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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)

Lasse Ishøi ,[1] Kasper Krommes,[1] Rasmus Skov Husted,[2,3] Carsten B Juhl,[4] Kristian Thorborg [1,2]

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[1]Department of Orthopedic Surgery, Copenhagen University Hospital, Amager-Hvidovre, Sports Orthopedic Research Center - Copenhagen (SORC-C), Hvidovre, Denmark
[2]Department of Orthopedic Surgery and Physical Therapy, Physical Medicine & Rehabilitation Research – Copenhagen (PMR-C), Copenhagen University Hospital, Hvidovre, Denmark
[3]Clinical Research Centre, Copenhagen University Hospital Hvidovre, Hvidovre, Denmark
[4]Research Unit of Musculoskeletal Function and Physiotherapy, Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark

Correspondence to
Lasse Ishøi, Department of Orthopedic Surgery, Copenhagen University Hospital, Amager-Hvidovre, Sports Orthopedic Research Center - Copenhagen (SORC-C), Hvidovre 2650, Denmark; lasse.ishoei@regionh.dk

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ABSTRACT
This statement summarises and appraises the evidence on diagnosis, prevention and treatment of the most common lower extremity muscle injuries in sport. We systematically searched electronic databases, and included studies based on the highest available evidence. Subsequently, we evaluated the quality of evidence using the Grading of Recommendations Assessment, Development and Evaluation framework, grading the quality of evidence from high to very low. Most clinical tests showed very low to low diagnostic effectiveness. For hamstring injury prevention, programmes that included the Nordic hamstring exercise resulted in a hamstring injury risk reduction when compared with usual care (medium to large effect size; moderate to high quality of evidence). For prevention of groin injuries, both the FIFA 11+programme and the Copenhagen adductor strengthening programme resulted in a groin injury risk reduction compared with usual care (medium effect size; low to moderate quality of evidence). For the treatment of hamstring injuries, lengthening hamstring exercises showed the fastest return to play with a lower reinjury rate compared with conventional hamstring exercises (large effect size; very low to low quality of evidence). Platelet-rich plasma had no effect on time to return-to-play and reinjury risk (trivial effect size; moderate quality of evidence) after a hamstring injury compared with placebo or rehabilitation. At this point, most outcomes for diagnosis, prevention and treatment were graded as very low to moderate quality of evidence, indicating that further high-quality research is likely to have an important impact on the confidence in the effect estimates.

INTRODUCTION
Lower extremity muscle injuries are frequent in sports involving explosive actions such as high-speed running, jumping, change of direction and kicking.[1] In professional football, muscle injuries constitute up to half of all injuries,[1] and in sports, such as American football,[2] Australian football,[3] rugby,[4] basketball[5] and track and field,[6] the incidence is also high. The majority of muscle injuries in football occur during non-contact situations,[7] classified as 'indirect muscle injuries' or 'muscle strains'.[8 9] These are typically thought to occur in the muscle-tendon junction[8] when the force applied exceeds the tissue capacity.[10]

In football, muscle strain injuries constitute up to 31% of all injuries, and up to 37% of players experience absence from training and/or match play during a season due to a muscle injury.[1 7] Besides from significant financial costs at the professional level,[11] the high injury burden of muscle injuries[12] also have substantial implications on player availability, potentially affecting team performance.[13] Up to 92% of all muscle strain injuries encountered in football are located in the hamstrings (37%), adductors (23%), rectus femoris/quadriceps (19%) and calf muscles (13%),[7] with hamstring strain injuries also being the most common diagnosis in sports such as Australian football[3] and track and field.[6]

The fact that incidence of muscle strain injury has remained constant during the last decades in football[12] and Australian football[3] with slightly increased incidence for hamstring[14] and calf muscle strains,[3] highlights the ongoing challenge of muscle strain injuries in sport. Thus, to aid management of common muscle injuries in sport, the aim of this statement, commissioned by the Danish Society of Sports Physical Therapy, was to provide an overview of the existing literature. We identify, evaluate and grade the quality of evidence concerning the diagnostic effectiveness of clinical tests and the effect of preventive and treatment strategies for the most common lower limb muscle injuries including hamstring, adductor, rectus femoris/quadriceps and calf muscle injuries.

METHODS
This statement is divided into four sections: (1) hamstring, (2) adductor, (3) rectus femoris/quadriceps and (4) calf muscle strain injuries, and it includes three domains in each section: (1) diagnosis, (2) prevention and (3) treatment. We did not include studies solely reporting on non-acute problems, and/or clear traumatic injuries such as total muscle ruptures, avulsion injuries and muscle contusions.[8] A systematic search was employed to identify literature for the three domains in each section, with inclusion of studies based on the highest level of available evidence.[15] Data were synthesised and the quality of evidence were evaluated using the *Grading of Recommendations Assessment, Development and Evaluation* (GRADE) working group.[16]

Search

Twelve systematic searches covering diagnosis, prevention and treatment for each of the four sections (1: hamstring, 2: adductor, 3: rectus femoris/quadriceps and 4: calf) were conducted in MEDLINE (via PubMed), CENTRAL and Embase (via Ovid) during July 2018 and updated in September 2019.[17] No restrictions were applied concerning year of publication, however, only publications in English were included. We searched individual text words in title and abstract supplemented with Medical Subject Headings (MeSH) terms. We combined anatomical region of interest (eg, 'Groin (MeSH)' OR 'adductor' OR 'groin') AND type of injury (eg, 'Athletic Injury (MeSH)' OR 'Strains and Sprains (MeSH)' OR 'strain*' OR 'injur*' OR 're-injur*' OR 'reinjur*') AND outcome for diagnosis and treatment domains (eg, 'Diagnosis (MeSH)' OR 'exam*' and 'Return To Sport' OR 'full training,' respectively) or intervention for prevention domains (eg, 'Primary Prevention (MeSHs)' OR 'Reduc*'). If studies from one search was deemed relevant for one of the other 11 searches, the study was included as literature identified from other sources. In addition, reference lists of the included trials and relevant systematic reviews were scanned for relevant references. A flow chart of searches (see online supplementary file 1) and the complete search strategy for all searches and databases (see online supplementary file 2) is available as supplementary.

Selection

Three authors (LI, KK, RSH) screened records ordered from the most recent to the oldest records, using the Rayyan system (http://rayyan.qcri.org).[18] With 12 sets of search results, two authors screened 8 sets each, and thus all searches were screened independently by two authors. For all domains we included studies based on the highest level of available evidence.[15] For the diagnosis domain, we initially screened for systematic reviews and diagnostic cohort studies as these represent the highest starting point for the GRADE assessment.[16] Thus, for diagnosis, we intended to include systematic reviews of diagnostic studies supplemented with additional diagnostic cohort studies.[15] We aimed for studies that compared clinical tests to either ultrasonography or magnetic resonance imaging as the diagnostic reference standard. For the prevention and treatment domains, we initially screened for systematic reviews and randomised controlled trials (RCTs) as these represent the highest starting point for the GRADE assessment.[16] If no systematic reviews and/or RCTs were identified, we screened for observational studies. Thus, for prevention and treatment, we intended to include systematic reviews on RCTs supplemented with additional RCTs, or secondly observation studies if no systematic reviews or RCTs were identified.[15] For the prevention domain, we aimed for studies that assessed the risk of injury using a definition of injury based on time loss,[19] problems[20] or medical attention.[21] For the treatment domain, we aimed for studies that investigated the effect of treatment on risk of reinjuries and/or time to return-to-play, defined as completion of treatment,[22,23] criteria passed[24–27] or self-reported completion of a full training session or match play.[28–30] Studies that investigated the effect of treatment and/or prevention, but did not data extraction of individual muscle injuries were not included.

Appraisal

Two authors assessed risk of bias (LI and KK) of individual studies, as required for the GRADE framework[31] and in line with Cochrane procedures. [16] Therefore, tools assessing risk of bias rather than the study quality was chosen,[32] and thus we used The Cochrane Collaboration's risk of bias assessment tool (version 1) for RCTs,[33] QUADAS-2 tool for diagnostic studies[34] and Scottish Intercollegiate Guidelines Network Methodology Checklist 3 for cohort studies.[35] Details of each tool can be found in online supplementary file 4. Furthermore, two authors assessed risk of bias (RSH and CBJ) in systematic reviews using the ROBIS assessment tool.[36] Agreement was reached by consensus. If a systematic review included a risk of bias assessment of individual studies using one of the assessment tools stated above, no further risk of bias assessment was conducted for these individual studies. However, if these tools were not used, or if risk of bias was conflicting between two or more systematic reviews, we reassessed all risk of bias domains in the specific individual studies as part of this statement. The risk of bias assessments for systematic reviews and individual studies can be found in supplementary material (see online supplementary file 3; Table 1–11).

Data synthesis

Two authors assessed the quality of evidence (LI and KK) for each outcome relating to diagnostic tests (eg, effectiveness), prevention (eg, risk of injury) and treatment (eg, time to return-to-play) according to the approach from the GRADE working group.[16] Agreement was reached by consensus. The quality of evidence was graded as: (1) high, indicating that further research is unlikely to change the confidence in the estimate of effect, (2) moderate, indicating that further research is likely to have an important impact on confidence in the estimate of effect and may change the estimate, (3) low, indicating that further research is very likely have an important impact on the confidence in the estimate of effect and is likely to change the estimate or (4) very low, indicating high uncertainty about the estimate.[16] The starting quality of evidence was rated as 'high' when data was based on either RCTs for treatment and prevention purposes or rated as 'low' when based on observational studies.[16] For diagnostic purposes, the starting quality of evidence was rated as high when based on cohort studies (prospective or cross-sectional).[16] Subsequently, the quality of evidence could be downgraded one or two levels (eg, from high to moderate) for each of the following five domains of the GRADE approach: Study limitations (ie, serious risk of bias such as lack of blinding of outcome assessor or other concerns determined to influence the study result),[31] inconsistency (ie, the heterogeneity of the results across studies if more than one study was included for the specific outcome),[37] indirectness (ie, poor generalisability of the findings to the target population, eg, use groin injuries vs acute adductor injuries for prevention, and/or use of a clinically irrelevant outcome in relation to the question, eg, 'time to end of treatment' for 'time to return-to-play' outcomes),[38] imprecision of the estimates (ie, wide CIs)[39] and the risk of publication bias.[40] Furthermore, the level of evidence for cohort studies could be upgraded due to a large effect, a dose–response relationship or if no effect was found and all plausible confounding factors identified in the study could be expected to increase the effect.[16] An overview of the risk of bias and grading is provided as supplementary material (see online supplementary file 3; Table 1–11).

Diagnostic tests

The diagnostic effectiveness of clinical tests was estimated from positive (LR+) and negative (LR−) likelihood ratios, and express the change in probability of the patient having the injury.[41,42] A LR+ >1 increases the post-test probability of a diagnosis following a positive test, while a LR− <1 decreases the post-test probability of a diagnosis following a negative test. The diagnostic effectiveness of a positive and negative test was classified based on current guidelines as: very low (LR+: 1 to 2; LR−: 0.5 to 1), low (LR+: >2 to 5; LR−: 0.2 to <0.5), moderate (LR+: >5 to 10; LR−: 0.1 to <0.2); high (LR+: >10; LR−: <0.1).[41]

Prevention and treatment

Review Manager V.5.3 (The Nordic Cochrane Centre, Copenhagen) was used to calculate risk ratio and standardised effect sizes (Hedges' g) if not available through published meta-analyses or individual RCT's, to allow for consistency of interpretation across studies. Thus, if a meta-analysis did not report standardised effect size for continuous variables or risk ratio for dichotomised variables, we re-ran the analysis, if possible, using a random-effect model, unless otherwise stated in the original meta-analysis.[43] Heterogeneity in study results was calculated using the I^2 statistic, which is a measure to indicate the consistency of results across studies, from 0% (no inconsistency) to 100% (maximal inconsistency).[44] For continuous variables, for example, time to return-to-play, the effect of treatment was based on the standardised between-group difference calculated as Hedges' g and assessed as trivial ($g<0.2$), small ($g\geq0.2$), medium ($g\geq0.5$) and large ($g\geq0.8$).[45] For dichotomised variables (eg, risk of reinjury for treatment or risk of injury for prevention), the effect of treatment and prevention was based on the magnitude of the risk reduction following the intervention calculated as: $\text{Risk Ratio}\ (\text{RR}) = \frac{a/(a+b)}{c/(c+d)}$, where a is the number of injuries in the intervention group, b is the number without injuries in the intervention group, c is the number of injuries in the control group and d is the number without injuries in the control group.[46] The magnitude of effect was inspired by the risk ratios proposed by Bahr [47] for sample size calculations in sports injury prevention, and thus reflects arbitrary cut off values. Since these values were originally presented to study the magnitude of risk factors, that is a higher risk, we calculated the inverse values as 1/RR to determine the preventive effect and assessed the magnitude as trivial (RR >0.78), small (0.78≥ RR >0.61), medium (0.61≥ RR >0.47) and large (RR ≤0.47).[47]

RESULTS

In total 44 studies were included. For a detailed overview of included studies, including risk of bias assessment, GRADE and which individual studies are contained in systematic reviews, we refer to online supplementary file 3.

Hamstring injuries

Domain 1: diagnostic tests

In total 7081 studies were identified in the literature search. One systematic review[48] and three cohort studies were included.[49–51] No meta-analysis of diagnostic effectiveness was available from previous literature[48] or conducted as part of this statement. Based on one prospective study, where diagnostic effectiveness was calculated by the authors of this statement,[51] and two diagnostic studies,[49 50] the *'Taking off shoe test'* showed high diagnostic effectiveness, with perfect agreement between clinical testing and ultrasonography (n=140) (very low quality of evidence; table 1).[50] However, since no false positives were observed in Zeren and Oztekin[50] this precludes calculation of LR+ for tests in that study. All other tests displayed very low to low diagnostic effectiveness (LR+: 0.95 to 1.50; LR−: 0.37 to 0.96) in predicting a positive or negative MRI (n=58 to 180) (moderate to high quality of evidence)[49 51] (table 1).

Domain 2: prevention

In total 2468 studies were identified in the literature search. Three systematic reviews[52–54] and 12 RCT's was included.[21 55–65] A systematic review and meta-analysis performed by van Dyk *et al* (2019) showed a medium and significant risk reduction (RR: 0.55, 95% CI 0.34 to 0.89; I^2=67.0%) of hamstring injuries in football players in interventions including the Nordic hamstring exercise versus usual care (n=5362) (moderate quality of evidence).[53] A systematic review and meta-analysis by Goode *et al* (2015) showed a medium but non-significant risk reduction (RR: 0.59, 95% CI 0.24 to 1.44; I^2=69.6%) of mixed eccentric hamstring exercises versus usual care on hamstring injuries in football players (n=1229) (low quality of evidence).[52] A systematic review and meta-analysis by Thorborg *et al* (2017) showed a large and significant risk reduction (RR: 0.39, 95% CI 0.24 to 0.64; I^2=0.0%) of the FIFA 11+programme versus usual care on hamstring injuries in football players (n=3417) (moderate quality of evidence).[54] Since the meta-analysis from van Dyk *et al* (2019) only assessed the effect of interventions that included the Nordic Hamstring exercise, a post hoc meta-analyses, as part of the present statement paper, was performed to investigate the isolated effect of the Nordic hamstring exercise protocol.[66] Thus, data from Petersen *et al*[56] and van der Horst *et al*[57] was pooled. Based on this, the Nordic hamstring exercise protocol showed a large and significant risk reduction (RR: 0.35, 95% CI 0.22 to 0.54; I^2=0.0%) compared with usual care on hamstring injuries in football (n=1521) (high quality of evidence).[56 57] Data from individual studies[62–65] are presented in table 2.

Domain 3: treatment

In total 978 studies were identified in the literature search. One systematic review[67] and 11 RCT's were included.[22–30 68 69]

Return to play

A systematic review by Pas *et al* (2015) performed two meta-analyses with time to return to play as outcome.[67] First, the effect of lengthening hamstring exercises versus conventional exercises was estimated as HR,[67] thus we re-ran the analysis to report Hedges' g for consistency across studies. Based on this, lengthening hamstring exercises showed a large and significant effect versus conventional hamstring exercises (Hedges' g=1.23, 95% CI 0.85 to 1.60; I^2=0.0%) on return to play in elite football[28] and track and field[29] (n=131) (low quality of evidence). Second, platelet-rich plasma showed a trivial and non-significant effect versus control interventions (placebo saline[27 68] or rehabilitation[25 26]) (HR=1.03, 95% CI 0.87 to 1.22; I^2=75.0%)[67] on return to play in athletes (n=154) (moderate quality of evidence). No additional RCTs could be added to the meta-analysis by Pas *et al*[67] due to heterogeneous interventions. Data from individual studies[22–24 30 69] are presented in table 3.

Reinjuries

A systematic review by Pas *et al* from 2015 performed two meta-analyses with risk of reinjuries as outcome.[67] First, lengthening hamstring exercises showed a large but non-significant risk reduction (RR: 0.25, 95% CI 0.03 to 2.20; I^2=0.0%) versus conventional hamstring exercises[67] at 12-month follow-up in elite football[28] and track and field athletes[29] (n=131) (very low quality of evidence). Second, platelet-rich plasma showed a trivial and non-significant risk reduction (RR: 0.88, 95% CI

Table 1 Hamstring injury diagnosis: effectiveness of clinical tests and grading the quality of evidence

		Diagnostic effectiveness		
Clinical tests	**Likelihood ratio, (95% CI)**	**High**	**Moderate**	**Low/very low**
MRI used as reference standard				
Pain on trunk flexion[51]	LR+=1.48 (1.12 to 1.97)			Moderate quality of evidence
	LR−=0.37 (0.22 to 0.63)			Moderate quality of evidence
Pain on active knee flexion[51]	LR+=1.50 (0.91 to 2.49)			High quality of evidence
	LR−=0.78 (0.78 to 1.01)			High quality of evidence
Painful passive straight leg raise[51]	LR+=1.33 (1.04 to 1.70)			Moderate quality of evidence
	LR−=0.42 (0.23 to 0.74)			Moderate quality of evidence
Painful active knee extension[51]	LR+=1.33 (1.02 to 1.72)			Moderate quality of evidence
	LR−=0.48 (0.28 to 0.81)			Moderate quality of evidence
Painful resisted knee flexion 90°[51]	LR+=1.18 (0.99 to 1.41)			Moderate quality of evidence
	LR−=0.40 (0.19 to 0.87)			Moderate quality of evidence
Painful resisted knee flexion 30°[51]	LR+=1.13 (0.94 to 1.36)			Moderate quality of evidence
	LR−=0.55 (0.27 to 1.13)			Moderate quality of evidence
Active slump[51]	LR+=1.16 (0.59 to 2.28)			Moderate quality of evidence
	LR−=0.96 (0.79 to 1.16)			Moderate quality of evidence
Composite test*[49]	LR+=0.95 (0.89 to 1.02)			Moderate quality of evidence
	LR−=NA			
US used as reference standard				
Taking off shoe test[50]	LR+=NA			
	LR−=0.00	Very low quality of evidence		
Resisted range of motion test[50]	LR+=NA			
	LR−=0.39 (0.32 to 0.48)			Very low quality of evidence
Passive range of motion test[50]	LR+=NA			
	LR−=0.43 (0.35 to 0.52)			Very low quality of evidence
Active range of motion test[50]	LR+=NA			
	LR−=0.45 (0.38 to 0.54)			Very low quality of evidence

*Passive straight leg raise, active knee extension, manual muscle testing, active slump; MRI; The diagnostic effectiveness of the positive (LR+) and negative (LR−) likelihood ratios are classified individually as: very low (LR+: 1 to 2; LR−: 0.5 to 1), low (LR+: >2 to 5; LR−: 0.2 to <0.5), moderate (LR+: >5 to 10; LR−: 0.1 to <0.2); high (LR+: >10; LR−: <0.1). NA (non-applicable); diagnositc effectiveness unknown

NA, non-applicable; US, ultrasonography.

0.45 to 1.71; I^2=0.0%) versus control interventions (placebo saline[27 68] or rehabilitation[25 67] at 6 and 12-month follow-up in athletes (n=129) (moderate quality of evidence). No additional RCTs was added to the existing meta-analysis[67] due to heterogeneous interventions. Data from individual studies[24 30] are presented in table 3.

Adductor injuries

Domain 1: diagnostic tests

In total 6832 studies were identified in the literature search. Two cohort studies[70 71] were identified, however, due to duplication of data between these studies, only the study focusing on

Table 2 Hamstring injury prevention: effect and grading the quality of evidence

		Effect size			
Outcomes	**RR (95% CI)**	**Large**	**Medium**	**Small**	**Trivial**
Risk of injury					
Meta-analyses					
Interventions including the Nordic hamstring exercise versus usual care*; n=5362, male/female football[53]	0.55 (0.34 to 0.89); I^2=67.0%		Moderate quality of evidence		
Mixed eccentric hamstring training versus usual care based*; n=1229, male football[52]	0.59 (0.24 to 1.44); I^2=69.6%		Low quality of evidence		
FIFA 11+ programme versus usual care;* n=3417, male/female football[54]	0.39 (0.24 to 0.64); I^2=0.0%	Moderate quality of evidence			
Nordic hamstring exercise protocol versus usual care;* n=1521, male football[56 57]	0.35 (0.22 to 0.54); I^2=0.0%	High quality of evidence			
Individual studies					
Bounding exercise programme versus usual care; n=400, male football[63]	0.89 (0.55 to 1.44)				Moderate quality of evidence
FIFA 11+ programme performed pre-football and post-football versus FIFA 11+ performed pre-football; n=280, male football[62]	0.21 (0.05 to 0.95)	Very low quality of evidence			
Modified FIFA 11+ with rescheduling of Part 2 versus standard FIFA 11+; n=806, male football[64]	0.86 (0.59 to 1.25)				Moderate quality of evidence
Balance board training versus usual care; n=140, female football[65]	0.18 (0.02 to 1.42)	Very low quality of evidence			

*Based on pooled data from meta-analysis. RR (risk ratio); I^2 (heterogeneity in study results); The preventive effect is assessed as RR assessed as trivial (RR >0.78), small (0.78≥ RR >0.61), medium (0.61≥ RR >0.47) and large (RR ≤0.47).[47]

Table 3 Hamstring rehabilitation after injury: effect and grading the quality of evidence

Outcomes		Effect size: Large	Medium	Small	Trivial
Time to return-to-play					
Meta-analyses	**Hedges' g (95% CI)**				
Lengthening hamstring exercises versus conventional hamstring exercises*; n=131, male football and track and field athletes[67]	1.23 (0.85 to 1.60); I^2=0.0%	Low quality of evidence			
	HR (95% CI)				
Platelet-rich plasma versus placebo or rehabilitation*; n=154, various athletes[67]	1.03 (0.87 to 1.22); I^2=75.0%				Moderate quality of evidence
Individual studies	**Hedges' *g* (95% CI)**				
Lengthening hamstring exercises versus a criteria-based algorithm; n=48, male football[30]	0.23 (–0.34 to 0.80)			Low quality of evidence	
Hamstring stretching four times per day versus hamstring stretching one time per day; n=80, track and field athletes[22]	2.31 (1.75 to 2.88)	Very low quality of evidence			
Agility and trunk stabilisation versus hamstring stretching and strengthening; n=24, various athletes[24]	0.75 (–0.08 to 1.58)		Very low quality of evidence		
Running and eccentric hamstring strengthening versus agility and trunk stabilisation; n=29, various athletes[23]	0.39 (–0.42 to 1.20)			Very low quality of evidence	
	HR (95% CI)				
Pain-threshold (≤4 on the 0 to 10 NRS) versus pain-free (0 on the 0 to 10 NRS) rehabilitation; n=37, male/female[69]	0.75 (0.40 to 1.40)			Low quality of evidence	
Reinjuries					
Meta-analyses	**RR (95 % CI)**				
Lengthening hamstring exercises versus conventional hamstring exercises*; n=131, male football and track and field athletes[67]	0.25 (0.03 to 2.20); I^2=0.0%	Very low quality of evidence			
Platelet-rich plasma versus placebo or rehabilitation at 6–12 month follow-up*; n=129, various athletes[67]	0.88 (0.45 to 1.71); I^2=0.0%				Moderate quality of evidence
Individual studies					
Criteria-based algorithm versus lengthening hamstring exercises at 6 month follow-up, n=48, male football[30]	0.17 (0.02 to 1.28)	Low quality of evidence			
Agility and trunk stabilisation versus hamstring stretching and strengthening at 12 months follow-up, n=24, various athletes[24]	0.10 (0.01 to 0.70)	Very low quality of evidence			
	HR (95 % CI)				
Pain-threshold (≤4 on the 0 to 10 NRS) versus pain-free (0 on the 0 to 10 NRS) rehabilitation at 6 month follow-up; n=37, male/female[69]	1.05 (0.14 to 7.47)				Low quality of evidence

*Based on pooled data from meta-analysis. RR (Risk ratio); HR; I^2 (Heterogeneity in study results); NRS (Numeric Rating Scale); the effect of treatment regarding return to play is assessed by Hedges' *g* as trivial (g<0.2), small (g≥0.2), medium (g≥0.5) and large (g≥0.8).[39] The effect of treatment on reinjuries is assessed as risk ratio as trivial (RR >0.78), small (0.78≥ RR >0.61), medium (0.61≥ RR >0.47) and large (RR ≤0.47).[47]

Table 4 Adductor injury diagnosis: effectiveness of clinical tests and grading the quality of evidence

Clinical tests	Likelihood ratio, (95% CI)	Diagnostic effectiveness High	Moderate	Low/very low
MRI used as reference standard				
Adductor palpation (adductor longus, gracilis, pectineus)[71]	LR+=2.23 (1.51 to 3.29)			Moderate quality of evidence
	LR−=0.08 (0.02 to 0.31)	Low quality of evidence		
Squeeze 0°[71]	LR+=3.13 (1.75 to 5.59)			Low quality of evidence
	LR−=0.26 (0.14 to 0.48)			Moderate quality of evidence
Squeeze 45°[71]	LR+=1.81 (1.13 to 2.92)			Moderate quality of evidence
	LR−=0.52 (0.33 to 0.81)			Moderate quality of evidence
Resisted outer range adduction[71]	LR+=3.30 (1.85 to 5.87)			Low quality of evidence
	LR−=0.20 (0.10 to 0.41)			Moderate quality of evidence
Passive adductor stretching[71]	LR+=3.04 (1.51 to 6.14)			Low quality of evidence
	LR−=0.49 (0.34 to 0.71)			Moderate quality of evidence
Flexion abduction external rotation test[71]	LR+=1.45 (0.81 to 2.60)			Moderate quality of evidence
	LR−=0.79 (0.59 to 1.06)			Moderate quality of evidence

MRI; the diagnostic effectiveness of the positive (LR+) and negative (LR–) likelihood ratios are classified individually as: very low (LR+: 1 to 2; LR–: 0.5 to 1), low (LR+: >2 to 5; LR–: 0.2 to <0.5), moderate (LR+: >5 to 10; LR–: 0.1 to <0.2); high (LR+: >10; LR–: <0.1).[37]

diagnostic effectiveness was included (n=81).[71] Adductor palpation showed high diagnostic effectiveness in predicting a negative MRI (LR−: 0.08) (low quality of evidence).[71] For the remaining tests (see table 4), very low to low diagnostic effectiveness (LR+: 1.45 to 3.30; LR−: 0.20 to 0.79) were observed in predicting a positive or negative MRI (low to moderate quality of evidence).

Domain 2: prevention

In total 1566 studies were identified in the literature search. Two systematic reviews[54 72] and 13 RCTs were included.[21 58 60 62 64 65 73–79] None of the studies specifically reported on acute adductor injuries. A systematic review by Esteve *et al* (2015) performed three meta-analyses with risk of groin injuries as outcome.[72] First, mixed groin prevention programmes showed a trivial and non-significant risk reduction (RR: 0.81, 95% CI 0.60 to 1.09; I^2=7.0%) versus usual care on groin injuries in football (n=4191) (low quality of evidence).[72] Second, specific adductor strength training showed a trivial and non-significant risk reduction (RR: 0.80, 95% CI 0.53 to 1.22; I^2=3.0%) versus usual care on groin injuries in football (n=1067) (low quality of evidence).[72] Third, the FIFA 11+ programme showed a small but non-significant risk reduction (RR: 0.64, 95% CI 0.27 to 1.49; I^2=59.0%) versus usual care on groin injuries in football (n=2476) (very low quality of evidence).[72] Furthermore, a systematic review and meta-analysis by Thorborg *et al* (2017) investigating the effect of the FIFA 11+ programme in football showed a medium and significant risk reduction (RR: 0.58, 95% CI 0.40 to 0.84; I^2=8.0%) versus usual care on groin injuries in football (n=3417) (low level of evidence).[54] No additional RCTs were added to the existing meta-analyses[54 72] due to heterogeneous interventions, populations and injury definitions (eg, groin injuries vs groin problems as used in Haroy *et al*[73]). However, two additional studies on the preventive effect of the FIFA 11+ programme in mixed sports and basketball were pooled in a post hoc meta-analysis.[78 79] Based on this, the FIFA 11+ programme showed a medium but non-significant risk reduction (RR: 0.58, 95% CI 0.06 to 5.93; I^2=62.0%) versus usual care on groin injuries in mixed sports (n=3732) (very low quality of evidence). Data from individual studies are presented in table 5.

Domain 3: treatment

In total 217 studies were identified in the literature search; however, no studies on the effect of treatment of groin injury could be included.

Rectus femoris/quadriceps injuries

Domain 1: diagnostic tests

In total 8729 studies were identified in the literature search. Two cohort studies[70 71] were eligible, however, due to duplication of data between these studies, only the study focusing on diagnostic effectiveness was included (n=81 athletes).[71] Proximal rectus femoris palpation showed high diagnostic effectiveness when positive (LR+: 11.20) and negative (LR−: 0.00) in predicting a positive or negative rectus femoris injury on MRI (low to moderate quality of evidence).[71] Furthermore, resisted knee extension showed high diagnostic effectiveness when negative (LR−: 0.00) in ruling out a rectus femoris injury on MRI (moderate quality of evidence). For the remaining tests (see table 6), very low to moderate diagnostic effectiveness (LR+: 1.45 to 5.47; LR−: 0.15 to 0.55) were observed (low to moderate quality of evidence).[71]

Domain 2: prevention

In total 3002 studies were identified in the literature search. No systematic reviews and five RCTs were included.[21 60 62 64 65] As part of this statement data from Soligard *et al*[60] and Silvers-Granelli *et al*[21] was pooled post hoc, as this analysis was not available in the existing literature. Based on this, the FIFA 11+ programme showed a small and not significant effect versus usual care (RR: 0.73, 95% CI 0.48 to 1.12; I^2=0.0%) in reducing anterior thigh injuries in football (n=3417) (low quality of evidence).[21 60] Data from individual studies[62 64 65] are presented in table 7.

Domain 3: treatment

In total 484 studies were identified in the search. No systematic reviews or RCT's were included. One study (case-series) was included with a total of 18 Australian rules football players.[80] A two-phase criteria-based intervention with increasing running and kicking intensity led to a return to full training at a mean of 13 days (range: 2 to 43) with no reinjuries during an unreported time-frame (very low quality of evidence).[80]

Table 5 Groin injury prevention: effect and grading the quality of evidence

Outcomes		Effect size			
		Large	Medium	Small	Trivial
Risk of injury					
Meta-analyses	**RR (95% CI)**				
Mixed groin prevention programmes versus usual care*; n=4191, male/female football[72]	0.81 (0.60 to 1.09); I^2=7.0%				Low quality of evidence
Specific adductor strength training versus usual care*; n=1067, male football[72]	0.80 (0.53 to 1.22); I^2=3.0%				Low quality of evidence
FIFA 11+ programme versus usual care*; n=2476, male/female football[72]	0.64 (0.27 to 1.49); I^2=59.0%			Very low quality of evidence	
FIFA 11+ programme versus to usual care*; n=3417, male/female football[54]	0.58 (0.40 to 0.84); I^2=8.0%		Low quality of evidence		
FIFA 11+ programme versus usual care*; n=3732, male/female from mixed sports[78 79]	0.58 (0.06 to 5.93); I^2=62.0%		Very low quality of evidence		
Individual studies	**OR (95% CI)**				
Adductor strengthening programme versus usual care; n=486, male football[73]	0.59 (0.40 to 0.86)		Moderate quality of evidence		
	RR (95% CI)				
FIFA 11+ programme performed pre-football and post-football versus FIFA 11+ performed pre-football; n=280, male football[62]	0.16 (0.02 to 1.29)	Very low quality of evidence			
Modified FIFA 11+ with rescheduling of Part 2 versus standard FIFA 11+; n=806, male football[64]	1.19 (0.81 to 1.76)				Moderate quality of evidence

*Based on pooled data from meta-analysis. RR (risk ratio) ORs; I^2 (heterogeneity in study results); the preventive effect is assessed as RR assessed as trivial (RR >0.78), small (0.78≥ RR >0.61), medium (0.61≥ RR >0.47) and large (RR ≤0.47).[47]

Calf injuries

Domain 1: diagnostic tests

In total 5410 studies were identified in the search; however, no studies were included.

Domain 2: prevention

In total 2944 studies were identified in the search. No systematic reviews or RCTs were identified. One prospective cohort study could be included (n=24).[81] A soccer-specific balance programme performed during five half-seasons were superior to a 6-month control period with a medium effect size (rate ratio: 0.57; 95% CI not reported) on reducing gastrocnemius injuries in football (very low quality of evidence).[81]

Domain 3: treatment

In total 91 studies were identified in the search. No systematic reviews or RCTs were identified. Three studies (two case-series and one retrospective observational) were included with a total number of 825 subjects.[82–84] Very low quality of evidence was observed for a multimodal treatment consisting of passive treatment modalities and progressive

Table 6 Rectus femoris/quadriceps injury diagnosis: effectiveness of clinical tests and grading the quality of evidence

Clinical tests	Likelihood ratio (95% CI)	Diagnostic effectiveness		
		High	Moderate	Low/very low
MRI used as reference standard				
Rectus femoris palpation[71]	LR+=11.20 (4.85 to 25.86)	Low quality of evidence		
	LR−=0	Moderate quality of evidence		
Resisted hip flexion at 0°[71]	LR+=1.45 (0.90 to 2.32)			Moderate quality of evidence
	LR−=0.55 (0.15 to 1.79)			Low quality of evidence
Resisted hip flexion at 90°[71]	LR+=2.47 (1.41 to 4.34)			Moderate quality of evidence
	LR−=0.36 (0.11 to 1.21)			Low quality of evidence
Resisted hip flexion (modified Thomas test position)[71]	LR+=2.36 (1.53 to 3.66)			Moderate quality of evidence
	LR−=0.20 (0.03 to 1.27)		Low quality of evidence	
Resisted knee extension (modified Thomas test position)[71]	LR+=4.17 (2.54 to 6.82)			Moderate quality of evidence
	LR−=0	Moderate quality of evidence		
Passive hip extension (modified Thomas test position)[71]	LR+=2.70 (1.50 to 4.86)			Moderate quality of evidence
	LR−=0.35 (0.10 to 1.17)			Low quality of evidence
Passive knee flexion (modified Thomas test position)[71]	LR+=5.47 (2.75 to 10.87)		Low quality of evidence	
	LR−=0.15 (0.02 to 0.94)		Low quality of evidence	

MRI; the diagnostic effectiveness of the positive (LR+) and negative (LR−) likelihood ratios are classified individually as: very low (LR+: 1 to 2; LR−: 0.5 to 1), low (LR+: >2 to 5; LR−: 0.2 to <0.5), moderate (LR+: >5 to 10; LR−: 0.1 to <0.2); high (LR+: >10; LR−: <0.1).[37]

Table 7 Quadriceps/anterior thigh injuries injury prevention: effect and grading the quality of evidence

Outcomes	RR (95% CI)	Effect size: Large	Medium	Small	Trivial
Risk of injury					
Meta-analyses					
FIFA 11+ programme versus usual care; n=3417, male/female football*[21 60]	0.73 (0.48 to 1.12); I^2=0.0%			Low quality of evidence	
Individual studies					
FIFA 11+ programme performed pre-football and post-football versus to FIFA 11+ performed pre-football; n=280, male football[62]	0.16 (0.02 to 1.35)	Very low quality of evidence			
Modified FIFA 11+ with rescheduling of Part 2 versus standard FIFA 11+; n=806, male football[64]	1.95 (1.11 to 3.43)				High quality of evidence
Balance board training versus usual care; n=140, female football[65]	3.76 (0.16 to 90.77)				Very low level of evidence

*Based on pooled data from meta-analysis. RR (risk ratio); I^2 (heterogeneity in study results); the preventive effect is assessed as RR assessed as trivial (RR >0.78), small (0.78≥ RR >0.61), medium (0.61≥ RR >0.47) and large (RR ≤0.47).[47]

exercises, which led to an average treatment time of 9 days (range: not reported) in one study[82] and a 1 year reinjury rate of 6.8% (95% CI not reported) in another study.[84] Furthermore, platelet-rich plasma and rehabilitation showed a large and significant effect versus rehabilitation alone (Hedges' g=1.78, 95% CI 1.19 to 2.37) on return to previous sport activity (very low quality of evidence).[83]

DISCUSSION

The following sections discuss the statements for each type of injury and domain including the limitations in the existing literature.

Hamstring injuries

Domain 1: diagnostic tests

Based on the existing literature, conducted mostly in male football players,[49–51] very low to low diagnostic effectiveness was observed for most clinical tests. This means that the shift in pre-test to post-test probability, and thus the change in the certainty of an injury or not, was minimal for most tests. For example, in Wangensteen *et al*[51] the certainty of an MRI-defined hamstring injury was 78% (pre-test probability) before clinical testing, and this changed to 80% to 84% for a positive test and to 59% to 73% for a negative test (moderate to high quality of evidence).[51] In practice, this means that 59% to 73% of players will still have a hamstring injury following a negative test, and thus commonly used tests, such as pain during strength testing and/or stretching of the hamstring muscles, seems to provide limited value in ruling in or out a hamstring injury. This, notion is confirmed by Schneider-Kolsky *et al*,[49] who observed no shift in pre-test to post-test probability (67% to 67%) following a cluster of tests (moderate quality of evidence).[51] The only test with high diagnostic effectiveness was the *'Taking off shoe test,'* which showed perfect agreement with ultrasound when positive, which means that a negative test is highly effective at ruling out a hamstring injury.[50] However, the study was associated with serious risk of bias due to lack of blinding, which results in very low quality of evidence for this test.[50] The limited diagnostic effectiveness of most tests may be explained by inclusion of athletes with acute onset of posterior thigh pain during sport[49 51] or a verified hamstring injury on ultrasonography,[50] that is a high pre-test probability of a hamstring strain injury. Thus, if a clear medical history, such as self-reported onset of acute posterior thigh pain during sport, is present it is questionable whether pain on stretching and/or contraction provide additional value in the clinical setting when diagnosing hamstring strain injuries, despite being considered important by most experts.[85]

Domain 2: prevention

Several interventions for prevention of hamstring muscle injuries have been investigated, with most included subjects being male football players, with one study conducted in Australian football[55] and one study in female football players.[59] The highest quality of evidence for a preventive effect on hamstring injuries was observed for interventions including the Nordic hamstring exercise (moderate quality of evidence),[53] the FIFA 11+ intervention (moderate quality of evidence)[54] and the isolated 10-week Nordic hamstring exercise protocol (high quality of evidence).[56 57] These interventions resulted in a significant 45% to 65% lower risk of injury. These findings are partly in line with prevention practices utilised in elite football. In a survey of 44 elite clubs 66% reported using the Nordic hamstring exercise as a preventive strategy,[86] however, most elite clubs (>80%) are non-compliant to the 10-week Nordic hamstring exercise protocol,[87] making the preventive effect of the exercise questionable in real-life settings.[52] Similarly, in professional youth football teams the FIFA 11+ intervention was only performed fully in 12% of training sessions across a season.[88] These observations, regarding low compliance, could likely explain the continuous rise in hamstring strain injuries in elite football.[14 21 52] We also found moderate quality of evidence for a trivial non-significant effect of a comprehensive bounding programme involving plyometric and running drills directed towards the injury mechanisms during high-speed running.[63]

In summary, hamstring training, in form of the Nordic hamstring exercise, may be essential for prevention of hamstring injuries, where improvements in eccentric strength,[66 89] fatigue resistance[90 91] and alterations in muscle morphology and architecture,[89 92] collagen expression at the myotendinous junctions[93] and angle of peak torque[94] are suggested mechanisms of effect.

Domain 3: treatment

Several interventions for treatment of hamstring injuries have been investigated, including targeted hamstring exercises and running,[23 28–30 69] stretching,[22 24] agility and trunk exercises[23 24] and injection therapy.[25–27] The majority of included subjects were male football players[25 27 28 30 68] or track and field athletes.[22 26 29] For the outcome measure *'time to return-to-play,'* large heterogeneity in the outcome definitions (eg, criteria-based vs self-reported vs medical clearance) preclude any clear recommendations of a superior rehabilitation strategy for return to play. However, rehabilitation programmes with a focus on progressive targeted eccentric hamstring exercises supplemented with progressive running drills seems to result in the shortest return-to-play times with an associated low reinjury risk.[28–30 69] Thus, lengthening hamstring exercises showed significant faster return to play and no reinjuries compared with conventional exercises in elite football players[28] and track and field athletes.[29] However, in a recent study, lengthening hamstring exercises showed a substantial higher reinjury rate of 25% compared with a multifactorial criteria-based programme with a reinjury rate of 4% with only small, and non-significant, differences in return-to-play time.[30] Interestingly, the return-to-play times were markedly faster in the latter study, suggesting that longer return-to-play times may decrease risk of reinjury.[10 95 96] It should however be noted, that due to the small absolute number of reinjuries in the above studies the effect of the interventions on reinjury risk is associated with substantial imprecision of the estimate leading to a downgrade of the evidence.[39]

Finally, moderate quality of evidence was observed for a trivial, non-significant, effect of platelet-rich plasma on time to return-to-play and reinjury risk.[67]

Adductor injuries

Domain 1: diagnostic tests

Based on one study concerning primarily male football players,[71] high diagnostic effectiveness was observed for a negative adductor palpation test in ruling out a diagnosis of a MRI-verified adductor injury. Accordingly, Serner *et al* (2016) observed that 57% of athletes presented with an MRI-defined acute adductor injury (pre-test probability) but after negative palpation test the probability of injury decreased to 9%.[71] Thus, the clinician can be fairly certain that no adductor injury is present if the athlete reports no pain on palpation. The test was downgraded to low quality of evidence due to indirectness (clinical value of a negative or positive test unknown)[38] and imprecision (wide CIs).[39] Additionally, potential important clinical implications for diagnosis were also observed for pain during the squeeze test, outer range isometric adduction and passive adductor stretch, with shifts in pre-test to post-test probability from 57% to 80% to 81% for a positive test.[71] Thus, these tests could be used to rule-in an adductor injury, although a positive test is still associated with uncertainty; that is one out of five athletes with a positive test do not have an adductor injury on MRI. Currently, no evidence is available concerning potential implications for return-to-play prognosis, and therefore all tests were downgraded due to indirectness (clinical value of a negative or positive test unknown).[38]

Domain 2: prevention

Several interventions for prevention of groin injuries have been investigated primarily in football including both males and females,[54 72 73] however, no RCT's have specifically reported on adductor strain injuries. Thus, the quality of evidence for all studies/outcomes have been downgraded due to indirectness.[38] The highest quality of evidence for a preventive effect was observed for an adductor strengthening programme consisting of the Copenhagen adduction exercise[97] performed at different levels of intensity (moderate quality of evidence).[73] The outcome measure in the study was the Oslo Sports Trauma Research Center Overuse Injury Questionnaire,[20] which captures all problems rather than only time-loss injuries. Thus, the risk reduction of 41% following the adductor strengthening programme encompass all groin problems from delayed onset muscle soreness to more severe injuries, hence the preventive effect specifically on acute adductor strain injures is uncertain.[73] The FIFA 11+ programme also showed a medium risk reduction of 42% in football players and is a viable option for prevention of groin injuries.[54] The preventive effect of an adductor strengthening programme[98] indicates the importance to focus on hip adduction strength gains for prevention.[97 99] These findings are partly in line with prevention practices of groin injuries in football, with a recent survey of 64 professional youth academies demonstrating focus on adductor strengthening, although only few academies specifically performed the Copenhagen adduction exercise.[100]

Domain 3: treatment

No studies were identified for treatment of acute adductor injuries, which is remarkable since acute adductor injuries are considered a common muscle injury in football.[7] However, based on current literature concerning long-standing adductor-related pain, an exercise-based approach with a large focus on strengthening the adductor muscles has been recommended.[101]

Rectus femoris/quadriceps injuries

Domain 1: diagnostic tests

One study including primarily male football players was included.[71] However, it should be noted that this study only included athletes with acute onset of groin pain, and thus only encompass proximal rectus femoris injuries.[71] High diagnostic effectiveness was observed for proximal rectus femoris palpation in predicting a rectus femoris injury in MRI-positive cases, that is cases are only included if they had positive MRI. The test showed a substantial shift in pre-test to post-test probability from 13% to 62% for a positive test and from 13% to 0% for a negative test.[71] Although the test showed high diagnostic effectiveness, the post-test probability of 62% suggest that a positive test is still associated with large uncertainties in the diagnosis; that is one out of three athletes with a positive palpation test do not have an injury.[71] Conversely, the clinician can be fairly certain that no injury is present if the athlete report no pain on palpation. Currently, no evidence is available concerning potential implications for return-to-play prognosis, and thus all tests were downgraded due to indirectness (clinical value of a negative or positive test unknown).[38]

Domain 2: prevention

The highest quality of evidence for a preventive effect was observed for the FIFA 11+ programme compared with usual care, which resulted in a 27% lower risk (non-significant) of quadriceps/anterior thigh injuries (low quality of evidence).[21 60] Since the FIFA 11+ programme improve hip and knee strength,[102] the preventive effect could result from this. It should, however, be noted that anterior thigh injuries may encompass different injury locations, and thus the effect on rectus femoris injuries is uncertain. Furthermore, none of the included studies investigated the preventive effect on rectus femoris/quadriceps injuries as the primary outcome measure.

Domain 3: treatment

Limited literature was found to guide treatment of rectus femoris/quadriceps injuries. Thus, a single small case-series in male Australian rules football observed no reinjuries after a two-phase criteria-based intervention with increasing running and kicking intensity (very low quality of evidence).[80] It should, however, be noted that assessment of reinjury rate was not the purpose of the study, and thus these findings should be treated with caution.

Calf injuries

Despite calf muscle injuries being prevalent in football[3 7] very limited literature was found to guide diagnosis, treatment and prevention. Thus, very low quality of evidence was observed for both a multimodal treatment approach, consisting of passive therapy, stretching and strengthening[82 84] or platelet-rich plasma for treatment[83] and a soccer-specific balance programme in elite female football players for prevention.[81]

Limitations and methodological considerations

The current statement is not without limitations. First, risk of bias assessments of individual studies were not conducted by the authors of this statement, if an assessment was already available as part of a systematic review. This was chosen a priori in acknowledgement of the original study findings; however, this introduces several risk of bias rater teams, and potential rating discrepancies may exist due to differences in interpretation of risk of bias domains. However, since GRADE represents an overall assessment encompassing several domains, and thus does not rely only on risk of bias,[16] potential minor discrepancies in the risk of bias assessments are unlikely to change the quality of evidence provided in the present study. Second, for evaluating the effect of treatment and prevention, we have reported estimates and compared interventions using effect sizes, rather than using absolute measures (eg, days to return to play). This approach was chosen to allow standardised comparisons across studies and to account for the different definitions of return to play (eg, criteria-based, self-reported or medical clearance) or number reinjuries (self-reported, imaging-defined, length of follow-up). Third, the cut off values used to estimate the magnitude of a preventive effect are based on arbitrary values proposed to aid sample size calculations for risk factor studies in sports injury research.[47] Finally, post hoc meta-analyses were performed on existing literature if the results were not available in published meta-analyses, and if the post hoc analysis was deemed to add clinical value. Since post hoc analyses increase the risk of false positive findings these should be interpreted with caution.[103]

What is already known

- ► Lower extremity muscle strain injuries are very common in multidirectional sports.
- ► The quality of evidence related to diagnosis, prevention and treatment for the most common muscle injuries (hamstring, adductor, calf, rectus femoris/quadriceps) have not been investigated.

What are the new findings

- ► Most clinical tests for acute muscle injuries show very low to low diagnostic effectiveness.
- ► Hamstring and groin injuries can be reduced 40% to 65% using specific exercise interventions.
- ► Lengthening hamstring exercises show fastest return to play and lower reinjury rate compared with conventional exercises, and platelet-rich plasma offers no additional effect to current rehabilitation.
- ► Most outcomes were graded as very low to moderate quality of evidence, thus further high-quality research is likely to have an important impact on the confidence in the effect estimates.

CONCLUSION

We have graded the quality of evidence concerning diagnosis, prevention and treatment of the most common muscle injuries and provide a comprehensive and up-to-date summary of the best available evidence. Most clinical tests showed very low to low diagnostic effectiveness. For hamstring injury prevention, programmes that included the Nordic hamstring exercise resulted in a risk reduction of 45% to 65% when compared with usual care. For prevention of groin injuries, both the FIFA 11+ programme and the Copenhagen adductor strengthening programme resulted in risk reduction of 41% when compared with usual care. For treatment of hamstring injuries, lengthening hamstring exercises showed fastest return to play with a lower reinjury rate when compared with conventional hamstring exercises. Platelet-rich plasma had no effect on time to return-to-play and reinjury risk after a hamstring injury when compared with placebo or rehabilitation. Most outcomes for all muscle injuries and domains were graded as very low to moderate quality of evidence, indicating that further high-quality research is likely to have an important impact on the confidence in the effect estimates. At this point, research on diagnosis, prevention and treatment of muscle injuries primarily concerns hamstring muscle injuries, with only limited research on quadriceps, adductor and calf muscle injuries. Furthermore, muscle injury prevention research is mainly conducted in football, whereas muscle injury treatment research is conducted across different sports.

Twitter Lasse Ishøi @LasseIshoei, Kasper Krommes @krommes, Rasmus Skov Husted @Husted_RS, Carsten B Juhl @BoghJuhl and Kristian Thorborg @KThorborg

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ORCID iDs
Lasse Ishøi http://orcid.org/0000-0002-2716-6567
Kristian Thorborg http://orcid.org/0000-0001-9102-4515

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