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SYSTEMATIC REVIEW

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Inciting Events of Lower-Limb Muscle Injury: A Systematic Review and Meta-analysis of Video-Based Studies

Aaron Miralles-Iborra[1], Heidy Rondón-Espinosa[1], Francisco J. Vera-Garcia[1,2], Javier Courel-Ibáñez[3*], Manuel Manchón-Davó[1], Juan Del Coso[4,5] and Víctor Moreno-Pérez[1,6]

Abstract

Background Understanding the situational contexts of lower-limb muscle injuries in football is critical for informing the design of effective prevention strategies. While their frequency and burden are well documented, the frequently observed inciting events and situational patterns underlying these injuries remain insufficiently synthesised.

Objective To systematically review and meta-analyse video-based analysis studies examining the inciting events, timing, field location, and situational patterns associated with lower-limb muscle injuries in professional football players.

Methods A PRISMA-guided systematic review was conducted across five databases (PubMed, Web of Science, Embase, Scopus, SPORTDiscus) from inception to October 1, 2025. Eligible studies used video analysis to examine inciting events (type, kinetic chain, vertical and horizontal velocities), timing (match half, minute), field location (short and long axis), and situational/tactical patterns (specific action, defensive/offensive context, ball possession status) of lower-limb muscle injuries in professional football. Dichotomous outcomes were pooled using random-effects odds ratios (OR), and multi-category outcomes were synthesised via a Bayesian hierarchical multinomial-logit model with study-level pooled random-effects marginal proportions (RE) and 95% credible intervals (CrI). Risk of bias and methodological quality of included studies were appraised using the AXIS, QA-SIVAS and STROBE-SIIS tools.

Results Twelve studies (513 players [434 male and 79 female]; 538 injuries [452 in males, 86 in females]) were included. Hamstring injuries predominated (74.7%), followed by adductor (14.3%), quadriceps (7.1%), and calf (3.9%) injuries. Sufficient data for meta-analysis were available only for male players. Non-contact injuries ($n=322$) were significantly more frequent than indirect contact ($n=108$) injuries ($OR=8.01$, *95% CI* 3.85–16.64; $p<0.001$). These injuries occurred predominantly during moderate-to-high horizontal velocity actions, compared with zero-to-low velocity actions ($OR=19.56$, *95% CI* 2.55–150.12; $p=0.004$). Pooled proportions were highest during running (RE = 0.29, 95% CrI: 0.17–0.44), stretching/reaching (RE = 0.24, 95% CrI: 0.12–0.40), or kicking actions (RE = 0.22, 95% CrI: 0.09–0.38), although no credible differences were observed between categories. No consistent effects were found for the kinetic chain, match time, field location, or tactical phase.

Conclusions In professional football, lower-limb muscle injuries were predominantly observed during non-contact inciting events occurring at moderate-to-high horizontal speed, frequently involving the hamstrings during running,

*Correspondence:
Javier Courel-Ibáñez
courel@ugr.es
Full list of author information is available at the end of the article

stretching/reaching, or kicking actions. No consistent effects were found for match time, field location, or tactical phase. Methodological heterogeneity and the absence of exposure-adjusted data limit the certainty of these findings.

Trial Registration: The protocol for this systematic review was registered a priori in the INPLASY database (registration number INPLASY2024100091).

Key Points

- In the included video-based analysis studies, lower-limb muscle injuries in football (soccer) were most frequently reported in the hamstrings (75%), followed by the adductors (14%), quadriceps (7%) and calf muscles (4%).
- Lower-limb muscle injuries were frequently observed during non-contact events at moderate-to-high horizontal speed.
- Running (29%), followed by stretching/reaching (24%), and kicking (22%) were frequently observed inciting actions. These patterns should be interpreted as descriptive rather than evidence of a clear hierarchy of actions.
- Standardised reporting practices across video-based studies are essential to facilitate reliable data synthesis and to enhance the precision of future meta-analyses on muscle injuries in football.

Keywords Soccer, Muscle strain, Video analysis, Injury mechanism, Team sport, Risk factor, Professional athletes

Introduction

Muscle injuries are among the most prevalent in professional football (soccer), accounting for approximately 20–37% of all injuries, with an incidence of 3.16 injuries per 1000 h of exposure in males [1] and 6.7 injuries per 1000 h in females [2]. They represent a considerable injury burden, with mean time-loss estimates ranging from 8.3 to 34.7 days per 1000 h of football exposure in both sexes [1, 2]. This burden is further compounded by high reinjury rates, which can significantly affect player availability and, consequently, team performance [3]. Although muscle injuries are not always the most severe type of injury in professional football in terms of time lost per case, their high frequency and recurrence make this type of injury the leading contributor to the overall injury burden in professional football [4].

Muscle injury incidence in professional football is rising (~ 2.3% annually) due to increased demands [5] and congestion [6]. These conditions, alongside exposure to greater-than-habitual high-intensity running, elevate injury risk [7, 8], underscoring the need to understand lower-limb muscle injury inciting events. Still, elucidating the frequently observed inciting events and injury patterns of lower-limb muscle injuries remains a major challenge in professional football. Previous studies have not identified a single causative factor, as lower-limb muscle injuries arise from a complex interplay of elements, including high-speed running, sudden accelerations and decelerations, changes of direction, overstretching actions, accumulated fatigue, and contextual factors such as congested match schedules and inadequate recovery [9]. Although most football-related muscle injuries occur through non-contact mechanisms, contact-related events, particularly indirect contact situations, may also contribute to their occurrence [10]. The complexity of the inciting events leading to lower-limb muscle injuries may explain why, despite decades of injury surveillance and prevention efforts, the escalating physical demands of the game, congested match schedules, and heightened competitiveness continue to drive a high burden of soft-tissue injuries in professional football. Furthermore, most available studies have included relatively small and homogenous samples, which limits the generalisability of their findings. Therefore, cumulative and systematic analyses of existing evidence represent the best approach to clarify the predominant inciting events and patterns of these injuries.

Traditionally, attempts to identify muscle injury mechanisms have relied on subjective methods (i.e. player recall, written incident reports, or cadaveric simulations), which often lack ecological validity and yield inconsistent conclusions [11]. Video analysis has become an increasingly valuable tool in football medicine, offering objective, frame-by-frame assessment of injury events under real match conditions and offering insights that traditional methods often miss. Video-based analysis studies have been proven to be reliable and valid for capturing the complexity of real-world injury mechanisms (conceptualised as the inciting event or observable situational sequence immediately preceding injury onset, rather than underlying tissue loading, muscle–tendon behaviour, or biomechanical failure) in football [12] and have already been successfully applied across several high-risk sports to better understand how injuries occur during dynamic, game-specific actions [13–15]. For lower-limb muscle injuries in football, video-based analysis offers unique value by enabling clinicians to describe observable inciting situations that may help clinicians contextualise prevention and rehabilitation planning. Several recent investigations have employed video analysis to examine the mechanisms and biomechanical patterns underlying lower-limb muscle injuries in professional football [16, 17]. These studies have provided valuable insights into the situational context of injuries by capturing real-time match scenarios, such as the proportion of contact, non-contact, and indirect contact involvement, movement type, velocity, contextual factors and tactical situations [10, 18–20]. However, despite the growing number of video-based studies, their findings remain fragmented.

Previous reviews have substantially advanced the understanding of video-based injury patterns in sport [21, 22]. Xiao et al. [21] provided a valuable synthesis of video-based evidence on lower-limb injuries in football, highlighting the utility of match footage for characterising injury situations. In that review, however, muscle injuries were analysed together with ligamentous and tendon injuries, meaning that muscle-specific inciting events and situational patterns were not the primary focus. More recently, Finnern et al. [22] conducted a comprehensive systematic review and meta-analysis of indirect and non-contact muscle injuries, offering important insights into recurrent situational and kinematic patterns across muscle groups. Notably, this review adopted a sport-wide perspective, integrating evidence from football and other sporting contexts. While this broader approach provides a valuable overview of muscle strain patterns across sports, a football-specific synthesis may offer additional insight into the distinct physical, technical, tactical and contextual demands of professional football. Therefore, although these reviews represent valuable contributions, neither was specifically designed to provide a football-specific quantitative synthesis integrating lower-limb muscle injury events with technical, tactical and contextual match variables across football cohorts. Consequently, a muscle-specific quantitative synthesis remains warranted to better characterise the football-specific inciting events and situational patterns of muscle injuries. Addressing this gap, the present study aimed to systematically review and meta-analyse video-based studies examining the frequently observed inciting event and situational patterns associated with lower-limb muscle injuries in professional football players.

Methods

This systematic review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [23]. This study was prospectively registered in the INPLASY database (registration number INPLASY2024100091).

Search Strategy

A comprehensive electronic search was conducted in five online databases (Embase, PubMed, Scopus, SPORTDiscus, and Web of Science) from their inception to October 1, 2025 without applying any filters. The search strategy utilised free-text terms combined with Boolean operators ('AND' and 'OR') across four principal categories: (1) lower-limb muscle injuries, (2) video analysis, (3) professional football, and (4) injury mechanisms (Appendix A). In addition to the electronic search, a backward snowballing approach was applied by manually screening the reference lists of relevant studies to identify any additional eligible articles. All retrieved records were imported into Mendeley citation manager (Elsevier, Amsterdam, Netherlands), where duplicates were identified and removed. Titles and abstracts were then screened for relevance, followed by full-text assessment of potentially eligible studies. The searches and study screening processes were conducted independently by two reviewers (M.M-D. and H.R-E.). Disagreements were resolved through discussion, and when necessary, by consultation with a third reviewer (A.M-I.).

Study Selection and Eligibility Criteria

Studies were selected based on the Population, Exposure, and Outcome (PEO) framework [24]: *Population*: professional football players; *Exposure:* lower-limb muscle injuries sustained during football practice captured on video and analysed using video-analysis techniques; *Outcome:* mechanisms (i.e. inciting events), timing, field location, and situational or tactical patterns associated with lower-limb muscle injuries. Original, full-text research articles published in peer-reviewed scientific journals written in English or Spanish (reflecting the language proficiency of the review team) were included. Conference abstracts, editorials, commentaries, dissertations, and other grey literature were excluded. Eligible studies had to meet the following criteria: (1) involved male or female professional football players; (2) employed an observational study design; (3) reported outcomes related to the video-based analysis of lower-limb muscle injuries; (4) were original full-text research articles published in peer-reviewed scientific journals; and (5) were written in English or Spanish. The exclusion criteria were (1) conference abstracts, reviews, and grey literature; and (2) studies that included a sport other than 11-a-side football. When eligibility could not be determined from the information provided in the published study, the corresponding author(s) was(were) contacted via email to request clarification or additional information necessary for inclusion assessment. The inter-reviewer agreement during the study selection phase was calculated as percentage agreement, yielding a value exceeding 90%.

Data Extraction and Synthesis

The following data were extracted from each study: (1) study descriptors: authors, year of publication, and duration of follow-up; (2) participants' characteristics: sample size, main descriptors (i.e. sex, league of competition) and number of players per field position (i.e. forward, midfielder, defender, goalkeeper); (3) details of the video-analysis technique employed: number of videos analysed, number of raters, video sources; (4) injury characteristics: lower-limb muscle groups involved (i.e. hamstring muscles, adductor muscles, quadriceps muscles, calf muscles), type of mechanism (i.e. direct contact, indirect contact, or non-contact), location of contact only for contact injuries (i.e. upper body, pelvis, uninjured leg, injured leg), kinetic chain (i.e. open, closed, unsure), horizontal velocity (i.e. zero–low, moderate–high), and vertical velocity (i.e. zero–low, moderate–high) at injury time. Velocity variables were reported according to the categories defined in the included studies: zero–low (i.e. standing, walking, jogging) and moderate–high (i.e. moderate-intensity running, high-intensity running, sprinting); (5) type of action at the time of injury (i.e. running/sprinting, stretching/reaching, kicking, jumping, change of direction [COD] or other), (6) minutes played at the time of injury (i.e. 0–14, 15–29, 30–45, 46–59, 60–75, 76–90); (7) field location at the injury moment: long axis (i.e. defensive half, mid half and offensive half) and short axis (i.e. corridor, middle); (8) tactical phase (i.e. attacking or defending), and (9) ball possession status of the injured player (i.e. with or without the ball). All variables extracted from video-based observational analyses reflect externally observable events rather than underlying biomechanical or tissue-level processes. Two reviewers (M.M. and H.R-E.) independently screened the included articles and performed data extraction using a standardised Microsoft Excel template. Inter-rater reliability was calculated for both quantitative and qualitative variables on the data extraction using the Cohen's kappa coefficient (k), interpreted as slight (≤ 0.20), fair (0.20), moderate (0.40), substantial (0.60), and almost perfect agreement (0.80) [25]. Inter-rater reliability ranged from substantial to almost perfect (Cohen's $\kappa = 0.61–1.00$). In cases of disagreement, data were reviewed and double-checked by a third reviewer (A.M-I.) to resolve discrepancies and reach consensus. Given the variability in how situational action categories were reported across studies, some categories were not uniformly available in all datasets, which required harmonisation decisions during quantitative synthesis.

Risk of Bias and Methodological Quality Assessment

The risk of bias for the included studies was assessed using the Appraisal tool for Cross-Sectional Studies (AXIS tool) scale [26]. A positive response was interpreted as indicating high quality and low risk of bias, and item-level quality was categorised as low (< 60%), moderate (60–70%), good (70–80%), or excellent (≥ 80%) based on the proportion of studies fulfilling each item. Overall study quality was considered high (low risk of bias) for total scores between 15 and 20, and low (high risk of bias) for scores below 15. The quality of the video analysis for the included studies was assessed with the Quality Appraisal for Sports Injury Video-Analysis Studies (QA-SIVAS) scale [12] alongside the STROBE Sports Injury and Illness Surveillance (STROBE-SIIS) checklist [27], with scores closer to the maximum indicating a higher adherence to reporting standards and better methodological quality. QA-SIVAS scores were interpreted as low quality (< 60%), moderate quality (60–70%), good quality (71–80%) and high quality (81–100%). STROBE-SIIS scores were interpreted as excellent (≥ 85%), good (70–84%), fair (50–69%), and poor (< 50%). Two reviewers (M.M. and H.R-E.) independently performed the risk of bias and methodological quality assessments for the studies included in the systematic review. The F1-score was computed to assess precision and recall, interpreted as poor (≤ 0.70), fair (0.70), good (0.80) or excellent (0.90) [28]. Inter-rater agreement ranged from 80 to 100% and F1-scores between 0.78 and 0.89. A third reviewer (A.M-I.) was consulted when necessary to reach a consensus.

Statistical Analysis

Categorical variables are presented as counts (n). Continuous variables are reported as mean ± standard deviation (SD) or median with interquartile range (IQR), as appropriate.

For dichotomous variables (i.e. injury mechanisms, match halves at the moment of injury, and tactical situations), pooled odds ratios (ORs) with 95% confidence intervals (CI) were calculated using a random-effects meta-analysis model [29]. Analyses were conducted when ≥ 3 studies were available for a given outcome. Between-study heterogeneity was assessed with I^2, with values > 75% considered substantial. For multi-category variables (i.e. type of action, contact location, 15-min match intervals), a per-study count vector was constructed [30]. For the type of action at the time of injury, when a study reported counts for at least one category within the analysis but omitted others, the unreported categories were assigned a value of zero. This decision was based on the variability in reporting these actions across studies, the presence of fully specified categories, and the fact that the categories were mutually exclusive [29]. However, this assumption was made for harmonisation purposes only and does not imply that the event was truly absent. Because some studies may have incompletely reported action categories, assigning zero to unreported categories may have introduced misclassification bias and influenced the estimated distribution of actions. Accordingly, findings derived from these category distributions should be interpreted cautiously, particularly in analyses based on a small number of studies**.** To synthesise category proportions while accounting for between-study variability, we fitted a Bayesian hierarchical multinomial-logit model with study-level random effects. We used Lewandowski–Kurowicka–Joe (LKJ) distribution [31] for the correlation structure among random effects and half-normal priors for the random-effects standard deviations. This allowed the estimated proportions to vary across studies while avoiding restrictive assumptions about how these study-specific differences were related. In practical terms, this approach provides pooled estimates while acknowledging that the included studies may differ in their populations, definitions, and video-analysis methods. Convergence was assessed using trace plots, effective sample sizes, and the potential scale reduction factor, with values close to 1 indicating satisfactory convergence. Results are reported as pooled random-effects marginal proportions (RE) with 95% credible intervals (CrI). Forest plots show study-level posterior medians with 95% CrI and a pooled diamond representing the marginal proportion. Values are on a 0–1 scale and, within each domain, proportions sum to ≈1. We also summarise between-study heterogeneity on the logit scale (random-effects SDs and correlations across categories). To address specific injury profiles, subgroup analyses were planned for distinct muscle groups (i.e. hamstring, adductor) provided sufficient data (≥ 3 studies) were available for pooling. Analyses were also planned to be stratified by sex (male/female), but this was contingent on sufficient studies ($k \geq 3$) for each sex to permit a meta-analysis; otherwise, data would be synthesised descriptively. Analyses were conducted using Review Manager (version 5.0; Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2008) and custom Python 3.7 scripts incorporating the statsmodels library (version 0.15.0).

Results

Search Results and Study Characteristics

A flow diagram of the searching process and study selection is presented in Fig. 1. A full list of excluded studies with reasons is available in Supplementary file 1. The database search initially identified 650 records. After removing duplicates, 404 records remained and were screened by title and abstract. Of these, 53 studies were retained for full-text screening, resulting in 28 studies being assessed for eligibility. Of these, 13 were excluded during the initial full-text screening, and a further 6 were excluded after applying the second eligibility filter. Consequently, nine studies met all inclusion criteria and were initially included in the systematic review. An additional three studies were identified and added during subsequent search updates, resulting in a total of 12 studies included in the final review [10, 16–20, 32–37].

Full study characteristics are detailed in Table 1. The total sample comprised 513 players (434 male and 79 female), and the video analysis of 538 lower-limb muscle injuries (452 in males, 86 in females). Frequently observed injuries involved the hamstrings ($n=402$; 74.72%), followed by the adductors ($n=77$; 14.31%), quadriceps ($n=38$; 7.06%), and calf muscles ($n=21$; 3.90%). All reported injuries among female players involved the hamstrings. All cases involved professional players, primarily from European leagues (75%) and Qatar's top division (16.7%), while the remaining 8.3% were drawn from studies in which the competition was not specified. All included studies relied on 2D video analyses. Video sources varied: two studies analysed recordings from training sessions [20, 32], one study collected data directly from medical staff [16], and 11 studies obtained footage from television broadcasts, online platforms, archival systems, or other public sources (i.e. InStat, Youtube, Mediportal, AspireSport, Wyscout, Mediacoach, Kicker) [10, 16–20, 32–37].

A meta-analysis was conducted in male sample studies because only two studies were focused on female samples. Although four main muscle groups were identified across the included studies, sufficient data were available only for subgroup analyses of hamstring and adductor injuries. The male-only sample of the study by Della Villa et al. [33] was already included in another previous study [10]. For this reason, this study [33] was included in the systematic review but its data from the male-only sample were excluded in the meta-analyses and only the female sample was included in the descriptive analysis.

Risk of Bias and Methodological Quality

According to the AXIS tool (Appendix B), most items achieved > 80% positive responses, indicating overall

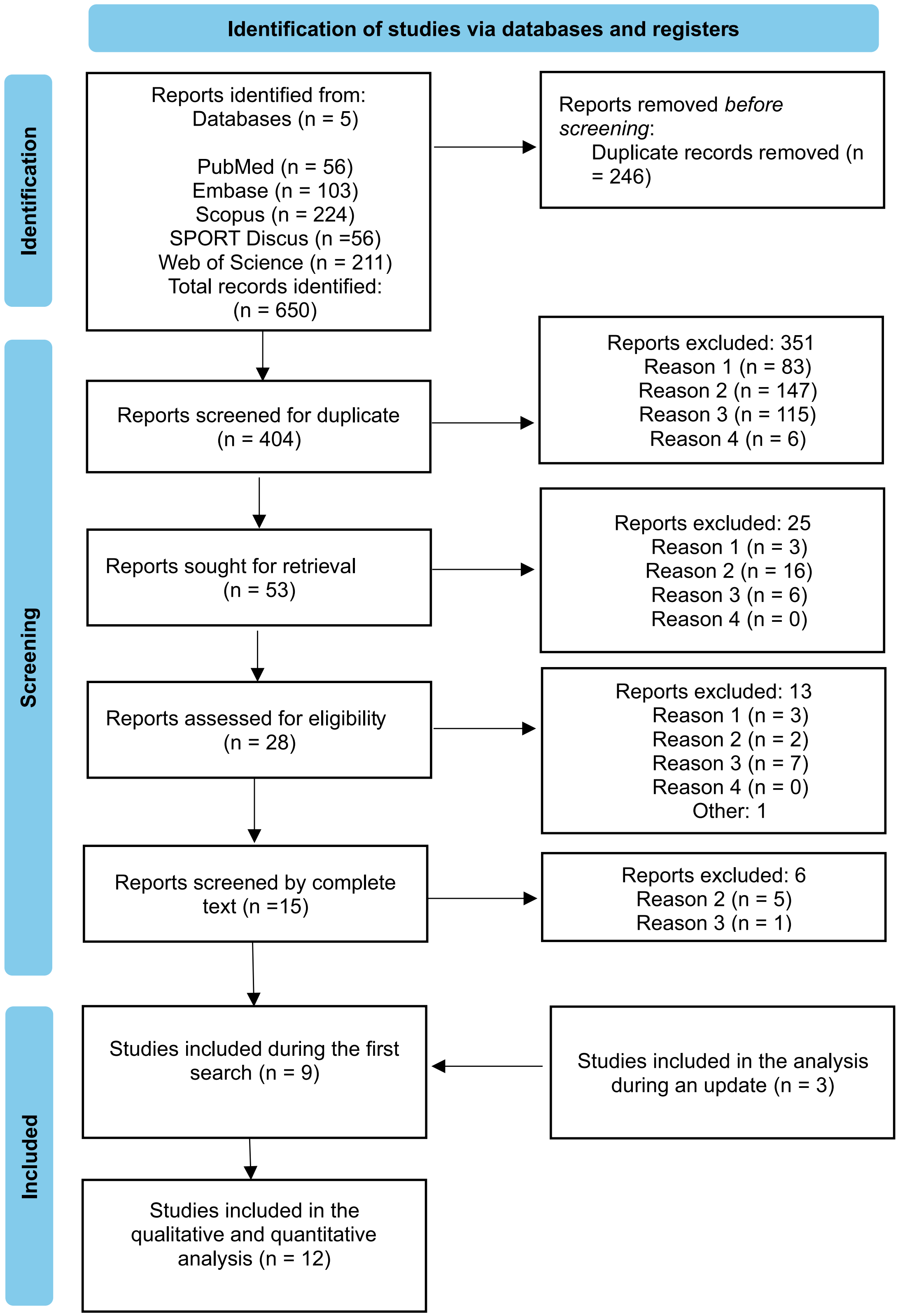

Fig. 1 Flowchart diagram of the screening process. The reasons for exclusion were as follows: reason 1 = study did not involve 11-a-side football; reason 2 = study did not address muscle injury mechanisms; reason 3 = study did not use video analysis; reason 4 = non-English or Spanish text

Table 1 Characteristics of video-analysis studies on muscle injury mechanisms in professional football

Study	Sample	Player field position	Video tools	Videos analysed (raters)	Injury events	Variables
Serner et al. [34]	*N* = 17 men Qatar 2013–2015	FW (*n* = 1) MF (*n* = 8) DF (*n* = 4) GK (*n* = 4)	AspireSport	17 (2)	Overall (*n* = 17) Adductor (*n* = 17)	Injury mechanism Kinetic chain Match time Tactical phase Ball possession Specific action
Klein et al. [19]	*N* = 56 men Germany 2014–2016	(Not specified)	DFL Medial Portal—Sportcast	345 (28)	Overall (*n* = 56) Hamstring (*n* = 31) Adductor (*n* = 18) Quadriceps (*n* = 7)	Injury mechanism Specific action
Gronwald et al. [18]	*N* = 52 men Germany 2014–2018	(Not specified)	DFL Medial Portal—Sportcast–Kicker	52 (2)	Overall (*n* = 52) Hamstring (*n* = 52)	Injury mechanism Kinetic chain Match time Specific action
Aiello et al. [32]	*N* = 29 men Italy 2019–2021	(Not specified)	Training seasons videorecording; TV broadcasting service	34 (2)	Overall (*n* = 29) Hamstring (*n* = 17) Adductor (*n* = 6) Quadriceps (*n* = 2) Calf (*n* = 4)	Injury mechanism Match time Tactical phase Ball possession Specific action
Della Villa et al. [10]	*N* = 103 men Italy 2018–2020	FW (*n* = 27) MF (*n* = 27) DF (*n* = 45) GK (*n* = 4)	InStat sport	103 (3)	Overall (*n* = 103) Hamstring (*n* = 61) Adductor (*n* = 16) Quadriceps (*n* = 9) Calf (*n* = 17)	Injury mechanism Contact location Kinetic chain Velocities Match time Tactical phase Specific action
Jokela et al. [16]	*N* = 19 men Spain Finland 2017–2022	FW/MF/DF (*n* = 15) GK (*n* = 4)	TV broadcasted video and medical staff	20 (2)	Overall (*n* = 20) Quadriceps (*n* = 20)	Injury mechanism Contact location Kinetic chain Velocities Specific action
Jokela et al. [17]	*N* = 13 men Spain Finland 2017–2022	FW (*n* = 5) MF (*n* = 3) DF (*n* = 4) GK (*n* = 1)	Archiving system or through public sources	14 (4)	Overall (*n* = 14) Hamstring (*n* = 14)	Injury mechanism Contact location Kinetic chain Velocities Specific action
Della Villa et al.* [33]	*N* = 61 men Italy 2017–2022	FW (*n* = 16) MF (*n* = 15) DF (*n* = 28) GK (*n* = 2)	Insta Sport, Youtube and Wyscout	61 (3)	Overall (*n* = 61) Hamstring (*n* = 61)	Injury mechanism Contact location Kinetic chain Velocities Match time Tactical phase Specific action
	N = 29 women National and International competitions 2017–2022	FW (*n* = 11) MF (*n* = 10) DF (*n* = 7) GK (*n* = 1)	Insta Sport, Youtube and Wyscout	29 (3)	Overall (*n* = 29) Hamstring (*n* = 29)	Injury mechanism Contact location Kinetic chain Velocities Match time Tactical phase Specific action
Vermeulen et al. [35]	*N* = 63 men Qatar 2013–2020	FW (*n* = 19) MF (*n* = 21) DF (*n* = 21) GK (*n* = 2)	IPTV local, wyscout; Stats perform	63 (3)	Overall (*n* = 63) Hamstring (*n* = 63)	Injury mechanism Velocities Match time Tactical phase Ball possession Specific action
Jokela et al. [20]	*N* = 20 men (Not specified) 2017–2023	FW (*n* = 7) MF (*n* = 4) DF (*n* = 8) GK (*n* = 1)	Public sources or through training crew	20 (2)	Overall (*n* = 20) Adductor (*n* = 20)	Injury Mechanism Kinetic chain Match time Tactical phase Specific action

Table 1 (continued)

Study	Sample	Player field position	Video tools	Videos analysed (raters)	Injury events	Variables
Gandiarias-Madariaga et al. [36]	*N* = 62 men Spain 2017–2019	FW (*n* = 8) MF (*n* = 26) DF (*n* = 43) GK (*n* = 1)	Transfermarket Mediacoach®	78 (2)	Overall (*n* = 78) Hamstring (*n* = 78)	Injury Mechanism Match time Tacticalphase Specific action
Pellegrini et al. [37]	*N* = 50 women National and International competitions 2017–2024	FW (*n* = 19) MF (*n* = 22) DF (*n* = 14) GK (*n* = 2)	Youtube, Wyscout	57 (3)	Overall (*n* = 57) Hamstring (*n* = 57)	Injury Mechanism Kinetic chain Match time Tacticalphase Specific action

All studies involved professional players. *FW* forward, *MF* midfielder, *DF* defender, *GK* goalkeeper

* The male players' sample was included in the cohort of the previous study by Della Villa et al. [10]

low risk of bias. Item 9 ("Were the risk factor and outcome variables measured correctly using instruments/measurements that had been trialled, piloted or previously published?") reached 75% positive responses. In contrast, < 30% positive responses were recorded for items 7 ("Were measures undertaken to address and categorise non-responders?"), 10 ("Is it clear what was used to determine statistical significance and/or precision estimates?"), 13 ("Does the response rate raise concerns about non-response bias?"), and 14 ("If appropriate, was information about non-responders described?"). All studies included in the meta-analysis were classified as low risk of bias (AXIS score ≥ 15), except one (score < 15) [36]. The QA-SIVAS (Appendix C) showed all studies demonstrating good or high video-analysis methodological quality (> 71% positive items). However, all the included studies were rated as low methodological quality in Domain 10, which evaluates whether a control group was included, and Domain 11, also for all studies except Pellegrini et al. [36], which evaluates whether a quantitative biomechanical analysis was done. The STROBE checklist scores were good to excellent, ranging from 16 to 20 points (Appendix D).

Meta-analyses for All Muscle Injuries

The characteristics of injury mechanism (direct contact, indirect contact, and non-contact), contact location, kinetic chain, vertical and horizontal velocity are provided in Supplemental file 2.

Injury Mechanism, Kinetic Chain and Speed at Injury Time

Non-contact muscle injuries were significantly more frequent than indirect contact injuries (Fig. 2a, $OR = 8.01$, 95% CI 3.85–16.64, $p < 0.001$, $I^2 = 79\%$, $k = 9$ studies). Direct contact muscle injuries were much less common than non-contact and indirect contact injuries with $OR > 139.79$ ($p < 0.001$). Regarding contact location in indirect and direct contact muscle injuries in three studies that reported them, 18 injuries occurred with contact to the upper body; 5 injuries with contact to the pelvis; 4 injuries in the uninjured leg and 1 injury with indirect contact to the injured leg. The Bayesian pooled model showed higher injury proportions after upper-body contact (RE = 0.69, 95% CrI = 0.39–0.89). Regarding the kinetic chain, there were no differences in the proportion of muscle injuries with open or closed kinetic chain (Fig. 2b, $OR = 0.67$, 95% CI 0.20–2.20, $p = 0.510$, $I^2 = 82\%$, $k = 6$ studies). However, muscle injuries were more likely to occur at estimated moderate–high horizontal velocities compared to estimated zero or low horizontal velocities (Fig. 2c, $OR = 19.56$, *95% CI* 2.55–150.12, $p = 0.004$, $I^2 = 89\%$, $k = 4$ studies), albeit with a very wide confidence interval reflecting substantial heterogeneity. Detailed information is provided in Supplemental files 2, 4 and 5.

Situational Patterns

Muscle injury proportions were highest during running (RE = 0.29, 95% CrI = 0.17–0.44), stretching/reaching (RE = 0.24, 95% CrI = 0.12–0.39) and kicking actions (RE = 0.22, 95% CrI = 0.09–0.38), although between-category contrasts were not credibly different and the overlapping CrI indicate no clear hierarchy of action categories. These distributions should therefore be interpreted as descriptive of observed frequencies. Detailed information is provided in Supplemental files 3, 4 and 6.

Time and Field Location and Tactical Situations

Muscle injuries occurred similarly during the first and the second half of the match (Fig. 3a: $OR = 1.54$, *95% CI* 0.77–3.06, $p = 0.220$, $I^2 = 80\%$, $k = 7$ studies). More specifically, the Bayesian pooled model showed similar injury proportions across 15-min match intervals (RE ranged between 0.13 and 0.22, $k = 7$ studies). The CrI overlap widely, indicating appreciable uncertainty and

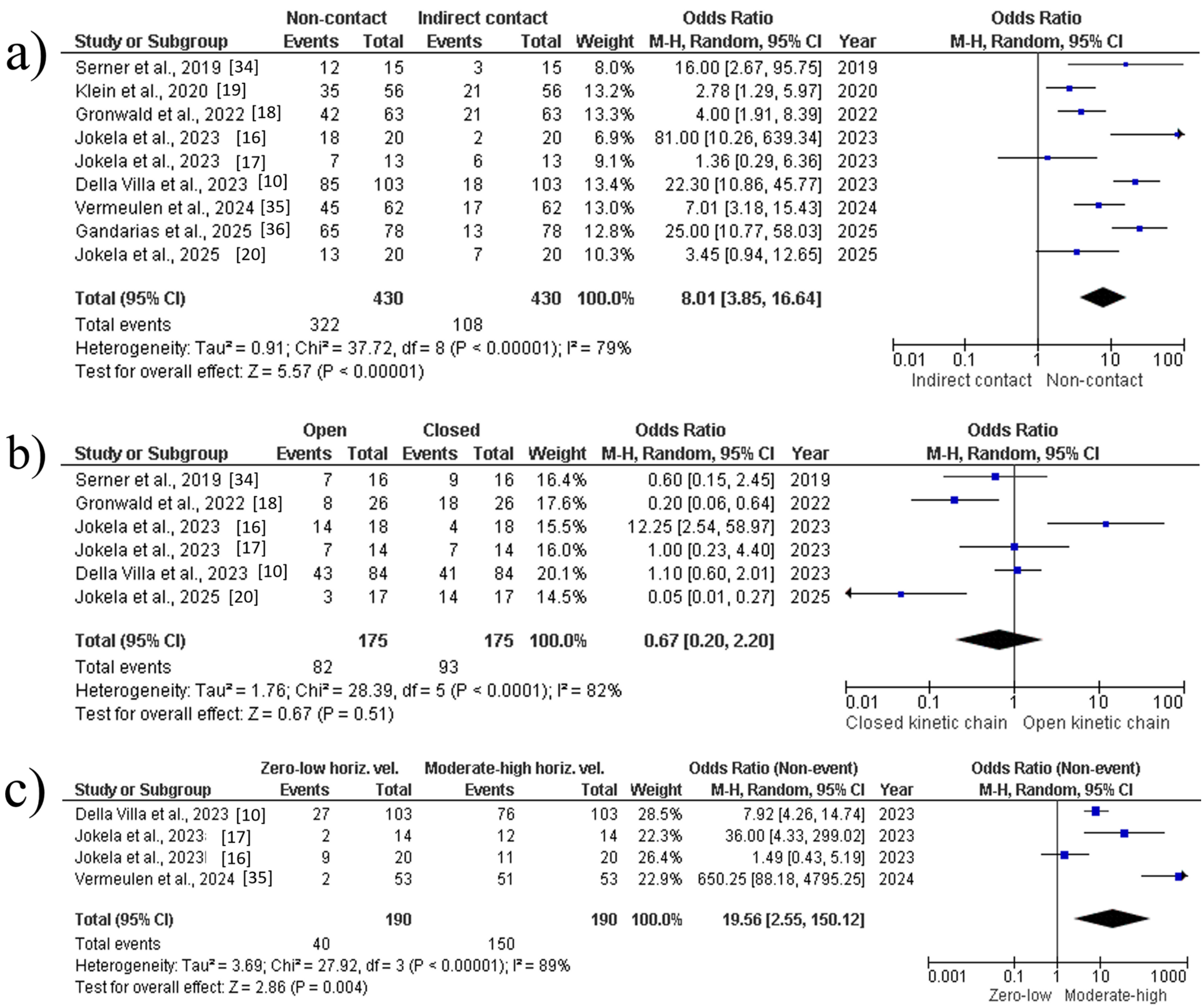

Fig. 2 Odds ratio for overall lower-limb muscle injuries in male football players depending on: **a** non-contact vs indirect contact; **b** open vs closed kinetic chain; **c** zero–low vs moderate–high horizontal velocity. *CI* confidence interval

between-study variability. Detailed data on time and field location are described in Supplemental files 4, 7 and 8. There were no differences in muscle injury ratios during defending or attacking (Fig. 3b, $OR = 1.13$, *95% CI* 0.77–1.67, $p = 0.470$, $I^2 = 27\%$, $k = 6$ studies), or with or without ball possession (Fig. 3c, $OR = 4.05$, *95% CI* 0.20–80.48, $p = 0.360$, $I^2 = 96\%$, $k = 4$ studies).

Meta-analyses for Hamstring Muscle Injury

Injury Mechanism and Kinetic Chain

Non-contact hamstring muscle injuries were significantly more frequent than indirect contact injuries (Fig. 4a $OR = 6.91$, *95% CI* 2.56–18.62, $p < 0.001$, $I^2 = 85\%$, $k = 6$ studies). There were no differences between open vs closed kinetic chain (Fig. 4b, $OR = 1.21$, *95% CI* 0.23–6.24, $p = 0.820$, $I^2 = 83\%$, $k = 3$ studies).

Situational Patterns

Hamstring injury proportions were highest during running (RE = 0.38, 95% CrI = 0.23–0.54), stretching/reaching (RE = 0.24, 95% CrI = 0.12–0.40) and kicking actions (RE = 0.17, 95% CrI = 0.06–0.35) although between-category contrasts were not credibly different. Accordingly, no single action can be considered predominant from a comparative perspective. Detailed information is provided in Supplemental files 9 and 10.

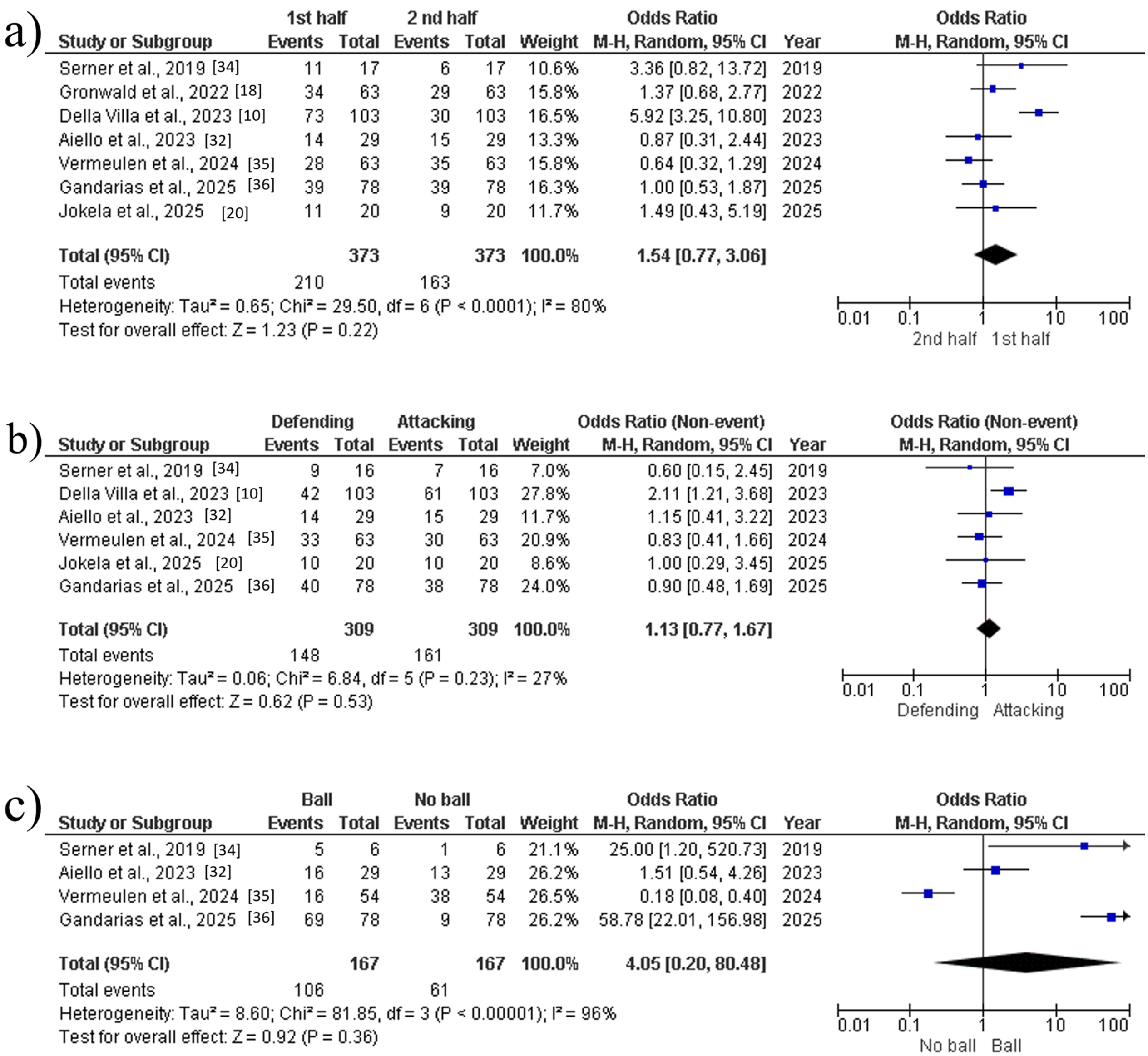

Fig. 3 Odds ratio for overall lower-limb muscle injuries in male football players depending on: **a** 1st vs 2nd match halves; **b** defending vs attacking playing situation; **c** ball vs no ball possession. *CI* confidence interval

Time and Field Location and Tactical Situations

Hamstring muscle injuries occurred with similar frequency in the first and second halves of the match (Fig. 4c: $OR = 1.22$, *95% CI* 0.58–2.56, $p = 0.590$, $I^2 = 78\%$, $k = 5$ studies), and with similar proportions during defending and attacking phases (Fig. 4d, $OR = 1.02$, *95% CI* 0.70–1.49, $p = 0.920$, $I^2 = 1\%$, $k = 4$ studies). Detailed information is provided in Supplemental files 9 and 11.

Meta-analyses for Adductor Muscle Injury

Injury Mechanism and Kinetic Chain

Non-contact adductor muscle injuries were significantly more frequent than indirect contact injuries (Fig. 5a $OR = 3.81$, *95% CI* 1.84–7.88, $p < 0.001$, $I^2 = 3\%$, $k = 4$ studies). There were no differences in the proportion of adductor muscle injuries sustained with open vs closed kinetic chain (Fig. 5b, $OR = 2.23$, *95% CI* 0.25–20.20, $p = 0.480$, $I^2 = 84\%$, $k = 3$ studies).

Situational Patterns

Adductor muscle injuries were frequently observed during stretching/reaching (RE = 0.34, 95% CrI = 0.15–0.55), running (RE = 0.19, 95% CrI = 0.06–0.42) or kicking (RE = 0.17, 95% CrI = 0.06–0.40) with no between-category differences. Detailed information is provided in Supplemental files 12 and 13.

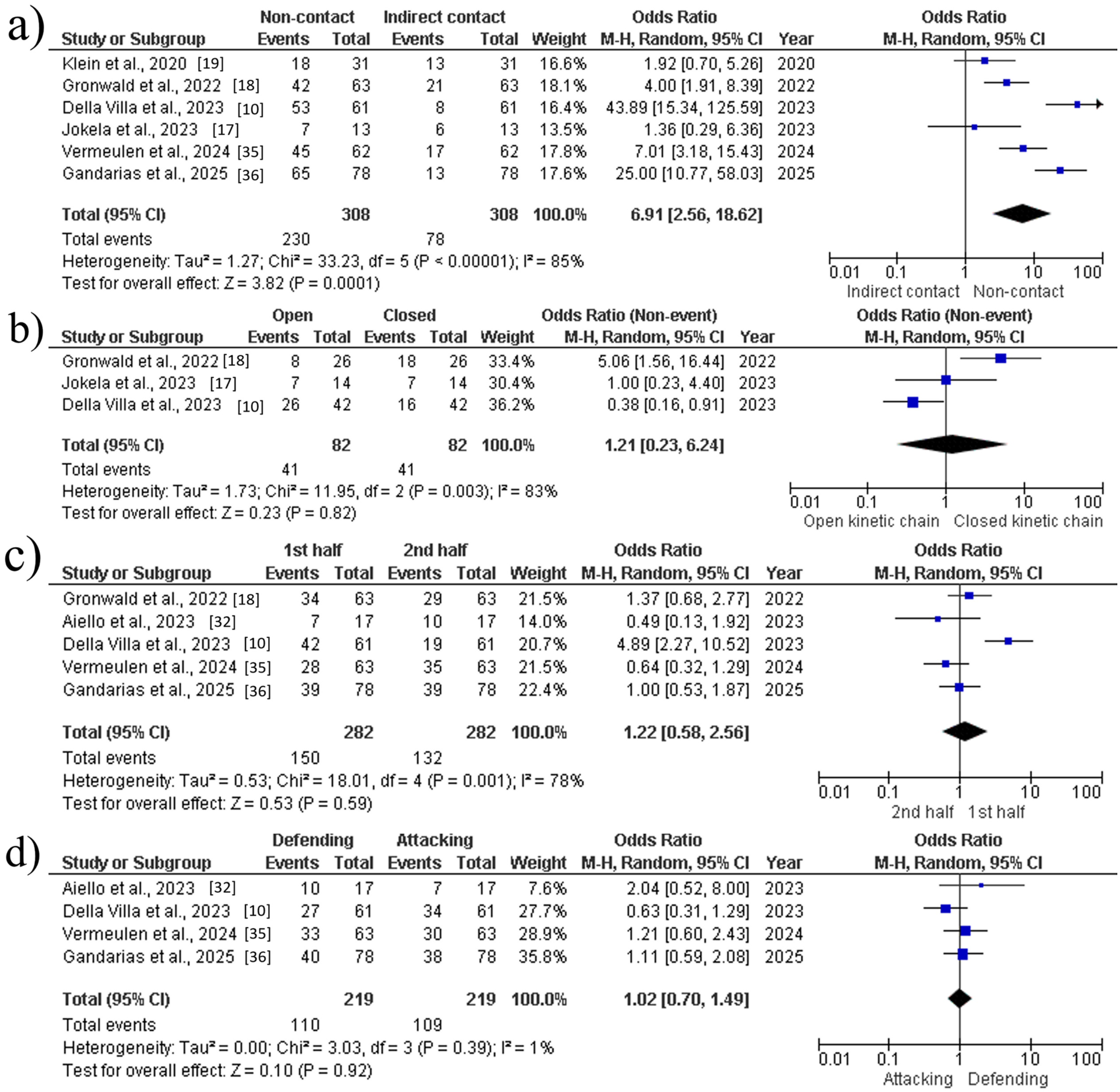

Fig. 4 Forest plot for hamstring muscle injury studies in male football players: **a** non-contact vs indirect contact; **b** open vs closed kinetic chain; **c** 1st vs 2nd match halves; **d** defending vs attacking playing situations. *CI* confidence interval

Time and Field Location and Tactical Situations

Adductor muscle injuries were more common during the first half of the match (Fig. 5c: $OR = 2.11$, *95% CI* 1.01–4.42, $p = 0.05$, $I^2 = 0\%$, $n = 4$ studies). Regarding match-time periods, adductor muscle injuries were particularly frequent during the 15–29 min period (RE = 0.28, 95% CrI = 0.11–0.47) and 60–74 min period (RE = 0.23, 95% CrI = 0.09–0.43) of the game, but the CrI were not clearly separated given the uncertainty. However, adductor muscle injuries were equally common during defending and attacking phases (Fig. 5d, $OR = 1.07$, *95% CI* 0.51–2.24, $p = 0.850$, $I^2 = 0\%$, $n = 4$ studies). Detailed information is provided in Supplemental files 12 and 14.s

Descriptive Analysis for Female Football Players

In the two studies involving female players (all hamstring injuries), non-contact muscle injuries were more common than indirect contact injuries ($n = 61$, 70.9% vs $n = 25$, 29.1%). A similar number of injuries occurred during closed kinetic chain actions ($n = 33$, 38.4%), open kinetic chain actions ($n = 25$, 29.1%) or unsure actions ($n = 28$, 32.5%). Most muscle injuries occurred

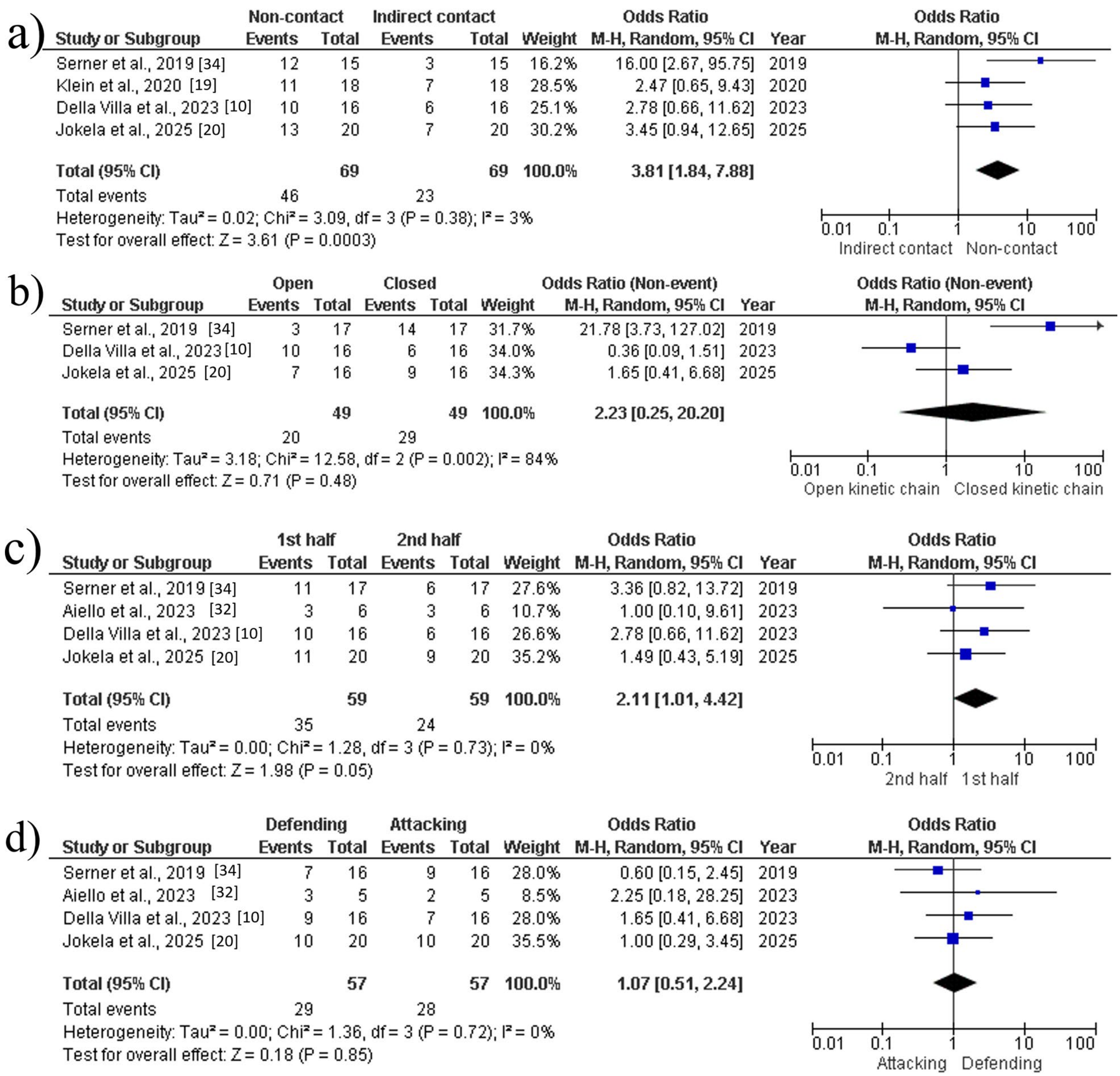

Fig. 5 Forest plot for adductor muscle injury studies in male football players: **a** non-contact vs indirect contact; **b** open vs closed kinetic chain; **c** 1st vs 2nd match halves; **d** defending vs attacking playing situations. *CI* confidence interval

during running ($n=47$, 54.7%), followed by kicking ($n=19$, 22.1%), stretching/reaching ($n=18$, 20.9%) and jumping ($n=2$, 2.3%). Injury occurrence was similar between the first and second halves of the match ($n=44$, 51.2% vs $n=42$, 48.8%).

Discussion

This systematic review and meta-analysis synthesised 12 video-based studies encompassing 538 lower-limb muscle injuries in professional football. Meta-analysis was restricted to male players due to limited female data. Overall, injuries were most frequently observed in non-contact, high-speed contexts, consistent with ground-based actions involving moderate–high horizontal velocity. Running, stretching/reaching, and kicking were among the frequently observed inciting events; however, no clear hierarchy was identified for action categories due to overlapping uncertainty. These patterns should therefore be interpreted as descriptive of observed situations rather than reflecting clinically meaningful differences between actions. Similarly, no consistent patterns emerged for match timing, field location, or tactical phase, although adductor injuries showed a tendency to occur more frequently in the first half.

Hamstring injuries accounted for the majority of cases, reinforcing their known vulnerability in high-speed actions. Collectively, these findings suggest that muscle injuries in elite football are most often observed during demanding football-specific actions, rather than broader situational contexts. Importantly, as these data are derived from video-based observational analyses, they capture externally observable inciting events and cannot determine the underlying tissue failure processes. Figure 6 provides an illustrative summary of the frequently observed muscle injury scenarios observed in football.

Muscle Injury Mechanisms

Hamstring and adductor injuries were the most frequently affected muscle groups, consistent with epidemiology data in elite football and the recent rise in hamstring incidence and burden [4, 38]. Across pooled male data, lower-limb muscle injuries were most often observed in non-contact, high-speed contexts, although the velocity-related estimates were imprecise and heterogeneous. This agrees with Finnern et al. [22], who found non-contact situations to be the predominant pattern across sport-related muscle injuries, while the present review refines this evidence within professional football. This general pattern is in line with external-load work showing that short windows of elevated high-speed running [8] and congested schedules often precede muscle injury [39]. It matches broader video evidence reporting a non-contact predominance for acute lower-limb muscle (and Achilles) injuries in football [21].

From a biomechanical perspective, the situational patterns observed in this review may be interpreted as contexts in which the muscle–tendon unit is exposed to high mechanical demand, particularly during high-speed running, stretching/reaching and kicking actions. These movements often involve rapid limb motion and muscle lengthening, especially in biarticular muscles such as the hamstrings, adductors and rectus femoris [22]. For example, joint configurations combining hip flexion and knee extension during the terminal swing phase of sprinting may increase the mechanical demand placed on the hamstrings [40]. However, these interpretations should be considered biomechanically plausible explanations rather than direct findings of the present review. The included studies relied on observational video analysis,

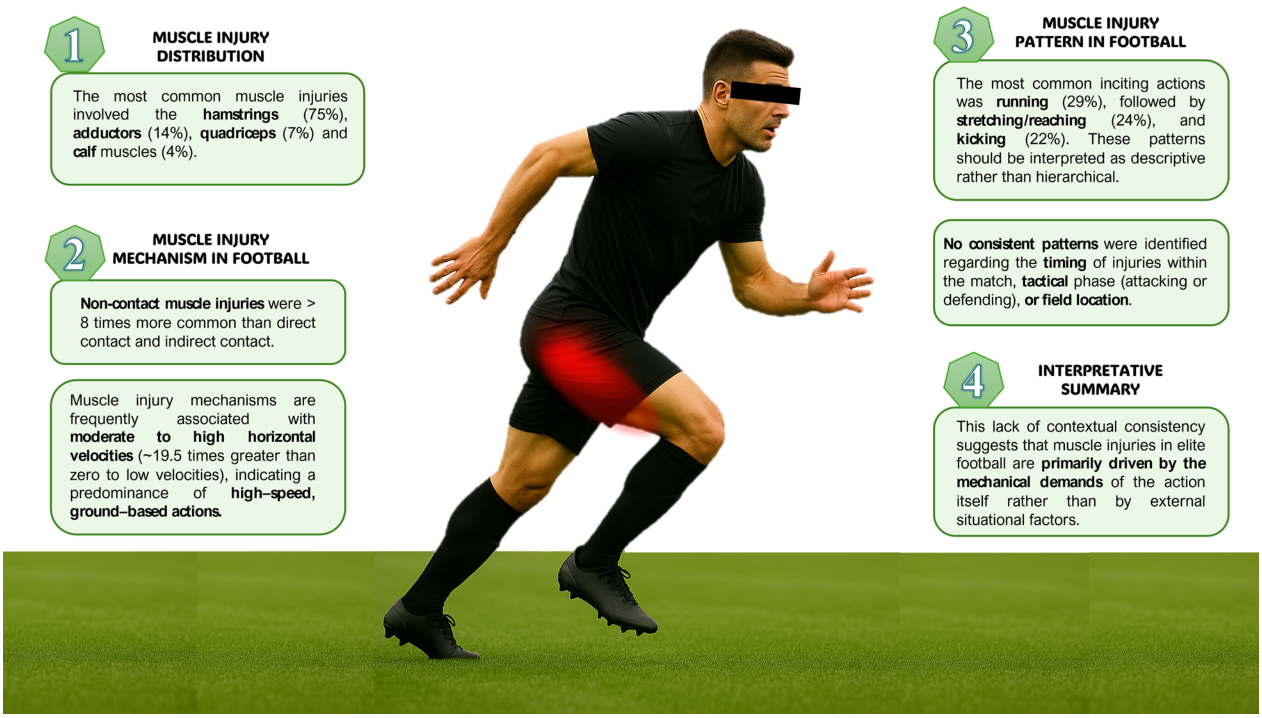

Fig. 6 Illustrative representation of frequently observed characteristics of lower-limb muscle injury in male football players, as identified through the systematic review and meta-analysis. It is important to highlight that muscle injury is a complex and interconnected event, and it is crucial to interpret the data as a whole, rather than in isolated portions. This figure was AI-assisted generated using ChatGPT-5 based on data from this systematic review and meta-analysis. The underlying data are fully attributable, have been checked for accuracy, and comply with ethical, copyright, and terms-of-use requirements

which allows the external injury situation to be characterised but does not quantify tissue loading, muscle–tendon behaviour, neuromuscular activation, or the precise structural failure process. Similarly, the greater frequency of injuries observed towards the end of each half (i.e. the final 15 min of each half) may be compatible with a role of fatigue, but the present data cannot establish whether fatigue altered eccentric capacity, coordination, or muscle–tendon loading at the time of injury. Future studies combining video analysis with player tracking, workload data, musculoskeletal modelling and, where possible, neuromuscular measures are needed to clarify how these observable injury scenarios relate to tissue-level mechanisms. The Munich consensus detailed structural and histological/anatomical features (i.e. intramuscular/central tendon involvement) that may heighten vulnerability under sprinting or rapid transition demands [41], a view that aligns with recent football-specific video and clinical analyses of hamstrings and adductors [18, 35]. For adductors, particularly adductor longus, injuries frequently occur during reaching/overstretching or rapid abduction–deceleration phases under high activation, often during ball interactions [20, 32]. Sub-analyses in our review showed consistent observable contextual profiles for both hamstrings and adductors, reinforcing the central role of high-velocity, non-contact situational patterns [17, 19, 35, 36].

Indirect-contact perturbations (i.e. pushes, collisions) can precipitate compensatory overstretching of the lower-limb, culminating in strain injury [10]. Importantly, this highlights a key sport-specific characteristic of football: players are involved in frequent unanticipated interactions (e.g., pushes, collisions, challenges) that may disrupt neuromuscular control and movement coordination. Nevertheless, the high incidence of hamstring strain injuries observed in purely non-contact sprinting sports reinforces that high-speed mechanical loading per se remains a central and shared mechanism across sporting contexts. Accordingly, prevention programmes may consider incorporating (i) exposure to sprint-mechanics and progressive high-speed running; (ii) lengthened-range eccentric strength for hamstrings and adductors muscles [10, 17, 18, 32, 35]; and (iii) neuromuscular training under conditions of fatigue (i.e. during a 5-min high-intensity bout) [7, 8]. However, these recommendations should be interpreted as the authors' interpretation of the meta-analytic findings, informed by the available video-based evidence and broader clinical and experimental knowledge, rather than as direct conclusions established solely by the present synthesis.

Situational Patterns

Running or sprinting, stretching or reaching, and kicking were the most frequent actions associated with lower-limb muscle injuries. These findings are consistent with previous video analyses showing that most muscle injuries occur during high-intensity locomotor or reaching tasks rather than static or low-speed situations review [10, 16–20, 32, 33, 35, 36]. However, given the substantial overlap in CrI across action categories, these distributions do not support a clear hierarchy of injury-related actions and should not be interpreted as indicating that any specific action carries greater injury risk. Instead, they likely reflect the relative frequency of these behaviours in match play. Moreover, these distributions should also be interpreted in light of the harmonisation rule applied to unreported categories, as absence of reporting in the original studies may not necessarily reflect true absence of occurrence.

Subgroup analyses showed similar contextual profiles for hamstrings and adductors, although with subtle nuances. Hamstring injuries were frequently observed during high-speed running or sprinting contexts, especially in terminal swing and early stance, when eccentric demand peaks [8, 17, 18, 22]. Adductor injuries, by contrast, were more often linked to stretching/reaching actions, directional changes, or ball-kicking sequences, reflecting their functional role in stabilising and decelerating the limb during rapid abduction–adduction transitions review [10, 20, 22, 32]. These contextual associations should be interpreted cautiously, as they do not imply action-specific risk but rather describe the situations in which injuries are frequently observed.

Collectively, these observations indicate that lower-limb muscle injuries, particularly muscle strain injuries, are commonly captured during complex, dynamic game actions demanding rapid acceleration, deceleration, or control under external perturbation. Importantly, these findings should not be used to prioritise specific actions (e.g., running vs kicking) in prevention or rehabilitation programmes, given the absence of clear between-category differences. Preventive and return-to-play programmes may therefore benefit from progressively exposing players to game-specific scenarios, including high-speed running, stretching or kicking under load, and directional changes with upper-body contact, while recognising that the present findings describe observed injury situations rather than proving action-specific risk.

Time and Field Location and Tactical Situations

Temporal [10, 20, 34], spatial [10, 17–19, 32, 35] and tactical [10, 20, 34] variables showed no consistent association with injury occurrence, suggesting that, within the available video-based evidence, injuries were more consistently observed in relation to the immediate action than to broader match-context variables. Preventive work may therefore place greater emphasis on preparing players for high-speed, multidirectional actions across all field zones and game phases, rather than targeting specific match moments or tactical contexts.

Video-Analysis Protocols

The included studies employed a range of video-based analytical protocols, mostly using broadcast footage, club recordings, or performance-analysis platforms to identify and characterise muscle injuries [10, 16–18, 32, 33, 35]. In most cases, injury confirmation was supported by medical records, imaging, or clinical diagnosis, ensuring alignment between contextual video information and verified injury data. These approaches strengthen external validity, as they capture the real-game dynamics surrounding injury occurrence [19, 36].

However, heterogeneity in video protocols was evident across studies. Differences in camera angles, frame rates, and coding frameworks may partly explain the variability in reported contextual factors and likely explain the substantial statistical heterogeneity observed in our pooled analyses. Moreover, many studies relied on 2D footage lacking depth perspective, which limits accurate estimation of joint angles, player velocities, or three-dimensional movement patterns. These methodological constraints could also contribute to the high heterogeneity observed in the pooled analyses. To improve reproducibility and comparability, future research should prioritise standardised video-coding frameworks, consistent operational definitions of velocity thresholds and action categories, and transparent reporting of inter-rater reliability. Integrating multi-camera 3D video, tracking data, or wearable sensors with video analysis would allow for more precise quantification of movement mechanics and contextual exposure. These refinements would enhance the interpretability of pooled findings and strengthen the ecological validity of video-based injury research in elite football.

Strengths and Limitations

This review offers the most comprehensive synthesis to date of video-based analyses of lower-limb muscle injuries in professional football, incorporating 538 injuries. By aggregating findings across multiple cohorts and synthesising outcomes from various video coding procedures, this study provides a clearer understanding of injury mechanisms during real-game scenarios in football. The use of video analysis adds robustness and enhances external validity for practitioners seeking to contextualise injury risk beyond laboratory settings. In addition, relative to the recent reviews by Finnern et al. [22] and Xiao et al. [21], which, respectively, examined muscle injuries across different sports and lower-limb injuries in football irrespective of tissue type, the present meta-analysis provides an updated football-specific, muscle-focused synthesis of situational variables, including injury inciting event, kinetic chain involvement, action type, match timing, field location, tactical phase, ball possession, and horizontal/vertical velocity.

Nonetheless, several limitations should be acknowledged. First, all included studies relied on 2D video footage, which limits kinematic precision and precludes quantification of forces, angles, or muscle activity. Second, heterogeneity in injury definitions, diagnostic confirmation, video availability, and the inclusion or exclusion of direct-contact injuries across studies may have influenced the reported distribution of injury inciting events. This is relevant because direct-contact muscle injuries, such as contusions caused by external impact, differ from indirect or non-contact muscle strains in terms of injury situation, tissue loading, and preventive implications. Accordingly, combining these injuries may reduce the precision of our pooled estimates, meaning that the overall findings reflect a mix of both direct trauma and strain-related events. Third, the sample was predominantly composed of male players from professional European or Qatari leagues, limiting generalisability to female athletes and lower competitive levels. Moreover, although most studies employed structured classification systems (i.e. Football Injury Inciting Circumstances Classification System [FIICCS]), some relied on custom checklists, potentially affecting consistency in coding contextual variables. In addition, for some multi-category analyses, unreported action categories were treated as zero occurrences to allow harmonised synthesis across studies. Although this approach was necessary given inconsistent reporting and mutually exclusive category structures, it may have introduced misclassification bias, as absence of reporting does not necessarily indicate absence of occurrence. This assumption may have influenced the estimated distribution of action categories and therefore warrants cautious interpretation. Finally, the cross-sectional and observational design of all included studies precludes causal inference. Therefore, heterogeneity and imprecision limit the interpretability of pooled findings. Future work integrating synchronised video, GPS, and wearable technology may allow more granular, real-time profiling of injury events [42].

Clinical Implications

By consolidating the available video-based evidence, this review may help contextualise football-specific injury prevention strategies for medical teams, coaches, and physical conditioning practitioners operating in professional football. However, a critical consideration for clinical interpretation is the absence of exposure-adjusted data. The findings presented here describe where and when injuries are observed, not where injury risk is necessarily highest. High frequencies of certain actions (e.g., running or high-speed efforts) may therefore reflect their prevalence in match play rather than an increased injury risk, and consequently, these results cannot directly inform load management or risk quantification. Importantly, the following considerations are not derived solely from the present findings but are informed by broader literature and current clinical practice.

From a pragmatic perspective, monitoring weekly and match high-speed running may be considered to help avoid abrupt spikes around congested periods, given the associations reported in professional cohorts. Any adjustments would typically be contextual, avoiding rigid thresholds and prioritising player-specific responses. Second, because some injuries were preceded by indirect-contact perturbations, programmes may consider incorporating trunk–pelvis control tasks and carefully supervised, contact-aware versions of sprinting, reaching, cutting, or kicking. This reflects the descriptive observation of upper-body interference immediately before certain events, while recognising that causal inference is not established. Third, we did not find consistent effects of time, field location, or tactical phase; therefore, targeting specific match moments or zones cannot be supported by the present data. Instead, preparation should maintain general readiness for high-speed, multidirectional actions across phases of play. Finally, late-stage rehabilitation may incorporate exposures that resemble high-speed, ground-based demands (i.e. accelerations, controlled decelerations, ball-involved actions), alongside options for lengthened-range eccentric work for hamstrings and adductors. These elements align with the contexts most often observed at the injury instant but should be introduced progressively and individualised. Because female data were limited, and between-study heterogeneity was substantial, these suggestions should be viewed as pragmatic, low-risk considerations informed by existing evidence and clinical reasoning, rather than evidence-based prescriptions derived from the present analysis, pending prospective evaluation in intervention studies. Importantly, this review also highlights the utility of video analysis as a complementary tool to clinical assessments, helping practitioners understand the observable situations in which injuries occur, while recognising that video analysis alone cannot determine tissue-level mechanisms or quantify individual injury risk.

Conclusion

This systematic review and meta-analysis, encompassing 12 studies with a total of 538 video-verified lower-limb muscle injuries, provides a clinically useful descriptive synthesis of the observable football-specific inciting events and situational patterns surrounding lower-limb muscle injuries in professional football, while underscoring the need for future studies integrating video analysis with exposure-adjusted data. Injury situations were typically characterised by non-contact inciting events, moderate-to-high horizontal velocity (i.e. running, stretching/reaching, and kicking), and hamstring injuries accounting for the largest proportion of cases, highlighting the frequent involvement of this muscle group in high-speed football actions. No consistent patterns were observed across match halves, field locations, or tactical phases. However, because no clear hierarchy was identified among action categories, these findings should be interpreted as descriptive, video-based observations rather than as evidence that any specific action carries a greater injury risk. Importantly, meta-analysis was restricted to male players due to the paucity of female data; therefore, the findings primarily apply to male professional football. In addition, tissue-level loading and precise biomechanical failure processes cannot be inferred from the available video data.

Abbreviations

ACL	Anterior cruciate ligament
AXIS	Appraisal tool for cross-sectional studies
COD	Change of direction
IQR	Interquartile range
LKJ	Lewandowski–Kurowicka–Joe distribution
NUTS	No-U-Turn Sampler (Bayesian MCMC Algorithm)
OR	Odds ratio
PEO	Population, exposure, outcome (framework for inclusion criteria)
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QA-IVAS	Quality appraisal for sports injury video-analysis studies
STROBE-SIIS	Strengthening the Reporting of Observational Studies in Epidemiology—Sports Injury and Illness Surveillance Extension
UEFA	Union of European Football Associations

Supplementary Information

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Supplementary material 1.

Supplementary material 2.

Author Contributions

AMI contributed to conceptualisation, data curation, formal analysis and the writing of the draft manuscript. HRE contributed data curation, formal analysis and reviewing/editing of the draft of the manuscript. FJVG was involved in the literature review and reviewing/editing of the draft of the manuscript. JCI contributed to the conceptualisation, data curation, formal analysis, and the reviewing/editing of the draft of the manuscript and supervision. MMD was involved in data curation and formal analysis. JDC was involved in

conceptualisation, data curation, formal analysis, and reviewing/editing of the draft of the manuscript. VMP supported the conceptualisation and study design, the reviewing/editing of the draft manuscript and supervision. All authors read and approved the final version of the article and agree with the authors' order of submission.

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Data Availability
Data are available from the corresponding author on reasonable request.

Declarations

Ethics Approval and Consent to Participate
Not applicable.

Consent for Publication
Not applicable.

Competing Interests
All authors certify that they have no affiliations with or involvement in any organisation or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Author details
[1]Sports Research Centre (Department of Sport Sciences), Miguel Hernandez University of Elche, Alicante, Spain. [2]Institute for Health and Biomedical Research (ISABIAL Foundation), Miguel Hernández University of Elche, Alicante, Spain. [3]Department of Physical Education and Sport, University of Granada, Granada, Spain. [4]Sport Sciences Research Centre, Rey Juan Carlos University, Fuenlabrada, Spain. [5]Institute of Health and Sport Sciences, Faculty of Health Sciences, Universidad Francisco de Vitoria, Madrid, Spain. [6]Translational Research Centre of Physiotherapy, Department of Pathology and Surgery, Faculty of Medicine, Miguel Hernandez University, Alicante, Spain.

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References
1. Pulici L, Certa D, Zago M, Volpi P, Esposito F. Injury burden in professional European football (soccer): systematic review, meta-analysis, and economic considerations. Clin J Sport Med. 2023;33:450–7. https://doi.org/10.1097/JSM.0000000000001107.
2. Hallén A, Tomás R, Ekstrand J, Bengtsson H, Van den Steen E, Hägglund M, et al. UEFA Women's Elite Club Injury Study: a prospective study on 1527 injuries over four consecutive seasons 2018/2019 to 2021/2022 reveals thigh muscle injuries to be most common and ACL injuries most burdensome. Br J Sports Med. 2018;58:128–36. https://doi.org/10.1136/BJSPORTS-2023-107133.
3. Ekstrand J, Krutsch W, Spreco A, Van Zoest W, Roberts C, Meyer T, et al. Time before return to play for the most common injuries in professional football: a 16-year follow-up of the UEFA Elite Club Injury Study. Br J Sports Med. 2020;54:421–6. https://doi.org/10.1136/BJSPORTS-2019-100666.
4. López-Valenciano A, Ruiz-Pérez I, Garcia-Gómez A, Vera-Garcia FJ, De Ste Croix M, Myer GD, et al. Epidemiology of injuries in professional football: a systematic review and meta-analysis. Br J Sports Med. 2020;54:711–8. https://doi.org/10.1136/BJSPORTS-2018-099577.
5. Manojlovic M, Ninkovic S, Matic R, Versic S, Modric T, Sekulic D, et al. Return to play and performance after anterior cruciate ligament reconstruction in soccer players: a systematic review of recent evidence. Sports Med. 2097;54:2097–108. https://doi.org/10.1007/S40279-024-02035-Y.
6. Dupont G, Nedelec M, McCall A, McCormack D, Berthoin S, Wisløff U. Effect of 2 soccer matches in a week on physical performance and injury rate. Am J Sports Med. 2010;38:1752–8. https://doi.org/10.1177/0363546510361236.
7. Moreno-Perez V, Campos-Vazquez MA, Toscano J, Sotos-Martinez VJ, López-Del Campo R, Resta R, et al. Influence of the weekly and match-play load on muscle injury in professional football players. Int J Sports Med. 2022;43:783–90. https://doi.org/10.1055/A-1533-2110.
8. Moreno-Perez V, Sotos-Martínez V, Lopez-Valenciano A, Lopez Del-Campo R, Resta R, Del CJ. Hamstring muscle injury is preceded by a short period of higher running demands in professional football players. Biol Sport. 2023;41:227. https://doi.org/10.5114/BIOLSPORT.2024.127387.
9. Buckthorpe M, Wright S, Bruce-Low S, Nanni G, Sturdy T, Gross AS, et al. Recommendations for hamstring injury prevention in elite football: translating research into practice. Br J Sports Med. 2019;53:449–56. https://doi.org/10.1136/BJSPORTS-2018-099616.
10. Della Villa F, Massa B, Bortolami A, Nanni G, Olmo J, Buckthorpe M. 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. Br J Sports Med. 2023;57:1550–8. https://doi.org/10.1136/BJSPORTS-2023-106850.
11. Zeblisky P, Collins AP, Cassinat J, Riemenschneider J, Ebaugh P, Shaath MK, et al. Is Video-based analysis a valid method for determining mechanisms of ankle injuries during gameplay in the National Basketball Association? Orthop J Sports Med. 2022;10:23259671221123028. https://doi.org/10.1177/23259671221123027.
12. Hoenig T, Rahlf L, Wilke J, Krauß I, Dalos D, Willwacher S, et al. Appraising the methodological quality of sports injury video analysis studies: the QA-SIVAS scale. Sports Med. 2024;54:203–11. https://doi.org/10.1007/S40279-023-01907-Z.
13. Krosshaug T, Nakamae A, Boden BP, Engebretsen L, Smith G, Slauterbeck JR, et al. Mechanisms of anterior cruciate ligament injury in basketball: video analysis of 39 cases. Am J Sports Med. 2007;35:359–67. https://doi.org/10.1177/0363546506293899.
14. Montgomery C, Blackburn J, Withers D, Tierney G, Moran C, Simms C. Mechanisms of ACL injury in professional rugby union: a systematic video analysis of 36 cases. Br J Sports Med. 2018;52:994–1001. https://doi.org/10.1136/BJSPORTS-2016-096425.
15. Bere T, Mok KM, Koga H, Krosshaug T, Nordsletten L, Bahr R. Kinematics of anterior cruciate ligament ruptures in World Cup alpine skiing: 2 case reports of the slip-catch mechanism. Am J Sports Med. 2013;41:1067–73. https://doi.org/10.1177/0363546513479341.
16. Jokela A, Mechó S, Pasta G, Pleshkov P, García-Romero-Pérez A, Mazzoni S, et al. Indirect rectus femoris injury mechanisms in professional soccer players: video analysis and magnetic resonance imaging findings. Clin J Sport Med. 2023;33:475–82. https://doi.org/10.1097/JSM.0000000000001131.
17. Jokela A, Valle X, Kosola J, Rodas G, Til L, Burova M, et al. Mechanisms of hamstring injury in professional soccer players: video analysis and magnetic resonance imaging findings. Clin J Sport Med. 2023;33:217–24. https://doi.org/10.1097/JSM.0000000000001109.
18. Gronwald T, Klein C, Hoenig T, Pietzonka M, Bloch H, Edouard P, et al. Hamstring injury patterns in professional male football (soccer): a systematic video analysis of 52 cases. Br J Sports Med. 2022;56:165–71. https://doi.org/10.1136/BJSPORTS-2021-104769.
19. Klein C, Luig P, Henke T, Bloch H, Platen P. Nine typical injury patterns in German professional male football (soccer): a systematic visual video analysis of 345 match injuries. Br J Sports Med. 2020. https://doi.org/10.1136/bjsports-2019-101344.
20. Jokela A, Pasta G, Della Villa F, Abrantes A, Kalogiannidis D, García-Romero-Pérez A, et al. Mechanisms of severe adductor longus injuries in professional soccer players: a systematic visual video analysis. Orthop J Sports Med. 2025. https://doi.org/10.1177/23259671241309647.
21. Xiao M, Lee JJ, Boissiere JC, Sherman SL, Safran MR, Abrams GD, et al. Video analysis of acute lower extremity injury mechanisms in soccer demonstrates most anterior cruciate ligament, Achilles, and muscle injuries occur without direct contact: a systematic review and meta-analysis. Arthroscopy. 2025. https://doi.org/10.1016/J.ARTHRO.2025.01.049.

22. Finnern LS, Wilke J, Willwacher S, Pasanen K, Hollander K, Dalos D, et al. Qualitative and quantitative situational characteristics of muscle strains in sports: a systematic review and meta-analysis. Br J Sports Med. 2026. https://doi.org/10.1136/BJSPORTS-2025-110327.
23. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2020. https://doi.org/10.1136/BMJ.N71.
24. Hosseini M-S, Jahanshahlou F, Akbarzadeh MA, Zarei M, Vaez-Gharamaleki Y. Formulating research questions for evidence-based studies. J Med Surg Public Health. 2024;2:100046. https://doi.org/10.1016/J.GLMEDI.2023.100046.
25. McHugh ML. Interrater reliability: the kappa statistic. Biochem Med (Zagreb). 2012;22:276. https://doi.org/10.11613/bm.2012.031.
26. Downes MJ, Brennan ML, Williams HC, Dean RS. Development of a critical appraisal tool to assess the quality of cross-sectional studies (AXIS). BMJ Open. 2016. https://doi.org/10.1136/BMJOPEN-2016-011458.
27. Bahr R, Clarsen B, Derman W, Dvorak J, Emery CA, Finch CF, et al. International Olympic Committee consensus statement: methods for recording and reporting of epidemiological data on injury and illness in sports 2020 (including the STROBE extension for sports injury and illness surveillance (STROBE-SIIS)). Orthop J Sports Med. 2020. https://doi.org/10.1177/2325967120902908.
28. Hripcsak G, Rothschild AS. Agreement, the F-Measure, and Reliability in Information Retrieval. J Am Med Inform Assoc. 2005;12:296. https://doi.org/10.1197/JAMIA.M1733.
29. Deeks J, Higgins J, Altman D, McKenzie E, Veroniki A. Chapter 10: Analysing data and undertaking meta-analyses. In: Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, et al., editors. Cochrane handbook for systematic reviews of interventions. Hoboken: Wiley; 2024.
30. Antonio ALM, Weiss RE, Saigal CS, Dahan E, Crespi CM. A Bayesian hierarchical model for discrete choice data in health care. Stat Methods Med Res. 2018;27:3544–59. https://doi.org/10.1177/0962280217704226.
31. Lewandowski D, Kurowicka D, Joe H. Generating random correlation matrices based on vines and extended onion method. J Multivar Anal. 2009;100:1989–2001. https://doi.org/10.1016/J.JMVA.2009.04.008.
32. Aiello F, Di Claudio C, Fanchini M, Impellizzeri FM, McCall A, Sharp C, et al. Do non-contact injuries occur during high-speed running in elite football? Preliminary results from a novel GPS and video-based method. J Sci Med Sport. 2023;26:465–70. https://doi.org/10.1016/j.jsams.2023.07.007.
33. Della Villa F, Buckthorpe M, Pellegrini A, Ranzini A, Esposito F, Crescenzo C, et al. A comparative video analysis of hamstring injuries mechanism and situational pattern in men's and women's football (soccer). Knee Surg Sports Traumatol Arthrosc. 2024. https://doi.org/10.1002/KSA.12313.
34. Serner A, Mosler AB, Tol JL, Bahr R, Weir A. Mechanisms of acute adductor longus injuries in male football players: a systematic visual video analysis. Br J Sports Med. 2019;53:158–64. https://doi.org/10.1136/BJSPORTS-2018-099246.
35. Vermeulen R, van Dyk N, Whiteley R, Chamari K, Gregson W, Lolli L, et al. Injury-inciting circumstances of sudden-onset hamstring injuries: video analyses of 63 match injuries in male professional football players in the Qatar Stars League (2013-2020). Br J Sports Med. 2013. https://doi.org/10.1136/bjsports-2023-106722.
36. Gandarias-Madariaga A, Martínez-Serrano A, Alcaraz PE, Calleja-González J, del Campo RL, Resta R, et al. Hamstring strain injury patterns in Spanish Professional Male Football (Soccer): a systematic video analysis of 78 match injuries. J Funct Morphol Kinesiol. 2025;10:201. https://doi.org/10.3390/JFMK10020201/S1.
37. Pellegrini A, Ranzini A, Esposito F, Della Villa F, Zago M. Systematic video analysis of 57 hamstring injuries in women's football (soccer): injury mechanisms, situational patterns and biomechanics. Br J Sports Med. 2025. https://doi.org/10.1136/BJSPORTS-2024-109157.
38. Ekstrand J, Bengtsson H, Waldén M, Davison M, Khan KM, Hägglund M. Hamstring injury rates have increased during recent seasons and now constitute 24% of all injuries in men's professional football: the UEFA Elite Club Injury Study from 2001/02 to 2021/22. Br J Sports Med. 2022;57:292. https://doi.org/10.1136/BJSPORTS-2021-105407.
39. Ekstrand J, Ueblacker P, Van Zoest W, Verheijen R, Vanhecke B, Van Wijk M, et al. Risk factors for hamstring muscle injury in male elite football: medical expert experience and conclusions from 15 European Champions League clubs. BMJ Open Sport Exerc Med. 2023;9:1461. https://doi.org/10.1136/BMJSEM-2022-001461.
40. Chumanov ES, Schache AG, Heiderscheit BC, Thelen DG. Hamstrings are most susceptible to injury during the late swing phase of sprinting. Br J Sports Med. 2012. https://doi.org/10.1136/bjsports-2011-090176.
41. Mueller-Wohlfahrt HW, Haensel L, Mithoefer K, Ekstrand J, English B, McNally S, et al. Terminology and classification of muscle injuries in sport: the Munich consensus statement. Br J Sports Med. 2012;47:342. https://doi.org/10.1136/BJSPORTS-2012-091448.
42. McCall A, Carling C, Nedelec M, Davison M, Le Gall F, Berthoin S, et al. Risk factors, testing and preventative strategies for non-contact injuries in professional football: current perceptions and practices of 44 teams from various premier leagues. Br J Sports Med. 2014;48:1352–7. https://doi.org/10.1136/BJSPORTS-2014-093439.

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