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Mechanisms of acute adductor longus injuries in male football players - a systematic visual video analysis

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Abstract

Introduction

Acute groin injuries are frequent in football, and the adductor longus is the most commonly injured muscle. Change of direction and kicking have been described as the main actions resulting in injury; however, detailed descriptions of inciting events are lacking.

Objective

Perform a standardised visual video analysis of acute adductor longus injuries in football.

Study design

Cross-sectional study

Methods

Video footage was reviewed by players, and assessed independently by 5 sports medicine professionals. Inciting events were described and categorised using standardised scoring, including playing situation, player/opponent behaviour, movement, and body positions.

Results

Videos of acute adductor longus injuries in 17 professional male football players were analysed. Most injuries occurred in non-contact situations (71%), following a quick reaction to a change in play (53%). Injury actions were: change of direction (35%), kicking (29%), reaching (24%), and jumping (12%). Change of direction and reaching injuries were categorised as closed chain movements (59%), characterised by hip extension and abduction with external rotation. Kicking and jumping injuries were categorised as open chain (41%), characterised by a change from hip extension to hip flexion, and hip abduction to adduction, with external rotation.

Conclusion

Acute adductor longus injuries in football occur in heterogeneous situations. Player actions can be categorized into closed (change of direction and reaching) and open (kicking and jumping) chain movements involving tri-planar hip motion. A rapid forceful muscle activation during a rapid muscle lengthening may be considered a fundamental injury mechanism for acute adductor longus injuries.

INTRODUCTION

Understanding injury mechanisms is crucial for improving prevention of sports injuries. In football, groin injuries are among the most frequent,[1] and a 25 player squad can expect 2-4 acute groin injuries each season.[2–4] The hip adductors muscles account for two-thirds of acute groin injuries in athletes, and the adductor longus is injured in 90% of these cases.[5,6] The adductor longus should therefore be the priority in the prevention of acute groin injuries, yet little is known about the injury mechanisms.

Acute adductor injury mechanisms are usually extrapolated from clinical history taking. In football, most acute adductor injuries are reported to occur during kicking or changing direction.[5] One study has attempted to analyse groin injuries in football using video footage, but none of the seven groin injuries reported could be identified on video.[7] The value of video analyses has been demonstrated for other acute injuries, primarily ligament injuries (knee and ankle) and head injuries.[8–14] No detailed video analysis studies of acute muscle injuries during sport currently exist.

Our aim was therefore to describe, and systematically categorise, the mechanisms of acute adductor longus injuries in male football players using video footage.

METHODS

Participants

Football players with an acute groin injury were included consecutively from the outpatient department at a specialised sports medicine hospital in Qatar from June 2013 to October 2015. The inclusion was performed in parallel with a larger prospective study on acute groin injuries.[6] Inclusion criteria were: elite male football players (age 18 to 40 years), presenting within 7 days of an acute onset of groin pain sustained while playing football. Available video footage, which included the injury situation, was required to include cases in the present study. Exclusion criteria were: pain of a non-musculotendinous cause or refusal to allow the use of video footage. As the majority of injuries affected the adductor longus muscle, we chose post hoc to exclude players with injuries not involving the adductor longus. Ethical approval was provided by the Shafallah Medical Genetics Center (IRB project no. 2013-008/2012-013) and the Anti-Doping Lab Qatar Institutional Review Board (EXT2014000006/EXT2014000004). Written informed consent was acquired from all players at inclusion.

Injury diagnosis

All injuries were diagnosed by sports medicine physicians using both clinical and radiological examination as previously described.[6] All MRI images were reassessed by an independent musculoskeletal radiologist, blinded to clinical information, using a standardized MRI scoring protocol with almost perfect intra- and inter-reproducibility for acute muscle injury location and grading (0-3) (kappa: 0.90-0.97).[15]

Video acquisition and processing

TV-broadcasted video footage was accessed through a tablet application (AspireSport, Aspire Zone Foundation, Doha, Qatar). The videos were stored as AVI format, further encoded into MP4 compressed format in Standard Quality. The video footage was subsequently edited with Adobe Premiere Pro CC software (Adobe System Inc., San Jose, CA, USA), and viewed by the authors in QuickTime Player (v.7, Apple, Cupertino, CA, USA). To gain an impression of the playing situation, the video was cut from the last stop in play prior to the injury to the stop in play immediately following injury. Additionally, shorter clips were made, which included footage of the specific injury situation from each available camera view. This means there was one clip of the full playing situation, as well a 1-6 additional clips depending on the number of available camera angles, allowing easy frame-by-frame navigation, enabling each view to be examined side by side.

Determination of injury movement

The lead researcher (AS) reviewed and discussed the video footage with each injured player to determine the specific movement and body position in which the player recalled feeling the pain. This review was performed within 24-48 h of initial consultation in the majority of cases. Based on this discussion with the player, the movement in which the pain occurred was subsequently divided into three time frames; beginning, middle, and end. Specific frame numbers for each short clip were selected by the lead researcher according to when the injured thigh changed movement direction and used as reference when scoring the videos. In cases where the player could not determine the specific body position, the assumed time of injury was set as the mid-point of the movement.

Analysis process

Standardized procedure

Initially, two authors (AS and AM) independently reviewed a subset of the injuries, answering open questions describing elements of the inciting event, based on a comprehensive model for injury causation.[16] This included information on the playing situation (such as type of play, pitch position and conditions), player/opponent behaviour (such as actions performed before and at injury time), and a biomechanical description of both whole body and joint movements/positions.

Based on the initial impressions, a standardized scoring form was developed and critically reviewed by all authors. All authors were then given access to all videos, and informed of the player's own description of the injury to ensure all descriptive elements were included in a final standardised scoring form (Supplementary file 1a). An additional categorisation was developed, defining the movements involved during the inciting event into either an ”open chain” movement, where the injured leg moved without touching the ground, or a ”closed chain” movement, where the injured leg had contact with the ground as the pelvis/trunk moved forward. (Supplementary file 1b).

Final scoring and analysis

All 5 authors (2 physiotherapists and 3 sports medicine physicians) scored the videos independently, blinded to each other’s scoring. Any discrepancies in the scoring were noted and discussed in a group consensus meeting where videos were viewed again. Consensus was said to have been reached when a minimum of 4 out of 5 authors agreed. As only 4 of the 5 authors were available for the consensus meeting, the missing author’s initial independent scoring counted in the consensus process. The scoring included a visual estimation of joint position and range of motion (ROM) angles. However, due to difficulty in scoring some of these variables, resulting in inability or high variability, certain variables were excluded during the consensus meeting. These were: leg loading, pelvic tilt (sagittal and frontal plane), ankle joint position (injured and uninjured side), and all specific range of motion degree measures. All 5 authors scored the additional categorisation of movements independently. For all variables included and for the additional categorisation, a final assessment was agreed upon, or it was agreed to categorise as “uncertain". Scoring was performed and analysed using Excel 2013 (Microsoft, Redmond, WA, USA).

RESULTS

Participants

Twenty-three football players were eligible for inclusion. Two players did not wish to participate in the study for personal reasons, and four players were diagnosed with injuries not involving the adductor longus (2 rectus femoris, 1 adductor brevis, and 1 psoas injury). Therefore, 17 football players with acute adductor longus injuries were included (mean (SD); player age: 27.5 y (3.2), range 21-32 y; height: 178 cm (7), range 169-189 cm; weight: 77 kg (10), range 64-94 kg. There were 4 goalkeepers, 4 defenders, 8 midfielders, and 1 forward. Fifteen played in the highest national league, and two in the second highest league.

Video acquisition

In total, 16 videos were acquired through AZF IPTV department and 1 from personal video footage. Five injuries were captured from 1 camera view, 2 were captured from 2 views, 5 from 3 views, 2 from 4 views, 1 from 5 views, and 2 from 6 views. Fourteen videos were in resolution 720x400 with 10320-10521 kbps total bitrate and 25 frames per second (fps), 1 video was in 1280x720 resolution, 11056 kbps bitrate and 25 fps, 1 video in 640x352 resolution, 9384 kbps bitrate and 30 fps, and 1 video in 480x360 resolution, 7927 kbps bitrate and 24 fps.

Injury situations

All 17 players were able to determine both the situation and movement causing the groin pain. Additionally, 13 players could select the exact limb position in which they remembered feeling the onset of pain. The players’ location on the pitch are depicted in Figure 1, and descriptive information regarding the injury is presented in Table 1. Player actions at the time of injury were categorised as change of direction in six cases (35%), kicking in five (29%), reaching in four (24%), and jumping in two (12%) cases. Examples are presented in Figure 2 with corresponding video clips in supplementary files 2-5. There was no clear pattern between MRI injury location, grading, and injury action (Supplementary file 6).

Table 1 Descriptive information on injury situations.

Time of injury	
- 0-15 min	4 (24%)
- 15-30 min	7 (41%)
- 30-45 min	-
- 45-60 min	1 (6%)
- 60-75 min	3 (12%)
- 75-90+ min	2 (18%)
Team action	
- Defensive	9 (53%)
- Offensive	7 (41%)
- No possession	1 (6%)
Player contact	
- Direct contact	2 (12%)
- Indirect contact (shoulder/uninjured leg)	3 (18%)
- No contact (opponent <2m away)	8 (47%)
- No contact (opponent >2m away)	4 (24%)
Foul play	
- No foul	15 (88%)
- Yellow card	1 (6%)
- No card	1 (6%)
Player attention/balance	
- Quick reaction to change in play	8 (53%)
- Player out of balance	9 (53%)
Movement speed	
- Running	14 (82%)
- Standing	3 (18%)

Change of direction and reaching injuries were categorised as closed chain movements, whereas kicking and jumping injuries were categorised as open chain (Table 2). Of the six change of direction injuries, four involved angles <45° and two >90° towards the side of the uninjured leg. Of the five kicking injuries, three were passes (two short, one long) and two were shots. Two were set plays (goal kick and penalty). Three were side-foot kicks and two in-step. Three of the four reaching injuries occurred when the player was reaching for the ball with the uninjured leg. The two jumping injuries occurred as the player was jumping off the uninjured leg. Descriptions of each case are included in Supplementary file 7. Body positions at the defined time of injury are described in Table 3.

Table 2 Categorisation and movement descriptions involved in the inciting event.

"Open chain"	Rapid change of movement involving hip extension to hip flexion?	Rapid change of movement involving hip abduction to hip adduction?	Hip externally rotated?	Ball impact
Kicking	Yes	Yes	Yes	Yes
Kicking	Yes	Yes	Yes	Yes
Kicking	-	Yes	-	Yes
Kicking	Yes	-	Yes	Yes
Kicking	No	Yes	No	Yes
Jumping	Yes	-	-	No
Jumping	Yes	-	-	No
"Closed chain"	Involving hip extension?	Involving hip abduction?	Hip externally rotated?	
Change of direction	No	Yes	-	
Change of direction	-	-	-	
Change of direction	Yes	Yes	Yes	
Change of direction	Yes	-	Yes	
Change of direction	Yes	Yes	Yes	
Change of direction	No	Yes	Yes	
Reaching for ball	Yes	-	-	
Reaching for ball	No	Yes	-	
Reaching for ball	Yes	Yes	Yes	
Unsure				
Reaching for ball	-	-	-	

Variables labelled with "-" are considered uncertain, as agreement could not be reached due to difficulties in scoring the specific variable. This was primarily related to the camera views, such as number or quality (e.g. distance/angle) of the views.

Table 3 Body positions at defined injury time.

	Trunk			Pelvis	Hip - injured side			Hip - uninjured side			Knee - injured side	Knee - uninjured side
Plane	*Sagittal*	*Frontal (flexion)* Related to injured side	*Transverse (rotation)* Related to injured side	*Transverse (rotation of injured side)*	*Sagittal*	*Frontal*	*Transverse (rotation)*	*Sagittal*	*Frontal*	*Transverse (rotation)*	*Sagittal*	*Sagittal*
ID	***Change of direction***											
C1	Flexion	Toward	Neutral	Posterior	Flexion	Abduction	External	Flexion	Abduction	External	Flexion <45°	Flexion 45-90°
C2	Neutral	-	-	Posterior	Extension	-	-	Flexion	-	-	Flexion <45°	-
C3	Flexion	Toward	Toward	Posterior	Extension	Abduction	External	Flexion	Abduction	External	Flexion <45°	Flexion <45°
C4	Neutral	Neutral	Away	Posterior	Extension	Neutral	External	Flexion	Adduction	Internal	Flexion <45°	Flexion >90°
C5	Neutral	Away	Toward	Posterior	Flexion	Abduction	-	Flexion	Abduction	External	Flexion <45°	Flexion 45-90°
C6	Neutral	Toward	Neutral	Neutral	Flexion	Abduction	Internal	Flexion	Abduction	External	Flexion >90°	Flexion 45-90°
	Kicking											
K1	Neutral	Neutral	Away	Posterior	Extension	Abduction	External	Flexion	Abduction	External	Flexion 45-90°	Flexion <45°
K2	Extension	Toward	Away	Posterior	Extension	Abduction	Neutral	Flexion	Adduction	External	Flexion 45-90°	Neutral
K3	Neutral	Neutral	Neutral	Neutral	-	Abduction	External	Flexion	Abduction	External	Flexion <45°	Flexion <45°
K4	Extension	Neutral	Away	Posterior	Extension	Abduction	External	Flexion	-	Neutral	Flexion 45-90°	Flexion <45°
K5	Neutral	Neutral	Neutral	Neutral	Flexion	Abduction	Neutral	Neutral	Neutral	External	Flexion <45°	Flexion <45°
	Reaching											
R1	-	-	-	-	-	-	-	Flexion	-	-	-	Extension
R2	Flexion	-	Toward	-	Flexion	-	-	Flexion	-	-	Flexion <45°	Flexion 45-90°
R3	-	Away	Away	Posterior	Neutral	Abduction	Neutral	Flexion	Abduction	-	Flexion 45-90°	-
R4	Extension	Neutral	Away	Posterior	Extension	Abduction	External	Flexion	Abduction	External	Flexion 45-90°	Flexion (<45°)
	Jumping											
J1	Neutral	Neutral	Away	Posterior	Extension	Neutral	Neutral	Flexion	-	Neutral	Flexion <45°	Flexion <45°
J2	Extension	Toward	Away	Posterior	Extension	Abduction	Internal	Flexion	Adduction	Neutral	Flexion <45°	Flexion 45-90°
	Most frequent positions											
Total	Neutral 53% (8/15)	Neutral 50% (7/14)	Away 53% (8/15)	Posterior 80% (12/15)	Extension 60% (9/15)	Abduction 86% (12/14)	External 54% (7/13)	Flexion 94% (16/17)	Abduction 67% (8/12)	External 62% (8/13)	Flexion <45° 63% (10/16)	Flexion <45° 47% (7/15)

Variables labelled with "-" are considered uncertain, as agreement could not be reached due to difficulties in scoring the specific variable. This was primarily related to the camera views, such as number or quality (e.g. distance/angle) of the views.

DISCUSSION

In this prospective visual video analysis study of acute adductor longus injuries in football, we show that injury situations vary greatly. Player actions were categorised into closed (change of direction and reaching) and open chain (kicking and jumping) movements with characteristic tri-planar hip movement.

The categorisation of player actions has a similar distribution as previously reported based on clinical history in a larger cohort with adductor injuries.[5] Change of direction, kicking, and reaching actions were confirmed as high risk actions for adductor longus injuries. There were large differences in the type of movement within each category, and determination of a single player action was sometimes difficult, indicating that no simple injury description can be ascertained.

Change of direction actions included both <45° and >90° angles towards the uninjured side. In an unanticipated change of direction movement, adductor longus muscle activity is highest during weight acceptance, and remain high through the final push-off phase.[17] Considering the typical movement pattern of hip extension and abduction with the hip externally rotated, these injuries likely occur as the adductor longus is lengthening. As such, the coupling of rapid forceful muscle activation combined with an increase in muscle-tendon unit length may be the key element leading to injury. This may be similar to the reaching injuries, as they appeared to follow a comparable closed chain movement.

Kicking actions involved different types of kicks, including short and long passes, as well as shots, indicating that focusing on maximal kicking only is inadequate. Kicking injuries were considered to occur in open chain movements, but also typically involved a diagonal movement with hip extension to flexion and hip abduction to adduction with the hip externally rotated. The two jumping injuries appeared to follow a comparable open chain movement. During a maximal in-step kick, maximal adductor longus activation and rate of stretch occurs in the backswing phase, while the maximal length of the adductor longus is seen in the leg cocking phase.[18] These phases, taken together, occur in less than 200 ms.[19,20] The rapid transition from hip extension to hip flexion is therefore suggested to place the adductor longus at risk of an acute strain injury.[18] This reasoning corresponds to our findings, which indicate that injuries during both open and closed chain movements may be a result of rapid forceful muscle activation while the muscle is undergoing a rapid lengthening. For open chain injury actions, this likely occurs as the thigh decelerates and changes movement direction, and in closed chain injury actions, during control of upper body propulsion.

Prevention of adductor longus injuries

Our findings suggest that increasing the capacity of the adductor longus to tolerate rapid loading at a lengthened state is recommended as a key element in injury prevention. Improving the ability of the muscle-tendon-unit to tolerate load at a lengthened state may be achieved with eccentric training. Eccentric training can induce extracellular matrix remodelling,[21,22] and addition of sarcomeres in series,[23] resulting in increased muscle fascicle length,[24–26] as well shift the angle of peak torque to longer muscle lengths.[27,28]. This is considered to lead to a reduction in total passive tension, which is an explanation why eccentric training has been in effective in reducing acute hamstring injury risk.[29,30] Acute hamstring injuries are considered to occur the terminal swing phase of running,[31–33] with a similar injury mechanism to the open chain category described in our study. Eccentric training may therefore have a similar benefit in relation to adductor longus injuries. Further strategies to increase capacity at length may also focus on influencing tendon compliance[34] or neural function,[35] although this has not been investigated specifically for the adductor longus.

Additionally, as most adductor longus injuries are described to occur at the MTJ,[5] increasing the force capacity of the MTJ is also recommended. Animal studies have shown that the MTJ is responsive to load through increased branching,[36,37] and particularly with higher intensity load,[38] indicating a potential for increased force distribution capacity through high load adductor longus exercises. When choosing specific exercises to target the adductor longus, studies exist on both muscle activation[39–41] and resulting strength gains.[42–44] These studies focus primarily on frontal plane movement. The present study suggests that a focus on tri-planar (diagonal movement) exercises, should be further explored.

A greater focus on the performance of synergist muscles involved in the different high risk actions as categorised in this study should also be considered. Due to the variance in injury actions, a synergist focus would include both anterior and posterior chain muscles, for the open and closed chain movements respectively. This would include the hip flexors, knee extensors, and trunk rotators,[45–47] and plantar flexors, knee extensors, hip extensors and abductors, and trunk lateral flexors,[48–53] respectively.

The variety of player actions resulting in injuries, and the lack of association between player actions and adductor longus injury location, suggests a need to focus on training and testing all potential injury actions during the return to play process. Additionally, it appears that many injury movements are influenced by the close presence of an opponent, resulting in a rapid decision-making process, which may influence player actions, and increase injury risk. Therefore, training reactive/unanticipated actions in addition to pre-planned actions may assist in both reducing injury risk and improving performance.

The heterogeneous injury situations identified, and the fact that most injuries were non-contact, without foul play, also means that there are no clear avenues for injury prevention through rule change.

Limitations

The validity of the defined injury moment was based on player recollection and there is no way to be certain that the injury actually occurred at the described time. A strength is that the study was conducted prospectively, and all players reviewed the footage shortly after the injury in order to minimize recollection bias. The approach of involving the player in determining the injury situation is novel, and we believe an important step for the feasibility of analysing muscle injuries in sport. Currently, a ‘gold standard" of determining the specific time of injury onset is lacking for muscle injuries. In ligament injuries, which have a more or less obvious timing of the injury, the optimal approach may include a decision on the initial ground contact.[8,9,11] Due to the heterogeneous and often relatively unremarkable injury situations observed, including both open and closed chain movements, a similar approach to encompass all injuries in this study would likely not be appropriate. Thus we would likely not have been able to perform this study using this approach nor retrospectively without player involvement, such as seen in a previous study.[7] Following the review and categorisation of player actions, there are still a few cases where the authors were uncertain about the player’s description. For instance, whether the exact pain onset during kicking was felt in the backswing phase or at ball impact. The ball impact occurs over only 8-10 ms, and the peak ball reaction force is described to be around 3000 N.[54] It is therefore not unreasonable to assume that ball impact may also have an influence on adductor longus load, potentially resulting in injury. Further research on this association is suggested.

Another limitation is the visual analysis process, which depended on the authors' interpretation of the video footage (influenced by video quality and number of available camera views), rather than a quantitative method such as 3D biomechanical computer modelling or model-based image matching technique, as used for other injury types.[31,55,56] All authors were involved in the development of the scoring to a varying extent with access to the included videos. As this is an exploratory rather than a confirmatory study, we believe this to be an appropriate methodological approach to ensure a comprehensive description. In order to increase the validity of the findings, all authors scored the videos independently. Additionally, scoring was discussed in a consensus meeting, and variables with disagreement, or deemed too difficult to score, were either labelled as uncertain or completely removed from the scoring, leaving only variables with a higher level of agreement. This was mainly due to the limited video footage with only one camera view in 5 injury situations, often from a distance, and also due to general difficulty in scoring joint angles visually.

Due to the many differences in injury situations, the relatively low number of injuries leaves some uncertainty to the generalisability of the findings, and also impedes a direct comparison with similar situations not resulting in injury. Further studies with a larger sample of players are therefore required, as well as analyses of adductor longus injuries occurring in different populations (e.g. other sports, female players etc.).

CONCLUSION

Acute adductor longus injuries in football occur in heterogeneous situations. Player actions can be categorized into: change of direction, kicking, reaching, and jumping. Change of direction and reaching injuries were categorised as closed chain movements, characterised by hip extension and abduction. Kicking and jumping injuries were categorised as open chain movements, characterised by a change from hip extension to hip flexion and abduction to adduction. Both open and closed chain movements frequently occurred with the hip externally rotated. Despite the variance in situations, a rapid high muscle activation during rapid muscle lengthening may be considered a fundamental injury mechanism for acute adductor longus injuries.

What are the new findings?

- Acute adductor longus injury situations vary greatly. Player actions can be categorised into change of direction, kicking, reaching, and jumping.
- Kicking and jumping injury actions follow an open chain movement, typically involving a rapid change of movement from hip extension to hip flexion, and hip abduction to adduction, with the hip externally rotated.
- Change of direction and reaching injury actions follow a closed chain movement, typically involving a combination of hip extension and hip abduction of the injured leg with the hip externally rotated.

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

- A rapid and high muscle activation while the muscle is undergoing a rapid lengthening may be considered the fundamental injury mechanism for acute adductor longus injuries.
- Training the adductor longus with the purpose of increasing its capacity to withstand the rapid high forces at a lengthened state, may be an effective injury prevention strategy.
- Incorporating focus on muscles working as synergists in change of direction, kicking, reaching, and jumping actions, may assist in reducing load on the adductor longus thereby decreasing injury risk.
- Training and testing several high-risk actions should be incorporated in the prevention and treatment progression of acute adductor longus injuries, including a focus on unanticipated actions.

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Competing interests
The authors declare no competing interests.

Ethics approval
Shafallah Medical Genetics Center (IRB project no. 2013-008/2012-013) and the Anti-Doping Lab Qatar Institutional Review Board (EXT2014000006/EXT2014000004).

Patient involvement
No patients were officially involved in the development of the study, however, discussions with all included patients regarding perceptions of their injury mechanism had a large influence on the methodological approach.

Figure legends

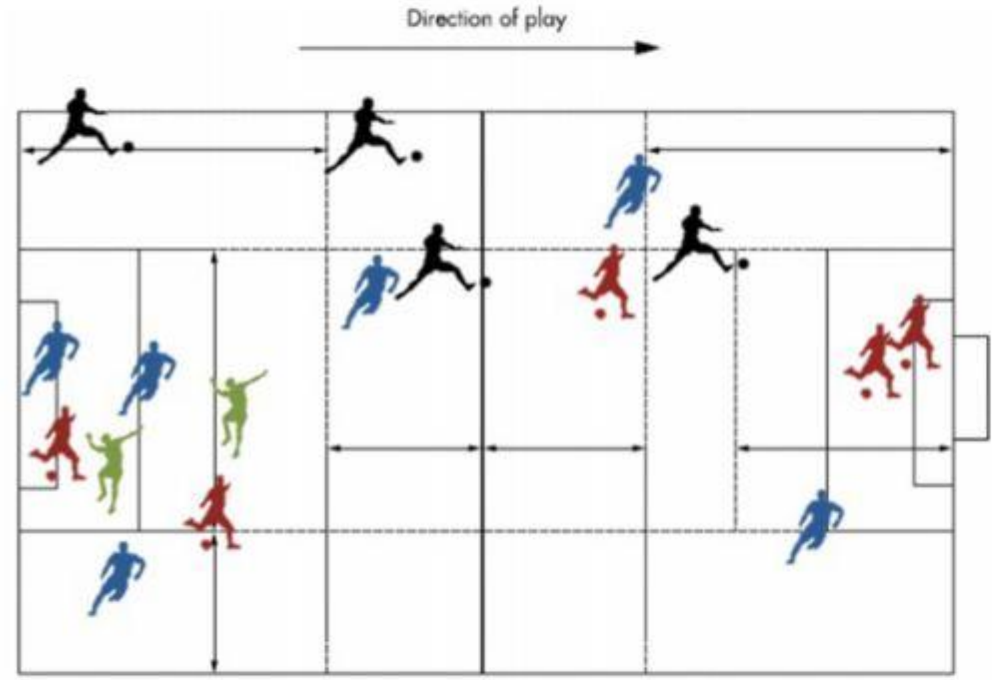

Figure 1: Football pitch divided into zones with player figures reflecting the location on the pitch where the acute adductor longus injury occurred. The different injury action categories are depicted with different player figures (Pitch figure adapted from Andersen et al, 2003 [12]):  = Change of direction,  = Kicking,  = Reaching,  = Jumping.

Figure 2: Examples of the 4 categories of player actions at the time of injury. A: Change of direction, B: Kicking, C Reaching, D: Jumping.

Supplementary Material

Supplementary file 1: a: Variables and categories used to describe injury situations and player actions; b: Categorisation options for the inciting event.

Supplementary file 2-5: Video examples of the four categorisations of player injury actions.

Supplementary file 6: Adductor longus MRI findings and player action at defined injury time.

Supplementary file 7: Short descriptions of each inciting event grouped by player action category.

Supplementary file 1a

Variables and categories used to describe injury situations and player actions.

Element	Describing factors
Playing situation	
Pitch conditions	
- Type of pitch	Grass, artificial turf
- Surface condition	Normal, wet, dry
- Pitch quality	Good (smooth), bad (patchy, bumpy)
Pitch position	
- End of pitch	Own third, mid-third (zone 1), mid-third (zone 2), opponent third
- Side of pitch	Right, left, central
Play	
- Team action	Defensive, offensive, free ball (no ball possession)
- Type of play	In play, set play (goal kick, free kick, corner, penalty, throw in)
Player/opponent behaviour	
Player action	
- Action at injury	Kicking (with injured leg/uninjured leg), approach to kick (set play), tackling, heading, dribbling, receiving pass (standing/running), screening, blocking, pressing (intention to tackle/no intention to tackle), goal keeping, collision, reaching for ball (with injured leg/uninjured leg), running (acceleration/in speed/deceleration), change of direction.
- Concurrent movement	Standing, walking, running, maximal sprinting.
if kicking	
- Type	Pass (short/long), cross, shot on goal, clearing.
- Direction	Forwards, backwards, to the side.
- Ball impact	Side-foot, instep, toe kick, heel, volley, half volley.
if change of direction	
- Angle	0-45 deg., 45-90 deg. >90 deg.
- Direction	Away from / towards injured side.
if tackling	
- Who	Tackling other player, tackled by other player, both players tackling.
- Movement	Sliding (one foot/both feet), upright (foot/shoulder).
- Direction	From side/front/back.
if goal keeping	Jump save (high/low, toward/away from inj. side/straight front), standing save (toward/away from inj. side/straight front), goal kick, punt kick.
Player contact at injury movement	Yes (direct contact to injured leg, indirect contact to trunk/shoulder/uninjured leg), No (opponent close <2m / >2m away).
Foul play	No, Yes (no card/yellow card/red card).
Player attention	Reaction to ball/opponent change (yes/no).
Balance	In balance, out of balance.
Whole body and joint/tissue biomechanics	
Movements	Assessed qualitatively
Body/joint positions	
- Trunk	Extension/flexion/neutral, Lateral flexion (toward injured/uninjured leg/neutral), Rotation (toward injured/uninjured leg/neutral).
- Pelvis	Neutral/anterior/posterior orientation of injured side, anterior/posterior/neutral tilt (removed after consensus), lateral tilt/neutral (removed after consensus).
- Hip (injured & uninjured leg)	Extension/flexion/neutral, specified with 5 deg. increments, Abduction/adduction/neutral, specified with 5 deg. increments, External/internal/neutral rotation, specified with 5 deg. increments.
- Knee (injured & uninjured leg)	Neutral, extension, flexion (<45 deg., 45-90 deg., >90 deg.), specified with 5 deg. increments.
- Ankle (injured & uninjured leg)	Dorsiflexion/plantar flexion/neutral (removed after consensus), internal/external/neutral rotation (removed after consensus).

Supplementary file 1b

Categorisation options for the inciting event

1		**”Open Chain“** – Injured leg moving without touching the ground.
		If yes, then a-d:
	a)	Rapid change of movement involving hip extension to hip flexion?
	b)	Rapid change of movement involving hip abduction to hip adduction?
	c)	Hip externally rotated during movement?
	d)	Ball impact during movement?
2		**“Closed Chain” -** Injured leg on the ground as the pelvis/trunk moves.
		If yes, then a-c:
	a)	Involving hip extension movement?
	b)	Involving hip abduction movement?
	c)	Hip externally rotated during movement?
3		**Other:**
		optional free text

All variables scored as yes, no, or uncertain.

Supplementary file 6
Player action at defined injury time and adductor longus MRI findings.

Player action	Injury location	Grade
Change of direction	Proximal insertion	3
Change of direction	Proximal insertion	3
Change of direction	Proximal insertion	3
Change of direction	Proximal MTJ	2
Change of direction	Proximal MTJ	1
Change of direction	Negative MRI	0
Kicking	Proximal insertion	3
Kicking	Proximal insertion	3
Kicking	Proximal MTJ	2
Kicking	Distal MTJ	1
Kicking	Distal MTJ	1
Reaching	Proximal insertion	3
Reaching	Proximal MTJ	2
Reaching	Distal MTJ	2
Reaching	Proximal MTJ	1
Jumping	Proximal insertion	3
Jumping	Distal MTJ	2

MTJ = Musculotendinous junction.

Supplementary file 7
Short descriptions of each inciting event grouped by player action category.

ID	**Change of direction**
C1	Goalkeeper changing direction to block a shot on goal. The player pushes off the ground to move body forward and contralateral to the injured side to save the ball which is at hip height. This results in a hip abduction, extension, and external rotation movement of the injured leg (defined injury time), followed by a change of movement to hip flexion and hip adduction.
C	Midfielder changing direction while chasing opponent. The player is in high running speed as he changes direction contralateral to injured side attempting a shoulder tackle. This results in hip abduction and extension of the injured leg after the foot hits the ground (defined injury time), followed by a change of movement to hip flexion and hip adduction.
C3	Defender changing direction as he attempts to regain balance after shoulder tackle. The player performs a shoulder tackle at high running speed and changes direction as he attempts to regain balance. The injured leg is planted on the ground. Following this, the body moves forward while the foot remains on the ground resulting in large hip extension, abduction and external rotation (defined injury time), followed by a change of movement to hip flexion and hip adduction.
C4	Midfielder accelerating after changing direction. The player reaches for the ball with the uninjured leg (potential injury time) and loses control of the ball. He then changes direction towards the injured side and pushes off with injured leg to accelerate towards the ball, resulting in a hip extension and abduction (defined injury time). This is followed by a change of movement to hip flexion and hip adduction.
C5	Goalkeeper turning to chase ball. The ball is headed over the player, who then turns app 180 deg. to chase the ball. The player performs an upper body rotation followed by a push off with the injured leg in a hip abduction, extension and external rotation movement (defined injury time). This is followed by a change of movement to hip flexion and hip adduction.
C6	Defender sliding on the grass while attempting to change direction. The player makes a fast approach towards opponent and has to change direction towards the injured side. As he attempts to push off with the uninjured leg, it slides on the ground and the injured leg gets stuck on the ground as the body is moving forward, resulting in a hip abduction and extension of the injured leg with the hip externally rotated (defined injury time).
	Kicking
K1	Defender passing to goalkeeper. The player is in high speed and passes ball back to goalkeeper with the injured leg while screening opponent. As the ball is behind the stance leg there is a large active hip extension and abduction movement of the injured leg while the hip is externally rotated (defined injury time), followed by an active hip flexion with hip externally rotated.
K2	Goalkeeper performing goal kick. The player attempts a long goal kick with the injured leg. There is a change from an active hip extension to active hip flexion with the hip in minor external rotation and abduction (potential injury time). The active hip flexion with the hip in minor abduction continues to ball impact (potential injury time).
K3)	Forward performing half volley shot at goal. The player attempts a shot on goal around a defender after taking down the ball inside the box. The player rotates on uninjured leg resulting in a large hip abduction and hip extension followed by a fast hip flexion and adduction movement with the injured leg (defined injury time).
K4	Midfielder performing penalty kick. The player takes a penalty with the injured leg with a hard kick. There is a change from active hip extension to active hip flexion possibly with minor external rotation and abduction (defined injury time) prior to ball impact, which appear to be an instep kick. After scoring the player kick the ball again hard into the empty net (potential exacerbation).

K5	Midfielder passing ball behind standing leg. The player takes down the ball, rolls it back with the injured leg, and passes it behind the contralateral leg resulting in a fast hip abduction and minor hip extension movement followed by a fast hip adduction movement (defined injury time). The player lands on the injured leg in adduction likely causing a fast contraction of the adductor longus at short length to assist in stabilizing the hip (potential injury time).
	Reaching
R1 (5)	Defender reaching for ball to regain possession. The player attempts to dribble, but gets tackled and the ball bounces. The player reaches for the ball with the uninjured leg, while the injured leg is on the ground, resulting in a hip extension of the injured leg (defined injury time).
R2	Midfielder reaching for ball twice. The player gets a pass in front of him and reaches for the ball with the uninjured leg resulting in a large hip extension of the injured leg which is on the ground (potential injury time). He touches the ball and then reaches for the ball in front of him now with the injured leg straight, and gets tackled from the uninjured side (defined injury time).
R3	Midfielder reaching for ball after tackle. The player performs a shoulder tackle and then reaches for the ball with the uninjured leg to gain possession. The knee of the injured leg is on the ground as his body is moving forward, resulting in a hip abduction and external rotation movement (defined injury time).
R4	Midfielder reaching for ball to intercept pass. The player attempts to intercept a pass reaching for the ball with the uninjured leg while the injured leg is on the ground. This results in a hip extension and minor abduction of the injured leg while the hip is externally rotated (defined injury time).
	Jumping
J1	Goalkeeper jumping to catch ball. The player is running towards the ball coming from a long pass, and jumps on uninjured leg to catch the ball resulting in a hip flexion movement of the injured leg from full hip extension and minor abduction (defined injury time).
J2	Midfielder jumping over tackling opponent. The player is running with the ball, while opponent attempts a sliding tackle. The player reached for the ball with the uninjured leg, while the injured leg is stretched behind him (potential injury time), and then jumps on the uninjured leg resulting in a hip flexion and minor adduction movement of the injured leg from a large hip extension and minor abduction (defined injury time).