Magnetic Resonance Imaging Parameters for Assessing Risk of Recurrent Hamstring Injuries in Elite Athletes

George Koulouris,[*†] FRANZCR, David A. Connell,[‡] FRANZCR,
Peter Brukner,[§] FACSP, and Michal Schneider-Kolsky,[†||] PhD
From the [†]Department of Medical Imaging, Victoria House Hospital, Prahran, Melbourne, Victoria, Australia, the [‡]Department of Radiology, Royal National Orthopaedic Hospital, Stanmore, London, United Kingdom, [§]Centre for Health, Exercise and Sports Medicine, University of Melbourne, Melbourne, Victoria, Australia, and the [||]Department of Medical Imaging & Radiation Sciences, Monash University, Clayton, Victoria, Australia

Background: Magnetic resonance (MR) imaging has established its usefulness in diagnosing hamstring muscle strain and identifying features correlating with the duration of rehabilitation in athletes; however, data are currently lacking that may predict which imaging parameters may be predictive of a repeat strain.

Purpose: This study was conducted to identify whether any MR imaging-identifiable parameters are predictive of athletes at risk of sustaining a recurrent hamstring strain in the same playing season.

Study Design: Cohort study; Level of evidence, 3.

Methods: Forty-one players of the Australian Football League who sustained a hamstring injury underwent MR examination within 3 days of injury between February and August 2002. The imaging parameters measured were the length of injury, cross-sectional area, the specific muscle involved, and the location of the injury within the muscle-tendon unit. Players who suffered a repeat injury during the same season were reimaged, and baseline and repeat injury measurements were compared. Comparison was also made between this group and those who sustained a single strain.

Results: Forty-one players sustained hamstring strains that were positive on MR imaging, with 31 injured once and 10 suffering a second injury. The mean length of hamstring muscle injury for the isolated group was 83.4 mm, compared with 98.7 mm for the reinjury group ($P = .35$). In the reinjury group, the second strain was also of greater length than the original (mean, 107.5 mm; $P = .07$). Ninety percent of players sustaining a repeat injury demonstrated an injury length greater than 60 mm, compared with only 58% in the single strain group ($P = .01$). Only 7% of players (1 of 14) with a strain <60 mm suffered a repeat injury. Of the 27 players sustaining a hamstring strain >60 mm, 33% (9 of 27) suffered a repeat injury. Of all the parameters assessed, only a history of anterior cruciate ligament sprain was a statistically significant predictor for suffering a second strain during the same season of competition.

Conclusion: A history of anterior cruciate ligament injury was the only statistically significant risk factor for a recurrent hamstring strain in our study. Of the imaging parameters, the MR length of a strain had the strongest correlation association with a repeat hamstring strain and therefore may assist in identifying which athletes are more likely to suffer further reinjury.

Keywords: hamstring; magnetic resonance (MR); strain; muscle; reinjury; anterior cruciate ligament (ACL)

Recent studies evaluating the use of magnetic resonance (MR) imaging assessment of hamstring muscle strain have demonstrated that MR abnormalities can not only confirm the clinical diagnosis of a strain,[2,18,23] but can also provide the referring clinician with a reasonable estimation of the rehabilitation period based on the cross-sectional area[18] and length of the tear.[2,18] It is generally accepted that the dimension of the injury is directly proportional to the degree of myofibril damage and therefore, understandably, an increased convalescence period.[2,18] However, medical staff, physical therapists, and trainers face enormous pressures to return an athlete to competition as soon as possible, potentially undermining the rehabilitation process. A cautious rehabilitation period is critical, as a relative

*Address correspondence to George Koulouris, FRANZCR, Department of Medical Imaging, Victoria House Hospital, 316 Malvern Road, Prahran 3181, Australia (e-mail: drgeorgek@gmail.com).

No potential conflict of interest declared.

The American Journal of Sports Medicine, Vol. 35, No. 9
DOI: 10.1177/0363546507301258

increase in risk of 6.3 for repeat injury is present for an 8-week period after initial strain.[11] Furthermore, even in the event of returning to competition without recurrent injury, it has been established that player performance rating is reduced in the first 2 weeks of competition.[20] Despite these facts, players commonly return early to competition because the risk of reinjury is often judged a reasonable compromise compared with an extended convalescence period.[13] Unfortunately, repeat injury occurs in approximately 30% of players, despite what is often thought to be an apparently sufficient time out of competition and a rehabilitation program.[12] It is disappointing that this figure has not changed significantly over the last several years; however, it is hoped that this will decline with the widespread application of preventive eccentric exercises,[1,4,9,14,15] sports-specific training,[21] rehabilitation,[17] injury management, and accurate anatomic localization with MR imaging.[10]

Currently, specific imaging parameters such as the length, volume, or area of injury may be used in conjunction with the clinical assessment to categorize the severity of the injury on which the rehabilitation protocol and duration is based.[16] Whether these parameters can be used to assess the risk of repeat injuries has yet to be assessed. It would be of tremendous interest to the medical team and a benefit to the athlete if an injury could be noninvasively and objectively characterized using a reproducible MR imaging parameter of the strain as an estimate for the risk of repeat injury within that season of competition.

We have therefore designed our study with this aim in mind. Specifically, we wish to investigate if we can use MR imaging parameters to predict which injuries are at greater risk of recurring based on certain imaging parameters.

MATERIALS AND METHODS

Recruitment of Subjects and Selection Criteria

Between February and August 2002, professional footballers playing in the Australian Football League who sustained an acute hamstring injury either during training or during competition were invited to participate in the study by their respective club doctor. Within 3 days of injury, the players were assessed by an investigator as to whether they were eligible for the study. Players were included if their symptoms included acute onset of posterior thigh pain or stiffness and if they were unable to complete their training session or game. Players were excluded if they were suffering from either a chronic or an ongoing hamstring injury at the time of presentation at the clinic, were unwilling to comply with follow-up, or had contraindications to MR imaging, including severe claustrophobia, intracranial aneurysm clips, a pacemaker, or foreign metallic objects. Furthermore, players identified during imaging as having complete tears of the hamstring muscles and requiring surgical repair were excluded from the study. The study protocol received approval by the human research ethics committee affiliated with our clinic, with all players giving informed consent.

Magnetic Resonance Imaging

The players were positioned prone on the table and examined using a 1.5-T superconducting unit (Sigma LX, GE Medical Systems, Milwaukee, Wis). A phased-array surface coil (EXTREMPA, Medrad, Indianola, Pa) was strapped over the thigh and centered over the region of maximal tenderness as identified by the player. A coronal localizing image was obtained followed by these sequences: (1) axial and coronal oblique fast spin-echo imaging along the longitudinal axis of the hamstring complex (repetition time [TR]/echo time [TE] 4000/45 [effective]), 512 × 384 matrix, 2 signals acquired, 20-cm field of view, 5-mm section thickness with no gap, echo-train length of 8 to 12; and (2) axial and coronal oblique fast spin-echo inversion recovery imaging along the longitudinal axis of the hamstring complex (TR/TE 5000-6500/35-55 inversion time [TI] 120), 256 × 224 matrix, 2 signals required, 20-cm field of view, 5-mm section thickness with no gap.

Outcome Parameters

Two experienced musculoskeletal radiologists interpreted each image and scored the lesion characteristics according to a prespecified score sheet. A consensus agreement was reached in cases of differences in interpretation. The injured area (muscle, location of injury) was identified and the longitudinal length and cross-sectional injured area of the strain recorded (mm). An acute injury was considered to be present if abnormal increased signal intensity on the fluid-sensitive sequences was detected. This description is based on our previous method of interpreting hamstring lesions.[10] Details regarding the players' progress toward returning to full training and play were collected via a questionnaire sent to the treating club doctor or physical therapist. The number of days from the initial injury until return to competition (completed game) was used as the reference for successful recovery of the player. The treating physician was informed whether a hamstring strain was present on MR imaging; however, no further information was provided, such as the dimensions and location of the strain, to avoid bias with respect to treatment and period of convalescence. Players were informed by the referring clinician of the result of the MR examination. Those who reinjured the hamstring muscle during the competition period were again scanned within 3 days of injury using the same imaging protocol and the same outcome parameters. Both first and second injuries were interpreted by the same 2 radiologists.

Statistical Analyses

Differences between player demographic and injury characteristics were compared using the Mann-Whitney *U* test. Changes in injury parameters between the first and second injury were analyzed using the Wilcoxon signed rank test. Differences in proportions between those players suffering a single versus those with a repeat injury were analyzed

TABLE 1
Demographic Characteristics of Professional Footballers Who Presented With a Single or Repeated Hamstring Strain in One Season

	Single Strain	Repeat Strain	*P* Value
	Mean ± Standard Deviation		
Total (N)	31	10	
Age (y)	24 ± 3.8	25.5 ± 3.8	.3[a]
Height (cm)	186.7 ± 6.3	186.2 ± 7.8	.9[a]
Weight (kg)	88.3 ± 9.3	89.4 ± 9.9	.7[a]
	n/N (%)		
Previous hamstring injury	23/31 (74.2)	10/10 (100)	.07[b]
Previous ACL graft	2/31[c] (6.5)	4/10[d] (40)	.002[b]

[a]Mann-Whitney *U* test.
[b]χ^2 test.
[c]1 patellar tendon and 1 hamstring graft.
[d]2 patellar tendon grafts, 2 hamstring grafts.
ACL, anterior cruciate ligament.

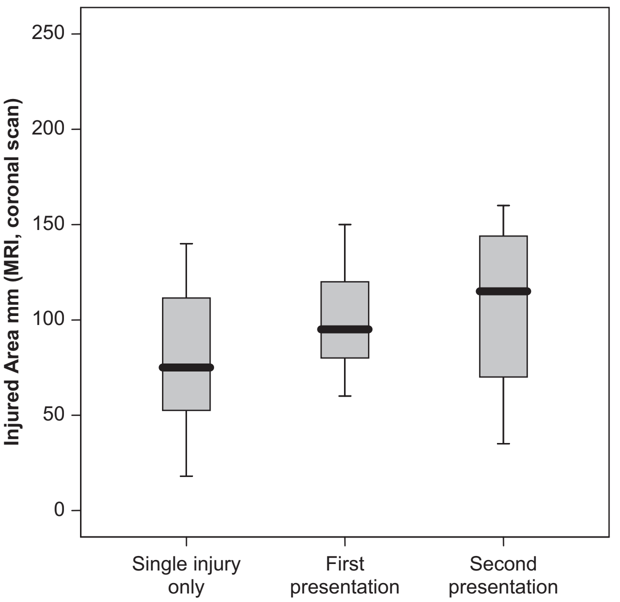

Figure 1. Hamstring injury characteristics according to presentation on MRI (length of injury). *P* = .35 (Mann-Whitney *U* test) between single injury and first presentation. *P* = .07 (Mann-Whitney *U* test) between single injury and second presentation. Figure denotes medians and interquartile ranges. MRI, magnetic resonance imaging.

using a χ^2 test. Individual injury criteria were assessed as a predictor for reinjury risk using univariate logistic regression. Significance was afforded when $P < .05$.

All analyses were performed using SPSS for Windows, version 14.0 (SPSS, Chicago, Ill).

RESULTS

A total of 41 Australian Rules footballers sustained an MR-positive hamstring strain during the 2002 playing season; 10 of them were reinjured during the same playing season. No statistical difference was demonstrated between the age of those athletes suffering a single and repeat strain (Table 1), with a mean age of 24 and 25.5 years, respectively (*P* = .3, Mann-Whitney *U* test). Similarly, no significant difference was found in the height (*P* = .9) and weight (*P* = .7) range for these athletes. Confirmation of a prior strain was made with the player's medical history, as recorded by the club medical officer or physical therapist. Twenty-three of 31 players (74.2%) in the single injury group reported a history of hamstring strain, whereas all of the athletes (10/10) in the repeat injury group were positive for a history of strain before their first injury during the competition season of 2002 (*P* = .07). Furthermore, a history of anterior cruciate ligament (ACL) reconstruction demonstrated an association with reinjury within the same season of competition, as this was seen in 40% of the athletes in this group (*P* = .002, χ^2 test), as opposed to only 6.5% in the single strain cohort (*P* = .002, χ^2 test). In the recurrent and solitary injury group, the hamstring strain occurred on the same side as the ACL reconstruction. The biceps femoris was the most commonly injured muscle in both groups, and the musculotendinous junction within the muscle-tendon-bone unit was the most commonly injured site of injury (Table 2).

TABLE 2
Hamstring Injury Characteristics According to Presentation on Magnetic Resonance Imaging

	Single Injury N = 31	First Presentation N = 10	Second Presentation N = 10
Muscle injured n/N (%)			
Biceps femoris	26/31 (83.9)	8/10 (80)	9/10 (90)
Semitendinosus	2/31 (6.5)	0/10 (0.0)	0/10 (0.0)
Semimembranosus	3/31 (9.7)	0/10 (0.0)	1/10 (10)
Mixed	0/31 (0.0)	2/10 (20)	0/10 (0.0)
Injury location n/N (%)			
Musculotendinous junction	16/31 (51.6)	5/10 (50)	5/10 (50)
Myofascial	11/31 (35.5)	4/10 (40)	5/10 (50)
Mixed	2/31 (6.4)	0/10 (0.0)	0/10 (0.0)
Tendon-bone	2/31 (6.4)	0/10 (0.0)	0/10 (0.0)
Proximal tendon	0/31 (0.0)	1/10 (10)	0/10 (0.0)

TABLE 3
Injury Characteristics and Rehabilitation Duration According to Presentation[a]

	Single Injury	First Injury	Repeat Injury
Total N	31	10	10
Length injury (mm)			
Median (range)	75 (18-240)	95 (60-150)	115 (35-160)
Mean (± SD)	83.8 (44)	98.7 (27)	107 (41)
95% CI	67-100	79-118	78-137
Cross-sectional (%, axial view)			
Mean (± SD)	19.7 (15.3)	18.5 (11.7)	20.5 (18.1)
Median (range)	15 (5-60)	12.5 (5-40)	10 (5-60)
95% CI	14-25	10-27	7.5-33.5
Return to full play (days)			
Mean (± SD)	23.7 (11.5)	26.6 (8.3)	34.4 (11.8)
Full game within 2 weeks			
n/N (%)	6/31 (19.3)	-	-
Full game within 4 weeks			
n/N (%)	14/31 (45.1)	6/10 (60)	3/10 (30)
Full game within 6 weeks			
n/N (%)	9/31 (29)	3/10 (30)	3/10 (30)
Full game after 6 weeks			
n/N (%)	2/31 (6.4)	1/10 (10)	4/10 (40)

[a]SD, standard deviation; CI, confidence intervals.

TABLE 4
Number of Players Presenting With a Reinjury According to Initial Injury Length (on Magnetic Resonance Imaging) During One Season

Injury Length (mm)	No. (%) Single Injury N = 31	No. (%) Reinjured N = 10
<20	1 (3.2)	0 (0)
21-40	2 (6.4)	0 (0)
41-60	10 (32.3)	1 (10)
61-80	5 (16.1)	2 (20)
81-100	3 (9.6)	3 (30)
>100	10 (32.3)	4 (40)

TABLE 5
Reinjury Prediction Based on Demographic and MRI Injury Measurements According to Level of Significance (Logistic Regression [Univariate]) for Professional Footballers Suffering a Single (N = 31) or Repeat (N = 10) Hamstring Injury (Total N = 41)[a]

Variable	*P* Value
Previous ACL injury	.024
Muscle injured	.20
Age of player	.28
Injury length (MRI)	.32
Return to competition	.45
Weight of player	.76
Cross-sectional injured area (MRI)	.82
Height of player	.84
Injury location	.89
Previous hamstring injury	.95

[a]MRI, magnetic resonance imaging; ACL, anterior cruciate ligament.

Although a significant degree of overlap exists between the lengths of a strain when the 2 groups are compared, those players who reinjured the hamstring muscle in the same competition season recorded a longer injury (mean, 98.7 mm) at the initial presentation than those who went on to suffer an injury only once (mean, 83.8 mm) ($P = .35$) (Table 3 and Figure 1). Furthermore, the length of the repeat strain was, on average, 8.3 mm longer than the original injury (mean 107 mm, compared with 98.7 mm) ($P = .07$). Overall, the time to return to full competition between the single injury and initial injury of the repeat injury group was similar ($P = .9$), with 64.4% and 60% of athletes completing a full game by 4 weeks after the original injury, respectively. Beyond 6 weeks, only 6.5% and 10% of athletes, respectively, had yet to return to competition, in contrast to the repeat injury group, where 40% remained sidelined. The mean number of days out of competition between the single injury group and the initial injury group were similar (23.7 days and 26.6 days, respectively); however, the average number of days out of competition for the repeat injury group was 34.4 days ($P = .01$) (Table 3).

Nine of the 10 players who suffered a repeat injury demonstrated injuries with muscle damage extending over more than 60 mm. In contrast, only 18 of 31 players (58.1%) with a solitary strain during the season recorded injury lengths of >60 mm ($P = .01$) (Table 4). Nine of 27 players (33%) who had an injury measuring >60 mm went on to suffer a repeat strain. Alternatively, of those players who had an injury measuring <60 mm on MR imaging, only 1 of 14 (7%) recorded a reinjury during the same playing season ($P = .14$).

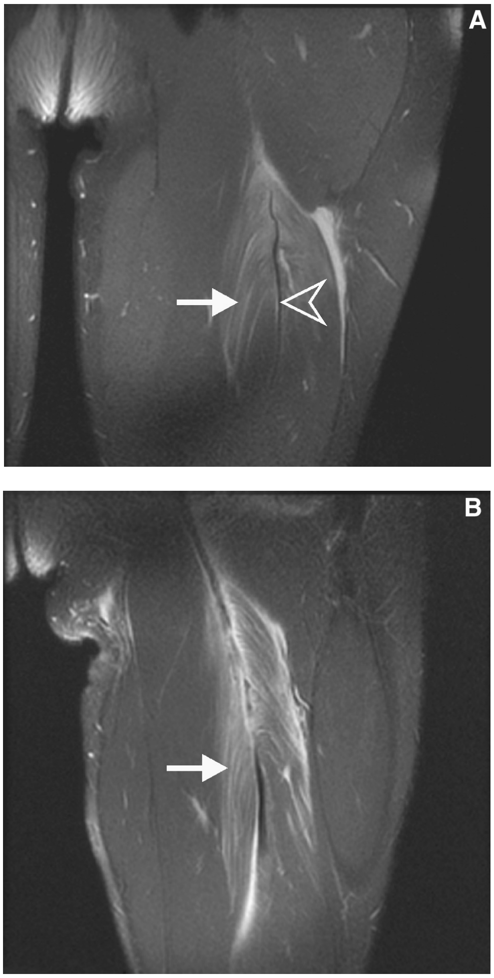

Figure 2. Coronal fat-saturated proton density magnetic resonance image (A) demonstrates a strain (arrow) at the proximal musculotendinous junction (arrowhead) of the long head of biceps femoris >60 mm in longitudinal length. This player subsequently sustained a second injury (B) during the same playing season, with increased dimension of the strain demonstrated (arrow).

Univariate logistic regression of all variables (MR imaging measurements, age, height, weight, previous hamstring injury, previous ACL surgery, and return to play [days]) for the prediction of reinjury identified only "previous ACL surgery" as a statistically significant predictor for reinjury in our model (Table 5). Because only 1 of the 10 variables was a statistically significant predictor of reinjury, a multivariate analysis was not performed.

DISCUSSION

Injury to the hamstring musculature remains a common athletic injury and a challenge to the referring clinician. Our results demonstrate that the longitudinal length of a tear in players who sustained only one strain was shorter than injuries sustained by players who subsequently reinjured during the same season of competition, although this did not reach statistical significance (P = .35). With repeat injury, the longitudinal length of the recurrent strain further increased on average compared with the dimensions of the original tear (Figure 2). Accordingly, players in our study had a longer rehabilitation time after reinjuring their hamstring in the one season (P = .01).

Increased myofibril damage is demonstrated on MR imaging by a proportional increase in the dimensions of a strain, as reflected by an increase in the degree of abnormal intramuscular T2-weighted hyperintensity. A greater degree of muscle disruption results in an inherently weaker muscle-tendon unit, as more myofibrils are disrupted. This results in decreased muscle function—namely, reduced contractile strength and an inevitable decrease in ability to transmit and dissipate forces. This is of particular relevance to the professional athlete, in whom substantial demands are placed on myofibril units. If these units are inadequately rehabilitated (and therefore inadequately strengthened), they are at an increased risk of future injury. This possibly accounts for the observation made in our study that players with a longer tear were more susceptible to a recurrent injury. On sustaining the second injury, it is thought that the weakened muscle undergoes even further deleterious disruption, as reflected by the progressively increased strain dimensions on MR imaging. Conversely, an MR examination demonstrating a smaller tear is associated with a decreased predicted convalescence period.[16] It has also been established that an MR study that fails to demonstrate *any* intramuscular signal abnormality in an athlete with acute posterior thigh pain is associated with an even shorter convalescence period and does not carry the concomitant increased association for a recurrent strain.[2,6,16,23] In this latter subset of athletes, debate does exist as to whether genuine hamstring disruption has occurred; it has been suggested that the pain may be referred from the lumbar spine or secondary to adverse neuromeningeal tension.[23] It is also possible that an injury may be present but at a microscopic level and beyond the resolution of MR imaging, which has been previously demonstrated to have a lower initial hamstring injury detection rate compared with ultrasound (70% versus 75%, respectively).[2]

Given the above findings, it is not surprising that the convalescence period in our study increased after a second injury, consistent with the greater time required for adequate healing of a greater amount of disrupted myofibrils.[5] This finding is supported by prior clinical observations recording, on average, an overall convalescence period of 17 days for a hamstring strain, with 14 days required for the initial injury and 25 days for a repeat strain.[1] Residual abnormal signal intensity of the initial injury may contribute in part to the degree of T2 hyperintensity measured on the second injury. This is thought to be due to the subsequent healing process, in which granulation tissue formation and neovascularization have been demonstrated histologically[8] and observed on a radiologic basis,[2] even with successful return to competition.

The only statistically significant predictor for risk of reinjury in our study was a previous ACL tear. In our series, players who suffered a recurrent hamstring strain underwent prior ACL reconstruction surgery on the same side as the strain, with either an ipsilateral hamstring (2 cases) or patellar tendon graft (2 cases). Athletes are believed to be at an increased risk for hamstring strain after ACL reconstruction,[23] and our data have provided further support for this hypothesis. Because our data are limited by a small population, it remains unknown whether the use of a hamstring tendon autograft in ACL reconstruction serves as an additional risk factor for future hamstring strain; anecdotally, however, many sports medicine clinicians and musculoskeletal radiologists believe this to be the case. Independent of graft selection, the risk of recurrent strain may be accounted for by altered biomechanics after surgical reconstruction and the loss of the native ACL, which in its intact state is inherently superior to the reconstructed graft. The ACL acts as a static stabilizer, preventing excessive anterior tibial translation on heel strike and supported by the hamstring muscles that act as dynamic agonists. Hence, it is hypothesized that increased forces and a higher workload are required of the hamstring muscles when the native ACL has been disrupted and reconstructed by either the patellar tendon or distal hamstring tendon. In the context of a recent strain, which results in weakness of the hamstring muscles, it is conceivable that such athletes are at a disproportionately increased risk of recurrent strain during the same playing season. This is in addition to the loss of normal joint proprioception, which likely occurs after ACL injury because of loss of the physiologic ACL-hamstring reflex.[19] Loss of this feedback mechanism may result in a deleterious effect on hamstring neural feedback, altered proprioception, and ultimately an adverse effect on hamstring contraction during the gait cycle, again predisposing such athletes to strain. Loss of muscle strength and range of motion commonly occurring after ACL surgery may also contribute to this observation. Our data demonstrate that those athletes who had undergone a second injury in the one season universally reported a prior injury of hamstring strain, again reinforcing the notion that a prior hamstring injury is a significant risk for future injury.[3,7,12]

Our study has shown that 24.4% of athletes (10 of 41) sustaining a hamstring strain suffered a second strain during the same playing season. Only one of these 10 players had a documented injury length at the initial presentation <60 mm. We therefore suggest that injuries >60 mm in length should be managed with caution because such injuries appear to have a higher likelihood of restraining. Similar criteria useful in assessing risk of reinjury have previously been reported. An observed volume (>21.8 cm^3) and transverse area (>55%) of a hamstring injury are considered significant when the data for the same year and subsequent year of competition are combined.[22] These values independently resulted in a 2-fold increase in risk of hamstring strain recurrence. Our data demonstrated that the mean cross-sectional area of a strain was not sufficiently different between the 2 groups and, as such, significant discrimination between these 2 was not possible. This is likely due to the limited numbers in our study cohort (N = 10), which was smaller than in prior research (N = 19). However, in the earlier study, data were combined over 2 consecutive playing seasons. Although the area and volume of a hamstring strain are relatively easy to measure, the MR imaging computer console with which the images are acquired is needed to make the necessary calculations, which may slightly limit the applicability of these parameters, particularly if images have been obtained at another institution. In contrast, measurements of the longitudinal length of the injury are easily obtained by viewing the images directly. This approach facilitates diagnosis and communication between radiologists and sports physicians. Further research into the intraobserver and interobserver variability of the measurements of muscle strain is currently lacking and therefore indicated.

Limitations to our study exist, such as the fact that our patients were limited to elite Australian Football League participants, thus our findings may not be as directly applicable to the general population nor to athletes in other sports. Also, the study population sustaining a second strain was small (N = 10). Despite this, however, given the absence of such data in the medical literature to date, we anticipate that our findings will find their way initially into clinical practice, where they will serve as a useful adjunct to clinical examination and a valuable guide to prognostication until further sports-specific research, as well as data from studies with larger populations, are published.

In conclusion, our results show that a history of an ACL tear is the only statistically significant risk factor for developing a repeat hamstring strain in the same playing season in a group of elite athletes. Therefore, these athletes may benefit from a more cautious return to competition and a more intensive rehabilitation program. Furthermore, this finding may assist the medical and coaching staff in team selection dilemmas and the appropriate timing of a player's return to full competition. Of the MR imaging parameters, the length of the strain had a stronger correlation with recurrent injury than the cross-sectional area; however, neither reached statistical significance. The MR features of a strain may assist in risk stratification of reinjury, particularly when combined and correlated with the clinical history. Given the expectations and demands placed on elite athletes, it is anticipated that these preliminary data will be of assistance to sports clinicians and may potentially be applicable across sporting disciplines, such as rugby, soccer, and other types of football.

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