Injury mechanisms and situational patterns of severe lower limb muscle injuries in male professional football (soccer) players: a systematic video analysis study on 103 cases

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ABSTRACT

Objective The objective of this study is to describe the mechanism of injury and situational patterns (based on ball possession and playing action leading to injury) of severe (lay-off time >28 days) lower limb muscle injuries in professional male football (soccer) players during match play.

Methods Players experiencing a severe muscle injury of the lower limb during Italian first (Serie A) division male football matches over three consecutive seasons (2018–2021) were identified. Video footage was obtained and three raters independently categorised injury mechanism and situational patterns using a standardised checklist. Injury epidemiology (month), timing of injuries within the match and location of injuries on the pitch were also examined.

Results We identified 121 lower limb severe muscle injuries. Videos of sufficient quality were available for 103 (85%) cases, including 61 (60%) hamstring, 17 (16%) calf, 16 (15%) adductor and 9 (9%) quadriceps muscle injuries. Nearly two-thirds of injuries involved the dominant/kicking leg (n=65, 63%). Eighty-five (83%) injuries were non-contact and 18 (17%) indirect contact. Four main situational patterns were identified and accounted for 88% of injuries: (1) running/acceleration (n=35, 34%); (2) closed kinetic chain stretching (n=21, 20%); (3) open kinetic chain stretching (n=19, 18%) and (4) kicking (n=16, 16%), with differences between muscle groups. 71% of injuries occurred in the first half of the match (p<0.01), with a gradual increase through the first half.

Conclusion Most severe muscle injuries during football matches were non-contact and occurred in the first half during running/acceleration, open and closed kinetic chain stretching, or kicking.

INTRODUCTION

Reducing injury burden is vitally important for the medical and performance team in football, due to the economic and competitive implications of time-loss. Muscle injuries are the most common type of injury in elite male football and constitute about a third of total time-loss. Hamstring injuries in particular are on the rise and now constitute nearly one in every four injuries. Most muscle injuries in football have relative short lay off times (within 4 weeks), while 11% are severe (absence >28 days). These severe injuries are the most challenging ones to treat and are associated with a high risk of reinjury.

Few video analysis studies have been performed examining muscle injuries in football players. These are focused on the thigh and include a mix of severities, with no study reporting only severe muscle injuries.

Muscle injuries are predominantly non-contact or indirect contact injuries occurring during running/cutting, stretching or kicking activities.

Muscle injuries are thought to occur in part due to fatigue, often occurring later in each half and more commonly in the second half.

Muscle injuries occur similarly on the dominant and non-dominant kicking limbs, but with slight preference for dominant limb quadriceps injuries.

WHAT IS ALREADY KNOWN ON THIS TOPIC

WHAT THIS STUDY ADDS

This is the first study to use video analysis of all severe lower limb muscle injuries.

We showed severe lower limb muscle injuries occur more commonly during offensive situations, during horizontal orientated high intensity movements, on the dominant kicking leg, and during four situational patterns. Closed kinetic chain stretch-type injuries are common and an underrepresented situational pattern.

Severe muscle injuries occur later in each half but more commonly in the first half.
cases.”27 Klein et al26 researched the pattern of 81 thigh muscle injuries as part of a broader football injuries video analysis study and Gronwald et al25 described the hamstring injury patterns in 52 professional male football players. Finally, Jokela et al24 studied the correlation between MRI findings and video analysis on 14 high-grade hamstring injuries. Although these studies are well performed, there is a need for more studies, with large sample size,27 to increase our understanding of how muscle injuries occur in football. There is a lack of understanding of severe muscle injuries and if they have unique injury mechanism and situational pattern. Additionally, no study has detailed injury mechanisms and situational patterns using video analysis for quadriceps and calf muscle injuries. Finally, there is limited research detailing the distribution of severe lower limb muscle injuries across the season, as well as within the match and on the pitch location.

The primary purpose of this study was to describe in a large cohort of professional football players the mechanisms and situational patterns of severe lower limb muscle injuries during male football matches. A secondary purpose of this study was to report the seasonal, match and pitch distribution of severe muscle injuries. In studying how severe muscle injuries occur, we aim to support clinicians in diagnosing injuries and designing/tailoring interventions to reduce injury incidence.

METHOD
Study design, injury identification
In this cross-sectional observational study on a total population cohort, all male first division (Serie A) football players who competed in at least one competitive match during three consecutive seasons (from 2018/2019 to 2020/2021, until June 2021) were included. A systematic search of online database resources (ie, legaseria.it; single team websites) was performed to identify players in each team roster across the three seasons. Each player was then searched on Transfermarkt.De (Transfermarkt, Hamburg, Germany) for details on injury history and to identify lower limb muscle injuries occurring during matches. This methodology has been recently validated for identification of injuries in professional football and was also adopted by very recent studies on mechanisms of muscle injuries27 and injury patterns26 in professional male football.25 Subsequently, additional data sources including national (eg, www.Gazzetta.it; www.Corrieredellosport.it) and local media were searched to identify any injuries which may have been missed. Finally, lower limb muscle injuries were included only when they are associated with a loss of time from competition more than 28 days (ie, severe muscle injuries).8 30

Video extraction
Videos of matches were obtained from an online digital platform (instatsport.com; InStat). Videos were then processed and downloaded to a personal computer. Match video processing was done with a cloud available tool (Digital Log, Digital Soccer Project). Each video of lower limb muscle injury was cut to approximately 1 min prior to and 30 s after the suspected injury frame (IF) to accurately evaluate the playing situation that preceded the injury. Additionally, all available replays from the television broadcast (in slow motion and from different angles) were added to the video.

Video evaluation
The videos were independently evaluated by three different reviewers (FDW, GN and MB) according to a predetermined checklist (online supplemental table 1). All reviewers participate in sport medicine and orthopaedic rehabilitation practice (MD, MD and PhD) and video analysis research. Each video of lower limb muscle injury was downloaded on the personal computer and opened with Kinovea (KinoveaInk), an available online software and analysed through an evaluation flow. Each reviewer evaluated the injury situation according to ball possession and playing situation (offensive or defensive). The injured side was determined based on injury history information gathered as well as video data. The dominant leg was defined as the preferred kicking leg, categorised as right or left and if the injury occurred to dominant limb determined. Leg loading was established as, if on the injured, uninjured or both limbs and injury according to kinetic chain was characterised. Open kinetic chain was defined as when the leg was injured while not in contact with the ground (eg, swing phase of running, reaching, ball striking) while closed kinetic chain injuries were when the leg was injured while in contact with the ground and not free to move (eg, landing, stopping, support leg while kicking).25 Subsequently, the intensity of action was determined based on estimated horizontal and vertical velocities (zero, low, moderate and high). Injury mechanism was determined with three categories of injury mechanism used: (1) non-contact, defined as an injury occurring without any contact (at the lower limb or any other level) prior to or at IF; (2) indirect contact, defined as an injury resulting from an external force applied to the footballer, but not directly to the muscle injured; and (3) direct contact, defined as an external force directly applied to the muscle injured.26 We used the term ‘situational pattern’ to determine the playing action and context and was interpreted as running, acceleration from stand-still or low velocity, stretching in open kinetic chain and stretching in closed kinetic chain, kicking, jumping, reaching or other. Kicking was considered the injurious pattern only when the injured lower limb was the kicking one, based on video data and collected injury information. Following independent review of the videos, the reviewers met for a 1-day comprehensive discussion about the main injury mechanism and situational patterns. In the presence of disagreement between reviewers, differences were solved through collegiate decision making, as in previous research.24 25 30 Consensus agreement on all the items was reached during the meeting.

Seasonal, match and field distribution
For each available injury video, a list of data regarding the seasonal, match and field distribution were gathered through
systematic web revision and analysis of videos in relation to the position of the injured player according to our previously published research.\(^1\)\(^8\)\(^9\) We considered (1) month of lower limb muscle injury, (2) phase of the game when the muscle injury occurred (minute and half), (3) number of minutes played by the muscle-injured athlete and (4) field location at the time of injury. The location of the injury on the pitch was estimated by taking the field lines as a reference.\(^1\)\(^9\) The pitch was divided up into 11 zones.\(^2\)\(^0\) The size (m\(^2\)) of each zone was calculated considering the official FIFA football field size (105×70 m) (see online supplemental material for additional details).

**Patient and public involvement**

Where available through personal networks, we liaised with the injured football players and team physicians, to support our description of the injury. The results of the study will be shared with publicly available resources (eg, newspaper articles, television interviews, podcasts, blogs) to inform the audience regarding how severe lower limb muscle injuries occur and the implications for treatment.

**Equity, diversity and inclusion**

Millions of women play football around the world, and the British Journal of Sports Medicine encourages research that includes gender-based analysis. While the methodology that we used is certainly applicable to women's football, given the lack of media coverage of women's football across the same league (Italian Serie A), there was insufficient severe muscle injuries available across all four lower limb muscles for this study. Further video analysis research of muscle injuries in women's football is warranted, and our research group is undertaking work in this area. We acknowledge the study may not be representative across all levels of sport and cultures and further work to examine muscle injuries via video analysis across levels of sport and across nations, including low-income countries is warranted.

**Statistical analysis**

Continuous variables are presented as mean (±SD) or median (range) as appropriate according to the distribution of variables. Discrete variables were presented as absolute numbers and as percentage of the total number of observations. The proportion test was used to explore differences in the distribution of lower limb muscle injuries between match halves. An alpha of less than 0.05 denoted statistical significance. Microsoft Excel 2016 (Microsoft, USA) and Stata V.12 were used for analyses.

**RESULTS**

One hundred and twenty-one severe lower limb muscle injuries were tracked. Video footage was available and identifiable for injury mechanism and situational pattern analysis in 103 cases (85%), with only these 103 injuries included in the study. Ninety-four injuries occurred during the Serie A matches, while six, two and one injuries occurred national, European and international cup competitions, respectively. Injuries occurred in four goalkeepers, 45 defenders, 27 midfielders and 27 forwards. There were 61 (60%) hamstring, 17 (16%) calf, 16 (15%) adductor and 9 (9%) quadriceps severe muscle injuries. The lay-off times for all injuries was 42.6±20.1 days (hamstring, 39.8±20.6; calf, 39.7±3.9; adductor, 54.2±23.8 and quadriceps, 46.4±24.8 days). There were 59 (57%) injuries to the right and 44 (43%) injuries to the left leg, with 65 (63%) injuries to the dominant kicking leg and 38 (37%) to the non-kicking leg. The injury limb dominance varied across muscle group (hamstring, 57%; calf, 64%; adductors, 69%; quadriceps, 89%). A detailed study flow chart is shown in figure 1.

**Injury mechanism analysis**

More injuries occurred in offensive (n=61, 59%) than defensive (n=42, 41%) situations. Offensive injuries were particularly common for quadriceps injuries (89%). There were 85 (83%) non-contact and 18 (17%) indirect contact injuries. The non-contact prevalence varied across muscle group (hamstring, 87%; calf, 88%; adductor, 63%; quadriceps, 78%). Injuries appeared to be largely horizontal propulsion/movement-based injuries, with 76 (74%) occurring at high or moderate horizontal movement speeds and only four (4%) involving moderate or high vertical speeds. The same number of cases involved loading the injured (n=41, 40%) and uninjured (n=41, 40%) limbs and in closed

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**Figure 1** Detailed study flow. Add, adductors; Ham, hamstring; Quad, quadriceps.
kinetic chain (n=41, 40%) and open kinetic chain (n=43, 42%), while 19 cases were unsure in both instances. All calf injuries were closed kinetic chain, while there was a mix of both for other muscle groups. See table 1 for additional details.

### Situational patterns

Four main situational patterns accounted for 88% of injuries. Running/acceleration injuries was most common (n=35, 34%), representing the typical pattern for posterior kinetic chain injuries (hamstring, calf). These injuries occurred during high-speed running (n=25), affecting predominately the hamstrings (n=24, 39% of all hamstring injuries) or during acceleration from low velocities/standstill (n=10), all affecting the calf muscle (59% of all calf injuries) (figure 2). Overstretching type injuries collectively accounted for two fifths of injuries (39%). These were similarly split across closed kinetic chain (n=21, 20%) and open kinetic chain (n=19, 18%) situations. Closed kinetic chain injuries were apparent for hamstring (n=12, 19%) (figure 3), calf (n=7, 41%) (figure 3) and quadriceps (n=2, 22%) muscles. Open kinetic chain stretching injuries affected hamstring (n=15, 26%) (figure 4) and adductors (n=4, 25%). Kicking injuries accounted for one in six injuries (n=16, 16%), affecting the quadriceps (n=5, 56%), adductors (n=5, 31%) and hamstrings (n=6, 9%). The other 12 cases did not fall into one of the categories. Of note five of these other injuries (all adductor muscle injuries) involved reaching, two jumping, two heel kicking, one twisting, one during a Rabona and one while kicking without the ball. Additional details are reported in table 2.

### Seasonal, match and field distribution

The seasonal distribution (n=103) showed a trimodal distribution with a first injuries’ peak at the beginning of the season (September–October), the highest peak in the middle of the season (December–January) and a last peak later in the season (March–April) (figure 5). The timing of injuries during the match was on average at 36.3±23.4 min (hamstring, 34.8±23.4; calf, 29.8±12.6; adductor, 43.9±27.4; quadriceps, 45.4±23.4 min). More injuries occurred during the first (n=73, 71%), than the second (n=30, 29%) half (p<0.01), with differences in first to second half percentage between muscle groups (1st half %, hamstring=69%, calf=94%, adductor=63% quadriceps=56%) (figure 6A). More than half (n=53), and three-quarters of injuries occurred in the first 30 and 45 min of effective match-time, respectively (figure 6B). Injuries according to pitch location (n=103) are detailed in online supplemental material.

### DISCUSSION

More than four in five severe lower limb muscle injuries in professional male football matches occur through a non-contact mechanism, with the remainder being indirect contact. Each muscle group showed distinctive injury mechanisms and situational patterns, but 88% of severe muscle injuries occurred during running/accelerating, open and closed kinetic chain stretching and kicking. Injuries were common in the first half of match play and peaked early in-season or over the December–January period.

### Injury mechanisms

This is the first study to systematically assess severe (>28 days) muscle injuries of the lower limb of football players using video analysis. Our work suggests the dominant leg is susceptible to high grade muscle injuries (63%), particularly the quadriceps (89%). Ekstrand et al. on a cohort of ~3000 football muscle injuries, reported limb dominance for quadriceps muscle injuries

### Table 1

<table>
<thead>
<tr>
<th>Variables</th>
<th>All</th>
<th>Hamstring (n=61)</th>
<th>Calf (n=17)</th>
<th>Adductor (n=16)</th>
<th>Quads (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Playing phase before injury</td>
<td>Offensive (61); defensive (42)</td>
<td>Offensive (34); defensive (27)</td>
<td>Offensive (10); defensive (7)</td>
<td>Offensive (9); defensive (7)</td>
<td>Offensive (8); defensive (1)</td>
</tr>
<tr>
<td>Injury side</td>
<td>Right (59); left (44)</td>
<td>Right (38); left (23)</td>
<td>Right (9); left (8)</td>
<td>Right (9); left (7)</td>
<td>Right (3); left (6)</td>
</tr>
<tr>
<td>Dominant (kicking) leg injured</td>
<td>Yes (65); no (38)</td>
<td>Yes (25); no (26)</td>
<td>Yes (11); no (6)</td>
<td>Yes (11); no (5)</td>
<td>Yes (8); no (1)</td>
</tr>
<tr>
<td>Field location at injury</td>
<td>Long axis of the field (zone)</td>
<td>Def third (43); middle third (27); off third (23)</td>
<td>Def third (24); middle third (5); off third (20)</td>
<td>Def third (10); middle third (6); off third (3)</td>
<td>Def third (6); middle third (4); off third (6)</td>
</tr>
<tr>
<td></td>
<td>Short axis of the field (corridor)</td>
<td>Left (23); middle (62); right (18)</td>
<td>Left (12); middle (35); right (14)</td>
<td>Left (2); middle (12); right (3)</td>
<td>Left (2); middle (11); right (3)</td>
</tr>
<tr>
<td></td>
<td>Player contact preceding injury</td>
<td>Yes (18); no (85)</td>
<td>Yes (8); no (53)</td>
<td>Yes (2); no (15)</td>
<td>Yes (6); no (10)</td>
</tr>
<tr>
<td></td>
<td>If contact, where?</td>
<td>Upper body (10); pelvis (3); injured leg (4); un-injured leg (1)</td>
<td>Upper body (4); pelvis (1); injured leg (3)</td>
<td>Upper body (2)</td>
<td>Upper body (3); pelvis (1); injured leg (1); un-injured leg (1)</td>
</tr>
<tr>
<td></td>
<td>Injury classification</td>
<td>Indirect contact (18); non-contact (85)</td>
<td>Indirect contact (8); non-contact (53)</td>
<td>Indirect contact (2); non-contact (15)</td>
<td>Indirect contact (6); non-contact (10)</td>
</tr>
<tr>
<td></td>
<td>Leg loading at IF</td>
<td>Injured leg (41); un-injured leg (41); none (2); unsure (19)</td>
<td>Injured leg (16); un-injured leg (25); none (1); unsure (19)</td>
<td>Injured leg (17)</td>
<td>Injured leg (5); un-injured leg (9); none (1)</td>
</tr>
<tr>
<td></td>
<td>Kinetic chain</td>
<td>Open (43); closed (41); unsure (19)</td>
<td>Open (26); closed (16); unsure (19)</td>
<td>Closed (17)</td>
<td>Open (10); closed (6)</td>
</tr>
<tr>
<td></td>
<td>Horizontal speed</td>
<td>Zero (4), low (23), Moderate (50) high (26)</td>
<td>Zero (2), Low (11), Moderate (30) High (18)</td>
<td>Low (7), Moderate (9) High (1)</td>
<td>Zero (1) Low (4), Moderate (6), High (5)</td>
</tr>
<tr>
<td></td>
<td>Vertical speed</td>
<td>Zero (97), low (2), moderate (3) high (1)</td>
<td>Zero (57), low (1), moderate (2), high (1)</td>
<td>Zero (16), low (1)</td>
<td>Zero (15), moderate (1)</td>
</tr>
</tbody>
</table>
but not for hamstring (50%), calf (51%) or adductors (54%). Our higher ratios of dominant leg injuries for all pathologies (hamstring, 57%; calf, 64%; adductors, 69%; quadriceps, 89%) may relate to inclusion of severe injuries.

Injuries were more common in offensive situations, particularly for the quadriceps, likely due to high dominance of kicking injuries for this muscle group. The fact most injuries involved moderate/high horizontal speeds, and minimal vertical speeds, has implications for designing injury risk reduction programmes.

All injuries were either non-contact or indirect contact, supporting previous research, thus, highlighting the potential for injury risk mitigation strategies. Slight differences existed between muscle groups in non-contact incidence. The proportion of indirect contact adductor muscle injuries is higher than previous research (37% vs 17%). Virtually all indirect contact injuries were associated with contact to the upper body leading to stretching or reaching type injuries. Upper body perturbation has been associated with anterior cruciate ligament (ACL), medial collateral ligament (MCL) and Achilles tendon rupture (ATR) injuries and likely results in loss of neuromuscular control, leading to altered kinematics, and more extreme joint position, leading to overstretching of the muscle group. Maintaining neuromuscular control in response to upper body mechanical perturbation appears to be an important factor in preventing numerous lower limb injuries. Given most injuries occur at moderate and high horizontal and low vertical velocities, perturbation training during horizontal accelerations, running and decelerations appears more important, as opposed to typical stationary or vertical (e.g., landing) perturbation training.

Situational patterns

Eighty-eight per cent of severe muscle injuries occurred during four main situations: (1) running/acceleration; (2) closed kinetic chain stretching; (3) open kinetic chain stretching and (4) kicking. There are inconsistencies in the literature in the methods of reporting situational patterns and often it is difficult to place an injury within a specific situational pattern.

Running/acceleration injuries were common, with high-speed running being associated with two in five hamstring strain injuries, like previous research. High-speed running is associated with large forces, negative muscle work and high activation of the hamstring muscles (specifically the biceps femoris during late-swing phase), explaining why it is a high-risk inciting event. Calf injuries were common while accelerating from stand-still or low velocities. This situational pattern is similar to the reported pattern we detailed for Achilles tendon rupture and likely involves high forces through the triceps surae at long muscle lengths/end joint range during the transition from eccentric to concentric actions of the stretch-shortening cycle (SSC), indicative of muscle injury causation.

We found few running based adductor injuries in contrast to previous research that reported it to be the dominant injury mechanism for adductor longus strains. Again, our inclusion of severe injuries may explain these discrepancies. Future research on adductor strain mechanism should look to delineate potentially differences in mechanisms and situational patterns between grades.

Stretching injuries collectively explained a large proportion of injuries, especially for hamstring and calf muscles. We reported
closed kinetic chain and open kinetic chain mechanism as separate situational patterns. Although they have similarities, in our opinion, they are distinct categories. Open kinetic chain stretch-type injuries affected the adductors and hamstrings and appear to occur purely due to overstretch, in which the muscle in the open kinetic chain is placed at a long length, likely in excess of its active joint range of motion (ROM)/muscle length. On the contrary, closed kinetic chain injuries involve intense deceleration actions which likely involve high eccentric forces, at long muscle lengths. Each pattern likely has differing requirements for prevention, in which for open kinetic chain injuries, muscle length/ROM is likely a predominant factor, while eccentric force capabilities at long muscle length in conjunction with muscle length/ROM appear important for closed kinetic chain injuries. Our results support previous research on moderate and severe injuries, that overstretching is the most dominant causal pathway for hamstring injuries. It further highlights the need for more holistic injury risk mitigation programmes. Including more closed kinetic chain-based strengthening (eg, hip extensions, good mornings, stiff leg deadlifts, calf raises) at longer muscle lengths appears relevant. Further consideration of deceleration training as opposed to just acceleration and

**Figure 3** Closed kinetic chain stretching severe muscle injuries. (A–C) Right hamstring muscle injury during closed kinetic chain movement (deceleration). (D–F) Right calf muscle injury during a closed kinetic chain movement (contralateral kicking support). Arrows indicate the injured muscle group.

**Figure 4** Open kinetic chain stretching severe muscle injury. (A–C) Right hamstring muscle injury in the attempt to touch the ball with open kinetic chain stretching. Please note the combination hip flexion and knee extension. The arrow indicates the injured muscle group.
**Table 2** A breakdown of situational pattern and contact mechanism for each muscle group (n=103)

<table>
<thead>
<tr>
<th>Muscle group</th>
<th>Pattern</th>
<th>Contact mechanism</th>
<th>Non-contact</th>
<th>Indirect contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>All injuries</td>
<td>Total injuries (n=103)</td>
<td>85 (83%)</td>
<td>18 (17%)</td>
<td></td>
</tr>
<tr>
<td>Running/acceleration (n=35, 34%)</td>
<td>35 (100%)</td>
<td>0 (0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open kinetic chain stretching (n=19, 18%)</td>
<td>16 (84%)</td>
<td>3 (16%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed kinetic chain stretching (n=21, 20%)</td>
<td>11 (52%)</td>
<td>10 (48%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kicking (n=16, 16%)</td>
<td>15 (94%)</td>
<td>1 (6%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others (n=12, 12%)</td>
<td>8 (67%)</td>
<td>4 (33%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamstring</td>
<td>Total hamstring (n=61)</td>
<td>53 (87%)</td>
<td>8 (13%)</td>
<td></td>
</tr>
<tr>
<td>Running (n=24, 39%)</td>
<td>24 (100%)</td>
<td>0 (0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open kinetic chain stretching (n=15, 26%)</td>
<td>13 (87%)</td>
<td>2 (13%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed kinetic chain stretching (n=12, 19%)</td>
<td>6 (50%)</td>
<td>6 (50%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kicking (n=6, 9%)</td>
<td>6 (100%)</td>
<td>0 (0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others (n=4, 7%)</td>
<td>4 (100%)</td>
<td>0 (0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calf</td>
<td>Total calf (n=17)</td>
<td>15 (88%)</td>
<td>2 (12%)</td>
<td></td>
</tr>
<tr>
<td>Acceleration (n=10, 59%)</td>
<td>10 (100%)</td>
<td>0 (0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed kinetic chain stretching (n=7, 41%)</td>
<td>5 (71%)</td>
<td>2 (29%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adductors</td>
<td>Total adductors (n=16)</td>
<td>10 (63%)</td>
<td>6 (37%)</td>
<td></td>
</tr>
<tr>
<td>Kicking (n=5, 31%)</td>
<td>4 (80%)</td>
<td>1 (20%)</td>
<td></td>
<td></td>
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<tr>
<td>Open kinetic chain stretching (n=4, 25%)</td>
<td>3 (75%)</td>
<td>1 (25%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other—reaching (n=4, 25%)</td>
<td>1 (25%)</td>
<td>3 (75%)</td>
<td></td>
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</tr>
<tr>
<td>Other—jumping (n=2, 13%)</td>
<td>1 (50%)</td>
<td>1 (50%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (n=1, 6%)</td>
<td>1 (100%)</td>
<td>0 (0%)</td>
<td></td>
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<tr>
<td>Quadriceps</td>
<td>Total quadriceps (n=9)</td>
<td>7 (78%)</td>
<td>2 (22%)</td>
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</tr>
<tr>
<td>Kicking (n=5, 56%)</td>
<td>5 (100%)</td>
<td>0 (0%)</td>
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</tr>
<tr>
<td>Closed kinetic chain stretching (n=2, 22%)</td>
<td>0 (0%)</td>
<td>2 (100%)</td>
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<td></td>
</tr>
<tr>
<td>Running (n=1, 11%)</td>
<td>1 (100%)</td>
<td>0 (0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (n=1, 11%)</td>
<td>1 (100%)</td>
<td>0 (0%)</td>
<td></td>
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</tr>
</tbody>
</table>

High-speed running appears warranted, especially for hamstring muscle injury risk mitigation.

Kicking injuries were the dominant pattern for quadriceps injuries, like previous research using recall techniques (59% vs 54%). Kicking was also a common pattern for adductor injuries in our cohort, with near identical proportion to the work of Serner et al on football adductor longus injuries (31% vs 29%). Kicking actions are associated with high activation, rate of stretch and long muscle lengths during the backswing phase of kicking actions, with rapid movements (<200 ms) involving transition from eccentric to concentric actions. We also found kicking injuries to result in hamstring muscle injuries, although the strain pattern likely differ versus adductor and anterior thigh injuries, and may be more associated with either overstretch, or rapid eccentric actions to decelerate the thigh and shank (thus, eccentric muscle contractions for limb deceleration, as opposed to SSC actions), likely during the follow through phase of kicking when the muscle is more active. Hamstring activation is low (20%–30% max voluntary contraction, activity) during the leg cocking and acceleration phases of ball kicking, when the hip flexors and adductors are highest. We grouped hamstring-based kicking injuries, as kicking injuries and not stretching injuries, like previous research, as it is not possible to determine the specific injury situation (eg, if due to high activation at long muscle lengths or due to overstretch) or time point in which they occur, using video analysis.

**Seasonal, position, match and field distributions of severe muscle injuries**

The higher prevalence of severe lower limb muscle injuries in the first half of match play contrasts with some previous research, which found more injuries in the second half, but aligns to the work of Serner et al who reported an identical proportion of first half adductor longus injuries to our severe adductor injuries. Ekstrand et al on a large cohort of muscle injuries (~3000) also showed a gradual increase in muscle injuries during the first half, like we found. However, the authors reported a similar/slightly higher number of injuries in the second than first half, in contrast to our findings. Unlike previous research, we corrected for substitution and reported effective match minutes. It is possible that higher grade muscle injuries occur earlier in the match due to higher intensities and engagements of match play, and thus higher internal forces of the lower limb muscles. Alternatively, cumulative fatigue between matches and a lack of preparation (eg, warm up routine) for in-match actions (eg, peak speeds, end-range actions in open kinetic chain and close kinetic chain) could contribute. Although, we found a gradual increase in injuries over the course of the first half, as there was a much lower number of injuries in the second half of the match, our work suggests that cumulative fatigue over the course of match play is not a major risk factor for severe muscle injuries.

The higher number of injuries in-season was likely due to increased match exposure, as match play carries a substantially higher risk of injury for muscle injuries versus training. We found the highest proportion of severe lower limb muscle injuries during the middle of the season (December–January), which could be either due to congested match play during this period and/or chronic fatigue. A limitation of this work is the relatively small number of injuries for this type of research and the lack of detailed and match exposure data. Importantly, we do not suggest based on our data that these months (December–February) carry a higher risk of injury per se, but that in our sample of more than 100 severe muscles these were the months in which they typically occurred. Further research should look to examine if there is a relatively higher risk of severe muscle injuries during the middle of the season when controlling for exposure.

**Strengths and limitations**

The strengths of our study are (1) its sample size, which is the largest to date in a systematic video analysis study of severe lower limb muscle injuries; (2) the consecutive nature of the 103 injuries analysed and (3) the presentation of field, match and seasonal distribution data. Furthermore, this is the first study to detail using video analysis the injury mechanisms and situational patterns of calf and quadriceps muscle injuries in football. The weaknesses of
the study are (1) the methodology used to identify muscle injuries, which was different from the gold standard (ie, prospective study with frequent contact with the teams and single footballers);45 46 (2) the lack of information on muscle injury diagnosis, meaning we could not distinguish between muscles of the constituent group; (3) the exclusion of training injuries, which could potentially interfere with the overall presentation of severe-only lower limb muscle injuries in professional football4 5 and (4) the lack of training and match exposure data. In addition, it is important to note that while we adopted a predefined evaluation workflow, modified from our previous research on other pathologies in football (eg, ACL, MCL, Achilles tendon rupture),18–20 this slightly differs from evaluation flows of other groups,25–27 particularly previous research on muscle injuries.25 This does make comparisons to other research on muscle injuries in football more challenging. The field needs to move towards establishing consensus on approaches to video analysis and use of evaluation flows, terms and definitions, and is moving in this direction. Finally, our work includes elite male level football players in a singular high-income country (Italian Serie A), which make impact generalisability across sex, cultures, levels of play and nations of different wealth status. Further work to fill these gaps is warranted.

**CONCLUSION**

Most severe football muscle injuries occur with a non-contact mechanism during four main situational patterns, including acceleration/running, both open and closed kinetic chain stretching and kicking. A specific muscle group distribution was noted, especially for situational patterns. Injuries were more common in the first half. A detailed comprehension of the injury mechanism, situational pattern and

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**Figure 5** Distribution of severe muscle injuries (n=103) throughout the football season according to month of the year. The trend line displays the two month rolling average.

**Figure 6** Distribution of severe muscle injuries (n=103) throughout the match according to match minute and specific time period (A) and minutes of effective playing time (B). Dotted lines represent the linear trend line.
epidemiology is supportive in designing injury and return to play programmes.

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Contributors FDV and MB were responsible for the conception and design of the study, and MB supported the collection of videos, injury data and video editing. FDV, GN and MB analysed and rated the video footage regarding injury mechanism and situational patterns. MB analysed and interpreted the results. All authors provided intellectual contribution to the writing and drafting of the manuscript. FDV and MB were responsible for the overall content as guarantors.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient and public involvement Where available through personal networks, we liaised with the injured football players and team physicians, to support our description of the injury. The results of the study will be shared with publicly available resources (e.g., newspaper articles, television interviews, podcasts, blogs) to inform the audience regarding how severe lower limb muscle injuries occur and the implications for treatment.

Patient consent for publication Not applicable.

Ethics approval All the videos we accessed are publicly available and no personal player information was accessed. Therefore, ethical permission was not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All the important data are presented in the paper or in the supplementary material.

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Original research


