

1 **Title:**

2 Criteria for progressing rehabilitation and determining return to play clearance following hamstring strain injury: A
3 systematic review

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29 **ABSTRACT**

30 **Background:** Rehabilitation progression and return to play (RTP) decision making following hamstring strain
31 injury (HSI) can be challenging for clinicians, due to the competing demands of reducing both convalescence and
32 risk of re-injury. Despite increased focus on the RTP process following HSI, little attention has been paid to
33 rehabilitation progression and RTP criteria, and subsequent time taken to RTP and re-injury rates.

34 **Objective:** The aim of this systematic review is to identify rehabilitation progression and RTP criteria implemented
35 following HSI and examine subsequent time taken to RTP and rates of re-injury.

36 **Methods:** A systematic literature review of databases MEDLINE, CINAHL, SPORTDiscus, Cochrane Library,
37 Web of Science and EMBASE was conducted to identify studies of participants with acute HSI reporting time taken
38 to RTP and rates of re-injury after a minimum six month follow-up. General guidelines and specific criteria for
39 rehabilitation progression were identified for each study. In addition RTP criteria were identified and categorised as
40 performance tests, clinical assessments, isokinetic dynamometry or the Askling H-test.

41 **Results:** Nine articles were included with a total of 601 acute HSI confirmed by clinical examination or magnetic
42 resonance imaging within ten days of initial injury. A feature across all nine studies was that the injured individual's
43 perception of pain was used to guide rehabilitation progression, whilst clinical assessments and performance tests
44 were the most frequently implemented RTP criteria. Mean RTP times were lowest in studies implementing
45 isokinetic dynamometry as part of RTP decision making (12 to 25 days) whilst those implementing the Askling H-
46 test had the lowest rates of re-injury (1.3 to 3.6%).

47 **Conclusions:** This systematic review highlights the strong emphasis placed on the alleviation of pain to allow HSI
48 rehabilitation progression, and the reliance on highly subjective clinical assessments and performance tests as RTP
49 criteria. These results suggest a need for more objective and clinically practical criteria, allowing a more evidence
50 based approach to rehabilitation progression, and potentially reducing the ambiguity involved in the RTP decision
51 making process.

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57 **Key Points:**

- 58 • Hamstring strain injury (HSI) rehabilitation progression is largely based around the alleviation of pain, and
59 typically only allowed within pain-free limits.
- 60 • Clinical assessments and performance tests are the most commonly implemented return to play (RTP)
61 criteria and are often highly subjective.
- 62 • Implementation of the Askling H-test as RTP criteria appears to reduce rates of re-injury, but may increase
63 time taken to achieve RTP clearance.
- 64 • The addition of isokinetic dynamometry to clinical assessments and performance tests as RTP criteria may
65 result in a more desirable balance between RTP times and rates of re-injury.

66

67 **1. INTRODUCTION**

68 Hamstring strain injury (HSI) is the most prevalent cause of time lost from competition in sports involving high
69 speed running [1-5]. Individuals with a previous HSI often exhibit deficits in hamstring muscle structure and
70 function, well after completing rehabilitation and being cleared to return to play (RTP) [6-11]. Regardless of
71 whether these deficits were a result or cause of injury, they suggest current rehabilitation and RTP practices may be
72 inadequate to address these, potentially explaining the elevated risk of re-injury in those with a history of HSI [12-
73 14]. In elite sport environments, financial [15] and performance [16] consequences of athletes remaining on the
74 sidelines due to injury may modify the decision to progress rehabilitation and ultimately provide clearance to RTP
75 [17-19]. As a result, clinicians may have reduced authority over such decisions [17, 19], potentially explaining the
76 aforementioned residual deficits in hamstring muscle structure and function [6-11].

77

78 From a clinician's perspective, progression through stages of HSI rehabilitation (eg. from acute to end stage) can be
79 based on pathophysiological time-frames for healing tissue [20-28] or specific criteria [29-35]. Whilst time-frames
80 for the physiological healing of muscle injury exist, much of this evidence is based on experimental animal models
81 [20, 25, 27, 36, 37] and it remains unknown if these models are relevant to guide rehabilitation progression in
82 humans. More recently, criteria-based rehabilitation progressions have gained popularity [29-34], as this approach
83 is more individualised than relying on time-frames for healing alone. Despite this recent interest, specific criteria to
84 progress through stages of HSI rehabilitation have not been examined rigorously.

85

86 In contrast, criteria to determine RTP clearance following HSI have received much greater attention [18, 30, 34, 38-
87 43], including a recent systematic review [44] which reported that RTP criteria for HSI have little evidence base.

88 That systematic review [44], however, did not investigate time taken to achieve RTP clearance and rates of re-injury
89 for studies implementing different criteria. It could be argued that implementing different rehabilitation progression
90 and RTP criteria would result in altered RTP times and risk of subsequent re-injury, and investigation of this could
91 help clinicians make evidence based decisions. It is, therefore, the aim of this systematic review to identify and
92 discuss the rationale for criteria to determine both rehabilitation progression and RTP clearance following HSI and
93 investigate subsequent time taken to RTP and rates of re-injury.

94

95 **2. METHODS**

96 **2.1 Study Design**

97 This review is compliant with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)
98 guidelines[45]. A comprehensive systematic literature search of MEDLINE, CINAHL, SPORTDiscus, Cochrane
99 Library, Web of Science and EMBASE was conducted from inception until July 2015.

100

101 **2.2 Search Strategy**

102 The search terms (Table 1) aimed to identify muscle group, definition of injury, intervention and outcome. Citation
103 tracking via PubMed was performed to identify any studies published following the original literature search as well
104 as cross checking of reference lists. Studies identified through this search were imported into EndNote software and
105 duplicates were subsequently removed.

106

107 *INSERT TABLE 1 HERE*

108

109 **2.3 Study Selection**

110 Titles and abstracts were screened for relevance by the lead author (JH), after which full text assessment was carried
111 out on remaining items by two authors (JH & RT) based on pre-determined selection criteria (Table 2). Where

112 multiple studies reported on the same data, the study with the greatest number of participants was selected for
113 inclusion. Any disputes were discussed and resolved in consultation with a third author (DO).

114

115 *INSERT TABLE 2 HERE*

116

117 **2.4 Study Quality Assessment**

118 Methodological quality was assessed using a modified version of a previously validated checklist (Table 3) [46].

119 Items 5, 8, 14, 15, 20, 21, 23 and 24 were removed due to their lack of applicability across all studies in order to not

120 unfairly favour randomised controlled trials over cohort studies and retrospective investigations. Item 27 relating to

121 sample size calculation and statistical power was altered so one point was awarded if sample size was calculated and

122 a second point if the sample size was subsequently met. An additional two items 28 and 29 were included by the

123 authors to assess method of injury diagnosis and level of control and supervision over rehabilitation.

124

125 *INSERT TABLE 3 HERE*

126

127 **2.5 Data Extraction**

128 Participant details, each study's method of HSI diagnosis, definition of RTP time, mean RTP time in days and the

129 number of re-injuries following RTP clearance were extracted from each study. Where data were not available or

130 reported as median rather than mean, corresponding authors were contacted for additional information. Both general

131 guidelines and specific criteria for rehabilitation progression and RTP clearance implemented in each study were

132 identified.

133

134 Given the wide range of specific RTP criteria, these were subsequently categorised as either clinical assessments,

135 which are typically implemented in regular practice, or performance tests which assess the athlete's ability to

136 complete sports-specific movements and tasks. In addition, isokinetic dynamometry and the Askling H-test were

137 considered in their own separate categories, as they require specialised laboratory based equipment, are not typically

138 implemented in regular clinical practice, or have only been described in the literature recently [38].

139

140 **2.6 Statistical Analysis**

141 Where individual studies reported mean RTP times and re-injuries within different intervention groups, but
142 implemented identical rehabilitation progression and RTP criteria across interventions, the mean RTP times and
143 overall re-injury rates for these studies were calculated. These means were used in order to investigate subsequent
144 RTP times and re-injury rates, independent of differences between interventions within studies.

145
146 Mean RTP times for these studies were calculated using the “weighted.mean” function in R [47]. Weights were
147 chosen as the inverse of the estimated variance in RTP time for each intervention. Overall rate of re-injury was
148 calculated by dividing the total number of re-injuries by the total number of participants who completed re-injury
149 follow-up in each individual study and expressing this quotient as a percentage. These results along with the
150 categories of RTP criteria implemented by each study were then plotted in a figure created using the “ggplot2”
151 package [48] in R [47].

152

153 **2.7 Primary Outcome**

154 The primary outcome of this systematic review was the mean RTP time and overall rate of re-injury for each study,
155 in the context of the criteria implemented to progress through stages of rehabilitation and determine RTP clearance.

156

157 **3. RESULTS**

158 **3.1 Literature Search**

159 The literature search consisted of five steps (Figure 1). Following full text assessment, ten studies met the eligibility
160 criteria, however, two of these studies reported on the same data set from a large-scale intervention [49, 50]. One
161 study analysed a smaller subset of the data that performed follow-up testing post RTP clearance [49], therefore only
162 the study with greater participant numbers [50] was included in the review.

163

164 *INSERT FIGURE 1 HERE*

165 **Fig. 1** PRISMA flowchart outlining study selection process

166

167

168 **3.2 Study Quality Assessment**

169 Study quality ranged from 10 [51] to 18 [52] out of a possible score of 22, with a mean (\pm SD) score of 14.4 (\pm 2.2).

170 Full quality assessment results for each study are detailed in Table 4.

171

172 *INSERT TABLE 4 HERE*

173

174 **3.3 Participant and Study Details**

175 A total of 601 participants with an acute HSI diagnosed by either clinical examination, magnetic resonance imaging

176 (MRI), or a combination of both within 10 days of initial injury were recruited across the included studies. These

177 participants included a mixture of males (80.6%) and females (19.4%) participating in sports at professional,

178 collegiate and recreational levels. Definitions of RTP time included the number of days from injury until

179 participation in full training or availability for competition [50, 53-55], completion of rehabilitation protocol and

180 clearance from treating sports medicine physician [52] or meeting RTP criteria [51, 56-58] as detailed in Table 7.

181 Further details of participants and studies included are seen in Table 5.

182

183 *INSERT TABLE 5 HERE*

184

185 **3.4 Rehabilitation Progression Guidelines and Criteria**

186 Progression of rehabilitation exercises was only allowed within pain-free limits in six studies [50, 52-55, 58], whilst

187 one allowed up to 1-2 out of 10 pain during their running rehabilitation protocol [51]. Five studies [50, 52, 56-58]

188 implemented specific criteria-based progressions through stages of rehabilitation, with the alleviation of pain during

189 walking [50, 56-58], pain-free manual assessment of isometric knee flexor strength [50, 58] and pain-free normal

190 jogging [50, 58] most common. Further details of rehabilitation progression guidelines and criteria are shown in

191 Table 6.

192

193 *INSERT TABLE 6 HERE*

194

195

196 **3.5 RTP Criteria**

197 A wide range of specific RTP criteria were identified across the nine included studies with pain-free sprinting [50,
198 51, 57, 58], manual assessment of isometric knee flexor strength [53, 54, 57, 58], range of motion (ROM) tests [50,
199 53, 54, 56] and pain-free palpation of the injury site [53, 54, 57, 58] most common. Clinical assessments and
200 performance tests were the most widely implemented categories of RTP criteria, used by eight [50, 52-58] and seven
201 [50-52, 55-58] of the included studies, respectively.

202
203 Four studies implemented a combination of clinical assessments and performance tests as their criteria for RTP
204 clearance [50, 55, 57, 58]. In addition to performance tests [51] or a combination of clinical assessments and
205 performance tests [52, 56], three studies implemented isokinetic dynamometry as part of RTP decision making [51,
206 52, 56]. Finally, two studies implemented the Askling H-test as RTP criteria once no signs or symptoms of HSI were
207 present during clinical assessments [53, 54]. Further details of the specific RTP criteria included within each of these
208 categories can be seen in Table 7.

209

210 *INSERT TABLE 7 HERE*

211

212 **3.6 RTP times and Re-injury Rates**

213 In the four studies implementing a combination of clinical assessments and performance tests as RTP criteria, mean
214 RTP times and re-injury rates were 23 days and 34.8% [57], 26 days and 9.1% [58], 27 days and 63.3% [55] and 45
215 days and 34.8% [50]. Mean RTP times and rates of re-injury in the three studies implementing isokinetic
216 dynamometry as part of RTP decision making were 12 days and 6.25% [51], 15 days and 13.9% [56] and 25 days
217 and 9.6% [52]. In the two studies implementing the Askling H-test as RTP criteria, mean time taken to RTP and
218 rates of re-injury were 63 days and 3.6% [54] and 36 days and 1.3% [53]. Figure 2 shows each study's mean RTP
219 time, rate of re-injury and indicates the combination of RTP criteria implemented in each of these studies.

220

221 *INSERT FIGURE 2 HERE*

222 **Fig. 2** Mean time taken to return to play (RTP) and overall rates of re-injury for each individual study are plotted on
223 the x and y axis respectively. The combination of RTP criteria implemented by each study is indicated by the shape
224 of the data point as per the key in the top right hand corner of the figure.

225

226 **4. DISCUSSION**

227 **4.1 Statement of Main Findings**

228 The main findings of this systematic review are i) progression of HSI rehabilitation is largely based around the
229 injured individual's perception of pain and typically only allowed within pain-free limits; ii) the most commonly
230 implemented RTP criteria, performance tests and clinical assessments, are generally based on either the injured
231 individual's perception of pain, or a clinician's subjective interpretation, such as manually resisted strength testing;
232 iii) studies implementing the Askling H-test had lower rates of re-injury but prolonged RTP times and iv) studies
233 implementing isokinetic dynamometry had faster mean RTP times compared to studies implementing a combination
234 of clinical assessments and performance tests as RTP criteria.

235

236 **4.2 Rehabilitation Progression Guidelines and Criteria**

237 In all included studies the injured individual's perception of pain was used to guide rehabilitation progression to
238 some extent, either through general progression guidelines [50-55, 58] or specific criteria to advance through stages
239 of rehabilitation [50, 52, 56-58]. With the exception of one study [51], which was of the lowest methodological
240 quality, rehabilitation was kept completely pain-free, consistent with conventional clinical practice and guidelines
241 for the treatment of muscle injury [20-23, 28, 31-35, 43]. However, as acknowledged in some of these articles [20-
242 23], such guidelines lack a solid scientific basis, and the efficacy of remaining completely pain-free during HSI
243 rehabilitation has never been scientifically investigated.

244

245 Specific criteria for rehabilitation progression, such as the alleviation of pain during isometric knee flexor
246 contraction, also reflect the aforementioned treatment guidelines, which advise that isometric muscle contractions
247 should be pain-free prior to implementing concentric before eccentric exercises [20-23, 26, 28]. As mentioned
248 above, such guidelines lack empirical evidence, leaving the possibility that this approach may unnecessarily delay
249 and reduce exposure to eccentric exercise. This is of critical importance, as eccentric knee flexor exercise reduces

250 HSI risk [59-62], likely due to improving known risk factors such as eccentric hamstring strength [63, 64] and
251 muscle fascicle length [65, 66]. A potential lack of exposure to eccentric exercise during rehabilitation may partly
252 explain residual deficits in such variables seen in those with a previous HSI [6, 7], potentially contributing to
253 elevated risk of re-injury in this population [12, 13].

254

255 **4.3 RTP Criteria**

256 The RTP decision was also heavily weighted to the resolution of signs and symptoms of HSI during performance
257 tests and clinical assessments, consistent with recently published work [42, 44]. Being able to sprint and perform
258 sports specific movements without pain is a logical milestone prior to RTP clearance; however, these performance
259 tests do not directly assess any know risk factors for HSI. Therefore, although such performance tests should be
260 included to indicate readiness to RTP, they do not necessarily provide any information as to the subsequent risk of
261 re-injury [67].

262

263 Clinical assessments were frequently implemented as both rehabilitation progression and RTP criteria, and these
264 have been shown to provide a relatively time and cost effective indicator of recovery from HSI [11, 68, 69].
265 However, the subjective nature of clinical assessments implemented by the studies in this review, such as manual
266 muscle testing, lack reliability and sensitivity in detecting deficits in strength [70, 71]. The use of more objective
267 measures of isometric strength, such as hand-held and externally fixed dynamometry has been shown to provide a
268 more reliable guide to clinical recovery and may indicate risk of re-injury [49, 68]. In addition to isometric strength
269 testing, the implementation of ROM tests may also provide a good guide to clinical recovery [11] and indicate
270 increased risk of re-injury [49].

271

272 Compared to the prevalence of performance tests and clinical assessments, isokinetic dynamometry was only
273 implemented as RTP criteria in three of the included studies [51, 52, 56]. The high cost, lab-based nature and
274 technical requirements of this methodology, likely explain its low rate of implementation. Whilst potentially
275 providing a more objective measure than manual strength assessment, the ability of isokinetic dynamometry to
276 assess risk of initial and recurrent HSI at the individual level has been shown to be limited [29, 72].

277

278 A more recent and less frequently implemented criterion for RTP was the Askling H-test, which provides an
279 assessment of the athlete's ability to tolerate dynamic lengthening of the hamstring muscles without pain or
280 apprehension [38]. The H-test has been shown to be both reliable and sensitive to detect differences in active ROM
281 in athletes recovering from HSI [38] and can also potentially be implemented with relatively little and inexpensive
282 equipment.

283

284 **4.4 Rehabilitation Progression and RTP Criteria and Subsequent RTP times and Re-injury Rates**

285 It has been established that RTP times and re-injury rates following HSI are influenced by a multitude of factors
286 such as injury type/severity [68, 73, 74] and mode of rehabilitation [53, 54, 57, 75]. The current systematic review,
287 for the first time, provides data related to the implementation of different rehabilitation progression and RTP criteria
288 and subsequent RTP times and re-injury rates.

289

290 The combination of the Askling H-test and clinical assessments as RTP criteria appears to be associated with the
291 lowest risk of re-injury [53, 54]. These findings do require further validation, as the H-test has only been
292 implemented in two studies by the same author, who is also credited with developing the assessment. These studies
293 also demonstrated extended mean RTP times, which may be seen as too conservative in an elite sport environment,
294 where non-medical decision modifiers often mean accepting an increased risk of re-injury instead of missing an
295 important game [15-19, 76]. By comparison, studies implementing a combination of clinical assessments and
296 performance tests were generally associated with shorter mean RTP times but increased rates of re-injury of up to
297 nearly two thirds of participants [55]. However, it should be noted that of these studies, the study with the highest re-
298 injury rate [55] was of low methodological quality and rehabilitation was not fully controlled by the investigators.

299

300 Despite this apparent trade-off between RTP times and re-injury rates, the implementation of isokinetic
301 dynamometry as part of RTP criteria appears to be associated with a more desirable balance between these variables.
302 Reduced rates of re-injury may be due to the fact that isokinetic dynamometry provides a more objective measure of
303 eccentric knee flexor strength which is a known risk factor for HSI [63, 64]. Unfortunately, the aforementioned
304 limitations of isokinetic dynamometry (see section 4.3), reduce the practicality of its implementation, highlighting

305 the need to develop and implement more clinically practical and objective measures of variables such as eccentric
306 hamstring strength.

307

308 The improved balance between RTP time and re-injury rates seen with the implementation of isokinetic
309 dynamometry may be further reduced with more aggressive rehabilitation progression guidelines. The single study
310 in this review to allow a small amount of pain during rehabilitation running drills also had the fastest mean RTP
311 time and relatively low rate of re-injury [51]. There is potential that these outcomes may be due to greater exposure
312 to rehabilitation stimuli, driving beneficial adaptation to rehabilitation [77]. However, this study was of the lowest
313 methodological quality [51], lacked a comparison group and did not objectively measure desired adaptations,
314 leaving this as mere speculation.

315

316 **4.5 Limitations**

317 The major limitation of this systematic review is that RTP times and re-injury rates have been reported regardless of
318 factors such as injury type/severity and rehabilitation intervention. Studies confirmed HSI diagnosis via either
319 clinical examination, MRI or a combination of both, making it difficult to differentiate between structural and
320 functional HSI, which are known to influence time to RTP and rates of re-injury [74]. In order to truly investigate
321 time taken to achieve RTP clearance and re-injury rates in response to different rehabilitation progression and RTP
322 criteria, the aforementioned factors must be accounted for in randomised controlled trials.=

323

324 The categories chosen to group specific RTP criteria were selected by the authors and are somewhat open to
325 interpretation. However, this categorisation allowed for easier interpretation of results due to the wide range of
326 specific RTP criteria implemented across different studies. Mean RTP time and re-injury data should also be viewed
327 with some caution as definition of RTP time and follow-up periods varied across the included studies. However, the
328 definitions of RTP time have been discussed in section 3.3 and the inclusion criterion of six month follow-up
329 minimum should account for the majority of re-injury risk following RTP clearance. It is also acknowledged that
330 although the original Downs and Black quality assessment has been validated [46], the modified version
331 implemented in the current systematic review has not. These modifications are, however, similar to those
332 implemented in another recently published systematic review [11]. Finally, our literature search was limited to

333 articles published in the English language only, and we are not able to account for non-English literature that would
334 have otherwise fit the inclusion criteria.

335

336 **5. CONCLUSIONS**

337 This systematic review highlights the strong emphasis placed on the alleviation of pain to allow HSI rehabilitation
338 progression and reliance on highly subjective clinical assessments and performance tests as RTP criteria.
339 Implementation of the Askling H-test appears to reduce rates of re-injury, although this requires further validation,
340 whilst implementing isokinetic dynamometry as part of RTP criteria may result in a more desirable balance between
341 RTP times and rates of re-injury when compared to relying on a combination of clinical assessments and
342 performance tests alone. These results suggest a need for more objective and clinically practical criteria, allowing an
343 evidence based approach to rehabilitation progression, and potentially reducing the ambiguity involved in the RTP
344 decision making process.

345

346 **Compliance with Ethical Standards:**

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349 Conflicts of Interest

350 Jack Hickey, Ryan Timmins, Nirav Maniar, Morgan Williams and David Opar declare that they have no conflict of
351 interest relevant to the content of this review.

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526 **Table 1** Summary of keyword grouping employed during database searches.

Muscle group	Definition of injury	Intervention	Outcome
Hamstring	Strain	Rehab*	Return*
“Posterior thigh”	Injur*	Conserv*	Resum*
“Biceps femoris”	Tear*	Treat*	Time
Semimembranosus	Rupture	Intervention*	Train*
Semitendinosus	Pain*	Therap*	Participat*
	Dysfunction	Manag*	Recurr*
	Trauma*	Clinical*	Re-inj*
		Criteri*	Reinj*
		Progress*	Re-occur*
			Reoccur*
			Outcome*
			Sport*
			Function*
			Convalescen*
			Recover*

527 Boolean term OR was used within categories; AND was used between categories.

528 * denotes truncation.

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538 **Table 2** Criteria for inclusion and exclusion in the systematic review.

Inclusion criteria	Exclusion criteria
Participants with acute hamstring strain injury diagnosed within 10 days of initial injury by either clinical examination or magnetic resonance imaging	Participants with complete hamstring muscle ruptures (grade 3), avulsion injuries and hamstring tendinopathy
Studies that clearly describe rehabilitation progression and return to play criteria	Studies involving surgical interventions
Studies reporting time taken to return to play	Individual case studies
Studies reporting rates of re-injury with a minimum six month follow-up period	

Table 3 Study quality assessment checklist modified from Downs and Black [27].

Category	Item	Question	
Reporting	1	Was the hypothesis/aim/objective of the study clearly described?	
	2	Were the main outcomes to be measured clearly described in the introduction or methods section?	
	3	Were the characteristics of the patients included in the study clearly described?	
	4	Were the interventions of interest clearly described?	
	6	Were the main findings of the study clearly described?	
	7	Did the study provide estimates of the random variability in the data for the main outcomes?	
	9	Were the characteristics of patients lost to follow up been described?	
	10	Were actual probability values been reported for main outcomes except where the probability value is less than 0.001?	
	External validity	11	Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
		12	Were those subjects who were prepared to participate representative of the entire population from which they were recruited?
13		Were the staff, places and facilities where the patients were treated representative of the treatment the majority of patients receive?	
Internal validity (bias)	16	If any of the results of the study were based on “data dredging” was this made clear?	
	17	In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case-control studies, was the time period between the intervention and outcome the same for cases and controls?	
	18	Were the statistical tests used to assess the main outcomes appropriate?	

	19	Was compliance with the intervention reliable?
Internal validity	22	Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies)
(Confounding)		recruited over the same period of time?
	25	Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?
	26	Were losses of patients to follow-up taken into account?
Power	27 ^a	Did the study have a calculation of power and was this met?
Additional internal	28 ^b	Was diagnosis of acute hamstring strain appropriate?
Validity (bias)		
Additional internal	29 ^b	Was rehabilitation controlled and supervised by the authors at least once per week?
Validity (confounding)		

^aModified items

^bAdditional items

Table 4 Results of itemised scoring of study quality using a modified quality assessment checklist^a.

Reference	1	2	3	4	6	7	9	10	11	12	13	16	17	18	19	22	25	26	27	28	29	Total	%
Askling et al. [54]	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	0	1	0	1	1	15	68
Askling et al. [53]	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	1	0	1	0	1	1	15	68
Hamilton et al. [52]	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	0	1	2	1	1	18	82
Kilcoyne et al. [51]	0	1	0	1	1	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	1	10	45
Malliaropoulos et al. [56]	1	1	1	0	1	1	1	1	0	0	0	1	1	1	0	1	1	0	0	0	1	13	59
Reurink et al. [50]	1	1	1	1	1	1	0	1	0	0	0	1	1	1	0	1	0	1	2	1	0	15	68
Sherry and Best [57]	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0	1	1	0	0	1	15	68
Silder et al. [58]	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	0	1	1	0	1	16	72
Verrall et al. [55]	1	1	1	1	1	1	1	0	0	0	0	1	0	1	0	1	1	1	0	1	0	13	59

^aSee Table 3 for questions relating to the listed items.

Table 5 Participant and study details.

Reference	Participants (% male)	Population	Diagnosis	Re-injury follow-up period
Askling et al. [54]	56 (68%)	Elite Swedish sprinters and jumpers	CE and MRI \leq 5 days of injury	12 months
Askling et al. [53]	75 (92%)	Elite Swedish footballers	CE and MRI \leq 5 days of injury	12 months
Hamilton et al. [52]	90 (100%)	Athletes from a range of sports at professional or competitive level	CE and MRI \leq 5 days of injury	6 months
Kilcoyne et al. [51]	48 (83%)	Athletes from a range of sports competing at Division 1 collegiate level	CE \leq 24 hours of injury	6 months
Malliaropoulos et al. [56]	165 (59%)	Elite track and field athletes	CE and US \leq 48 hours of injury	24 months
Reurink et al. [50]	80 (95%)	Athletes from a range of sports competing at recreational or competitive level	CE and MRI \leq 5 days of injury	12 months
Sherry and Best [57]	28 (75%)	Athletes from a range of sports	CE \leq 10 days of injury	12 months

Silder et al. [58]	29 (79%)	Athletes from a range of sports involving high speed running	CE and MRI \leq 10 days of injury	12 months
Verrall et al. [55]	30 (100%)	Elite Australian Rules footballers	CE and MRI between 2 and 6 days of injury	Same and following playing season

CE = clinical examination, MRI = magnetic resonance imaging and US = ultrasound

Table 6 General rehabilitation progression guidelines and specific criteria to progress through stages of rehabilitation.

General guidelines			Specific criteria for progression through stages of rehabilitation									
Reference	Within pain-free limits	Within limits of 1-2/10 pain (no sharp pain)	Pain-free single leg squat	Pain-free bike at 150W for 5mins	Full knee extension in supine	Pain-free high knee march	Pain-free normal walking gait	Pain-free ROM or >75% of uninjured side	Pain-free normal jog	Run at 70% perceived maximum speed	Pain-free submaximal then full isometric knee flexor strength assessed manually	Pain-free change of direction and 100% speed run
Asklings et al. [54]	✓											
Asklings et al. [53]	✓											
Hamilton et al. [52]	✓		✓	✓	✓			✓		✓		✓
Kilcoyne et al. [51]		✓										
Malliaropoulos et al. [56]								✓	✓			
Reurink et al. [50]	✓							✓		✓		✓
Sherry and Best [57]							✓	✓				
Silder et al. [58]	✓							✓		✓		✓
Verrall et al. [55]	✓											
Total	6	1	1	1	1	1	4	2	2	1	2	1

ROM = range of motion.

Table 7 Specific criteria for return to play (RTP) within each category.

Clinical assessments					Performance tests				Isokinetic dynamometry			Askling H-test
Reference	Manual assessment of isometric knee flexor strength	Pain-free palpation of injury site	ROM tests	“Normal” clinical assessment (details of assessment not reported)	Pain-free and subjective readiness following sprinting	Pain-free and subjective readiness following agility tests or sports specific movements	Pain-free full training	“Equal” single-leg triple hop for distance	Isokinetic strength difference $\leq 5\%$ at 60 and 180°/s	Results of isokinetic strength test considered	Perceived equal between limb isokinetic strength	No pain or insecurity during ballistic hip flexion with full knee extension in supine
Askling et al. [54]	✓	✓	✓									✓
Askling et al. [53]	✓	✓	✓									✓
Hamilton et al. [52]				✓		✓				✓		
Kilcoyne et al. [51]					✓						✓	
Malliaropoulos et al. [56]			✓					✓	✓			
Reurink et al. [50]			✓		✓	✓						
Sherry and Best [57]	✓	✓			✓	✓						
Silder et al. [58]	✓	✓			✓							

Verrall et al. [55]				✓			✓					
Total	4	4	4	2	4	3	1	1	1	1	1	2

ROM = range of motion.