Clinical findings just after return to play predict hamstring re-injury, but baseline MRI findings do not

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ABSTRACT

Background Acute hamstring re-injuries are common and hard to predict. The aim of this study was to investigate the association between clinical and imaging findings and the occurrence of hamstring re-injuries.
Methods We obtained baseline data (clinical and MRI findings) of athletes who sustained an acute hamstring injury within 5 days of initial injury. We also collected data of standardised clinical tests within 7 days after return to play (RTP). The number of re-injuries was recorded within 12 months. We analysed the association between the possible predictive variables and re-injuries with a multivariate Cox proportional-hazards regression model.
Results Eighty patients were included at baseline and 64 patients could be included in the final analysis because data after RTP were not available in 16 cases. There were 17 re-injuries (27%). None of the baseline MRI findings were univariately associated with re-injury. A higher number of previous hamstring injuries (adjusted OR (AOR) 1.33; 95% CI 1.11 to 1.61), more degrees of active knee extension deficit after RTP (AOR 1.13; 95% CI 1.03 to 1.25), isometric knee flexion force deficit at 15° after RTP (AOR 1.04; 95% CI 1.01 to 1.07) and presence of localised discomfort on hamstring palpation after RTP (AOR 3.95; 95% CI 1.38 to 11.37) were significant independent predictors of re-injury. Athletes with localised discomfort on hamstring palpation just after RTP were consequently almost four times more likely to sustain a re-injury.
Conclusions The number of previous hamstring injuries, active knee extension deficit, isometric knee flexion force deficit at 15° and presence of localised discomfort on palpation just after RTP are associated with a higher hamstring re-injury rate. None of the baseline MRI parameters was a predictor of hamstring re-injury.
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INTRODUCTION

High re-injury rates remain a major problem following acute hamstring injuries, despite increasing use of sophisticated imaging techniques, prevention and treatment options.[1 2] Hamstring re-injury rate is 14–63% within 2 years after the initial injury.[3] Re-injuries require longer rehabilitation.[1]

A recent systematic review on risk factors for hamstring *re-injury* has reported limited evidence for an association with (1) a previous ipsilateral ACL reconstruction, (2) a larger volume measured by MRI and (3) a grade 1 lesion on MRI of the initial injury as predicting recurrence.[3] Athletes who undertook progressive daily home-based

agility and stabilisation exercises were at lower risk for such re-injury.[3] Although there is no evidence for fibrous tissue formation and reduced hamstring strength as re-injury risk factors, they are frequently mentioned as risk factors.[4 5] This is thought to result from inadequate rehabilitation, a premature return to play (RTP) or a combination of both.[6 7]

The timing of RTP is challenging and generally based on expert opinion. Currently there is no consensus on RTP decision-making.[8] There is one retrospective study comparing different rehabilitation protocols and RTP strategies.[9] In daily clinical practice an athlete is normally regarded as being fit to RTP if there is a pain-free full range of motion and asymptomatic completion of sports-specific activities.[6 10] Despite this approach, re-injury rates remain high. Ideally, the results of a subjective assessment in combination with radiological and clinical findings would enable the clinician to predict a safe RTP without a high risk of re-injury. However, findings just after RTP have never been described in association with hamstring re-injury.

The aim of this study, a substudy of the Dutch Hamstring Injection Therapy study reported in the *New England Journal of Medicine*,[11] is to describe the association between clinical and imaging findings at baseline (including MRI findings of the initial injury) and standardised clinical tests just after RTP with the occurrence of hamstring re-injuries.

METHODS
Participants
The patients included in this study were involved in a double-blind randomised controlled trial (RCT) on the effect of platelet-rich plasma in acute hamstring injuries (ClinicalTrial.gov number NCT01812564).[11] In brief, the study was performed at three sports medicine departments (a large general district hospital, a university hospital and the medical centre of the national football association). Participants received either two injections of 3 mL of either platelet-rich plasma (Autologous Conditioned Plasma, Biocore, Arthrex Inc, Karlsfeld, Germany) or normal saline at the site of injury. There was no difference in the primary outcome measure (time to RTP) and re-injury rate between these two groups, and therefore it represents a normal cohort.[11]

As outlined in our previous publication,[11] the eligibility criteria for the present study are age 18–50 years, a clinical and radiological diagnosis of acute hamstring injury within 5 days from injury, MRI grade 1 or 2 hamstring lesion and the availability of re-assessment within 7 days after RTP. The criteria for a clinical diagnosis of a hamstring muscle

strain were: acute onset of posterior thigh pain, pain on hamstring stretch and resisted contraction and pain on hamstring muscle palpation. The clinical diagnosis was established by one of the six participating sports medicine physicians. MRI was performed in each participant within 5 days from initial injury, using a 1.5 T magnet system (Magnetom Essenza, Siemens) and a body matrix coil. MRIs were assessed by a musculoskeletal radiologist to confirm the diagnosis of a hamstring muscle injury. Patients and the supervising physiotherapist were blinded to the severity of the lesion on MRI. Exclusion criteria were a contraindication for MRI, chronic posterior thigh symptoms, persistent chronic low back pain, posterior thigh injury due to extrinsic trauma, inability to perform active rehabilitation, no desire to return to full sports activity, unwillingness to receive intramuscular injections and previous injection therapy for this injury.

At inclusion, informed consent was acquired from all patients. Approval was obtained from the Medical Ethics Committee Zuidwest Holland, Voorburg, The Netherlands.

Procedure

Baseline patient characteristics at the time of initial injury

At baseline we recorded age, sex, type of sports, sports activity level (recreational or competitive), type of injury (sprinting type or non-sprinting type) and number of prior ipsilateral and contralateral hamstring injuries. Competitive athletes were individuals who played league matches at the highest levels of their club. A sprinting-type injury was an injury that occurred during a maximum or near maximum sprint.[12] Injuries that occurred during stretching, deceleration phase of sprinting, high kicking or otherwise not specified were classified as non-sprinting type.

MRI findings at the time of initial injury

We used standardised scoring forms to assess MRIs at baseline.[13] We measured the increased T2 signal intensity on the fluid sensitive sequences (short T1 inversion recovery or proton-density-fat-saturated) in craniocaudal, transverse and anteroposterior dimensions. We recorded the longitudinal length (craniocaudal in cm) of the lesion and the distance in cm from the ischial tuberosity. The cross-sectional area was calculated as a percentage of the total muscle cross-sectional area in the transversal plane. The volume of the muscle lesion in cm^3 was measured using the formula for a prolate ellipsoid (($\pi/6$)×anteroposterior×transverse×craniocaudal extent).[14] We recorded the involved muscle (s) and performed grading of the injury[13]: grade 1 increased signal intensity on fluid sensitive sequences without evidence of a macroscopic tear and grade 2 increased signal intensity on fluid sensitive sequences with a partial tear. Good to excellent interobserver and intraobserver reliability was found for these MRI findings used in a previous study.[15]

Rehabilitation programme

All patients included performed a progressive-phased, criteria-based rehabilitation programme which was based on the best available evidence.[6 16 17] The rehabilitation programme consisted of twice-weekly physiotherapist-supervised training sessions combined with daily home-based exercises (see online supplementary table S1).[11] The home exercise programme consisted of a progressive agility and trunk stabilisation exercise protocol.[17] The number of supervised physiotherapy sessions and daily home-based exercise sessions were logged. Instructional videos of the exercises were supplied on an openly accessible website. The physiotherapists and patients were instructed to progress through the rehabilitation programme as fast as possible according to the prespecified functional progression criteria. With these instructions, we aimed to stimulate early RTP. However, we also emphasised that criteria were symptom-based, as opposed to time-based progressions.

RTP decision

Clearance for RTP was given by the supervising physiotherapist once the patient completed the criteria-based rehabilitation programme. According to standardised rehabilitation protocol an athlete was ready to RTP once he or she met the following criteria: symptom-free (eg, pain and stiffness) during: (1) full range of motion; (2) full-speed sprinting and (3) sport-specific movements (such as jumping and cutting).[6 17] The final phase of the rehabilitation programme consisted of unhindered functional sports-specific testing.

The physiotherapist was blinded to the data of the clinical findings collected by the principal investigator. The physiotherapist and the patient were informed that a lesion was present on the baseline MRI and therefore proved the clinical diagnosis, but they were blinded for the grading and extent of the injury. The principal investigator was not involved in the RTP decision and did not advise patients on RTP decision based on the baseline MRI or clinical findings just after RTP.

Questionnaire and recovery score just after RTP

All patients included were invited for a re-assessment within 7 days of RTP. The Hamstring Outcome Score (HaOS) was completed,[18 19] consisting of five categories (symptoms, muscle soreness, pain, function in sports and quality of life). The mean score is calculated and displayed between 0% (lowest score) and 100% (maximum score). The HaOS is a screening tool for assessment during normal activities of daily living and sports and used in previous cohorts.[18 19] For our study, the questionnaire was translated into Dutch by a registrar in Sports Medicine who is a native speaker (GR).

Perceived recovery was measured with a seven-point Likert self-rating scale ranging from 'completely recovered' (0 points) to 'worse than ever' (7 points). Complete recovery was considered as a successful outcome. The time to RTP was measured as the number of days from the initial injury until return to full training or match play in the desired sport.

Clinical assessment just after RTP

The post-RTP clinical evaluation consisted of hamstring flexibility testing, strength testing and muscle palpation. The flexibility of the hamstring muscles was assessed with the active knee extension test[20] and the passive straight leg raise test.[16–18 20] Participants were examined in the supine position and an inclinometer was placed on the anterior tibial border. Both the injured and the uninjured legs were tested. For the active knee extension test, participants were positioned with the ipsilateral hip in 90° flexion. Subsequently, participants were asked to extend the knee until experiencing maximal tolerable stretch, with the contralateral leg fixed flat on the examination table. The maximum absolute knee angle was measured.

For the passive knee extension test participants were instructed to fully relax the leg. Subsequently the leg was lifted by the principal investigator with the hip still in 90° flexion, and the knee in increasing extension until the maximal tolerable stretch was experienced. The contralateral leg remained flat on the examination table. At the end point of maximal tolerable stretch, the angle between the leg axis and the horizontal examination table was measured. For both tests the absolute flexibility deficit was calculated by subtracting the established angle of the

injured leg from the uninjured leg. Furthermore, participants were asked whether they experienced normal stretch or localised discomfort in the posterior thigh during the tests.

Isometric knee flexion force was measured using handheld dynamometry.[21] Participants were tested in prone with a knee flexion angle of 90° and 15°. Each leg was tested three times in both angles. The principal investigator positioned the dynamometer at the participant's heel and applied force to the heel in upward direction, gradually increasing in 3–5 s. Participants were instructed to resist the force applied by the principal investigator (break test). At the point that the participants were not able to resist the force, the test was terminated and the force level was recorded. For each angle the highest force value was documented. The relative strength deficit was established as a portion of the maximal force value of the injured leg divided by maximal force value of the uninjured leg.

Palpation of the hamstring muscles was performed with the patient in prone with the leg relaxed and neutral hip and knee position. The entire ipsilateral posterior thigh was carefully palpated from the hamstring origin at the ischial tuberosity to the insertions medial at the pes anserinus and lateral at the head of the fibula. The presence of localised discomfort on palpation was recorded as a dichotomous variable (present or absent).

Outcome measures
The primary outcome measure in this study was the occurrence of a re-injury. Re-injury was defined as acute posterior thigh pain in the index leg within the prospective study follow-up period of 12 months after the initial injury, which caused time loss from training or match play.[22] All patients were instructed to contact the principal investigator in case of a possible re-injury. We confirmed re-injury based on a telephone interview. The principal investigator took a thorough history and instructed the patient to perform stretching and contraction manoeuvres of the hamstring muscles to identify localised pain on stretch and contraction. All patients in the study were also asked about the occurrence of re-injuries at the standard 6-month and 12-month follow-ups.

Statistical analysis
We performed statistical analyses with SPSS software (V.20.0; SPSS, Chicago, Illinois, USA). Descriptive statistics were used to analyse baseline patient characteristics. If the data were normally distributed they were presented as means with a SDs, otherwise median and IQRs are used. To aid in data interpretation, a number of variables were categorised.

We analysed the association between the possible predictor variables and re-injuries with a Cox proportional-hazards regression model. In this model the time (days) from RTP to the event (re-injury) or the end of the follow-up is the main variable. All patients who were available for examination shortly after RTP were included in the final analysis. We excluded patients from the analysis if we could not obtain RTP measurements, because cases with missing values are routinely excluded from the multivariate analysis. Participants that sustained another severe injury (defined as absence from training and matches >28 days[1 23]) during follow-up that was not considered a hamstring re-injury were censored at the time of this injury. Participants lost to follow-up were censored at the time of their last available follow-up.

We first analysed the association between predictor variables and re-injuries in a univariate model. Variables with a p value of <0.1 were analysed in a multivariate stepwise regression. We considered a p value <0.05 statistically significant.

RESULTS
Participants
One-hundred sixty-one patients were assessed for eligibility and 80 patients were included in the RCT. Finally, 64 patients were available for inclusion in the analysis. In 16 cases (20%) data just after RTP were not available. The number of re-injuries did not differ significantly between the patients included and excluded from the analysis (p=0.49, see table 1). The progress of patients in the study is displayed in a flow chart (figure 1). We performed measurements at a median of 3 days (IQR 2–5) after the RTP date. The characteristics of the patients included and excluded are presented in table 1.
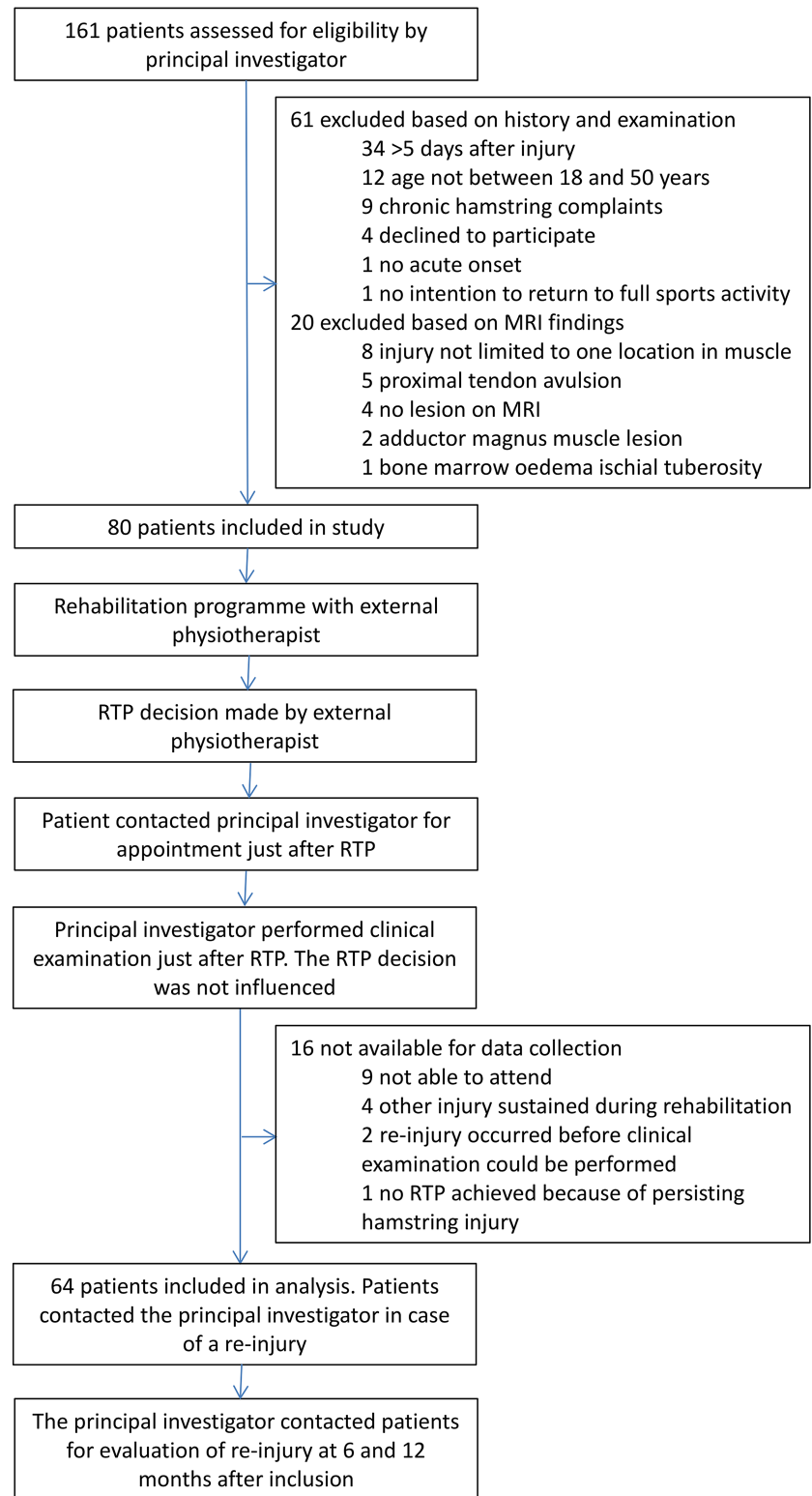
Descriptive measurements at baseline and just after RTP
The results of the clinical and imaging findings at baseline and just after RTP are displayed in table 2. Twenty-eight per cent of the patients sustained a grade 1 injury and 72% a grade 2 injury as graded on MRI. In 88% of the patients a biceps femoris long head injury was present and in 12% a semitendinosus/semimembranosus injury.

Table 1 Patient characteristics (n=80)

	Included (n=64)	Excluded (n=16)
Median age (IQR)	28 (23–33)	28 (22–32)
Gender male/female	61/3	15/1
Sports		
Football	45	11
Futsal (indoor football)	1	0
Field hockey	11	1
Athletics	4	0
Tennis	1	0
American football	1	2
Fitness	1	1
Cricket	0	1
Level of sports		
Competitive	49	10
Recreational	15	6
Median days (IQR) to initial presentation	3 (2–4)	3 (2–4)
Median number(IQR) of previous hamstring injuries	1 (0–3)	1 (0–3)
Severity of injury on MRI		
Grade 1	18	5
Grade 2	46	11
Involved muscles		
Biceps femoris	56	13
Semitendinosus/semimembranosus	8	3
Mean (SD) longitudinal length (craniocaudal) on MRI	11.4 (5.7)	14.6 (6.9)
Mean (SD) distance from the ischial tuberosity on MRI	15 (7.8)	14.8 (7.7)
Mean (SD) cross-sectional area on MRI	37% (28)	33% (21)
Mean (SD) volume of the muscle lesion on MRI (cm³)	285 (302)	486 (677)
Median (IQR) time to RTP (days)	40 (31–55)	46 (33–67) (n=11)
Median days (IQR) between RTP and clinical findings	3 (2–5)	NA
Number of re-injuries	17 (27%)	4 (36%) (n=11)

Only 11 patients in the excluded group achieved RTP, therefore some analyses are displayed for these 11 patients (n=11).
NA, not applicable; RTP, return to play.

Figure 1 Progress of patients through the study (RTP, return to play).

161 patients assessed for eligibility by principal investigator

61 excluded based on history and examination
    34 >5 days after injury
    12 age not between 18 and 50 years
    9 chronic hamstring complaints
    4 declined to participate
    1 no acute onset
    1 no intention to return to full sports activity
20 excluded based on MRI findings
    8 injury not limited to one location in muscle
    5 proximal tendon avulsion
    4 no lesion on MRI
    2 adductor magnus muscle lesion
    1 bone marrow oedema ischial tuberosity

80 patients included in study

Rehabilitation programme with external physiotherapist

RTP decision made by external physiotherapist

Patient contacted principal investigator for appointment just after RTP

Principal investigator performed clinical examination just after RTP. The RTP decision was not influenced

16 not available for data collection
    9 not able to attend
    4 other injury sustained during rehabilitation
    2 re-injury occurred before clinical examination could be performed
    1 no RTP achieved because of persisting hamstring injury

64 patients included in analysis. Patients contacted the principal investigator in case of a re-injury

The principal investigator contacted patients for evaluation of re-injury at 6 and 12 months after inclusion

Just after RTP, 66% of the patients reported a 'complete recovery' on the Likert scale. Discomfort during hamstring flexibility, hamstring resistance testing or on localised palpation was present in 25% of cases when the independent principal investigator tested those athletes who had been cleared to RTP.

In total, 50% of the patients kept their daily logs of the rehabilitation programme and returned their logbook. The mean percentage adherence for the supervised physiotherapy programme was 80%. The mean percentage adherence for the home exercise programme was 64%. Owing to these missing data, we refrained from including adherence in the Cox proportional hazards regression model.

Prognostic factors for re-injury

None of the 64 patients were lost to follow-up during the 12-month follow-up period. There were 17 (27%) re-injuries. The re-injuries occurred at a median (IQR) of 100 (6–138) days

Table 2 Descriptive statistics of clinical findings just after RTP

Clinical test	Measurement just after RTP
Mean (SD) HaOS (0–100)	88 (12)
Median (IQR) Likert self-rating scale (0–7)	0 (0–1)
Active knee extension test	
Mean (SD) deficit in angle (degrees)	−2 (5)
Discomfort (present/absent)	1/63
Passive straight leg raise test	
Mean (SD) deficit in angle (degrees)	−1 (4)
Discomfort (present/absent)	1/63
Isometric knee flexion resistance in 90°	
Mean (SD) force deficit (Newton)	2 (15)
Discomfort (present/absent)	8/56
Isometric knee flexion resistance in 15°	
Mean (SD) force deficit (Newton)	1 (16)
Discomfort (present/absent)	8/56
Localised discomfort on palpation hamstring muscles (present/absent)	16/48

HaOS, Hamstring Outcome Score; RTP, return to play.

after RTP. There were 7 (11%) re-injuries within the first 2 months.

The number of previous hamstring injuries (p=0.006), presence of discomfort during isometric knee flexion resistance test at 15° (p=0.008) and localised discomfort on hamstring palpation (p=0.008) were univariately associated with hamstring injury recurrence. For the baseline MRI findings examined we did not find significant univariate associations, as well as for all other measured variables. The results of the univariate analysis are shown in table 3.

Five variables (number of previous hamstring injuries, active knee extension deficit, isometric knee flexion force deficit at 15°, presence of discomfort during isometric knee flexion resistance test at 15° and localised discomfort on posterior thigh palpation) were included in the multivariate model based on a p value <0.1 in the univariate analysis (table 4).

The multivariate model showed that athletes with a higher number of previous ipsilateral and/or contralateral hamstring injuries (adjusted OR (AOR) 1.33; 95% CI 1.11 to 1.61), more degrees of active knee extension deficit (AOR 1.13; 95% CI 1.03 to 1.25), isometric knee flexion force deficit at 15° (AOR 1.04; 95% CI 1.01 to 1.07) and presence of localised discomfort on hamstring palpation (AOR 3.95; 95% CI 1.38 to 11.37) were more likely to have a re-injury. The presence of discomfort during isometric knee flexion resistance test at 15° was not a significant independent predictor of re-injury (AOR 2.66; 95% CI 0.83 to 8.55).

DISCUSSION
Hamstring re-injury[3] may have a different set of risk factors to primary hamstring injury.[24] We evaluated clinical and MRI findings to identify factors associated with re-injury following hamstring injury in competitive and recreational athletes. We evaluated the athletes just after the initial injury and just after RTP, when they successfully completed a criteria-based rehabilitation programme. Some players exhibited a deficit in several functional tests after RTP. Four specific clinical findings that had not fully returned to normal—as compared to the unaffected side—just after RTP appear to be associated with an increased

re-injury risk (a higher number of previous hamstring injuries, more degrees of active knee extension deficit, isometric knee flexion force deficit at 15° and the presence of localised discomfort on posterior thigh palpation just after RTP).

Independent predictors of re-injury which can be used in daily clinical practice
Significant independent predictors of hamstring re-injury were a higher number of previous hamstring injuries, more degrees of active knee extension deficit, isometric knee flexion force deficit at 15° and the presence of localised discomfort on posterior thigh palpation just after RTP. These various independent predictors were analysed using a multivariate model. These results provide useful prognostic information for clinicians involved in the treatment of hamstring injuries and who are responsible for the RTP decision.

These findings are important as acute hamstring injuries frequently result in a recurrence with a prolonged rehabilitation time. With easy-to-assess clinical evaluation—performed by clinicians or physiotherapists—those participants with an increased re-injury risk can be identified. These findings emphasise that it is of major importance to monitor the athlete in the first week after RTP and not only at RTP.

We found that athletes with localised discomfort on hamstring palpation just after the RTP date were almost four times more likely to sustain a re-injury compared with athletes with absence of discomfort on palpation. Also, the continuous variables number of previous hamstring injuries (AOR 1.33, 33% increased risk per number of previous hamstring injury), degrees of active knee extension deficit (AOR 1.13, 13% increased risk per deficit in degree) and isometric knee flexion force deficit at 15° (AOR 1.04, 4% increased risk per deficit in Newton) showed to be of prognostic value. For example, an athlete is at 33% more risk for re-injury if there is one previous hamstring injury and at 77% more risk (HR increases with 1.33×1.33=1.77) if there are two previous hamstring injuries, compared with no previous hamstring injury.

MRI findings at baseline is not a predictor of re-injury—comparison with previous studies
Clinical findings just after RTP have not been related to hamstring re-injury rate in previous studies. A recent study from our group described the MRI findings just after RTP.[13] We reported that in 89% of clinically recovered hamstring injuries, increased intramuscular signal intensity on fluid sensitive sequences was observed just after RTP.[13] The presence of increased signal intensity was not discriminative as a predictor for re-injury. The number of re-injuries was too small to draw conclusions on the effect of the presence of fibrous tissue on MRI. These results emphasise that clinical and functional tests seem to be better associated with re-injury rates than findings on MRI just after RTP.[10 25]

In a previous study, Warren et al[26] reported on the value of baseline history and clinical signs measured within 0–3 days in 59 athletes who sustained an acute hamstring injury. They concluded that hamstring injury in the previous medical history predicted re-injury (relative risk of 19.5 and 95% CI 1.5 to 261.1). Baseline clinical findings for hamstring flexibility, pain on resistance and palpation at the site of the injury were also included, but were found not to be significant early predictors. A comparable study in 30 athletes with acute hamstring injury did not show an association with re-injury and the baseline clinical findings assessed at 12–18 h postinjury.[27] The lack of association between clinical test in the acute phase and re-injury risk might

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Table 3 Univariate results of the association between the clinical findings just after RTP and event of re-injuries

Variable	n	HR (95% CI)	p Value
Patient characteristics			
Categorical variables			
Previous hamstring injury		2.9 (0.8 to 10.1)	0.094
No (reference)	23		
Yes	41		
Previous ipsilateral hamstring injury		1.8 (0.7 to 5.0)	0.233
No (reference)	30		
Yes	34		
Previous hamstring injury within 12 months		1.6 (0.6 to 4.3)	0.309
No (reference)	45		
Yes	19		
Previous ipsilateral hamstring injury within 12 months		1.6 (0.6 to 4.2)	0.388
No (reference)	47		
Yes	17		
Level of sport		2.5 (0.6 to 11)	0.218
Recreational (reference)	15		
Competitive	49		
Continuous variables			
Age		1.00 (0.94 to 1.07)	0.952
Number of previous hamstring injuries		1.26 (1.07 to 1.48)	0.006
Injury characteristics			
Categorical variables			
Sprinting injury type		1.9 (0.5 to 6.5)	0.321
No (reference)	17		
Yes	47		
Injured muscle		0.5 (0.1 to 3.4)	0.440
Biceps femoris (reference)	56		
Semitendinosus/semimembranosus	8		
MRI grade		1.3 (0.4 to 4.1)	0.624
Grade I (reference)	18		
Grade II	46		
Continuous variables			
Time to RTP		0.98 (0.94 to 1.01)	0.126
MRI hyperintensity volume		1.00 (1.00 to 1.00)	0.112
MRI cross-sectional area (% of total muscle)		0.95 (0.18 to 5.11)	0.947
MRI craniocaudal length		1.00 (0.99 to 1.01)	0.525
MRI distance to tuber		1.00 (0.98 to 1.00)	0.978
Characteristics just after RTP			
Categorical variables			
Subjective complete recovery		0.5 (0.2 to 1.3)	0.136
Yes (reference)	22		
No	42		
Localised discomfort on palpation		3.7 (1.4 to 9.6)	0.008
No (reference)	48		
Yes	16		
Active knee extension discomfort		0.1 (0 to 303265.6)	0.704
No (reference)	63		
Yes	1		
Passive straight leg raise discomfort		2.2 (0.3 to 16.7)	0.445
No (reference)	62		
Yes	2		
Discomfort on isometric knee flexion resistance in 15°		3.7 (1.4 to 9.6)	0.008
No (reference)	56		
Yes	8		
Continuous variables			
HaOS		0.98 (0.95 to 1.01)	0.198
Active knee extension deficit		1.10 (1.00 to 1.24)	0.059
Passive straight leg raise deficit		0.95 (0.85 to 1.07)	0.376
Isometric knee flexion force deficit in 15°		1.03 (1.00 to 1.06)	0.074

HaOS, Hamstring Outcome Score; RTP, return to play.

Table 4 Independent predictors of re-injuries

Clinical test	Adjusted HR (95% CI)	p Value
Number of previous hamstring muscle injuries	1.33 (1.11 to 1.61)	0.002
Active knee extension deficit	1.13 (1.03 to 1.25)	0.012
Isometric knee flexion resistance discomfort in 15°	2.66 (0.83 to 8.55)	0.100
Isometric knee flexion force deficit in 15°	1.04 (1.01 to 1.07)	0.020
Localised discomfort on palpation hamstring muscles	3.95 (1.38 to 11.37)	0.011

be explained by the fact that almost all these patients experience pain at the early stages of the injury and therefore the discriminative power of these tests are not yet present in the acute stage. For this reason—and also because it is common in clinical practice—we repeated the assessment of clinical findings just after the RTP moment.

The predictive value of baseline MRI findings of the initial injury for re-injury has been reported in previous studies. One study[28] did not show an association between the size of the initial injury and re-injury rate. They found, however, that a higher frequency of re-injury was reported in grade 1 hamstring injury at the initial trauma, compared with MRI negative injuries. In a study of 30 Australian Rules Footballers, Verrall and colleagues[27] found that baseline MRI features were not associated with increased recurrent injury risk within the same playing season. Larger transverse size and volume of injury on MRI was reflected in re-injury risk if the subsequent playing season was also included in the analysis. Koulouris et al[29] performed a cohort study in 41 Australian Football players and showed a correlation between length of the lesion on MRI and re-injury risk.

Owing to the above mentioned study results, it is suggested that a more severe injury on MRI might result in a longer expected recovery time and postponed RTP decision. In our study, patients were blinded for the severity of the injury on baseline MRI; only the presence of a lesion was confirmed. The RTP decision was therefore not influenced by the grading of the lesion on MRI. We did not find any of the baseline MRI findings to be associated with re-injury. As 89% of the MRIs still showed abnormalities at RTP,[13] MRI at RTP did not provide stronger associations (data not shown). Based on our study—in which blinding of the patients and care-providers was performed—baseline MRI is not a predictor of hamstring re-injury.

Study strengths and limitations
The strength of this study is that one single independent principal investigator performed all clinical tests. He was not involved in the RTP decision and only assessed the clinical findings once the player returned to play. The independent physiotherapist—who made the RTP decision—was blinded to the outcomes of the clinical tests performed by the principal investigator. This allows for the opportunity to study the effects of some of these variables that were tested but not included in the RTP decision-making algorithm.

There are also some study limitations. First, the number of patients was relatively low with a subsequent low number of re-injuries. Therefore, the study might be underpowered to provide a definite answer on the effect size of the clinical predictors for re-injury at RTP. A previous article reports that 20–50 cases are needed to detect moderate to strong associations.[30] In

our study, 17 re-injuries were found, meaning that only strong associations could probably be detected. The sample size of the original study was based on the primary outcome (days between injury and RTP) of the RCT.[11] Therefore, small associations are less likely to be detected with our study. However, the clinical relevance of finding small associations is also questionable.

Furthermore, not all athletes (n=16, 20%) had clinical examination performed after RTP, which may have resulted in risk of bias. However, the percentage of re-injuries did not differ between the patients included and excluded from the analysis. It was challenging to evaluate all patients shortly after the RTP date and there were athletes who did not achieve RTP due to other injuries. To minimise the risk of bias, these athletes were excluded from the analysis. Two athletes sustained a re-injury after RTP before we could do a clinical assessment and therefore, there may be bias because the outcome (re-injury) resulted in missing data. Another potential source of bias is the fact that re-injuries were diagnosed with a telephone interview. This might have resulted in an overestimation of the re-injuries since posterior thigh pain after an initial hamstring injury is not always due to a hamstring re-injury. However, the principal investigator aimed to collect as much data as possible to establish the diagnosis of a re-injury.

Not all clinical tests we performed have well-examined reliability or validity. The active and passive knee extension tests have good intertester reliability.[20] For the other clinical tests these characteristics are unknown. Especially discomfort on palpation is difficult to standardise, as pressure of the palpating fingers might influence the results. To prevent large variability in test results, all clinical examinations were performed by one single trained principal investigator. He was not blinded to the side of the injury during the clinical assessment after RTP, which potentially might have led to bias. As this clinical examination was performed within 5 days after RTP (range 2–5), it remains unknown if recorded abnormalities were present at the moment of RTP decision-making or developed within the 2–5 days after RTP.

Last the independent treating physiotherapists were advised to use the standardised rehabilitation protocol; however, they did not log the actual rehabilitation performed. Variations on the protocol might have been used; although the physiotherapists were instructed to follow the protocol. The amount of bias for daily clinical practice is questionable, as many different protocols and RTP decision criteria are described in literature.[8 31] The observation that the re-injuries occurred at a median (IQR) of 100 (6–138) days after RTP suggest that the re-injuries were not a consequence of poor RTP decision-making by the supervising physiotherapists. Furthermore, in our study 27% of the athletes had a re-injury, which is within the normal range of re-injury rate in the scientific literature (14–63%).[3]

Recommendations for future studies
Re-injury prevention could be a focus in future studies. We found that a higher number of previous hamstring injuries, more degrees of active knee extension deficit, isometric knee flexion force deficit at 15° and the presence of localised discomfort on posterior thigh palpation were associated with higher re-injury risk after patients completed a criteria-based rehabilitation programme. These factors might be implemented in criteria-based rehabilitation programmes. The associated factors can also be used to test this clinical prediction rule in a prospective study. If they are found to hold up to this scrutiny then an intervention study could be performed to see if more stringent RTP criteria results in lower recurrence rates.

Original article

Re-injury prevention might be another interesting focus in future studies. In future research, rehabilitation programmes could be more focused on recovery of the clinical findings that are associated with re-injury. If the re-injury rate in these identified high-risk athletes can be reduced with prevention programmes, it will potentially have a major influence on the number needed to treat.

CONCLUSION

A higher number of previous hamstring injuries, more degrees of active knee extension deficit, isometric knee flexion force deficit at 15° and the presence of localised discomfort on posterior thigh palpation after RTP were associated with hamstring re-injury in athletes who completed a criteria-based rehabilitation programme. These factors could be taken into account by clinicians when making an RTP decision and monitoring athletes after RTP. Based on this study, none of the baseline MRI parameters was a predictor of hamstring re-injury.

What are new findings?

- ► Clinical findings within 5 days after return to play (RTP) are most valuable for estimating the re-injury risk.
- ► The number of previous hamstring injuries, active knee extension deficit, isometric knee flexion force deficit at 15° and presence of localised palpation discomfort after RTP are significantly associated with hamstring re-injury.
- ► Baseline MRI findings of the initial injury (injured muscle, grade I or II, hyperintensity volume, cross-sectional area, craniocaudal length and distance to tuber) are not associated with the occurrence of hamstring re-injury.

How might it impact on clinical practice in the near future?

- ► These study results provide useful prognostic information for clinicians involved in the treatment of hamstring injuries and who are responsible for the return to play (RTP) decision. With positive clinical findings in patients who are subjectively recovered after a standardised rehabilitation and RTP, athletes at risk for hamstring re-injuries can be identified.
- ► Future studies can focus on the impact of postponed RTP decision and prevention programmes in high-risk athletes. Rehabilitation programmes could focus more on recovery of the clinical findings that are associated with re-injury. If the re-injury rate in these identified high-risk athletes can be reduced with re-injury prevention programmes, it will potentially have a major influence.

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Clinical findings just after return to play predict hamstring re-injury, but baseline MRI findings do not

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