Sports Med (2015) 45:133–146
DOI 10.1007/s40279-014-0243-1

SYSTEMATIC REVIEW

Magnetic Resonance Imaging in Acute Hamstring Injury: Can We Provide a Return to Play Prognosis?

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Published online: 15 August 2014

Abstract

Background Sports physicians are increasingly requested to perform magnetic resonance imaging (MRI) of acute hamstring muscle injuries and to provide a prognosis of the time to return to play (RTP) on the basis of their findings.

Objectives To systematically review the literature on the prognostic value of MRI findings for time to RTP in acute hamstring muscle injuries.

Data Sources The databases of PubMed, EMBASE, CINAHL, Web of Science and Cochrane Library were searched in June 2013.

Study Eligibility Criteria Studies evaluating MRI as a prognostic tool for determining time to RTP in athletes with acute hamstring injuries were eligible for inclusion.

Data Analysis Two authors independently screened the search results and assessed risk of bias using criteria for quality appraisal of prognosis studies. A best-evidence synthesis was used to identify the level of evidence.

Results Of the 12 studies included, one had a low risk of bias and 11 a high risk of bias. There is moderate evidence that injuries without hyperintensity on fluid-sensitive sequences are associated with a shorter time to RTP and that injuries involving the proximal free tendon are associated with a longer time to RTP. Limited evidence was found for an association of central tendon disruption, injury not affecting the musculotendinous junction and a total rupture with a longer time to RTP. The other MRI findings studied showed either no association or there was conflicting evidence.

Conclusion There is currently no strong evidence for any MRI finding that gives a prognosis on the time to RTP after an acute hamstring injury, owing to considerable risks of bias in the studies on this topic.

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Key Points

Based on the current evidence, there is no strong evidence for any magnetic resonance imaging (MRI) finding that can guide sports physicians and radiologists in predicting prognosis for the time to return to play (RTP) after an acute hamstring injury.

There is considerable risk of bias in the majority of current studies on the prognostic value of MRI for the time to RTP in acute hamstring injuries.

There is moderate evidence that injuries without hyperintensity on fluid-sensitive sequences are associated with a shorter time to RTP and that injuries involving the proximal free tendon are associated with a longer time to RTP.

1 Background

Hamstring injuries are the most prevalent time-loss injuries in major sports such as American and Australian football, soccer and track and field athletics [1–5]. After injury, the main question of the athlete, coaching staff and press is: when can he or she return to play?

Magnetic resonance imaging (MRI) is more readily available than ever before and plays an increasing role in diagnosing and predicting prognosis in hamstring muscle injuries, especially in the elite athlete [6, 7]. Sports physicians and radiologists are increasingly asked to assess MRIs of these injuries and to help provide a prognosis in the time to return to play (RTP) on the basis of their findings.

In the last two decades, a number of studies have been published on the prognostic value of MRI in acute hamstring injuries that reported multiple findings as indicators for the time to RTP, but the large variation of the time to RTP from 1 day [3] all the way up to 104 weeks [8] makes estimating the prognosis a challenge.

The purpose of this paper was to systematically review the literature on the prognostic value of MRI findings for time to RTP in acute hamstring injuries.

2 Methods

All reviewers involved in the literature search, study selection, data extraction and risk of bias assessment were medical doctors with at least 2 years of experience as a clinical researcher in sports medicine.

2.1 Literature Search

The databases of PubMed, EMBASE, CINAHL, Web of Science and Cochrane Library were searched without any time limits in June 2013. An overview of the complete electronic search is shown in Table 1. Additional citation tracking was performed by manual screening of the reference lists of the eligible studies.

2.2 Study Selection

Two reviewers independently assessed all records identified by the search strategy. Studies were eligible if they met the following criteria: subjects had a clinical diagnosis of an acute hamstring injury; MRI examination of the acute injury was performed; MRI findings as a prognostic tool for time to RTP were studied, injury time or time to return to pre-injury level were studied; the study had to be an original report; full text of the article had to be available; the article was written in English, Dutch or German. The two reviewers read all relevant full text articles to assess whether they met the eligibility criteria. If there was a difference in opinion on eligibility, a consensus was reached by the two reviewers. If no consensus was reached, the independent opinion of a third reviewer was decisive.

2.3 Data Extraction

One reviewer recorded the population, details of the MRI protocol, MRI findings, time to RTP and the outcome of the analysis of association between MRI findings and time to RTP using standardised data extraction forms. Authors of the eligible studies were contacted if additional information was required.

2.4 Risk of Bias Assessment

Two reviewers independently assessed the potential risk of bias of the studies included, using the criteria of the consensus statement of Hayden et al. [9]. This risk of bias assessment tool assesses six potential bias domains, each consisting of specific items for opportunity of bias (Table 2). If there was a difference in opinion on an item, a consensus was reached by the two reviewers. If no consensus was reached, the independent opinion of a third reviewer was decisive.

As shown in Table 2, each of the six potential bias domains consists of three to five specific items. When ≥75 % of these items within a domain was fulfilled, we considered the bias low in that domain. To have overall low risk of bias, a study should have low bias on:

1. At least five out of the six domains.

   and

2. The outcome measurement time to RTP (domain 4).

2.5 Best-Evidence Synthesis

Because of the heterogeneity of the MRI findings, outcome measures and methodological quality, we refrained from statistical pooling of the data. We used a best-evidence synthesis, consisting of a five levels of evidence based qualitative analysis [10]:

1. Strong evidence: provided by two or more studies with low risk of bias and by generally consistent findings in all studies (≥75 % of the studies reported consistent findings).
2. Moderate evidence: provided by one study with low risk of bias and/or two or more studies with high risk of bias and by generally consistent findings in all

Table 1 Search strategy[a]

Search strategy	Records
PubMed	246
((hamstring*[tiab])) AND ("magnetic resonance imaging"[mh] OR diagnostic imaging[mh:noexp] OR (magnetic resonance imaging[tiab] OR mri[tiab] OR radiodiagnos*[tiab] OR imaging[tiab])) AND ("Wounds and Injuries"[mh] OR (injur*[tiab] OR tear*[tiab] OR strain*[tiab] OR rupture*[tiab] OR trauma*[tiab])) NOT (animals[mh] NOT humans[mh])	
Embase	415
(hamstring/exp OR (hamstring*):ab,ti) AND ('nuclear magnetic resonance imaging'/exp OR radiodiagnosis/de OR 'diagnostic imaging'/de OR ('magnetic resonance imaging' OR mri OR radiodiagnos* OR imaging):ab,ti) AND (injury/exp OR (injur* OR tear* OR strain* OR rupture* OR trauma*):ab,ti) NOT ([animals]/lim NOT [humans]/lim)	
Cochrane central	7
((hamstring*):ab,ti) AND (('magnetic resonance imaging' OR mri OR radiodiagnos* OR imaging):ab,ti) AND ((injur* OR tear* OR strain* OR rupture* OR trauma*):ab,ti)	
Web of science	224
TS = (((hamstring*)) AND ((magnetic resonance imaging OR mri OR radiodiagnos* OR imaging)) AND ((injur* OR tear* OR strain* OR rupture* OR trauma*)) NOT ((animal* OR mouse OR mice OR rat? OR nonhuman OR dog? OR rabbit? OR chicken? OR swine? OR cat? OR rodent?) NOT (human* OR patient*)))	
CINAHL	177
TX ((hamstring*)) AND (MH magnetic resonance imaging + OR MH diagnostic imaging + OR TX (magnetic resonance imaging OR mri OR radiodiagnos* OR imaging)) AND (Wounds and Injuries + OR TX (injur* OR tear* OR strain* OR rupture* OR trauma*)) NOT (MH animals + NOT MH Humans)	

[a] Search performed June 2013

studies (≥75 % of the studies reported consistent findings).
3. Limited evidence: provided by only one study with high risk of bias.
4. Conflicting evidence: inconsistent findings in multiple studies (<75 % of the studies reported consistent findings).
5. No evidence: when no studies could be found.

3 Results

3.1 Literature Search

Figure 1 shows the study selection flow diagram; 12 studies met the inclusion criteria [11–22].

3.2 Description of Included Studies

Table 3 presents the characteristics of the studies included [11–22]. Two reports [15, 16] used the same data set and are therefore considered as one study (confirmed by the corresponding author). Table 4 presents an overview of the MRI protocols used in the studies included.

3.3 Risk of Bias Assessment

The scores on the potential risk of bias domains of the studies included are shown in Table 5. One study had a low risk of bias [20] and 11 studies had a high risk of bias [11–19, 21, 22]. The detailed score sheets for each individual study are presented in Electronic Supplementary Material Appendix S1.

There was 100 % agreement between the two reviewers on the classification of the studies into high or low risk of bias. For the specific items for opportunity of bias there was disagreement on 18 out of the 264 assessed items (6.8 %), for which consensus was reached by the two reviewers.

3.4 MRI Finding and Association with Time to Return to Play

Table 6 presents an overview of all the reported MRI findings, their association with RTP and the corresponding level of evidence according to the best-evidence synthesis.

3.4.1 MRI Negative Injury

Moderate evidence was found that the absence of any focal hyperintensity on fluid-sensitive sequences (MRI negative injury) is associated with a reduced time to RTP. Six studies showed that MRI-negative injuries had a significantly shorter time to RTP than MRI-positive injuries [13, 15–18, 21, 22].

3.4.2 Number of Muscles Involved

There is conflicting evidence for the association of the number of muscles injured and time to RTP, as there were

Table 2 Risk of bias assessment tool

Potential bias domain	Items for assessment of potential opportunity for bias	Yes	No/not reported
1. Study participation			
The study sample represents the population of interest on key characteristics, sufficient to limit potential bias of the results ☐ **Yes** ☐ **No**	• The source population is adequately described for the key characteristics of type and level of sport	☐	☐
	• Inclusion and exclusion criteria are adequately described	☐	☐
	• There is adequate participation in the study by eligible individuals	☐	☐
	• The baseline study sample is adequately described for the key characteristics: sex, age, type and level of sport	☐	☐
2. Study attrition			
Loss to follow-up is not associated with key characteristics (i.e. the study data adequately represent the sample), sufficient to limit potential bias ☐ **Yes** ☐ **No**	• Losses to follow-up are reported	☐	☐
	• Reasons for loss to follow-up are described	☐	☐
	• Loss to follow-up is less than 20 %	☐	☐
	• To assess when lost to follow-up is more than 20 %: there are no important differences between key characteristics and the prognostic MRI measures in participants who completed the study and those who did not	☐	☐
3. Prognostic factor measurement			
The prognostic factor of interest is adequately measured in study participants to sufficiently limit potential bias ☐ **Yes** ☐ **No**	• The prognostic MRI measures are adequately defined or described	☐	☐
	• The prognostic MRI measures and methods are adequately valid and reliable to limit misclassification bias (may refer to relevant outside sources of information on measurement properties)	☐	☐
	• The prognostic MRI measures are blinded for the outcome measure time to RTP or injury time	☐	☐
	• More than 80 % of the study sample has complete data for the prognostic MRI measures	☐	☐
4. Outcome measurement			
The outcome of interest is adequately measured in study participants to sufficiently limit potential bias ☐ **Yes** ☐ **No**	• The outcome measure time to RTP or injury time is adequately defined or described	☐	☐
	• Criteria for RTP clearance or recovery of the injury are clearly described and are the same for all study participants	☐	☐
	• The clinicians/therapists involved in the rehabilitation and/or RTP decision and the subjects are blinded to the prognostic MRI measure	☐	☐
5. Confounding measurement and account			
Important potential confounders are appropriately accounted for, limiting potential bias with respect to the prognostic factor of interest ☐ **Yes** ☐ **No**	Important potential confounders: –Type of sport or injury mechanism –Index injury being a re-injury (assessed at least for the 2 previous months) –Rehabilitation protocol		

Table 2 continued

Potential bias domain	Items for assessment of potential opportunity for bias	Yes	No/not reported
	• The important potential confounders measured are adequately defined or described	☐	☐
	• All important potential confounders are measured and accounted for in the study design or analysis	☐	☐
6. Analysis			
The statistical analysis is appropriate for the design of the study, limiting potential for presentation of invalid results ☐ **Yes** ☐ **No**	• There is a description of the association of the prognostic MRI measure and the outcome measure time to RTP or injury time, including information about the statistical significance	☐	☐
	• The selected model is adequate for the design of the study	☐	☐
	• To assess when multivariate models are used: the strategy of inclusion of variables is appropriate and is based on a conceptual framework or model	☐	☐
	• There is no selective reporting of results	☐	☐
	• Continuous variables are reported or appropriate (i.e. not data dependent) cut-off points are used	☐	☐

To score 'yes' on a potential bias item at least 75 % of the assessment criteria should be scored 'yes'

RTP return to play, *MRI* magnetic resonance imaging

no consistent findings in the two studies reporting this finding. Silder et al. [20] reported that a higher number of muscles injured was significantly correlated with a longer time to RTP ($r = 0.50$, $p = 0.010$). Gibbs et al. [18] reported no difference in the time to RTP between the athletes with a single muscle and those with two muscles injured ($p = 0.73$).

3.4.3 Muscle Involved

Moderate evidence was found that there is no association between involvement of the different hamstring muscles and time to RTP. Connell et al. and Schneider-Kolsky et al. [15, 16] reported that an injury of the biceps femoris was associated with longer time to RTP ($p = 0.049$). Three studies reported no difference between time to RTP and involvement of the different hamstring muscles ($p = 0.33$–0.86) [14, 17, 21].

3.4.4 Distance of Injury to the Muscle Origin

Conflicting evidence was found that the distance of the injury to the muscle origin is associated with time to RTP. Different methods were used to measure the distance of the injury to the muscle origin. Four studies measured the distance between the ischial tuberosity and the most cranial point of the hyperintensity [11–13] or the maximum hyperintensity [20]. Three of these studies reported a significant association of the distance to the ischial tuberosity

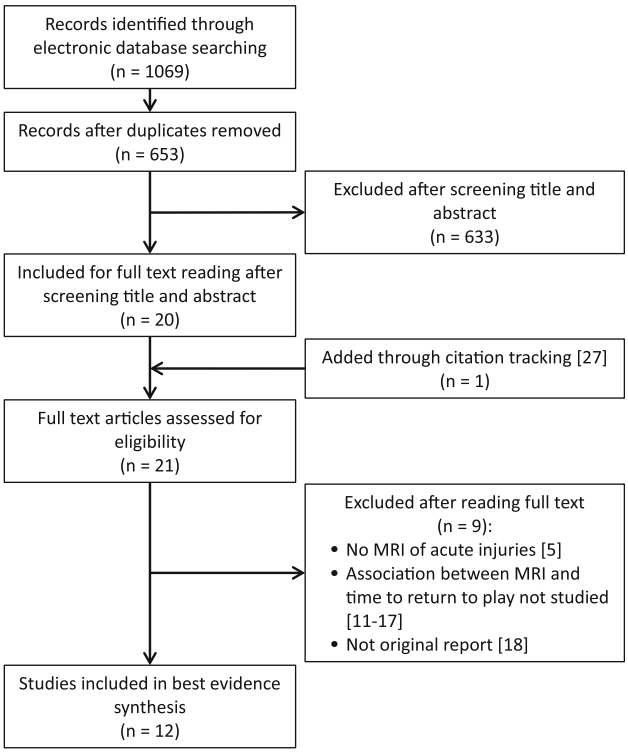

Fig. 1 Study selection flow diagram. *MRI* magnetic resonance imaging

($r = 0.44$–0.74, $p = 0.001$–0.043) with a longer time to RTP [11, 13, 20] and one found no association ($p > 0.05$) [12]. Slavotinek et al. assessed whether the injury was observed proximal or distal in the hamstring, with using the

Table 3 Characteristics of included studies

References	Population, timing of MRI examination and RTP characteristics	MRI finding	Association with time to RTP	
			Significant association[a]	Non-significant association
Askling et al. [11]	$n = 17$ Sprinters, national or international; Timing MRI: 4 d after injury; RTP: train or compete at pre-injury level; Time to RTP: median 16 w (range 6–50)	Proximal free tendon involvement	Involved 34.8 w vs. not involved 13 w ($p = 0.009$) $r = -0.544$ ($p = 0.044$)	
		Distance to origin	Proximal 25.6 w vs. distal 9.5 w ($p = 0.028$)	
		Longitudinal length		$r = 0.505$ ($p = 0.055$)
		Cross-sectional area	$r = 0.695$ ($p = 0.004$)	
		Volume	$r = 0.608$ ($p = 0.016$)	
		Antero-posterior extent	$r = 0.584$ ($p = 0.022$)	
		Medio-lateral extent		$r = 0.395$ ($p = 0.146$)
Askling et al. [12][b]	$n = 12$ Dancers, professional Timing MRI: 4 d after injury; RTP: train or compete at pre-injury level Time to RTP: median 50 w (range 30–76)	Involved muscle site Distance to origin Longitudinal length Cross-sectional area Volume Antero-posterior extent Medio-lateral extent		$r = 0.008$–0.625 ($p = 0.053$–0.981) for all MRI findings
Askling et al. [13]	$n = 75$ Football, professional; Timing MRI: ≤5 d after injury; RTP: full participation in team training and availability for match selection; Time to RTP: L-protocol mean 28 d (±15) C-protocol mean 51 d (±21)	Hyperintensity	Absence 6 d (±3) vs. presence 23 d (±11) ($p < 0.001$)[c]	
		Proximal free tendon involvement	L-protocol: involved > not involved ($p < 0.01$) C-protocol: involved > not involved ($p < 0.001$)	
		Distance to origin	L-protocol: $r = -0.736$ ($p < 0.001$) C-protocol: $r = -0.717$ ($p < 0.001$)	
		Longitudinal length	L-protocol: $r = 0.817$ ($p < 0.001$) C-protocol: $r = 0.320$ ($p < 0.001$)	
Comin et al. [14]	$n = 62$ Australian Football and Rugby, national; Timing MRI: NA; RTP: return to competition; Time to RTP: median 21 d (IQR 14–42)	Muscle injured		BF 21 d (IQR 12–56) vs. SM 32 d (IQR 21–35) vs. ST 14 d (IQR 12–22) ($p = 0.33$)
		Central tendon disruption	Disruption 72 d (IQR 42–109) vs. no disruption 21 d (IQR 9–28) ($p < 0.01$)	

Table 3 continued

References	Population, timing of MRI examination and RTP characteristics	MRI finding	Association with time to RTP	
			Significant association[a]	Non-significant association
Connell et al. [15] and Schneider-Kolsky et al. [16][d]	$n = 58$ Australian Football, professional; Timing MRI: ≤3 d after injury; RTP: return to competition; Time to RTP: median 21 d (IQR 4–56)	Hyperintensity	Absence 7 d (IQR 7–14) vs. presence 21 d (IQR 4–56) ($p < 0.001$)	
		Location within muscle	Musculotendinous junction involved < not involved r = NA ($p < 0.05$)	
		Cross-sectional area	r = NA ($p < 0.05$)	
		Intramuscular fluid collection		r = NA ($p > 0.05$)
		Extramuscular fluid collection		r = NA ($p > 0.05$)
		Multivariate:	$r^2 = 37.9$ %	
		–Longitudinal length	($p = 0.001$)	
		–Muscle injured	BF involved ($p = 0.049$)	
Ekstrand et al. [17]	$n = 207$ Football, professional; Timing MRI: 1–2 d after injury; RTP: clearance medical team for full training participation and match selection; Time to RTP: mean 19 d (±17)	Hyperintensity	Absence (=grade 0) vs. presence (=grade 1–3) ($p < 0.05$)	
		Grading	Grade 0 8 d (±3), grade 1 17 d (±10), grade 2 22 d (±11), grade 3 73 d (±60) ($p < 0.001$) Pairwise comparison ($p < 0.05$), except for grade 1 vs. grade 2	Grade 1 vs. grade 2 ($p = 0.053$)
		Muscle injured		BF 21 d (±19) vs. SM 19 d (±11) vs. ST 17 d (±11) ($p = 0.79$)
Gibbs et al. [18]	$n = 31$ Australian Football, professional; Timing MRI: 1–3 d after injury; RTP: full participation in team training; Time to RTP: median 18 d (IQR 14–27)	Hyperintensity	Absence 6.6 d (±8.2) vs. presence 20.2 d (±52.3) ($p < 0.001$)	
		Longitudinal length	$r = 0.84$ ($p < 0.001$)	
		Cross-sectional area	$r = 0.78$ ($p < 0.001$)	
		Number of muscles		Single vs. double ($p = 0.73$)
Rettig et al. [19][e]	$n = 21$ American football, professional; Timing MRI: NA; RTP: NA; Time to RTP: NA	Longitudinal length Tendon separation at musculotendinous junction		
Silder et al. [20]	$n = 25$ Sports requiring high-speed running; Timing MRI: ≤10 d after injury; RTP: Completion of rehabilitation; Time to RTP: median 23 d (IQR 20–23)	Distance to origin	$r = -0.44$ ($p = 0.043$)[f]	
		Longitudinal length	$r = 0.41$ ($p = 0.040$)	
		Cross-sectional area		$r = 0.30$ ($p = 0.182$)[f]
		Number of muscles	$r = 0.50$ ($p = 0.010$)[f]	

Table 3 continued

References	Population, timing of MRI examination and RTP characteristics	MRI finding	Association with time to RTP	
			Significant association[a]	Non-significant association
Slavotinek et al. [21]	$n = 30$	Hyperintensity	Absence vs. presence: $\gamma = -0.69$ ($p = 0.04$)	
	Australian Football, national or state;	Muscles injured		BF vs. ST ($p = 0.86$)
	Timing MRI: 2–6 d after injury;	Distance to origin		Proximal vs. distal ($p = 0.17$)
	RTP: return to competition;	Cross-sectional area	$r = 0.63$ ($p < 0.001$)	
	Time to RTP: median 27 d (range 13–48)	Volume	$r = 0.46$ ($p = 0.01$)	
		Extramuscular fluid collection		$r = 0.33$ ($p = 0.12$)
Verrall et al. [22]	$n = 83$	Hyperintensity	Absence 16 d vs. presence 27 d ($p < 0.01$)	
	Australian Football,			
	National or state;			
	Timing MRI: 2–6 d after injury;			
	RTP: return in competition;			
	Time to RTP: NA			

RTP return to play, *MRI* magnetic resonance imaging, *w* week, *d* days, *IQR* interquartile range, *BF* biceps femoris, *SM* semimembranosus, *ST* semitendinosus, *NA* not available

[a] Presented association measures are tested univariate, unless otherwise specified, $p < 0.05$ is considered statistical significant, *r* correlation coefficient, γ gamma statistics, r^2 variance in time to RTP explained by the multivariate model

[b] Contact with corresponding author: no data available for correlation of each MRI finding and RTP separately

[c] As part of a randomised controlled trial, prognostic MRI variables assessed separately for treatment groups. *L-protocol* lengthening exercises, *C-protocol* conventional exercises

[d] Studies of Connell et al. [15] and Schneider-Kolsky et al. [16] used the same dataset and are therefore considered one study (confirmed by the corresponding author)

[e] No statistical testing reported

[f] Association not determined in the original reports. A reviewer (GR) analysed the association using the data presented in the report

Table 4 Magnetic resonance imaging protocols used

References	Sides scanned	Magnetic field strength	Coil	Sequences	TR/TE	TI, ETL, flip angle	Thickness sections/gap (mm)	Field of view (cm)	Matrix (pixels)
Askling et al. [11]–[13]	Bilateral	1.0 T [11, 12] and 1.5 T [13]	Phased-array spine	Coronal STIR	4,000/30	TI 150 ms	5/0.5	42.0 × 48.0	294 × 512
				Sagittal STIR	4,000/30	TI 150 ms	5/0.5	30.0 × 48.0	210 × 512
				Axial STIR	5,035/30	TI 150 ms	5/0.5	26.3 × 35.0	154 × 256
				Axial T1	722/20		5/0.5	26.3 × 35.0	265 × 512
				Axial T2	5,500/110		5/0.5	21.9 × 35.0	168 × 256
Comin et al. [14]	NR	NR	NR	Proton density fat saturation	NR	NR	NR	NR	NR
Connell et al. [15] and Schneider-Kolsky et al. [16]	NR	1.5 T	Phased-array shoulder	Axial and coronal oblique fast spin-echo	4,000/45	ETL 8-12	5/0	20	512 × 384
				Axial and coronal oblique fast spin-echo IR	5,000–6,500/35–55		5/0	20	256 × 224
Ekstrand et al. [17]	NR	Minimum required: 1.5 T	NR	Minimum required: Axial and coronal T1 and T2 fat saturation or STIR	NR	NR	NR	NR	NR
Gibbs et al. [18]	Bilateral	1.5 T	NR	Coronal T1	NR	NR	4/1.5	NR	NR
				Coronal STIR			10/0		
				Axial T2 fat suppression			7/3.5		
Rettig et al. [19]	Bilateral	NR		NR	NR	NR	NR	NR	NR
Silder et al. [20]	Bilateral	1.5 T	Phased-array torso	Axial T2	2,200–3,200/70–88	NR	5/0	NR	512 × 512
				Coronal T2			4/0.4		
Slavotinek et al. [21]	NR	1.5 T	Polarized body array	Axial T1	802/12	ETL 3	10/2	30–32 × 40–42.7	213 × 512
				Axial IR T2	5,032/30	ETL 7; TI 150 ms	10/2	30–31.9 × 40–42.5	182 × 256
				Sagittal T1	676/12	ETL 3	7/1.4	24 × 32	213 × 512
				Sagittal IR T2	5,000/30	ETL 7; TI 150 ms	7/1.4	24 × 32	189 × 256
				Axial gradient-echo	610/18	Flip angle 20°	10/2	30–31.4 × 40–41.9	192 × 512
Verrall et al. [22]	NR	1.5 T	NR	Axial and sagittal T1, T2 and gradient echo	NR	NR	NR	NR	NR

TR time to repetition, *TE* time to echo, *TI* time to inversion, *ETL* echo train length, *T* tesla, *STIR* short tau inversion recovery, *NR* not reported, *IR* inversion recovery

Table 5 Risk of bias assessment

References	Potential risk of bias item						Risk of bias[a]
	1	2	3	4	5	6	
Askling et al. [11]	+	+	+	−	+	+	High
Askling et al. [12]	+	−	−	−	+	+	High
Askling et al. [13]	+	+	−	−	+	+	High
Comin et al. [14]	−	−	+	−	−	+	High
Connell et al. [15]	+	+	+	−	−	+	High
Schneider-Kolsky et al. [16]	+	−	−	−	−	+	High
Ekstrand et al. [17]	−	−	−	−	−	+	High
Gibbs et al. [18]	+	−	−	−	−	+	High
Rettig et al. [19]	−	−	−	−	−	−	High
Silder et al. [20]	+	+	+	+	−	+	Low
Slavotinek et al. [21]	−	−	+	±	+	+	High
Verrall et al. [22]	+	−	−	−	−	+	High

+, potential risk of bias limited sufficiently; −, potential risk of bias; ±, potential risk of bias limited sufficiently, except for the finding 'hyperintensity absence or presence'

[a] Low risk of bias requires positive scores for a minimum five out of six items and for item 4

femoral origin of the short head of the biceps femoris as a reference point. They reported no difference in time to RTP between proximally and distally located injuries ($p = 0.17$) [21].

3.4.5 Proximal Free Tendon Involvement

Moderate evidence was found for an association between involvement of the proximal tendon and time to RTP. Two studies reported that time to RTP was significantly longer in injuries with proximal tendon involvement than without ($p < 0.01$) [11, 13]. The proximal free tendon was considered injured if it was thickened, had an intratendinous high signal or a collar of high signal around it on a fluid-sensitive sequence.

3.4.6 Central Tendon Disruption

Limited evidence was found that involvement of the central tendon is associated with a longer time to RTP. Comin et al. [14] reported that injuries with MRI findings of central tendon disruption, determined by the presence of a focal defect separating proximal and distal parts of the tendon or waviness of the tendon, had significantly longer time to RTP than those injuries without these findings ($p < 0.01$).

3.4.7 Musculotendinous Junction Involvement

Limited evidence was found that injuries not affecting the musculotendinous junction are associated with a longer time to RTP. Connell et al. [15] reported that injuries at the musculotendinous junction had a significant longer recovery time than those that did not affect the musculotendinous junction ($p < 0.05$).

3.4.8 Longitudinal Length

Conflicting evidence was found for an association between the longitudinal length of hyperintensity on fluid-sensitive sequences and the time to RTP. In an univariate analysis, a larger longitudinal length was shown to be associated with a longer time to RTP in three studies ($r = 0.32$–0.84, $p = 0.001$–0.040) [13, 18, 20]. No association was found in two studies ($r = 0.51$, $p > 0.05$) [11, 12]. In a multivariate analysis, the longitudinal length was found to be independently associated with time to RTP ($p = 0.001$) [15, 16].

3.4.9 Cross-Sectional Area

Conflicting evidence was found for an association of the cross-sectional area of hyperintensity on fluid-sensitive sequences with time to RTP. All studies used a similar definition of the cross-sectional area: the maximal muscle cross-sectional area of hyperintensity expressed as a percentage of the total cross-sectional muscle area on the same axial image, measured on a fluid-sensitive sequence. Four studies [11, 15, 16, 18, 21] reported a significant association with a longer time to RTP ($r = 0.70$–0.84, $p = 0.001$–0.05) and two studies [12, 20] found no association with the time to RTP ($r = 0.30$, $p = 0.182$ and $p > 0.05$).

3.4.10 Volume

Conflicting evidence was found for an association between the volume of the hyperintensity on fluid-sensitive sequences and time to RTP. The volume in all three studies was calculated using the formula of an ellipsoid (volume $\approx$ cranio-caudal $\times$ antero-posterior $\times$ medio-lateral $\times$ 0.5) [11, 12, 21]. Two studies reported an association of a larger volume with a longer time to RTP ($r = 0.61$–0.63, $p = 0.01$–0.016) [11, 21]. In a cohort of dancers Askling et al. [12] found no significant correlation between the volume of the hyperintensity on fluid-sensitive sequences and time to return to pre-injury level ($p > 0.05$).

Table 6 Overview of the studied MRI findings and their association with the time to return to play, and the corresponding level of evidence according to the best-evidence synthesis

MRI finding	Univariate		Multivariate	Best-evidence synthesis[a]	
	Low risk of bias	High risk of bias	High risk of bias	Association	Level of evidence
Hyperintensity absence		−[13, 15–18, 21, 22]		Yes	Moderate
Number of injured muscles	+[20]	=[18]		Unknown	Conflicting
Location					
Muscle injured		=[14, 17, 21]	+[15, 16]	No	Moderate
Distance to origin	+[20]	+[11, 13], =[12, 21]		Unknown	Conflicting
Proximal free tendon involvement		+[11, 13]		Yes	Moderate
Central tendon disruption		+[14]		Yes	Limited
Musculotendinous junction involvement		−[15, 16]		Yes	Limited
Hyperintensity extent					
Longitudinal length	+[20]	+[13, 18], = [11, 12]	+[15, 16]	Unknown	Conflicting
Cross-sectional area	=[20]	+[11, 15, 16, 18, 21], =[12]		Unknown	Conflicting
Volume		+[11, 21], =[12]		Unknown	Conflicting
Antero-posterior (depth)		+[11], =[12]		Unknown	Conflicting
Medio-lateral (width)		= [11], =[12]		No	Moderate
Fluid collection					
Intramuscular		=[15, 16]		No	Limited
Extramuscular		=[15, 16, 21]		No	Moderate
Grading					
Grade 0–3		+[17]		Yes	Limited
Grade 1 vs. grade 2		=[17]		No	Limited

MRI magnetic resonance imaging

−, association with shorter time to return to play (negative association); +, association with longer time to return to play (positive association); =, no association with time to return to play

[a] The studies of Connell et al. [15] and Schneider-Kolsky et al. [16] used the same dataset and are therefore considered as one study in the best-evidence synthesis

3.4.11 Medio-Lateral Extent

Moderate evidence was found that there is no association between the maximal medio-lateral extent of hyperintensity measured on the axial images of fluid sensitive sequences and time to RTP, as Askling et al. [11, 12] found no significant correlations in both cohorts of sprinters and dancers ($r = 0.40$, $p = 0.146$ and $p > 0.05$).

3.4.12 Antero-Posterior Extent

Conflicting evidence was found for an association between the antero-posterior extent of hyperintensity measured on the axial images of fluid-sensitive sequences and time back to pre-injury level. A study by Askling et al. [11] in sprinters showed an association between a larger antero-posterior extent and a longer time to RTP ($r = 0.58$, $p = 0.022$). Conversely, a study of Askling et al. [12] in dancers showed no significant association ($p > 0.05$).

3.4.13 Fluid Collection

There is moderate and limited evidence that extramuscular and intramuscular fluid collections respectively seen on MRI, suggestive for hematoma, are not associated with the time to RTP ($r = 0.33$, $p = 0.12$ and $p > 0.05$) [15, 16, 21]. Connell et al. and Schneider-Kolsky et al. [15, 16] defined hematoma as a collection of fluid with abnormal signal intensity. Slavotinek et al. [21] considered extramuscular T2 hyperintensity to be extramuscular fluid.

3.4.14 Grading

Grading was studied in one report [17], using the following classification: (grade 0) negative MRI without any visible pathology, (grade 1) hyperintensity on fluid-sensitive sequences without evidence of a macroscopic tear, (grade 2) hyperintensity on fluid-sensitive sequences with a partial tear, (grade 3) total muscle or tendon rupture. Pairwise comparison showed that there was a significant difference

in time to RTP between the grades of injury ($p < 0.001$), except between grade 1 and 2 injuries ($p = 0.053$). This implies that there is limited evidence for an association with the time to RTP and a grading that differentiates between: (i) MRI-negative injuries, (ii) MRI-positive injuries without a total muscle or tendon rupture, and (iii) injuries with a total muscle or tendon rupture.

4 Discussion

The major findings of our systematic review are that there is moderate evidence that the absence of any hyperintensity on fluid-sensitive sequences is associated with a shorter time to RTP and that proximal free tendon involvement is associated with a longer time to RTP. There is currently no strong evidence for any MRI finding that can guide sports physicians and radiologists in predicting the prognosis for the time to RTP after an acute hamstring injury, as only one of the 12 studies included had a low risk of bias.

In the current clinical setting, MRI is considered as a valuable tool in athletes with hamstring injuries and there are high demands from the athletes and their medical staff to provide a prognosis on recovery time based on the MRI findings. However, our review shows that the sports physicians and radiologists cannot satisfy these high expectations from an evidence-based point of view.

4.1 Return to Play

The definition for RTP differed in the included studies: return to competition [14–16, 21, 22], return to full team training [18], full training participation and availability for match selection [13, 17], performing at a pre-injury level [11, 12] and completion of rehabilitation [20] These different definitions for time to RTP complicate comparison of the studies.

RTP is generally accepted as the primary outcome measure for acute muscle injuries, as it is the most clinically relevant outcome in athletes with these injuries [23, 24]. However, there are still no validated objective criteria to guide progression through rehabilitation protocols and assess readiness for RTP. Decision making for progression through rehabilitation protocols and clearance for RTP are therefore substantially affected by subjective judgements of athletes and medical staff involved. In the absence of well-defined RTP criteria, knowledge about the results of the MRI findings introduces a major potential source of bias. We therefore considered adequately measured time to RTP, by clearly defined RTP criteria and blinding of subjects and clinicians involved in the rehabilitation or RTP decisions, compulsory for a low risk of biased results (domain 4 of the risk of bias assessment tool). Only two of the studies included reported blinding of the subjects and managing clinicians for the prognostic MRI findings studied [20, 21].

4.2 Confounding Factors

The type of sport or injury mechanism, whether it was a new or recurrent injury and the treatment/rehabilitation protocol were considered to be important potential confounders in the prognostic value of MRI findings for time to RTP that should be appropriately accounted for in the analysis or study design to sufficiently limit potentially biased results (domain 5 of the risk of bias assessment tool).

Askling et al. [11, 12] reported more extensive MRI abnormalities and shorter time to RTP in sprinting athletes compared with stretch-type injuries in dancers. As this difference between sprinters and dancers may be caused by the type of sport or the injury mechanism, we considered the potential bias of this confounder sufficiently limited if either the type of sports or the injury mechanism was accounted for.

Re-injuries are a potential confounder, because they are associated with both more extensive MRI abnormalities and a longer time to RTP [25]. To prevent confounding, the treatment/rehabilitation protocol should be the same in all studied subjects or appropriately accounted for in the analysis.

In four of the studies, these important potential confounders were appropriately accounted for [11–13, 21].

4.3 Reliability of MRI Measures

Only one study presented any information on the reliability of the performed MRI measures: Comin et al. [14] reported 100 % agreement between the two radiologists on the presence or absence of central tendon disruption. None of the other studies included provided or referred to any information on reliability of the MRI measures and methods, introducing a risk of misclassification bias.

4.4 Limitations

We performed a qualitative analysis (best-evidence synthesis) instead of a quantitative analysis (meta-analysis of the data), because of the heterogeneity of the studies with regard to the MRI findings, reported outcome measures and methodological quality. This systematic review does not provide a quantitative synthesis on the strength or magnitude of the associations of the MRI findings with RTP, but is limited to whether there is evidence for a statistical significant association or not. This limits the interpretation of the magnitude and clinical relevance of the reported

associations. If we for example consider the difference between MRI-negative and MRI-positive injuries, studies reported a wide range of days to RTP: 6 (±3) vs. 23 (±11) [13], 7 (interquartile range 7–14) vs. 21 (interquartile range 4–56) [15, 16], 8 (±3) vs. 20 (±14) [17], 7 (±8) vs. 20 (±52) [18] and 16 vs. 27 [22] for MRI-negative versus MRI-positive injuries, respectively. One study reported gamma statistics, a measure of rank correlation, with a correlation coefficient of 0.69 between MRI-positive injuries and time to RTP. Although these different outcome measures cannot be appropriately pooled, a general overview of these numbers and their variability measures indicate that a MRI-negative injury may take several days up to weeks to RTP and MRI-positive injuries may take several days up to months to RTP.

For systematic reviews on prognostic findings, there is currently no standardized risk of bias assessment method and there are no generally accepted limits to determine whether a study has a high or low risk of bias. Instead, it is recommended that risk of bias criteria for prognostic studies should be applied on the basis of the relevance to the research question [9]. We used risk of bias criteria, which we thought the most appropriate for studies on the prognostic value of MRI findings in acute hamstring injuries. With this approach we aimed to perform a best available systematic risk of bias analysis.

The sample size of some of the studies included might have been insufficient to show statistical significance of clinically important associations, potentially introducing a type II error. The sample sizes of studies reporting no significant association on the number of muscles involved, distance to the muscle origin and the hyperintensity extent measures varied between 12 and 31 [11, 12, 18, 20, 21], and are therefore unable to detect weak to moderate associations [26]. When the sample size is large enough to show statistical significance, the outcome of the best-evidence synthesis could change from conflicting evidence to moderate evidence. However, large sample sizes can lead to statistical significant, but clinically irrelevant associations.

The majority of prognostic MRI findings are analysed with simple univariate statistical approaches, with only one of the studies using multivariate statistical analysis [16, 22]. In the absence of multivariate analysis, it remains unknown to what extent the MRI findings are independently associated with the time to RTP. This is because the majority can be expected to be related to each other, for example, larger longitudinal length is likely to have a larger volume.

4.5 Future Directions

This systematic review showed a lack of high-quality studies on the prognostic value of MRI in acute hamstring injuries. Common methodological limitations are the low number of participants, insufficient information about losses to follow-up, lack of blinding of subjects and clinicians to the MRI results, insufficient accounting for potential confounders, lack of information on the reliability of MRI measures used, and the use of simple univariate statistical analysis. Future studies should account for these methodological flaws.

The use of different definitions for the time to RTP, as an outcome measure, limits the comparability of the studies. Consensus on the definition of RTP is required to improve the comparability of studies using RTP as an outcome measure.

5 Conclusion

There is currently no strong evidence for any MRI finding that can guide sports physicians and radiologists in predicting prognosis for the time to RTP after an acute hamstring injury, as only one of the 12 studies included had a low risk of bias. There is only moderate evidence that injuries without hyperintensity on fluid-sensitive sequences are associated with a shorter time to RTP and that injuries involving the proximal free tendon are associated with a longer time to RTP. Limited evidence was found for an association between central tendon disruption, injury not affecting the musculotendinous junction and total hamstring ruptures with a longer time to RTP. The other MRI findings studied showed either no association with time to RTP or there was conflicting evidence.

Acknowledgments No sources of funding were used to assist in the preparation of this review. The authors have no potential conflicts of interest that are directly relevant to the content of this review.

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