Associations Between Initial Clinical Examination and Imaging Findings and Return-to-Sport in Male Athletes With Acute Adductor Injuries

A Prospective Cohort Study

Andreas Serner,*† PT, PhD, Adam Weir,†‡ MBBS, PhD, Johannes L. Tol,†§ MD, PhD, Kristian Thorborg,|| PT, PhD, Eduardo Yamashiro,† MD, Ali Guermazi,¶ MD, PhD, Frank W. Roemer,¶# MD, and Per Hölmich,†|| MD, DMSc
Investigation performed at Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar

Background: Time to return-to-sport (RTS) after acute adductor injuries varies among athletes, yet we know little about which factors determine this variance.

Purpose: To investigate the association between initial clinical and imaging examination findings and time to RTS in male athletes with acute adductor injuries.

Study Design: Cohort study (Prognosis); Level of evidence, 2.

Methods: Male adult athletes with an acute adductor injury were included within 7 days of injury. Standardized patient history and clinical and magnetic resonance imaging (MRI) examinations were conducted for all athletes. Athletes performed a supervised standardized criteria-based exercise treatment program. Three RTS milestones were defined: (1) clinically pain-free, (2) completed controlled sports training, and (3) first full team training. Univariate and multiple regression analyses were performed to determine the association between the specific candidate variables of the initial examinations and the RTS milestones.

Results: We included 81 male adult athletes. The median duration for the 3 RTS milestones were 15 days (interquartile range, 12-28 days), 24 days (16-32 days), and 22 days (15-31 days), respectively. Clinical examination including patient history was able to explain 63%, 74%, and 68% of the variance in time to RTS. The strongest predictors for longer time to RTS were pain on palpation of the proximal adductor longus insertion or a palpable defect. The addition of MRI increased the explained variance with 7%, 0%, and 7%. The strongest MRI predictor was injury at the bone-tendon junction. Post hoc multiple regression analyses of players without the 2 most important clinical findings were able to explain 24% to 31% of the variance, with no added value of the MRI findings.

Conclusion: The strongest predictors of a longer time to RTS after acute adductor injury were palpation pain at the proximal adductor longus insertion, a palpable defect, and/or an injury at the bone-tendon junction on MRI. For athletes without any of these findings, even extensive clinical and MRI examination does not assist considerably in providing a more precise estimate of time to RTS.

Keywords: groin; RTS; RTP; prognosis; MRI; clinical examination; muscle strains; sport; football

Time to return-to-sport (RTS) varies after acute adductor injuries in athletes,[4,5] and we know little about which factors determine this variance. It is unknown if initial clinical and imaging examinations can assist in estimating time to RTS. This is despite acute adductor injuries being the most common acute groin injury in athletes.[9,14,21] In comparison, numerous prognostic parameters of clinical and imaging examinations have been investigated in acute hamstring injuries, where the current literature provides no strong evidence for any initial findings being able to provide precise estimates for RTS.[11,12,18,19] Magnetic resonance imaging (MRI) is currently considered the gold standard to determine acute muscle injury extent and is also the most frequently used imaging modality in prognostic research of acute muscle injuries.[3,8]

Inadequate methodological quality of previous research and substantial risk of bias are key concerns, and clear

The American Journal of Sports Medicine
2020;48(5):1151–1159
DOI: 10.1177/0363546520908610

RTS definitions and criteria are recommended as essential parts of prognostic research studies.[11,12] Athletes also usually receive different treatment depending on the preferences of their treatment providers. This may affect RTS duration, thereby also influencing the potential prognostic ability of initial examination findings. Standardized treatment and specific criteria for RTS are therefore essential when examining potential prognostic variables. No previous studies have investigated the prognosis of initial examination findings in athletes with acute adductor injuries.

Our study aim was to investigate associations between findings of a standardized initial clinical and MRI examination of athletes with an acute adductor injury and time to RTS after a standardized criteria-based exercise treatment protocol.

METHODS

Participants

Athletes with acute groin injuries were consecutively included in a single-center prospective cohort study over 4 sports seasons (August 2013–June 2017) at an orthopaedic and sports medicine hospital in Qatar. Ethical approval was obtained from the Shafallah Medical Genetics Center and the Anti-Doping Lab Qatar Institutional Review Boards (project Nos. 2012-013 and EXT2014000004), and informed consent was acquired from all athletes before inclusion.

Eligibility criteria were male athletes aged 18 to 40 years who participated in competitive sports. Athletes had to present at the hospital within 7 days of an acute onset of groin pain that occurred during sport, and a diagnosis of an acute adductor injury by a sports medicine physician using a standardized clinical examination was a requirement for this study.[14] This examination consisted of hip adduction squeeze tests in 0° and 45° of hip flexion, resisted hip flexion in 0° and 90° of hip flexion, resisted straight and oblique abdominal flexion, hip adductor stretch, the modified Thomas test, the FABER test (flexion, abduction, external rotation), hip internal rotation range of motion restriction in 90° of hip flexion, the anterior hip impingement test (FADIR [flexion, adduction, internal rotation]), log roll, and palpation of all structures in the groin region, including an inguinal canal examination if lower abdominal pain was present. The location of the injury was based on a minimum of 1 positive finding on palpation, stretching, or muscle resistance testing.[14]

Clinical examination has been shown to be accurate in diagnosing acute adductor injuries.[15] To be considered an athlete, patients had to be officially registered through a sports association or federation corresponding to the 2 highest national leagues in soccer or highest national competition level in any other sport. Exclusion criteria were gradual onset or exacerbation of ongoing groin pain, acute groin pain not involving the adductors on clinical examination, clinical signs or symptoms of prostatitis or urinary tract infection, or other known coexisting chronic diseases, such as significant hip osteoarthritis.

Initial Examination

A standardized patient history and clinical examination were performed by a physiotherapist before the MRI investigation. The included variables for analysis are listed in Table 1. The clinical examination tests have been published in detail.[15,17]

MRI Assessment

Anonymized MRI scans were scored by 2 radiologists (F.W.R. and E.Y.), blinded to clinical information, using an extensive MRI scoring protocol, as previously reported.[13,16] In brief, the protocol included coronal, axial, and axial oblique T1-weighted sequences, triplanar short tau inversion recovery sequences, and axial oblique T2 fat-saturated and axial oblique proton density–weighted fat-suppressed sequences.[13] MRI variables included in the analysis are listed in Table 1. MRI injury grading was scored from 0 to 3: grade 0, no acute injury findings; grade 1, edema without any visible structural disruption; grade 2, edema collection indicating partial structural muscle fiber or intramuscular tendon disruption; and grade 3, complete tear/avulsion.[13] Muscle injury location was grouped as (1) isolated adductor longus injury, (2) adductor longus injury and another adductor injury, and (3) adductor injury other than adductor longus. A primary injury was defined according to (1) highest injury grade and (2) highest intramuscular edema extent or amount of retraction (with multiple grade 3 injuries only).

In general, intra- and interrater reproducibility for the included scoring variables was substantial to almost perfect (kappa values, 0.70-1.00; intraclass correlation coefficient values, 0.83-1.00) with a standard error of the quantitative measurements $<5\%$.[13]

---

*Address correspondence to Andreas Serner, PT, PhD, Aspetar Sports Groin Pain Centre, Aspetar Orthopaedic and Sports Medicine Hospital, Sports City Street, Near Khalifa Stadium, PO Box 29222, Doha, Qatar (email: andreas.serner@aspetar.com) (Twitter: @aserner).

†Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar.

‡Erasmus MC Center for Groin Injuries, Department of Orthopaedics, Erasmus MC University Medical Centre, Rotterdam, the Netherlands.

§Amsterdam University Medical Centers, Academic Medical Center, Amsterdam Movement Sciences, Academic Center for Evidence Based Medicine, Amsterdam IOC Center, Amsterdam Collaboration for Health and Safety in Sports, Amsterdam, the Netherlands.

||Sports Orthopedic Research Center–Copenhagen, Department of Orthopedic Surgery, Copenhagen University Hospital, Amager-Hvidovre, Denmark.

¶Quantitative Imaging Center, Department of Radiology, Boston University School of Medicine, Boston, Massachusetts, USA.

#Department of Radiology, University of Erlangen-Nürnberg & Universitätsklinikum Erlangen, Erlangen, Germany.

Submitted August 20, 2019; accepted January 2, 2020.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

TABLE 1
Overview of Included Patient History, Clinical Examination, and MRI Scoring Variables[a]

Patient History

Variable	Scoring
Age	y
Height	cm
Weight	kg
Body mass index	kg/m^2
Type of sport	Soccer, futsal, other
Injury mechanism	Kicking, changing direction, reaching, other
Maximum pain at injury onset	NPRS, 0-10
Discontinuation of sport within 5 min	No/yes
"Popping" sound at injury time	No/yes
Walking pain	NPRS, 0-10
Dominant leg injured	No/yes
Coughing pain	No/yes
HAGOS subscale symptoms	0-100
Pain	0-100
ADL	0-100
Sport/Recreation	0-100
QOL	0-100
Groin pain or discomfort on the same training or match as the injury	No/yes
Groin pain or discomfort during the week before injury	No/yes
Acute adductor time-loss injury within the previous 2 mo before injury	No/yes
Other groin time-loss injury within the previous 2 mo before injury	No/yes
Days from injury to the first supervised treatment session	d
Compliance with the treatment	%

Clinical Examination

Variable	Scoring
Bruising	No/yes
Swelling	No/yes
Adductor palpation pain	Negative/positive
0° squeeze	Negative/positive
45° squeeze	Negative/positive
Passive adductor stretch	Negative/positive
Outer-range resisted adduction	Negative/positive
FABER test	Negative/positive
No. of positive adductor tests	0-6
Palpation pain in abdominal muscle group	No/yes
Resistance/stretch pain in abdominal muscle group	No/yes
Palpation pain in hip flexor muscle group	No/yes
Resistance/stretch pain in hip flexor muscle group	No/yes
Palpation pain at proximal AL insertion	No/yes
Distance of proximal AL palpation pain from pubic insertion, when not at insertion	cm
Length of AL palpation pain	cm
Width of AL palpation pain	cm
Palpable defect	No/yes
Ability to perform eccentric adduction strength test	No/yes (pain or apprehension)
Eccentric adduction strength symmetry	%
ADD/ABD strength ratio on injured leg	%
Hip abduction range of motion symmetry	%
Bent knee fall-out test symmetry	%

MRI

Variable	Scoring
No. of adductor muscle injuries	0-6
Muscles involved	No adductor injury, isolated AL, AL and other adductor muscle, adductor muscle other than AL
Primary adductor muscle injury	AL, adductor brevis, adductor magnus, pectineus, gracilis, obturator externus
Highest injury grading	0-3
Injury location	BTJ/MTJ
Additional injury in abdominal muscle group	No/yes
Additional injury in hip flexor muscle group	No/yes
Additional injury in other muscle group	No/yes
For AL injuries only	
Proximal intramuscular edema distance from pubic insertion	mm
Peripheral fluid thickness	mm
Proximal-distal intramuscular edema extent	mm
Medial-lateral intramuscular edema extent	mm
Anterior-posterior intramuscular edema extent	mm
Intramuscular edema CSA index	%
MTJ injury location	Proximal MTJ/distal MTJ
Intramuscular collection / disruption CSA index	%
Intramuscular collection / disruption volume	cm^3
Intramuscular tendon disruption (grade 2 only)	No/yes

[a]ADD/ABD, adduction/abduction; ADL, activities of daily living; AL, adductor longus; BTJ, bone-tendon junction; CSA, cross-sectional area; FABER, flexion, abduction, external rotation; HAGOS, Copenhagen Hip and Groin Outcome Score; MRI, magnetic resonance imaging; MTJ, musculotendinous junction; NPRS, Numerical Pain Rating Scale; QOL, quality of life.

TABLE 2
Treatment Protocol Completion Criteria[a]

Clinically Pain-Free	Completed Controlled Sports Training Pain-Free
Adductor palpation	Illinois Agility Test at 100% self-reported intensity
Maximal isometric adduction in outer-range abduction	Spider test at 100% self-reported intensity
Maximal passive adductor stretch	Sports training/tests adjusted to athlete sport (eg, soccer)
Hip adduction exercise with elastics at 10 RM	• Preplanned and reactive change of directions with/without ball
Copenhagen adduction exercise 10 repetitions	• Jumps (bilateral/unilateral, horizontal/vertical)
Linear sprinting at 100% self-reported intensity (10 × 30 m)	• Straight passes, progressing distance
T test at 100% self-reported intensity	• Crosses (standing and running)
	• Corner kicks/goal kicks
	• Shooting scenarios
	• One vs one

[a]For a detailed description of the criteria tests, see Appendixes 1 and 2 (available in the online version of this article). RM, repetition maximum.

Treatment Protocol

All athletes followed a standardized criteria-based treatment program based on active exercises with independent progression of basic exercises and progressive running and change-of-direction drills, as well as a controlled sports-training/testing phase. Athletes were advised to attend 5 supervised sessions per week at the hospital. The details of the treatment protocol are presented and discussed separately.[17]

RTS Outcomes

Three milestones were used to evaluate the RTS continuum, and number of days was calculated until (1) completion of the clinically pain-free criteria, (2) completion of the controlled sports training, and (3) first full team training, regardless of completion of all protocol criteria. Criteria for items 1 and 2 are provided in Table 2, with detailed descriptions published separately.[17] If athletes discontinued treatment before meeting the specific completion criteria, they were excluded from the analyses (considered missing data). The "return to full team training" date was obtained through weekly phone calls to the athlete following the last supervised treatment session.

Blinding

Clinical examination tests were performed by a physiotherapist before the MRI examination, and MRI scoring was performed by 2 experienced musculoskeletal radiologists blinded to all clinical information. The treating physiotherapists and athletes were not blinded to the initial diagnosis and MRI result, as provided by the treating sports medicine physician. The treating physiotherapist was responsible for phase progression and completion according to the treatment protocol criteria, regardless of the initial clinical diagnosis and MRI findings.

Sample Size

We utilized a convenience sample based on consecutive inclusion over 4 years (2013-2017).

Statistical Methods

The individual potentially prognostic variables were initially examined in univariate analyses for each of the 3 dependent variables (RTS milestones). Extreme outliers (>3 SD) were removed from the analyses following discussion with the treating physiotherapist. Missing data were excluded from the analyses. By using simple scatter plots, it was evident that most continuous variables did not have a clear linear relationship with the dependent variables. Additionally, the dependent variables were all right-skewed; therefore, nonparametric tests were used for all univariate analyses. Standardized effect sizes were reported for continuous variables with Spearman r and calculated as $\frac{z}{\sqrt{n}}$ for dichotomous variables. Standardized effect sizes of 0.1 are considered small, 0.3 medium, and 0.5 large,[6] except for Cohen d, for which similar considerations are made at $\geq$0.2, 0.5, and $\geq$0.8.[2]

We built explanatory multiple regression models using a best subsets approach with the adjusted r^2 value as the selection criterion. The dependent variables were transformed through natural logarithms. Independent variables with a P value <.2 in the univariate analyses were considered candidate variables for further analyses, given a minimum prevalence of 10% in at least 2 variable options for discrete and categorical variables. Multicollinearity was tested, and where this was large, the variables with the lowest association with the dependent variable were removed. Five models were created: (1) history only; (2) clinical examination tests only; (3) MRI findings only; (4) history and clinical examination tests; and (5) history, clinical examination tests, and MRI findings. Results from models 1 to 3 were used in the development of models 4 and 5. Given the general lack of linearity, regression coefficients are not reported. The total variance in time to RTS explained by the models is reported with an adjusted r^2 with the predictor importance of each included variable. We also performed post hoc analyses with a similar approach. The only difference was that the dependent variable of return to full team training was normally distributed, meaning that parametric statistics were used where appropriate and no logarithmic transformations

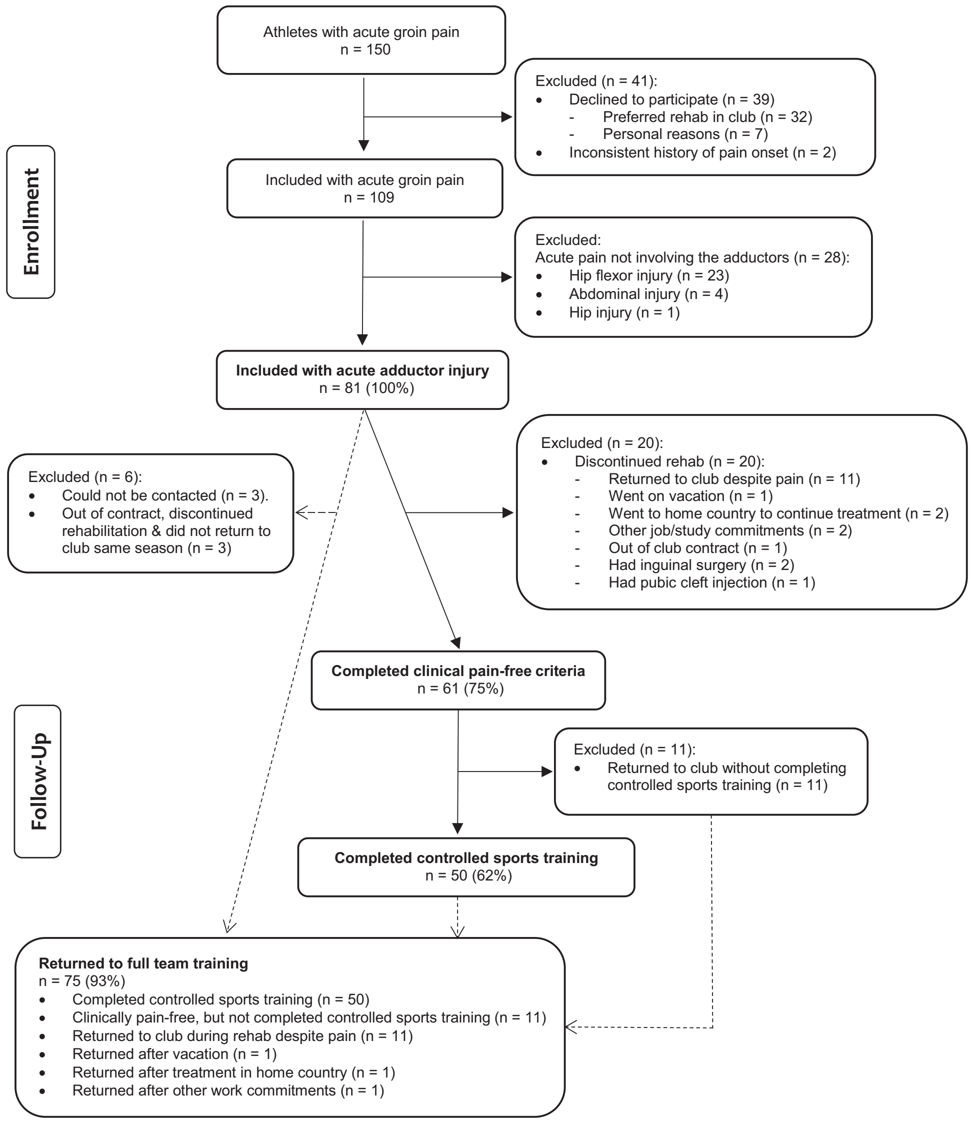

Figure 1. Flowchart of athlete inclusion for the 3 return-to-sport time points.

were applied. All statistical analyses were performed with SPSS software (v 21; IBM Corp).

RESULTS

Participants

A flowchart of athlete inclusion is provided in Figure 1. A total of 81 athletes were included: mean age, 25.7 years (SD, 4.3; range, 18-37); height, 179.6 cm (SD, 8.9; 162-210); weight, 77.6 kg (SD, 13.7; 47-115). The majority were soccer players (47) or futsal players (18). Other sports included handball (5), volleyball (5), basketball (4), shot put (1), and table tennis (1). Specific demographic data of athletes included in the analyses are available in Appendixes 1 and 3 (available in the online version of this article), and demographic data for the 6 athletes lost to follow-up were previously reported.[17] Two extreme outliers (>3 SD) were removed from the analyses after discussion with the treating physiotherapist. Both had an adductor longus avulsion. One prioritized his university studies, and the other prioritized his full-time work. Both did not desire to return to their previous levels of sport and had the lowest level of compliance (33% and 48%). Thus, they were not considered representative in terms of duration of recovery. Both are included in the results with follow-up on clinical measures as previously published.[17]

Primary Analyses

Multiple Regression Model Without MRI. In the multiple regression models based on patient history and clinical examination, we included 25, 26, and 22 candidate variables for analysis for the 3 RTS milestones. The final models, containing 8, 8, and 9 variables, were able to explain

TABLE 3
Multiple Regression Models for Patient History and Clinical Examination Test Only[a]

Clinically Pain-Free (n = 53)		Completed Sports Training (n = 43)		Return to Full Team Training (n = 63)	
Adjusted r^2	0.628	Adjusted r^2	0.737	Adjusted r^2	0.684
Variable	Predictor Importance	Variable	Predictor Importance	Variable	Predictor Importance
Palpation pain proximal AL insertion, y/n	0.29	Palpable defect, y/n	0.26	Palpable defect, y/n	0.51
Outer-range resisted adduction pain, y/n	0.18	Compliance, %	0.18	Palpation pain AL insertion, y/n	0.11
Palpable defect, y/n	0.15	Coughing pain, y/n	0.13	Discontinuation of sport within 5 m, y/n	0.10
HAGOS-Symptoms, 0-100	0.11	Resistance/stretch pain of abdominal muscles, y/n	0.10	HAGOS-Pain, 0-100	0.10
Coughing pain, y/n	0.10	Resistance/stretch pain of hip flexors, y/n	0.10	Eccentric adductor strength test ability, y/n	0.06
Resistance/stretch pain of hip flexors, y/n	0.07	Bent knee fall out symmetry, %	0.07	Squeeze 0° pain, y/n	0.06
Age, y	0.06	HAGOS-QOL, 0-100	0.06	Walking pain, 0-10	0.03
Walking pain, 0-10	0.03	Palpation pain proximal AL insertion, y/n	0.06	Hip abduction ROM symmetry, %	0.02
		Outer-range resisted adduction pain, y/n	0.04	Coughing pain, y/n	0.02

[a]Predictors are listed in descending order of importance. Predictor importance indicates relative importance of the final model. Adjusted r^2 is presented for each of the 3 return-to-sport milestones. AL, adductor longus; HAGOS, Copenhagen Hip and Groin Outcome Score; QOL, quality of life; ROM, range of motion; y/n, yes/no.

TABLE 4
Multiple Regression Models for Patient History, Clinical Examination Test, and MRI Variables[a]

Clinically Pain-Free (n = 56)		Completed Sports Training (n = 46)		Return to Full Team Training (n = 63)	
Adjusted r^2	0.700	Adjusted r^2	0.740	Adjusted r^2	0.748
Variable	Predictor Importance	Variable	Predictor Importance	Variable	Predictor Importance
MRI injury location, BTJ/MTJ	0.52	Palpable defect, y/n	0.20	MRI injury location, BTJ/MTJ	0.31
Age, y	0.16	Compliance, %	0.19	Palpable defect, y/n	0.22
Outer-range resisted adduction, y/n	0.10	Coughing pain, y/n	0.15	Eccentric adductor strength test ability, y/n	0.11
HAGOS-Symptoms, 0-100	0.09	Resistance/stretch pain of hip flexors, y/n	0.13	Discontinuation of sport within 5 m, y/n	0.09
Palpation pain proximal AL insertion, y/n	0.07	Resistance/stretch pain of abdominal muscles, y/n	0.11	HAGOS-Pain, 0-100	0.08
Walking pain, 0-10	0.03	HAGOS-QOL, 0-100	0.08	Walking pain, 0-10	0.06
Coughing pain, y/n	0.03	Bent knee fall-out symmetry, %	0.06	Palpation pain proximal AL insertion, y/n	0.05
		Palpation pain proximal AL insertion, y/n	0.05	Squeeze 0° pain, y/n	0.04
		MRI injury grading (0-3)	0.03	Hip abduction ROM symmetry, %	0.03

[a]Predictors are listed in descending order of importance. Predictor importance indicates relative importance within the final model. Adjusted r^2 is presented for each of the 3 return-to-sport milestones. AL, adductor longus; BTJ, bone-tendon junction; HAGOS, Copenhagen Hip and Groin Outcome Score; MRI, magnetic resonance imaging; MTJ, musculotendinous junction; QOL, quality of life; ROM, range of motion; y/n, yes/no.

63%, 74%, and 68% of the variance in time to RTS, with the most important predictors resulting in longer RTS times being palpation pain at the proximal adductor longus insertion or a palpable defect (Table 3).

Multiple Regression Model With MRI. We added MRI variables to the results from the previous final models, which meant inclusion of 16, 18, and 15 candidate variables for analysis. This created multiple regression models that were able to explain 70%, 74%, and 75% of the variance in RTS duration (Table 4).

Added Value of MRI

The added value of MRI for the 3 RTS milestones was 7%, 0%, and 7%. The most important MRI predictor for longer RTS time was an injury at the bone-tendon junction.

Multiple regression models for each examination type are provided in Appendix 2 (available online).

Post Hoc Analyses

As palpation pain at the proximal adductor longus insertion and a palpable defect were the most important clinical predictors of longer RTS duration (correspondingly, the MRI finding of a bone-tendon junction injury), we performed additional post hoc analyses on the group of athletes who did not have either of these 2 clinical findings. We compared this group and the athletes who had positive results for one or both tests. The group of athletes with at least 1 positive test finding had a significantly longer RTS time (Table 5). Results of post hoc univariate analyses on the group of athletes without either clinical finding

TABLE 5
Post Hoc Comparison Between Athletes With and Without Palpation Pain at the Proximal Adductor Longus Insertion and/or a Palpable Defect[a]

	Palpation Pain or Palpable Defect			
	No	Yes	Standardized ES	*P* Value
Clinically pain-free[b]	13 [11-19], 6-33	31 [24-55], 8-79	0.501	<.001
Completed controlled sports training[c]	17 [15-27], 9-37	61 [31-71], 13-117	0.577	<.001
Returned to full team training[d]	18 [13-27], 5-41	57 [29-78], 13-112	0.560	<.001

[a]ES, effect size.
[b]No, n = 42; yes, n = 17.
[c]No, n = 33; yes, n = 16.
[d]No, n = 50; yes, n = 23.

TABLE 6
Post Hoc Multiple Regression Models for Patient History and Clinical Examination Test Only[a]

Clinically Pain-Free (n = 39)		Completed Sports Training (n = 32)		Return to Full Team Training (n = 49)	
Adjusted r^2	0.311	Adjusted r^2	0.248	Adjusted r^2	0.240
Variable	Predictor Importance	Variable	Predictor Importance	Variable	Predictor Importance
Eccentric adduction strength symmetry, %	0.38	Eccentric adduction strength symmetry, %	1.00	Discontinuation of sport within 5 min, y/n	0.48
Age, y	0.30			Eccentric adduction strength test ability, y/n	0.36
0° squeeze pain, y/n	0.16			0° squeeze pain, y/n	0.16
Width of AL palpation pain, cm	0.16				

[a]Predictors are listed in descending order of importance. Predictor importance indicates relative importance within the final model. Adjusted r^2 is presented for each of the 3 return-to-sport milestones. AL, adductor longus; y/n, yes/no.

TABLE 7
Post Hoc Multiple Regression Models for Patient History, Clinical Examination Test, and MRI[a]

Clinically Pain-Free (n = 39)		Completed Sports Training (n = 32)		Return to Full Team Training (n = 49)	
Adjusted r^2	0.311	Adjusted r^2	0.248	Adjusted r^2	0.279
Variable	Predictor Importance	Variable	Predictor Importance	Variable	Predictor Importance
Eccentric adduction strength symmetry, %	0.38	Eccentric adduction strength symmetry, %	1.00	Eccentric adduction strength test ability, y/n	0.39
Age, y	0.30			Muscles involved on MRI	0.39
0° squeeze pain, y/n	0.16			Discontinuation of sport within 5 min, y/n	0.23
Width of AL palpation pain, cm	0.16				

[a]Predictors are listed in descending order of importance. Predictor importance indicates relative importance within the final model. Adjusted r^2 is presented for each of the 3 return-to-sport milestones. AL, adductor longus; MRI, magnetic resonance imaging; y/n, yes/no.

(insertional palpation pain/palpable defect) are presented in Appendix 3 (available online). Post hoc multiple regression results of patient history and clinical examination are provided in Table 6. These models were able to explain 31%, 25%, and 24% of the variance in RTS duration. The added value of MRI is shown in Table 7, where it explained 0%, 0%, and 4% more of the variance as compared with clinical findings alone. Post hoc multiple regression results for each examination type are provided in Appendix 4 (available online).

DISCUSSION

Our study explored which initial clinical and MRI variables are associated with time to RTS after acute adductor injury. The most severe injuries are at the proximal adductor longus insertion and take around 4 to 11 weeks for a full return to team training. Insertional injuries can be identified through clinical examination with palpation pain at the proximal adductor longus insertion, a palpable defect, and/or MRI to identify injury at the bone-tendon junction. The remaining variables explain a small amount of the variance in time to RTS. Noninsertional injuries have a smaller variance in time to RTS, with around 2 to 4 weeks to return to full team training.

Predicting how long RTS will take is a clinical challenge. RTS decision making is influenced by medical and nonmedical factors, which explains the wide variance in RTS. With other acute muscle injuries, most of the research has been done in hamstring injuries. For hamstrings, there is no strong evidence that any initial clinical examination or MRI finding can provide an accurate prognosis for time to RTS.[11,12] Similar to our findings, the clinician can get an indication of longer or shorter time to RTS based on a few of the initial findings; however, any specific finding or combination of findings comes with large variations in RTS timing.

Predicting RTS: With or Without MRI?

Clinical examination has some utility for clinical practice. Athletes with proximal adductor longus insertional pain on palpation and/or a palpable defect can expect RTS between 4 and 11 weeks. If there is no pain on palpating the proximal insertion and no defect, then RTS is sooner (2-4 weeks) and the variation smaller. Within this group, other variables of the clinical examination explain 24% to 31% of the variance, and adding MRI findings did not improve this. This is similar to the prognosis of acute hamstring injuries, where a study based on similar methods showed that combining patient history and clinical findings explained 29% of time to RTS and adding MRI findings improved this to 32%.[19] This means that in clinical practice a precise estimate of time to RTS is not possible, despite an extensive examination, and adding an MRI does not help to improve accuracy.

Strengths

A great strength of our study is the standardized criteria-based treatment program and well-defined RTS criteria. This minimizes potential variations that could influence time to RTS and blur the importance of the initial examination findings, thereby improving generalizability. When nonmedical factors influence RTS decisions, athletes may not be pain-free when returning to sport. This is not uncommon and was also the case for some athletes in our study, who were then excluded from the analyses. There will therefore be higher heterogeneity among athletes at the "return to full team training" time point in our study, whereas the criteria for the other time points will improve future comparisons.

Limitations

The main limitation of our study is the number of athletes included. While this is the largest detailed study on acute adductor injuries to date, the number of injuries included in the multiple regression analyses was less than some recommendations. Although a general rule of thumb is 10 events (injuries) per variable (k), some suggest a minimum 20 events per variable[10] or $50 + 8k$ variables[7]; however, as few as 2 patients per variable have been argued as being sufficient.[1] Most of our analyses were closest to the latter. Recognizing our limited statistical power, we performed univariate prescreening of variables, rather than preselecting variables to remove, as we considered all variables sufficiently relevant to be further explored. We chose clinical examination tests and MRI features that we thought were useful based on previous experience and the existing literature. Additionally, we had to transform our dependent variables because of nonlinearity. Both these steps introduce a risk of overfitting our models, implying that our model overestimates the calculated explained variance. To reduce the emphasis on statistical significance, we chose a best subsets approach, focusing on the adjusted r^2 value, to find the most relevant variables to consider for clinicians while realizing our inability to provide a useful model prediction formula. Even with the increased risk of overfitting, we were able to explain a small amount of variance in time to RTS. Potential future studies should focus on optimizing study methods, such as standardizing the exact day of examination or looking at different variables, rather than replicating this study with a larger sample.

By using a best subsets approach for model creation, it was evident that the less important predictors could be substituted with other variables with only a minor reduction of the adjusted r^2 values. The relatively low importance of these variables is also indicated in the change of included variables across the different RTS time points. The most important predictors in the post hoc multiple regression models were related to strength (either as asymmetry or ability). This may be a key element for further exploration. An important consideration in this regard is that strength improves continuously following acute muscle injury and more so earlier after injury.[22] The variation in the days from injury until assessment may have great influence on the importance of this variable. We recommend that potential future comparisons of strength measurements be compared for specific days postinjury. This will likely apply for most other clinical examination variables, as early improvements are also present for the extent of palpation pain, range of motion, and level of pain (Numerical Pain Rating Scale, 0-10).[22] This is in contrast to MRI variables, which do not change considerably during the first week after acute injury.[20] Some athletes were unable to perform the eccentric adduction strength test initially. This is likely due to the high demands of an eccentric test. While eccentric strength may still be relevant to monitor during the treatment, using an isometric adduction test in the initial assessment may enable most athletes to obtain even a small force output registration to be used in future prognostic estimations.

Another limitation is the use of a modified Copenhagen Hip and Groin Outcome Score (HAGOS) score. The HAGOS was not developed or validated for acute injuries and is time-consuming to complete in daily clinical practice (takes around 10 minutes). The HAGOS normally enquires about symptoms in the past week. This may influence the responses in the initial examination, specifically those related to the Sports/Recreation subscale, as they will usually be based on perceived ability/symptoms rather than actual experience. The results of the univariate analyses showed medium to large correlations of the individual subscales and RTS duration, suggesting that the included elements are still relevant for acute injuries. Further exploration of an optimized self-reported questionnaire for acute adductor injuries is therefore recommended.

CONCLUSION

The most important predictors of a longer time to RTS after an acute adductor injury are palpation pain at the proximal adductor longus insertion, a palpable defect, and an MRI injury at the bone-tendon junction. If these findings are present, RTS will take around 4 to 11 weeks, as compared with 2 to 4 weeks when absent. A more precise estimate of RTS currently appears unattainable despite an extensive initial examination. MRI did not add value to clinical examination in athletes without proximal insertional palpation pain and/or a palpable defect.

ACKNOWLEDGMENT

The authors acknowledge all physiotherapists who were involved in the treatment of the athletes (Roald Otten, Sean Lanzinger, Damien Delahunty, Philipp Jacobsen, Abdallah Itani, Kostas Epameinontidis, Einar Einarsson, Grani Gardarsson, and Dermot Simpson), the sports rehabilitators (Polyvios Kyritsis and Theodosia Palli), the Aspetar sports medicine physicians, and the doctors and physiotherapists from the National Sports Medicine Program, who all contributed to making this project possible.

REFERENCES

1. Austin PC, Steyerberg EW. The number of subjects per variable required in linear regression analyses. *J Clin Epidemiol*. 2015;68(6): 627-636.
2. Cohen J. A power primer. *Psychol Bull*. 1992;112(1):155-159.
3. Crema MD, Yamada AF, Guermazi A, Roemer FW, Skaf AY. Imaging techniques for muscle injury in sports medicine and clinical relevance. *Curr Rev Musculoskelet Med*. 2015;8(2):154-161.
4. Ekstrand J, Hagglund M, Kristenson K, Magnusson H, Walden M. Fewer ligament injuries but no preventive effect on muscle injuries and severe injuries: an 11-year follow-up of the UEFA Champions League injury study. *Br J Sports Med*. 2013;47(12):732-737.
5. Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). *Am J Sports Med*. 2011;39(6):1226-1232.
6. Field A. *Discovering Statistics Using IBM SPSS Statistics*. 4th ed. Thousand Oaks, CA; Sage Publications Inc; 2013.
7. Green SB. How many subjects does it take to do a regression analysis. *Multivar Behav Res*. 1991;26(3):499-510.
8. Hamilton B, Valle X, Rodas G, et al. Classification and grading of muscle injuries: a narrative review. *Br J Sports Med*. 2015;49(5):306.
9. Holmich P, Thorborg K, Dehlendorff C, Krogsgaard K, Gluud C. Incidence and clinical presentation of groin injuries in sub-elite male soccer. *Br J Sports Med*. 2014;48(16):1245-1250.
10. Katz MH. *Multivariable Analysis: A Practical Guide for Clinicians and Public Health Researchers*. 3rd ed. Cambridge, England: Cambridge University Press; 2011.
11. Reurink G, Brilman EG, de Vos R-J, et al. Magnetic resonance imaging in acute hamstring injury: can we provide a return to play prognosis? *Sports Med*. 2015;45(1):133-146.
12. Schut L, Wangensteen A, Maaskant J, Tol JL, Bahr R, Moen M. Can clinical evaluation predict return to sport after acute hamstring injuries? A systematic review. *Sports Med*. 2017;47(6):1123-1144.
13. Serner A, Roemer FW, Hölmich P, et al. Reliability of MRI assessment of acute musculotendinous groin injuries in athletes. *Eur Radiol*. 2017;27(4):1486-1495.
14. Serner A, Tol JL, Jomaah N, et al. Diagnosis of acute groin injuries: a prospective study of 110 athletes. *Am J Sports Med*. 2015;43(8): 1857-1864.
15. Serner A, Weir A, Tol JL, et al. Can standardised clinical examination of athletes with acute groin injuries predict the presence and location of MRI findings? *Br J Sports Med*. 2016;50(24):1541-1547.
16. Serner A, Weir A, Tol JL, et al. Characteristics of acute groin injuries in the adductor muscles: a detailed MRI study in athletes. *Scand J Med Sci Sports*. 2018;28(2):667-676.
17. Serner A, Weir A, Tol JL, et al. Return to sport following criteria-based rehabilitation of acute adductor injuries in athletes: a prospective cohort study. *Orthop J Sports Med*. 2020;8(1):2325967119897247.
18. van der Made AD, Almusa E, Whiteley R, et al. Intramuscular tendon involvement on MRI has limited value for predicting time to return to play following acute hamstring injury. *Br J Sports Med*. 2018; 52(2):83-88.
19. Wangensteen A, Almusa E, Boukarroum S, et al. MRI does not add value over and above patient history and clinical examination in predicting time to return to sport after acute hamstring injuries: a prospective cohort of 180 male athletes. *Br J Sports Med*. 2015;49(24): 1579-1587.
20. Wangensteen A, Bahr R, Van Linschoten R, et al. MRI appearance does not change in the first 7 days after acute hamstring injury—a prospective study. *Br J Sports Med*. 2017;51(14):1087-1092.
21. Werner J, Hägglund M, Waldén M, Ekstrand J. UEFA injury study: a prospective study of hip and groin injuries in professional football over seven consecutive seasons. *Br J Sports Med*. 2009;43(13): 1036-1040.
22. Whiteley R, van Dyk N, Wangensteen A, Hansen C. Clinical implications from daily physiotherapy examination of 131 acute hamstring injuries and their association with running speed and rehabilitation progression. *Br J Sports Med*. 2018;52(5):303-310.