9-12,14,15,17,20,21,24,29,33,34,39,41,44-46,48,51,55,56,59,62] There were data from 1987 soccer players (84% male) who were 24.0 ± 2.1 years of age (**TABLE 2**).

Basketball Strength results from healthy basketball players were reported in 4 studies.[16,29,33,47] There were data from 99 healthy basketball players (74% male) who were 22.5 ± 0.99 years of age (**TABLE 3**).

Handball Strength results from healthy handball players were reported in 4 studies.[2,16,31,44] There were data from 310 handball players (5% male) who were 21.3 ± 1.3 years of age (**TABLE 4**).

Other Pivoting Sports All other pivoting

TABLE 2 QUADRICEPS AND HAMSTRINGS STRENGTH REFERENCE VALUES FROM HEALTHY SOCCER PLAYERS[2,6,9-12,14,15,17,20,21,24,29,33,34,39,41,44-46,48,51,55,56,59,62]

		Isokinetic[a]			Isometric[a]
Sex/Sport Level	**Population[a]**	**60°/s**	**180°/s**	**300°/s**	**90°**
Male					
Elite	n = 58 adolescents Age, 17.1 ± 0.8 y[15,21,41]	Quadriceps Peak torque, 182 ± 28 Nm D/ND LSI[b] = 102% ± 15% Hamstrings Peak torque, 97 ± 18 Nm D/ND LSI[b] = 108% ± 18% Eccentric peak torque, 151 ± 29 Nm Ratio DCR[c] = 84%[d]	Quadriceps Peak torque, 145 ± 13 Nm D/ND LSI[b] = 99%[d] Eccentric peak torque, 244 ± 42 Nm Hamstrings Peak torque, 87 ± 15 Nm D/ND LSI[b] = 98%[d] Eccentric peak torque, 138 ± 21 Nm Ratios HQR[e] = 61% ± 9% DCR[c] = 96% ± 20%	Quadriceps Peak torque, 122 ± 14 Nm D/ND LSI[b] = 99%[d] Eccentric peak torque, 249 ± 41 Nm Hamstrings Peak torque, 72 ± 9 Nm D/ND LSI[b] = 99%[d] Eccentric peak torque, 141 ± 23 Nm Ratios HQR[e] = 61% ± 7% DCR[c] = 117% ± 23%	Quadriceps MVIC, 409 ± 78 N Hamstrings MVIC, 173 ± 38 N
	n = 1499 young adults Age, 24.9 ± 1.2 y[2,6,9,11,12,14,17,20,21,24,33,34,45,46,51,55,59,62]	Quadriceps Peak torque, 239 ± 16 Nm Peak torque per BW, 3.17 ± –0.10 Nm/kg D/ND LSI[b] = 99% ± 2% Eccentric peak torque, 299 ± 12 Nm Hamstrings Peak torque, 138 ± 4 Nm Peak torque per BW, 1.78 ± –0.10 Nm/kg D/ND LSI[b] = 102% ± 3% Eccentric peak torque, 187 ± 19 Nm Eccentric peak torque per BW, 2.60 ± –0.26 Nm/kg Ratios HQR[e] = 60% ± 3% DCR[c] = 75% ± 3%	Quadriceps Peak torque, 168 ± 14 Nm Peak torque per BW, 2.56 ± –0.10 Nm/kg D/ND LSI[b] = 103% ± 0% Eccentric peak torque, 249 ± 40 Nm Hamstrings Peak torque, 106 ± 7 Nm Peak torque per BW, 1.62 ± –0.05 Nm/kg D/ND LSI[b] = 102% ± 0% Eccentric peak torque, 154 ± 1 Nm Ratios HQR[e] = 62% ± 6% DCR[c] = 101% ± 3%	Quadriceps Peak torque, 134 ± 6 Nm Peak torque per BW, 1.87 ± –0.01 Nm/kg D/ND LSI[b] = 102% ± 0% Eccentric peak torque, 256 ± 15 Nm Hamstrings Peak torque, 93 ± 7 Nm Peak torque per BW, 1.33 ± –0.01 Nm/kg D/ND LSI[b] = 101% ± 4% Eccentric peak torque, 162 ± 4 Nm Ratios HQR[e] = 68% ± 6% DCR[c] = 126% ± 5%	

Table continues on page 146.

TABLE 2 Quadriceps and Hamstrings Strength Reference Values From Healthy Soccer Players[2,6,9-12,14,15,17,20,21,24,29,33,34,39,41,44-46,48,51,55,56,59,62] (continued)

		Isokinetic[a]			Isometric[a]
Sex/Sport Level	**Population[a]**	**60°/s**	**180°/s**	**300°/s**	**90°**
Nonelite	n = 10 adolescents Age, 17.8 ± 0.1 y[29]		Quadriceps Peak torque, 125 ± 15 Nm Peak torque per BW, 2.05 ± −0.20 Nm/kg Hamstrings Peak torque, 105 ± 7 Nm Peak torque per BW, 1.70 ± −0.10 Nm/kg Ratio HQR[e] = 86% ± 7%	Quadriceps Peak torque, 90 ± 15 Nm Peak torque per BW, 1.50 ± −0.20 Nm/kg Hamstrings Peak torque, 70 ± 5 Nm Peak torque per BW, 1.15 ± −0.05 Nm/kg Ratio HQR[e] = 82% ± 10%	
	n = 106 young adults Age, 23.5 ± 1.5 y[10,11,48,56]	Quadriceps Peak torque, 225 ± 0 Nm Peak torque per BW, 2.76 ± −0.41 Nm/kg D/ND LSI[b] = 106% ± 1% Eccentric peak torque, 310 ± 10 Nm Eccentric peak torque per BW, 2.69 ± −0.45 Nm/kg Hamstrings Peak torque, 130 ± 5 Nm Peak torque per BW, 1.57 ± −0.23 Nm/kg D/ND LSI[b] = 106% ± 6% Eccentric peak torque, 150 ± 10 Nm Eccentric peak torque per BW, 1.56 ± −0.35 Nm/kg Ratios HQR[e] = 61% ± 3% DCR[c] = 71% ± 7%	Quadriceps Peak torque, 150 ± 3 Nm Hamstrings Peak torque, 105 ± 7 Nm Ratio HQR[e] = 71% ± 8%	Quadriceps Peak torque, 125 ± 5 Nm Peak torque per BW, 1.27 ± −0.23 Nm/kg D/ND LSI[b] = 106%[d] Hamstrings Peak torque, 90 ± 7 Nm Peak torque per BW, 0.98 ± −0.19 Nm/kg D/ND LSI[b] = 114%[d] Ratio HQR[e] = 79% ± 1%	
Female					
Elite	n = 213 young adults Age, 21.3 ± 0.6 y[2,44]	Quadriceps Peak torque, 149 ± 3 Nm Peak torque per BW, 2.32 ± −0.36 Nm/kg D/ND LSI[b] = 101%[d] Hamstrings Peak torque, 87 ± 1 Nm Peak torque per BW, 1.36 ± −0.21 Nm/kg D/ND LSI[b] = 103%[d] Ratio HQR[e] = 59% ± 1%		Quadriceps Peak torque, 83 ± 12 Nm Hamstrings Peak torque, 60 ± 9 Nm Ratio HQR[e] = 72% ± 11%	
Nonelite	n = 101 young adults Age, 20.3 ± 4.1 y[39]	Quadriceps Peak torque, 88 ± 15 Nm D/ND LSI[b] = 101%[d]	Quadriceps Peak torque, 60 ± 10 Nm D/ND LSI[b] = 101%[d]		

Abbreviations: BW, body weight; D, dominant; DCR, dynamic control ratio; HQR, hamstrings-quadriceps ratio; LSI, limb symmetry index; MVIC, maximum voluntary isometric contraction; ND, nondominant.
[a]Values are mean ± SD unless otherwise indicated.
[b]Calculated as [(dominant leg)/(nondominant leg) × 100%].
[c]A ratio of eccentric hamstrings strength to concentric quadriceps strength.
[d]Standard deviation was not available.
[e]A ratio of concentric hamstrings strength to concentric quadriceps strength.

sports (volleyball, hockey, futsal, American football, Australian football, judo, alpine skiing, and modern ballet) were grouped with unspecified pivoting sports in **TABLE 5**. Strength results from other pivoting sports were reported in 11 studies.[1,2,4,10,13,26,36-38,42,63] There were data from 1566 pivoting-sport athletes (92% male) who were 21.7 ± 1.9 years of age.

Pivoting-Sport Athletes With ACLR Strength results from 6 studies of pivoting-sport athletes with ACLR at a specific time point during rehabilitation were combined in **TABLE 6**.[8,25,28,37,56,61] Strength tests were completed at 3, 4, 6, 7, 9, and 10 months after ACLR for 816 pivoting-sport athletes with ACLR (80% male) who were 21.8 ± 3.0 years of age. After 7 months, strength values for athletes with ACLR were comparable to those of healthy pivoting-sport athletes.

DISCUSSION

We aimed to synthesize and present reference values for quadriceps and hamstrings strength tests for pivoting-sport athletes with and without ACLR. We presented separate results for types of pivoting sport (including soccer, basketball, and handball), sexes, sport participation levels, and age groups. We aim for the reference values to help guide clinicians regarding what is normal strength for pivoting-sport athletes, and what to expect during rehabilitation and RTS progressions after ACLR.

Strength Testing Modes

Isokinetic dynamometry is the gold standard for strength tests. We chose to report reference values at 60°/s, 180°/s, and 300°/s. This was based on a recent Delphi study, in which experts (physical therapists, orthopaedic surgeons, and

TABLE 3 Quadriceps and Hamstrings Strength Reference Values From Healthy Basketball Players[16,29,33,47]

Sex/Sport Level	Population[a]	Isokinetic[a] 60°/s	180°/s	300°/s
Male				
Elite	n = 73 young adults Age, 22.7 ± 0.6 y[33,47]	Quadriceps Peak torque, 289 ± 3 Nm Peak torque per BW, 3.21 ± −0.47 Nm/kg D/ND LSI[b] = 105%[c] Hamstrings Peak torque, 157 ± 8 Nm Peak torque per BW, 2.06 ± −0.35 Nm/kg D/ND LSI[b] = 107%[c] Ratio HQR[d] = 55% ± 3%	Quadriceps Peak torque, 190 ± 12 Nm Peak torque per BW, 1.73 ± −0.31 Nm/kg D/ND LSI[b] = 98%[c] Hamstrings Peak torque, 107 ± 7 Nm Peak torque per BW, 1.45 ± −0.27 Nm/kg D/ND LSI[b] = 100%[c] Ratio HQR[d] = 58% ± 9%	Quadriceps Peak torque, 147 ± 27 Nm Hamstrings Peak torque, 82 ± 19 Nm Ratio HQR[d] = 56% ± 10%
Female				
Elite	n = 14 young adults Age, 24.4 ± 2.6 y[16]	Quadriceps Peak torque, 185 ± 15 Nm Peak torque per BW, 2.50 ± −0.15 Nm/kg Hamstrings Peak torque, 100 ± 10 Nm Peak torque per BW, 1.50 ± −0.8 Nm/kg Ratio HQR[d] = 57% ± 9%	Quadriceps Peak torque, 120 ± 10 Nm Peak torque per BW, 1.70 ± −0.08 Nm/kg Hamstrings Peak torque, 55 ± 5 Nm Peak torque per BW, 0.90 ± −0.06 Nm/kg Ratio HQR[d] = 55% ± 10%	Quadriceps Peak torque, 75 ± 10 Nm Peak torque per BW, 1.20 ± −0.08 Nm/kg Hamstrings Peak torque, 30 ± 4 Nm Peak torque per BW, 0.50 ± −0.08 Nm/kg Ratio HQR[d] = 51% ± 10%
Nonelite	n = 12 young adults Age, 20.1 ± 0.4 y[29]		Quadriceps Peak torque, 105 ± 8 Nm Peak torque per BW, 1.90 ± −0.20 Nm/kg Hamstrings Peak torque, 75 ± 7 Nm Peak torque per BW, 1.40 ± −0.10 Nm/kg Ratio HQR[d] = 69% ± 15%	Quadriceps Peak torque, 60 ± 5 Nm Peak torque per BW, 1.05 ± −0.10 Nm/kg Hamstrings Peak torque, 47 ± 7 Nm Peak torque per BW, 0.85 ± −0.08 Nm/kg Ratio HQR[d] = 78% ± 8%

Abbreviations: BW, body weight; D, dominant; HQR, hamstrings-quadriceps ratio; LSI, limb symmetry index; ND, nondominant.
[a]*Values are mean ± SD unless otherwise indicated.*
[b]*Calculated as [(dominant leg)/(nondominant leg) × 100%].*
[c]*Standard deviation was not available.*
[d]*A ratio of concentric hamstrings strength to concentric quadriceps strength.*

scientists) recommended a protocol of concentric knee extension and flexion testing, including 5 repetitions at 60°/s, 20 repetitions at 180°/s, and 15 repetitions at 300°/s, with 60 seconds of rest between sets.[50]

Isokinetic dynamometry is unfortunately only accessible for a small proportion of clinicians, due to its nonportability and high cost.[52]

When isokinetic dynamometry is not available, (belt-stabilized) handheld dynamometry can be a reliable alternative for measuring quadriceps and hamstrings strength.[23,27] Handheld dynamometry strength measurements can be compared to MVIC reference values in our scoping review. However, the MVIC reference values in our review are all measured with isokinetic dynamometry, and the validity of handheld dynamometry measurements, when judged against isokinetic dynamometry measurements, remains debated.[23,35]

Strength Tests During Rehabilitation After ACLR

Because RTS is a continuous process that starts from the beginning of rehabilitation, it is important to evaluate strength multiple times throughout rehabilitation.[5,53] Regular testing allows for easy modification of strength training programs, tailored to the athlete's strength training status and needs. The reference values from our scoping review may help guide goal setting and evaluation during rehabilitation, and guide clinicians to ideal and realistic expectations. Although reference values during rehabilitation are reported for 3, 4, 6, 7, 9, and 10 months post surgery, approximately 2 months are needed between measurements to observe clinically meaningful changes.[5] There are, of course, individual differences in how fast athletes make meaningful progress, but it is important not to test too little or too often in order to keep athletes motivated. With adequate rehabilitation, it is possible to strive for strength values comparable to those of healthy pivoting-sport athletes as soon as 7 months after ACLR.[56]

Strength Tests as Part of the RTS Decision

Return-to-sport decisions after ACLR should be based on a battery of tests.[3] However, the specific content of such a battery is the subject of ongoing and strident debate. Conflicting research in the ACL field compounds a complex debate. One key issue is that some studies include athletes who do not return to pivoting sports—a main confounder when interpreting the results, because not returning to pivoting sports almost eliminates the risk for a second ACL injury.[58] Therefore, when reading studies about the association between RTS tests and second ACL injuries, one should be aware of this. When eliminating the confounding factor of pivoting-sport participation, quadriceps strength test results are associated

TABLE 4 QUADRICEPS AND HAMSTRINGS STRENGTH REFERENCE VALUES FROM HEALTHY HANDBALL PLAYERS[2,16,31,44]

		Isokinetic[a]		
Sex/Sport Level	Population[a]	60°/s	180°/s	300°/s
Male				
Elite	n = 17 young adults Age, 25.9 ± 4.1 y[2]	Quadriceps Peak torque, 266 ± 51 Nm Hamstrings Peak torque, 163 ± 18 Nm Ratio HQR[b] = 63% ± 12%		Quadriceps Peak torque, 181 ± 36 Nm Hamstrings Peak torque, 113 ± 22 Nm Ratio HQR[b] = 63% ± 9%
Female				
Elite	n = 293 young adults Age, 21.1 ± 0.9 y[2,16,31,44]	Quadriceps Peak torque, 169 ± 5 Nm Peak torque per BW, 2.44 ± −0.05 Nm/kg D/ND LSI[c] = 100%[d] Hamstrings Peak torque, 95 ± 2 Nm Peak torque per BW, 1.38 ± −0.02 Nm/kg D/ND LSI[c] = 103%[d] Ratio HQR[b] = 57% ± 1%	Quadriceps Peak torque, 110 ± 7 Nm Peak torque per BW, 1.70 ± −0.08 Nm/kg Hamstrings Peak torque, 40 ± 7 Nm Peak torque per BW, 0.90 ± −0.06 Nm/kg Ratio HQR[b] = 55% ± 10%	Quadriceps Peak torque, 91 ± 16 Nm Peak torque per BW, 1.10 ± −0.08 Nm/kg Hamstrings Peak torque, 53 ± 18 Nm Peak torque per BW, 0.50 ± −0.06 Nm/kg Ratio HQR[b] = 61% ± 5%

Abbreviations: BW, body weight; D, dominant; HQR, hamstrings-quadriceps ratio; LSI, limb symmetry index; ND, nondominant.
[a]*Values are mean ± SD unless otherwise indicated.*
[b]*A ratio of concentric hamstrings strength to concentric quadriceps strength.*
[c]*Calculated as [(dominant leg)/(nondominant leg) × 100%].*
[d]*Standard deviation was not available.*

with ACL and knee reinjuries and cannot be denied as an important part of an RTS test battery.[3,18,19,30]

Clinical Relevance

If preinjury values are unavailable for injured athletes or previous-season values are unavailable for healthy athletes, clinicians could choose to use the reference tables from our scoping review as a guide to the expected quadriceps and hamstrings strength values for an individual athlete. Besides peak torque and MVICs for torque, peak torque normalized to BW and MVICs normalized to BW are reported as absolute reference values. We suggest using peak torque normalized to BW and MVIC normalized to BW for comparing between athletes, because they better account for the athlete's body weight. When these metrics are unavailable, peak torque or MVIC values are the best alternative.

Besides using absolute reference values, it is important to consider using an LSI. However, because the LSI-D/ND is used for reporting differences between the dominant leg and the nondominant leg in healthy pivoting-sport athletes, we advise clinicians to use the same measure

TABLE 5 Quadriceps and Hamstrings Strength Reference Values From Other Healthy Pivoting-Sport[a] Athletes[1,2,4,10,13,26,36-38,42,63]

Sex/Sport Level	Population[b]	Isokinetic[b] 60°/s	Isokinetic[b] 180°/s	Isokinetic[b] 300°/s	Isometric[b] 70°
Male					
Elite	n = 20 adolescents Age, 17.0 ± 0.5[4]	Quadriceps Peak torque per BW, 3.42 ± −0.40 Nm/kg D/ND LSI[c] = 99%[d] Hamstrings Peak torque per BW, 1.63 ± −0.16 Nm/kg D/ND LSI[c] = 103%[d] Ratio HQR[e] = 48% ± 6%		Quadriceps Peak torque per BW, 1.92 ± −0.20 Nm/kg D/ND LSI[c] = 102%[d] Hamstrings Peak torque per BW, 1.27 ± −0.17 Nm/kg D/ND LSI[c] = 102%[d] Ratio HQR[e] = 67% ± 12%	
	n = 1361 young adults Age, 22.5 ± 1.2 y[2,4,26,36,38,63]	Quadriceps Peak torque, 309 ± 3 Nm Peak torque per BW, 2.89 ± −0.03 Nm/kg D/ND LSI[c] = 102% ± 0% Hamstrings Peak torque, 208 ± 3 Nm Peak torque per BW, 1.94 ± −0.01 Nm/kg D/ND LSI[c] = 101% ± 0% Ratio HQR[e] = 68% ± 1%	Quadriceps Peak torque per BW, 2.52 ± −0.28 Nm/kg Hamstrings Peak torque per BW, 1.75 ± −0.27 Nm/kg Ratio HQR[e] = 70% ± 9%	Quadriceps Peak torque, 136 ± 40 Nm Peak torque per BW, 1.93 ± −0.07 Nm/kg D/ND LSI[c] = 103%[d] TW, 1813 ± 480 J (15 reps; range, 90°) TW D/ND LSI[c] = 102%[d] Hamstrings Peak torque, 94 ± 29 Nm Peak torque per BW, 1.29 ± −0.05 Nm/kg D/ND LSI[c] = 104%[d] TW, 1596 ± 486 J (15 reps; range, 90°) TW D/ND LSI[c] = 99%[d] Ratio HQR[e] = 68% ± 1%	Quadriceps MVIC per BW, 417 ± 56 N/kg Hamstrings MVIC per BW, 186 ± 24 N/kg Ratio HQR[e] = 45%[d]
Nonelite	n = 61 young adults Age, 23.7 ± 0.4 y[10,37]	Quadriceps Peak torque per BW, 2.70 ± −0.18 Nm/kg D/ND LSI[c] = 105% ± 3% Hamstrings Peak torque per BW, 1.58 ± −0.04 Nm/kg D/ND LSI[c] = 102% ± 2% Ratio HQR[e] = 55% ± 10%		Quadriceps Peak torque per BW, 1.33 ± −0.25 Nm/kg D/ND LSI[c] = 106%[d] Hamstrings Peak torque per BW, 0.86 ± −0.23 Nm/kg D/ND LSI[c] = 106%[d] Ratio HQR[e] = 65% ± 15%	

Table continues on page 150.

TABLE 5	Quadriceps and Hamstrings Strength Reference Values From Other Healthy Pivoting-Sport[a] Athletes[1,2,4,10,13,26,36-38,42,63] (continued)				
		Isokinetic[b]			Isometric[b]
Sex/Sport Level	Population[b]	60°/s	180°/s	300°/s	70°
Female					
Elite	n = 34 young adults Age, 21.0 ± 0.0 y[2,26]	Quadriceps Peak torque, 180 ± 42 Nm Hamstrings Peak torque, 92 ± 18 Nm Ratio HQR[e] = 53% ± 10%		Quadriceps Peak torque, 87 ± 18 Nm Hamstrings Peak torque, 62 ± 11 Nm Ratio HQR[e] = 72% ± 10%	Quadriceps MVIC per BW, 396 ± 45 N/kg Hamstrings MVIC per BW, 166 ± 22 N/kg Ratio HQR[e] = 42%[d]
Nonelite	n = 53 adolescents Age, 19.4 ± 1.3 y[13]	Ratio HQR[e] = 63% ± 8%		Ratio HQR[e] = 74% ± 15%	
	n = 37 young adults Age, 22.6 ± 1.5 y[1,42]	Quadriceps Peak torque, 123 ± 8 Nm Peak torque per BW, 2.27 ± −0.27 Nm/kg Hamstrings Peak torque, 0.49 ± −0.10 Nm Peak torque per BW, 0.96 ± −0.22 Nm/kg	Quadriceps Peak torque, 86 ± 5 Nm Peak torque per BW, 1.60 ± −0.22 Nm/kg Hamstrings Peak torque, 39 ± 8 Nm Peak torque per BW, 0.73 ± −0.17 Nm/kg	Quadriceps Peak torque, 61 ± 8 Nm Peak torque per BW, 1.20 ± −0.15 Nm/kg Hamstrings Peak torque, 30 ± 7 Nm Peak torque per BW, 0.58 ± −0.14 Nm/kg	

Abbreviations: BW, body weight; D, dominant; HQR, hamstrings-quadriceps ratio; LSI, limb symmetry index; MVIC, maximum voluntary isometric contraction; ND, nondominant; reps, repetitions; TW, total work.
[a]*Sports included volleyball, hockey, futsal, American football, Australian football, judo, alpine skiing, and modern ballet.*
[b]*Values are mean ± SD unless otherwise indicated.*
[c]*Calculated as [(dominant leg)/(nondominant leg) × 100%].*
[d]*Standard deviation was not available.*
[e]*A ratio of concentric hamstrings strength to concentric quadriceps strength.*

for supporting pivoting-sport athletes with ACLR when they are making RTS decisions. The LSI-D/ND between the dominant and nondominant legs ranged from 98% to 114% in healthy athletes. We suggest that clinicians use this as a benchmark for pivoting-sport athletes with ACLR instead of an LSI greater than 90%, as often advised.[32]

When athletes with ACLR do not meet the expected absolute values and have an LSI between the dominant and nondominant legs below the healthy reference, consider additional strength training before return to pivoting sports.

Limitations

We provided an extensive and detailed overview of quadriceps and hamstrings strength absolute and LSI reference values. However, there will always be outliers in each set of athletes, as reference values are based on a Gaussian curve.

We used broad selection criteria to maximize generalizability. However, due to sparse data in the group of athletes with ACLR, we were not able to present separate results for different graft types. Graft type can affect strength at different stages of rehabilitation. Therefore, we suggest interpreting reference values for pivoting-sport athletes with ACLR as minimum requirements and striving for higher values earlier in the rehabilitation process. It is probably better to use these reference values together with reference values from healthy pivoting-sport athletes, because we do not have insight into postoperative rehabilitation protocols.

Although we present these strength test reference values to help clinicians judge what "normal" strength is for pivoting-sport athletes, it has not yet been investigated whether there is an association between meeting reference values and sustaining a second ACL injury.

CONCLUSION

We synthesized and present absolute quadriceps and hamstrings strength reference values for pivoting-sport athletes with and without ACLR. Data from 42 articles are organized by type of sport (eg, soccer, basketball, handball), sex, sport participation level, and age group. In addition to using absolute reference values, the LSI between dominant and nondominant legs is valuable to use for RTS decisions. This LSI between dominant and nondominant legs ranged from 98% to 114% in healthy athletes. ◉

TABLE 6 QUADRICEPS AND HAMSTRINGS STRENGTH REFERENCE VALUES FOR PIVOTING-SPORT ATHLETES DURING REHABILITATION AFTER ACLR[8,25,28,37,56,61]

Time Point/Sex/Sport Level	Population,[a] Graft Type	Isokinetic[a] 60°/s	Isokinetic[a] 180°/s	Isokinetic[a] 300°/s	Isometric[a] 45°
3 mo					
Male					
Nonelite	n = 156 adolescents; age, 18.8 ± 3.1 y[25] Quadriceps	Quadriceps O-leg peak torque per BW, 1.41 ± −0.44 Nm/kg NO-leg peak torque per BW, 2.46 ± −0.58 Nm/kg LSI[b] = 58% ± 17% Hamstrings O-leg peak torque per BW, 1.18 ± −0.36 Nm/kg NO-leg peak torque per BW, 1.40 ± −0.48 Nm/kg LSI[b] = 86% ± 19%			
Female					
Nonelite	n = 164 adolescents; age, 17.4 ± 2.8 y[25] Quadriceps	Quadriceps O-leg peak torque per BW, 1.13 ± 0.54 Nm/kg NO-leg peak torque per BW, 2.28 ± −0.42 Nm/kg LSI[b] = 48% ± 16% Hamstrings O-leg peak torque per BW, 0.93 ± −0.27 Nm/kg NO-leg peak torque per BW, 1.20 ± −0.31 Nm/kg LSI[b] = 79% ± 22%			
4 mo					
Male					
Elite	n = 20 young adults; age, 24.2 ± 5.1 y[28] BPTB	Quadriceps O-leg peak torque, 101 ± 35 Nm NO-leg peak torque, 176 ± 38 Nm LSI[b] = 57%[c] Hamstrings O-leg peak torque, 92 ± 24 Nm NO-leg peak torque, 107 ± 21 Nm LSI[b] = 86%[c]	Quadriceps O-leg peak torque, 84 ± 22 Nm NO-leg peak torque, 126 ± 26 Nm LSI[b] = 67%[c] Hamstrings O-leg peak torque, 76 ± 17 Nm NO-leg peak torque, 85 ± 17 Nm LSI[b] = 89%[c]		Quadriceps O-leg MVIC, 142 ± 48 N NO-leg MVIC, 213 ± 55 N LSI[b] = 67%[c] Hamstrings O-leg MVIC, 107 ± 21 N NO-leg MVIC, 105 ± 26 N LSI[b] = 102%[c]
Nonelite	n = 38 young adults; age, 24.2 ± 4.7 y[56] BPTB and hamstrings	Quadriceps O-leg peak torque, 189 ± 52 Nm O-leg peak torque per BW, 2.40 ± −0.50 Nm/kg NO-leg peak torque, 262 ± 58 Nm NO-leg peak torque per BW, 3.30 ± −0.50 Nm/kg LSI[b] = 72% ± 12% Hamstrings O-leg peak torque, 128 ± 31 Nm NO-leg peak torque, 143 ± 31 Nm LSI[b] = 89% ± 14%			

Table continues on page 152.

TABLE 6 Quadriceps and Hamstrings Strength Reference Values for Pivoting-Sport Athletes During Rehabilitation After ACLR[8,25,28,37,56,61] (continued)

		Isokinetic[a]			Isometric[a]
Time Point/ Sex/Sport Level	**Population,[a] Graft Type**	**60°/s**	**180°/s**	**300°/s**	**45°**
6 mo					
Male					
Elite	n = 20 young adults; age, 24.2 ± 5.1 y[28] BPTB	Quadriceps O-leg peak torque, 122 ± 37 Nm NO-leg peak torque, 179 ± 40 Nm LSI[b] = 68%[c] Hamstrings O-leg peak torque, 99 ± 24 Nm NO-leg peak torque, 111 ± 21 Nm LSI[b] = 89%[c]	Quadriceps O-leg peak torque, 99 ± 31 Nm NO-leg peak torque, 129 ± 32 Nm LSI[b] = 77%[c] Hamstrings O-leg peak torque, 79 ± 16 Nm NO-leg peak torque, 84 ± 14 Nm LSI[b] = 94%[c]		Quadriceps O-leg MVIC, 165 ± 40 N NO-leg MVIC, 225 ± 50 N LSI[b] = 73%[c] Hamstrings O-leg MVIC, 111 ± 21 N NO-leg MVIC, 110 ± 22 N LSI[b] = 101%[c]
Nonelite	n = 156 adolescents; age, 18.8 ± 3.1 y[25] Quadriceps	Quadriceps O-leg peak torque per BW, 2.03 ± −0.51 Nm/kg NO-leg peak torque per BW, 2.79 ± −0.56 Nm/kg LSI[b] = 72% ± 15% Hamstrings O-leg peak torque per BW, 1.45 ± −0.34 Nm/kg NO-leg peak torque per BW, 1.52 ± −0.34 Nm/kg LSI[b] = 95% ± 17%			
	n = 118 young adults; age, 23.6 ± 5.8 y[37] BPTB	Quadriceps O-leg peak torque per BW, 2.00 ± −0.45 Nm/kg NO-leg peak torque per BW, 2.60 ± −0.45 Nm/kg LSI[b] = 77% ± 14% Hamstrings O-leg peak torque per BW, 1.46 ± −0.29 Nm/kg NO-leg peak torque per BW, 1.51 ± −0.28 Nm/kg LSI[b] = 97% ± 12%			
Female					
Nonelite	n = 164 adolescents; age, 17.4 ± 2.8 y[25] Quadriceps	Quadriceps O-leg peak torque per BW, 1.61 ± −0.45 Nm/kg NO-leg peak torque per BW, 2.53 ± −0.45 Nm/kg LSI[b] = 63% ± 16% Hamstrings O-leg peak torque per BW, 1.22 ± −0.25 Nm/kg NO-leg peak torque per BW, 1.35 ± −0.31 Nm/kg LSI[b] = 91% ± 18%			

Table continues on page 153.

TABLE 6 QUADRICEPS AND HAMSTRINGS STRENGTH REFERENCE VALUES FOR PIVOTING-SPORT ATHLETES DURING REHABILITATION AFTER ACLR[8,25,28,37,56,61] (CONTINUED)

		Isokinetic[a]			Isometric[a]
Time Point/Sex/Sport Level	Population,[a] Graft Type	60°/s	180°/s	300°/s	45°
7 mo					
Male					
Nonelite	n = 60 young adults; age, 25.8 ± 2.3 y[56,61] BPTB and hamstrings[d]	Quadriceps O-leg peak torque, 223 ± 51 Nm O-leg peak torque per BW, 2.90 ± −0.50 Nm/kg NO-leg peak torque, 267 ± 58 Nm NO-leg peak torque per BW, 3.30 ± −0.50 Nm/kg LSI[b] = 85% ± 13% Hamstrings O-leg peak torque, 144 ± 30 Nm NO-leg peak torque, 149 ± 34 Nm LSI[b] = 98% ± 8%	Quadriceps LSI[b] = 80% ± 12% Hamstrings LSI[b] = 102% ± 11%	Quadriceps LSI[b] = 82% ± 11% Hamstrings LSI[b] = 102% ± 27%	
9 mo					
Male					
Nonelite	n = 298 young adults; age, 24.2 ± 4.6 y[8] BPTB, hamstrings, and quadriceps	Quadriceps O-leg peak torque per BW, 2.24 ± −0.47 Nm/kg LSI[b] = 84% ± 14% Hamstrings O-leg peak torque per BW, 1.53 ± −0.29 Nm/kg LSI[b] = 97% ± 14%			
10 mo					
Male					
Nonelite	n = 38 young adults; age, 24.2 ± 4.7 y[56] BPTB and hamstrings	Quadriceps O-leg peak torque, 257 ± 51 Nm O-leg peak torque per BW, 3.20 ± −0.60 Nm/kg NO-leg peak torque, 270 ± 61 Nm NO-leg peak torque per BW, 3.40 ± −0.50 Nm/kg LSI[b] = 94% ± 15% Hamstrings O-leg peak torque, 150 ± 31 Nm NO-leg peak torque, 153 ± 34 Nm LSI[b] = 98% ± 8%			

Abbreviations: ACLR, anterior cruciate ligament reconstruction; BPTB, bone-patellar tendon-bone; BW, body weight; LSI, limb symmetry index; MVIC, maximum voluntary isometric contraction; NO, nonoperated; O, operated.
[a]*Values are mean ± SD unless otherwise indicated.*
[b]*Calculated as [(operated leg)/(nonoperated leg) × 100%].*
[c]*Standard deviation was not available.*
[d]*At 60°/s, BPTB and hamstrings; at 180°/s and 300°/s, BPTB.*

KEY POINTS

FINDINGS: Detailed reference values are presented for athletes with and without anterior cruciate ligament reconstruction (ACLR) who play the most common pivoting sports (including soccer, basketball, and handball).

IMPLICATIONS: Quadriceps and hamstrings strength test reference values help clinicians judge what "normal" strength is for healthy pivoting-sport athletes, and what to expect during rehabilitation and return-to-sport (RTS) progressions after ACLR.

CAUTION: The association between meeting reference values and (safe) RTS after ACLR requires more study.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: Dr van Melick performed data synthesis and drafted the article. All authors contributed to study design, study selection, and revision of the article.

DATA SHARING: All data relevant to the study are included in this article or are available as online supplemental files. All reference values are available at www.aclreferencevalues.nl.

PATIENT AND PUBLIC INVOLVEMENT: There was no patient or public involvement in this article.

REFERENCES

1. Agopyan A. Hamstring flexibility is not correlated with isokinetic knee muscle strength in female modern dancers. *Med Probl Perform Art*. 2018;33:95-101. https://doi.org/10.21091/mppa.2018.2016
2. Andrade MDS, de Lira CAB, Koffes FDC, Mascarin NC, Benedito-Silva AA, da Silva AC. Isokinetic hamstrings-to-quadriceps peak torque ratio: the influence of sport modality, gender, and angular velocity. *J Sports Sci*. 2012;30:547-553. https://doi.org/10.1080/02640414.2011.644249
3. Ashigbi EYK, Banzer W, Niederer D. Return to sport tests' prognostic value for reinjury risk after anterior cruciate ligament reconstruction: a systematic review. *Med Sci Sports Exerc*. 2020;52:1263-1271. https://doi.org/10.1249/MSS.0000000000002246
4. Bittencourt NFN, Amaral GM, dos Anjos MTS, D'Alessandro R, Silva AA, Fonseca ST. Isokinetic muscle evaluation of the knee joint in athletes of the Under-19 and Under-21 male Brazilian national volleyball team. *Rev Bras Med Esporte*. 2005;11:302e-306e.
5. Bodkin SG, Rutherford MH, Diduch DR, Brockmeier SF, Hart JM. How much time is needed between serial "return to play" assessments to achieve clinically important strength gains in patients recovering from anterior cruciate ligament reconstruction? *Am J Sports Med*. 2020;48:70-77. https://doi.org/10.1177/0363546519886291
6. Bogdanis GC, Kalapotharakos VI. Knee extension strength and hamstrings-to-quadriceps imbalances in elite soccer players. *Int J Sports Med*. 2016;37:119-124. https://doi.org/10.1055/s-0035-1559686
7. Burgi CR, Peters S, Ardern CL, et al. Which criteria are used to clear patients to return to sport after primary ACL reconstruction? A scoping review. *Br J Sports Med*. 2019;53:1154-1161. https://doi.org/10.1136/bjsports-2018-099982
8. Carolan D, King E, Richter C, Franklyn-Miller A, Moran R, Jackson M. Differences in strength, patient-reported outcomes, and return-to-play rates between athletes with primary versus revision ACL reconstruction at 9 months after surgery. *Orthop J Sports Med*. 2020;8:2325967120950037. https://doi.org/10.1177/2325967120950037
9. Carvalho A, Brown S, Abade E. Evaluating injury risk in first and second league professional Portuguese soccer: muscular strength and asymmetry. *J Hum Kinet*. 2016;51:19-26. https://doi.org/10.1515/hukin-2015-0166
10. Cheung RT, Smith AW, Wong DP. H:Q ratios and bilateral leg strength in college field and court sports players. *J Hum Kinet*. 2012;33:63-71. https://doi.org/10.2478/v10078-012-0045-1
11. Cometti G, Maffiuletti NA, Pousson M, Chatard JC, Maffulli N. Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. *Int J Sports Med*. 2001;22:45-51. https://doi.org/10.1055/s-2001-11331
12. Daneshjoo A, Mokhtar AH, Rahnama N, Yusof A. The effects of injury preventive warm-up programs on knee strength ratio in young male professional soccer players. *PLoS One*. 2012;7:e50979. https://doi.org/10.1371/journal.pone.0050979
13. Devan MR, Pescatello LS, Faghri P, Anderson J. A prospective study of overuse knee injuries among female athletes with muscle imbalances and structural abnormalities. *J Athl Train*. 2004;39:263-267.
14. Eniseler N, Şahan Ç, Vurgun H, Mavi HF. Isokinetic strength responses to season-long training and competition in Turkish elite soccer players. *J Hum Kinet*. 2012;31:159-168. https://doi.org/10.2478/v10078-012-0017-5
15. Forbes H, Sutcliffe S, Lovell A, McNaughton LR, Siegler JC. Isokinetic thigh muscle ratios in youth football: effect of age and dominance. *Int J Sports Med*. 2009;30:602-606. https://doi.org/10.1055/s-0029-1202337
16. Grammatikopoulou M, Zakas A, Zakas N, Vergou A, Sendelidis T. Peak torque and strength curve characteristic of the quadriceps and hamstring muscles in elite female basketball and handball players. *J Hum Mov Stud*. 2005;48:75-89.
17. Greig M. The influence of soccer-specific fatigue on peak isokinetic torque production of the knee flexors and extensors. *Am J Sports Med*. 2008;36:1403-1409. https://doi.org/10.1177/0363546508314413
18. Grindem H, Engebretsen L, Axe M, Snyder-Mackler L, Risberg MA. Activity and functional readiness, not age, are the critical factors for second anterior cruciate ligament injury—the Delaware-Oslo ACL cohort study. *Br J Sports Med*. 2020;54:1099-1102. https://doi.org/10.1136/bjsports-2019-100623
19. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. *Br J Sports Med*. 2016;50:804-808. https://doi.org/10.1136/bjsports-2016-096031
20. Grygorowicz M, Michalowska M, Walczak T, et al. Discussion about different cut-off values of conventional hamstring-to-quadriceps ratio used in hamstring injury prediction among professional male football players. *PLoS One*. 2017;12:e0188974. https://doi.org/10.1371/journal.pone.0188974
21. Gür H, Akova B, Pündük Z, Küçükoğlu S. Effects of age on the reciprocal peak torque ratios during knee muscle contractions in elite soccer players. *Scand J Med Sci Sports*. 1999;9:81-87. https://doi.org/10.1111/j.1600-0838.1999.tb00213.x
22. Hefti F, Müller W, Jakob RP, Stäubli HU. Evaluation of knee ligament injuries with the IKDC form. *Knee Surg Sports Traumatol Arthrosc*. 1993;1:226-234. https://doi.org/10.1007/BF01560215
23. Hirano M, Katoh M, Gomi M, Arai S. Validity and reliability of isometric knee extension muscle strength measurements using a belt-stabilized hand-held dynamometer: a comparison with the measurement using an isokinetic dynamometer in a sitting posture. *J Phys Ther Sci*. 2020;32:120-124. https://doi.org/10.1589/jpts.32.120
24. Hoshikawa Y, Iida T, Muramatsu M, Nakajima Y, Fukunaga T, Kanehisa H. Differences in thigh muscularity and dynamic torque between junior and senior soccer players. *J Sports Sci*. 2009;27:129-138. https://doi.org/10.1080/02640410802428063
25. Hunnicutt JL, Xerogeanes JW, Tsai LC, et al. Terminal knee extension deficit and female sex predict poorer quadriceps strength following ACL reconstruction using all-soft tissue quadriceps tendon autografts. *Knee Surg Sports Traumatol Arthrosc*. 2021;29:3085-3095. https://doi.org/10.1007/s00167-020-06351-4
26. Jordan MJ, Aagaard P, Herzog W. Rapid hamstrings/quadriceps strength in ACL-reconstructed elite alpine ski racers. *Med Sci Sports Exerc*. 2015;47:109-119. https://doi.org/10.1249/MSS.0000000000000375
27. Katoh M. Reliability of isometric knee extension muscle strength measurements made by a hand-held dynamometer and a belt: a comparison of two types of device. *J Phys Ther Sci*. 2015;27:851-854. https://doi.org/10.1589/jpts.27.851
28. Knezevic OM, Mirkov DM, Kadija M, Milovanovic D, Jaric S. Evaluation of isokinetic and isometric strength measures for monitoring muscle function recovery after anterior cruciate ligament reconstruction. *J Strength Cond Res*. 2014;28:1722-1731. https://doi.org/10.1519/JSC.0000000000000307
29. Kobayashi Y, Takeuchi T, Hosoi T, Arai Y, Loeppky JA. Comparison of aerobic and anaerobic power and leg strength between young distance runners and basketball/soccer players. *Biol Sport*. 2006;23:211-224.
30. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. Likelihood of ACL graft rupture: not meeting

six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. *Br J Sports Med*. 2016;50:946-951. https://doi.org/10.1136/bjsports-2015-095908
31. Lund-Hanssen H, Gannon J, Engebretsen L, Holen K, Hammer S. Isokinetic muscle performance in healthy female handball players and players with a unilateral anterior cruciate ligament reconstruction. *Scand J Med Sci Sports*. 1996;6:172-175. https://doi.org/10.1111/j.1600-0838.1996.tb00085.x
32. McGrath TM, Waddington G, Scarvell JM, et al. The effect of limb dominance on lower limb functional performance – a systematic review. *J Sports Sci*. 2016;34:289-302. https://doi.org/10.1080/02640414.2015.1050601
33. Metaxas TI, Koutlianos N, Sendelides T, Mandroukas A. Preseason physiological profile of soccer and basketball players in different divisions. *J Strength Cond Res*. 2009;23:1704-1713. https://doi.org/10.1519/JSC.0b013e3181b3e0c5
34. Minozzo F, Lopez P, Machado CLF, Wilhelm EN, Grazioli R, Pinto RS. Alternative assessment of knee joint muscle balance of soccer players through total work-based hamstring: quadriceps ratios. *Eur J Sport Sci*. 2018;18:1398-1404. https://doi.org/10.1080/17461391.2018.1495271
35. Muff G, Dufour S, Meyer A, et al. Comparative assessment of knee extensor and flexor muscle strength measured using a hand-held vs. isokinetic dynamometer. *J Phys Ther Sci*. 2016;28:2445-2451. https://doi.org/10.1589/jpts.28.2445
36. Nunes RF, Buzzachera CF, Almeida FA, Da Silva JF, Flores LJ, Da Silva SG. Relationships between isokinetic muscle strength, measures of aerobic fitness, single sprint performance, and repeated-sprint ability in elite futsal players. *Gazz Med Ital Arch Sci Med*. 2016;173:205-213.
37. O'Malley E, Richter C, King E, et al. Countermovement jump and isokinetic dynamometry as measures of rehabilitation status after anterior cruciate ligament reconstruction. *J Athl Train*. 2018;53:687-695. https://doi.org/10.4085/1062-6050-480-16
38. Orchard J, Marsden J, Lord S, Garlick D. Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *Am J Sports Med*. 1997;25:81-85. https://doi.org/10.1177/036354659702500116
39. Östenberg A, Roos E, Ekdahl C, Roos H. Isokinetic knee extensor strength and functional performance in healthy female soccer players. *Scand J Med Sci Sports*. 1998;8:257-264. https://doi.org/10.1111/j.1600-0838.1998.tb00480.x
40. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. *Syst Rev*. 2016;5:210. https://doi.org/10.1186/s13643-016-0384-4
41. Padulo J, Trajković N, Cular D, et al. Validity and reliability of isometric-bench for knee isometric assessment. *Int J Environ Res Public Health*. 2020;17:4326. https://doi.org/10.3390/ijerph17124326
42. Pua YH, Koh MT, Teo YY. Effects of allometric scaling and isokinetic testing methods on the relationship between countermovement jump and quadriceps torque and power. *J Sports Sci*. 2006;24:423-432. https://doi.org/10.1080/02640410500189124
43. Rambaud AJM, Ardern CL, Thoreux P, Regnaux JP, Edouard P. Criteria for return to running after anterior cruciate ligament reconstruction: a scoping review. *Br J Sports Med*. 2018;52:1437-1444. https://doi.org/10.1136/bjsports-2017-098602
44. Risberg MA, Steffen K, Nilstad A, et al. Normative quadriceps and hamstring muscle strength values for female, healthy, elite handball and football players. *J Strength Cond Res*. 2018;32:2314-2323. https://doi.org/10.1519/JSC.0000000000002579
45. Ruas CV, Minozzo F, Pinto MD, Brown LE, Pinto RS. Lower-extremity strength ratios of professional soccer players according to field position. *J Strength Cond Res*. 2015;29:1220-1226. https://doi.org/10.1519/JSC.0000000000000766
46. Śliwowski R, Grygorowicz M, Hojszyk R, Jadczak Ł. The isokinetic strength profile of elite soccer players according to playing position. *PLoS One*. 2017;12:e0182177. https://doi.org/10.1371/journal.pone.0182177
47. Theoharopoulos A, Tsitskaris G, Nikopoulou M, Tsaklis P. Knee strength of professional basketball players. *J Strength Cond Res*. 2000;14:457-463. https://doi.org/10.1519/00124278-200011000-00014
48. Tourny-Chollet C, Leroy D. Conventional vs. dynamic hamstring-quadriceps strength ratios: a comparison between players and sedentary subjects. *Isokinet Exerc Sci*. 2002;10:183-192. https://doi.org/10.3233/IES-2002-0102
49. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for Scoping Reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med*. 2018;169:467-473. https://doi.org/10.7326/M18-0850
50. van der Horst N, van Denderen R. Isokinetic hamstring and quadriceps strength interpretation guideline for football (soccer) players with ACL reconstruction: a Delphi consensus study in the Netherlands. *Sci Med Footb*. In press. https://doi.org/10.1080/24733938.2021.2024592
51. van Dyk N, Bahr R, Burnett AF, et al. A comprehensive strength testing protocol offers no clinical value in predicting risk of hamstring injury: a prospective cohort study of 413 professional football players. *Br J Sports Med*. 2017;51:1695-1702. https://doi.org/10.1136/bjsports-2017-097754
52. van Melick N, Hoogeboom TJ, Pronk Y, et al. Less than half of ACL-reconstructed athletes are cleared for return to play based on practice guideline criteria: results from a prospective cohort study. *Int J Sports Phys Ther*. 2006;15:1006-1018.
53. van Melick N, van Cingel RE, Brooijmans F, et al. Evidence-based clinical practice update: practice guidelines for anterior cruciate ligament rehabilitation based on a systematic review and multidisciplinary consensus. *Br J Sports Med*. 2016;50:1506-1515. https://doi.org/10.1136/bjsports-2015-095898
54. van Melick N, van Rijn L, Nijhuis-van der Sanden MWG, Hoogeboom TJ, van Cingel REH. Fatigue affects quality of movement more in ACL-reconstructed soccer players than in healthy soccer players. *Knee Surg Sports Traumatol Arthrosc*. 2019;27:549-555. https://doi.org/10.1007/s00167-018-5149-2
55. Voutselas V, Papanikolaou Z, Soulas D, Famisis K. Years of training and hamstring-quadriceps ratio of soccer players. *Psychol Rep*. 2007;101:899-906. https://doi.org/10.2466/pr0.101.3.899-906
56. Welling W, Benjaminse A, Lemmink K, Dingenen B, Gokeler A. Progressive strength training restores quadriceps and hamstring muscle strength within 7 months after ACL reconstruction in amateur male soccer players. *Phys Ther Sport*. 2019;40:10-18. https://doi.org/10.1016/j.ptsp.2019.08.004
57. Wellsandt E, Failla MJ, Snyder-Mackler L. Limb symmetry indexes can overestimate knee function after anterior cruciate ligament injury. *J Orthop Sports Phys Ther*. 2017;47:334-338. https://doi.org/10.2519/jospt.2017.7285
58. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Am J Sports Med*. 2016;44:1861-1876. https://doi.org/10.1177/0363546515621554
59. Wik EH, Mc Auliffe S, Read PJ. Examination of physical characteristics and positional differences in professional soccer players in Qatar. *Sports (Basel)*. 2018;7:9. https://doi.org/10.3390/sports7010009
60. World Health Organization. Adolescent health. Available at: https://www.who.int/health-topics/adolescent-health/#tab=tab_1. Accessed January 12, 2021.
61. Xergia SA, Pappas E, Georgoulis AD. Association of the single-limb hop test with isokinetic, kinematic, and kinetic asymmetries in patients after anterior cruciate ligament reconstruction. *Sports Health*. 2015;7:217-223. https://doi.org/10.1177/1941738114529532
62. Zabka FF, Valente HG, Pacheco AM. Isokinetic evaluation of knee extensor and flexor muscles in professional soccer players. *Rev Bras Med Esporte*. 2011;17:189-192. https://doi.org/10.1590/S1517-86922011000300008
63. Zvijac JE, Toriscelli TA, Merrick WS, Papp DF, Kiebzak GM. Isokinetic concentric quadriceps and hamstring normative data for elite collegiate American football players participating in the NFL Scouting Combine. *J Strength Cond Res*. 2014;28:875-883. https://doi.org/10.1519/JSC.0b013e3182a20f19