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Systematic video analysis of ACL injuries in professional Spanish male football (soccer): injury mechanisms, situational patterns, biomechanics and neurocognitive errors – a study on 115 consecutive cases

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ABSTRACT

Objective A few video analysis studies have been published in recent years, but none specifically on Spanish football. We aimed to describe the mechanisms, situational patterns, biomechanics and neurocognitive errors related to anterior cruciate ligament (ACL) injuries in professional Spanish football matches.

Methods We identified 167 consecutive ACL injuries across 12 seasons of the top two leagues in Spanish football. 115 (69%) injury videos were analysed for mechanism and situational pattern, while biomechanical analysis was possible in 81 cases. Neurocognitive errors were investigated for all non-contact injuries. Three independent reviewers evaluated each video. ACL injury epidemiology—month, timing within the match and pitch location at the time of injury was also documented.

Results More injuries occurred in defensive (n=68, 59%) than offensive (n=48, 41%) (p<0.01) playing situations. 16 (14%) injuries were direct contact, 49 (43%) indirect contact and 50 (43%) non-contact. Most injuries (89%) occurred during four main situational patterns: (1) pressing/tackling (n=47, 47%); (2) tackled (n=23, 23%); (3) landing from a jump (n=12, 12%) and regaining balance after kicking (n=6, 6%). Injuries generally involved a knee-dominant loading strategy in the sagittal plane with abducted hip and knee valgus. Of the non-contact injuries, 39 (78%) were deemed to involve a neurocognitive error. More (58%) injuries occurred in the first half of matches (p<0.01).

Conclusions ACL injuries in Spanish football occurred similarly with non-contact and indirect contact mechanisms (44%). Four in five non-contact injuries involved a neurocognitive error. Most injuries occurred during four previously identified situational patterns, with more injuries earlier in the match.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Anterior cruciate ligament (ACL) injury is a severe and concerning health issue for elite football players, causing long layoff time.
⇒ Several video-analysis studies of ACL injuries have been undertaken across different sports and in football.
⇒ Non-contact injuries are considered to be the most common ACL injury mechanism, but recent research suggests indirect contact ACL injuries are equally as prominent in elite football, with pressing/tackling being the dominant situational pattern.
⇒ Non-contact ACL injuries have been shown to involve 'neurocognitive errors' at the time of injury.
⇒ We know ACL injuries involve multiplanar kinematics.

WHAT THIS STUDY ADDS

⇒ This study highlights similar injury mechanisms, situational patterns, biomechanics and neurocognitive errors from previous research on Italian football matches.
⇒ This study confirms that indirect contact injuries are as common as non-contact injuries
⇒ Biomechanical analysis confirms a multiplanar mechanism, with a predominance of knee loading patterning in the sagittal plane accompanied by dynamic valgus on an abducted hip.
⇒ Injuries show a relatively consistent pattern across months during the in-season months but with a peak in February.
⇒ More injuries occurred in the first half, with a gradual decline in injuries as players played more match minutes.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Targeting the most frequent mechanisms, patterns and biomechanics may help design primary reduction measures and late-stage rehabilitation after ACL reconstruction.

INTRODUCTION

Reducing injury burden is of utmost importance for the medical and performance team in football due to the financial and team performance implications of time loss.[1] Anterior cruciate ligament (ACL) injuries are a major issue for football teams and players.

Despite a team of 25 players experiencing typically one ACL every two seasons, the high-time loss[2 3] results in a significant overall injury burden (~100 days), making it the second most burdensome injury in elite football, behind hamstring injuries.[2] Furthermore, ACL injuries are career-threatening injuries, even at the elite end of football,[4] carry a high risk for re-injury[5] and negatively impact player performance and career longevity.[3 6]

Understanding injury epidemiology and aetiology is crucial in designing injury risk mitigation programmes.[7] A key aspect of injury aetiology is establishing the contact mechanisms and context (situational patterns) in which injuries occur.[8] Video analysis is a frequently used and valid tool to investigate injury mechanisms, playing situations and gross biomechanics preceding and during actual injuries.[9] Several systematic video-analysis studies of ACL injuries have been published across different sports.[10–13] Several football articles have been published in recent years.[14–16] A previous study detailed a large consecutive number of ACL injuries (n=134), the injury mechanisms, situational patterns and kinematics of ACL injuries in Italian professional football.[14] While of important value, we do not know if these findings can be generalised across countries and leagues that might have different playing styles, levels of physicality and cultural norms. It is plausible that differences in injury mechanisms, situational patterns and injury epidemiology emerge in other countries. Furthermore, there is growing attention to the importance of neurocognitive errors in actual ACL injuries in football players,[17] which requires further study.

This study aimed to describe, using video analysis, the injury mechanisms, situational patterns, biomechanics (kinematics) and neurocognitive errors related to ACL injury in those professional football players playing in the topflight Spanish leagues (La Liga and La Liga 2). A further purpose was to document the ACL injury distribution across the match, season and pitch location.

MATERIALS AND METHODS

Injury identification and video extraction

We systematically searched online database resources across 12 seasons (from 2010/2011 to 2021/2022 until 05/2022) to identify ACL injuries occurring during matches in players of the two top leagues in Spain, La Liga and La Liga 2.

The study's methodology has previously been described[14 15] and conforms with a 'high' standard of the 'Quality Appraisal for Sports Injury Video Analysis Studies (QA-SIVAS) scale'.[18] To summarise, each season and team rosters were extracted from online databases (legaseriea.it; legab.it) and single-team websites to identify ACL injuries. Each player was then searched on the publicly available media-based platform Transfermarkt.de (Transfermarkt GmbH & Co. KG, Hamburg, Germany) to ascertain details of their injury history. This methodology has been validated for injury identification in professional football,[19] with sufficient validity and accuracy of retrieved injury-related data reported. It has been further adopted by studies on return to play in professional football.[6] The search was supplemented with further examination of data sources, which may have been missed, such as national and local media. Injuries were included only when we could corroborate the injury with official team media reports. Only injuries involving complete ACL rupture were included.

Match videos were obtained from an online digital platform (wyscout.com, Wyscout spa, (Genova, Italy)). A cloud tool (Digital Log, Digital Soccer Project S.r.l., Modena, Italy) was used to process the match videos. Each ACL injury video was cut to approximately 12–15 s before and 3–5 s after the estimated injury frame (IF) to accurately evaluate the playing situation that preceded the injury and injury mechanisms.

Video evaluation

Three reviewers (MB, JO, FDV), all involved in sports medicine and orthopaedic rehabilitation practice, with experience in video analysis research, independently evaluated the videos using two checklists (online supplemental tables 1 and 2). Each video was downloaded on a personal computer and opened with the available online software 'Kinovea' (KinoveaInk) before being analysed using an evaluation flow.

First, the injurious situation, characterised as defensive or offensive, was determined based on ball possession and a specific playing situation. A series of views were then used to determine the injury mechanism and situational pattern. Three categories of injury mechanism were used according to previous research:[14 15] (1) non-contact, defined as an injury occurring without any contact (at the knee or any other level) before or at IF; (2) indirect contact, defined as an injury resulting from an external force applied to the player, but not directly to the injured knee and (3) direct contact, defined as an external force directly applied to the injured knee. Situational patterning was performed for non-contact and indirect contact injuries only. Based on previous findings, we considered the estimation of IF as initial contact (IC) plus 40 ms.[12 14 20]

Following independent analysis, the reviewers met for 1 day to achieve consensus on all items regarding injury mechanisms and situational patterns and perform the biomechanical (kinematic) analysis (described below). Disagreements were resolved via consensus.[14 16] Before the meeting, the intraclass correlation index between the reviewers for the IC and IF was 0.99.

Biomechanical analysis (kinematics)

According to previous research, kinematic analysis was performed during the consensus meeting on non-contact and indirect contact injuries only when a sufficient quality frontal and/or sagittal view was available.[14 16] The analysis was performed to estimate intersegmental relationship and joint angles on the frontal and sagittal plane only at both the IC and IF.

Sagittal plane angles and trunk tilt were estimated using custom-made software (Screen Editor, GPEM srl, Genova, Italy) to the nearest 5°. The estimated joint positions of the remaining frontal and coronal planes were categorised according to appearance. Foot strike was evaluated according to the previous methodology[14,16] and after foot contact to the ground at IC and IF. The items that have been evaluated are listed in online supplemental table 2.

Neurocognitive analysis

The neurocognitive analysis has been described previously.[17] Like previous research,[17] we were interested in inhibitory control: motor response inhibition and attentional inhibition.[17,21] We defined motor response inhibition as stopping unwanted and incorrect motor actions.[17,21] As there is a delay between the presentation of a stimulus (eg, opposing players deceiving action) and generating an appropriate reactive response,[21] we, according to previous research, operationalised the player had around 450–1200 ms to change the motor response (eg, react to a deceiving action of a player such as faking to go one direction and moving in another).[22] For this assessment, on the checklist, the reviewers had to record if, during non-contact injuries, the opposing player performed a deceiving action during defensive situations (eg, pressing or tackling injuries) indicative of poor inhibitory control. The second aspect of our neurocognitive analysis was determining if the player had demonstrated an error in attentional inhibition. Selective attention was defined as the player focusing on a particular situation for a certain degree of time.[21] An error in attentional inhibition was determined as the player shifting their selective attention (looking elsewhere) away from the relevant task, leading to injury to other stimuli the player could not directly impact, such as the ball/environment, suggestive of attentional inhibition. We deemed that loss of attentional focus/direction of visual attention could lead to spatial unawareness and altered neuromuscular control (eg, altered muscle preactivation before landing).[17]

Seasonal, match and field distribution

For each available injury video, a list of data regarding the seasonal, match and field distribution was gathered through the systematic web revision and the analysis of the videos in relation to the injured player position. We considered (1) the month of ACL injury, (2) the phase of the game when the ACL injury occurred (minute and a half), (3) the number of minutes played by the ACL-injured athlete and (4) field location according to previously published methodology.[14] The player's position on the pitch at the time of ACL injury was gathered according to the field lines. The football pitch was divided into 11 zones according to online supplemental table 1.[14] The square-metre field zone dimensions were calculated considering the official Fédération Internationale de Football Association (FIFA) football field size (105 by 70 m) (see online supplemental material 1).

Patient and public involvement

The study results will be shared with publicly available resources (eg, newspapers) to sensitise the audience to the specific injury mechanisms, situational patterns, neurocognitive errors and biomechanics of ACL injuries specific to elite Spanish male football.

Equity, diversity, inclusion

Millions of women worldwide play football, and BMJ Open Sports and Exercise Medicine encourages research that includes sex and gender-based analysis. We have previously published a study using similar approaches to female football,[15] including a sample of ACL injuries across numerous European leagues, including Spain. Future research should look to delineate ACL mechanisms across leagues in female football.

Ethical considerations

All the videos we accessed are publicly available, in which data were treated confidentially and no personal player information was accessed. Therefore, ethical permission was not required.[14]

Statistical analysis

Continuous variables have been presented as mean (±SD) or median (range) as appropriate according to variable distribution. Discrete variables were presented as absolute numbers and percentages on the number of total observations. The proportion test was used to explore possible differences in the distribution of ACL injuries between match halves. An alpha less than 0.05 denoted statistical significance. Microsoft Excel 2016 (Microsoft, USA) and Stata V.12 (StataCorp, Texas, USA) were used for these analyses.

RESULTS

167 ACL injuries were tracked and included. 64 injuries occurred during La Liga, 70 during La Liga 2, 20 during friendlies, 6 during Copa del Rey, 3 during the Europa Cup, 2 during the Champions League and 1 each during national team and U21 European cup matches. There were 94 injuries to the right and 77 injuries to the left ACL, with 89 (53%) injuries to the dominant kicking leg and 77 (46%) to the non-kicking leg (1 unknown). There were 131 primary, 14 contralateral native and 21 previously reconstructed (ACL graft re-injuries) ACL injuries (1 case unsure). Video footage was available and identifiable for situational pattern and injury mechanism analysis in 115 cases (69%). A detailed study flow is shown in figure 1.

Injury mechanism analysis

More injuries occurred in defensive (n=68, 59%) than offensive (n=47, 41%) ($p<0.01$) situations. Most injuries (107 cases; 98% of identifiable cases) involved loading of the injured leg, with single limb loading on the ground frequently observed (83 cases; 76% of identifiable cases). We categorised 50 (43%) non-contact, 49 (43%) indirect contact and 16 (14%) direct contact injuries. A large

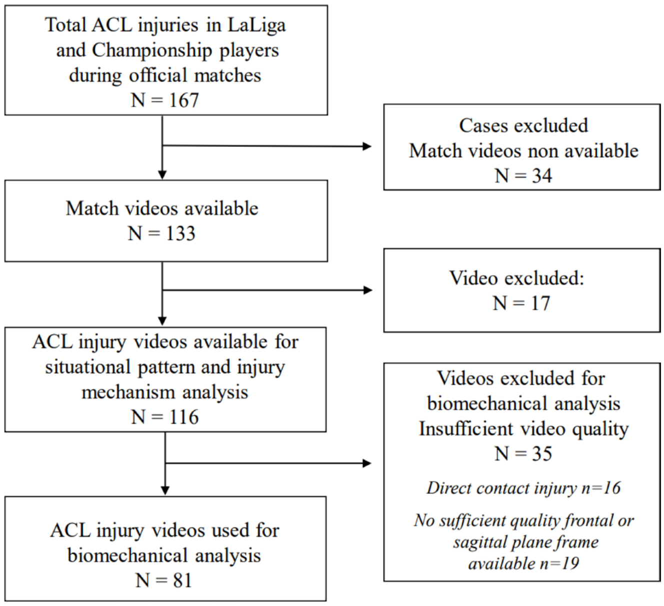

Figure 1 Detailed flow chart of the study. ACL, anterior cruciate ligament.

proportion of injuries involved high or moderate horizontal speeds (86 cases, 79% of identifiable cases), while few (16 cases, 15% of identifiable cases) involved high or moderate vertical speeds at IC (table 1).

Direct contact injuries

Direct contact injuries (n=16, n=14%) occurred in both defensive (n=8, 50%) and offensive (n=8, 50%) playing situations, with eight (50%) injuries occurring while being tackled, seven (44%) while tackling and one collision (6%).

Situational pattern of indirect and non-contact injuries

Four main situational patterns were identified for non-contact or indirect contact ACL injuries (n=99), accounting for 89% of injuries:

1. Pressing/tackling (n=47, 47%).
   a. Pressing (n=32, 32%).
   b. Tackling (n=15, 15%).
2. Tackled (n=23, 23%).
3. Landing from a jump (n=12, 12%).
4. Regaining balance after kicking (n=6, 6%).

Finally, the other 11 cases did not fall into one of the overmentioned categories. They included offensive change of direction (COD) (n=4), kicking/passing the ball (stance leg injured, n=3), reaching for the ball, diving to make a save (goalkeeper), sliding and tripping over. Additional details are reported in table 1.

Pressing and tackling injuries (n=47) were all defensive, where the player approached the opponent to close space and/or make a tackle. In pressing (n=32), the player was predominantly injured during non-contact (n=31, 97%) deceleration or cutting (figure 2A). All tackling injuries were indirect (n=15, 100%) and involved contact from an opposing player at or before IF to the upper body (n=13, 87%; the remaining two cases were unsure) (figure 2B).

Being 'tackled', the second most common situation (23%), typically involved a dual-type interaction between the opponent and the injured player (figure 2C), all being indirect contact (contact was typical to the upper body at or before IF) in offensive situations.

Landing from a jump (12%) was the third most common pattern, occurring more in indirect contact (n=8, 66%) than in non-contact (n=4, 33%). The indirect contact injuries typically involved contact before IC (n=8, 100%), generally to the upper body (n=7), but occurred without contact at IF (75%) (figure 2D).

Regaining balance after kicking was included as a main situational pattern despite a low proportion of injuries (6%). These were commonly non-contact (n=4, 66%).

Biomechanical analysis

Biomechanical analysis was possible in 81 cases. All angle data are reported as median values. On the sagittal plane at IC, players displayed an upright trunk (5°), an early flexed hip (45°), shallow knee flexion (25°) and an early plantar flexed ankle (−15°), generally with heel (52%) or flat foot (32%) appearance. On the frontal plane at IC, the trunk was tilted ipsilaterally (10°) and rotated towards the uninjured side (47%), with an abducted hip (86%), neutral (52%) or valgus knee (36%) appearance and externally rotated (59%) or neutral (30%) foot appearance.

From a sagittal plane perspective at estimated IF, the trunk remained upright (5°), with the same hip flexion (45°), greater knee flexion (55°, +30° from IC) and minimally dorsiflexed ankle (5°, +20° dorsiflexion from IC), with planted flat foot (83%). On the frontal plane, the trunk was still tilted ipsilaterally but to a lesser extent than at IC (5°, –5° from IC) and similarly rotated position as at IC (uninjured, 49%; neutral, 17%; injured, 23%). The hip remained abducted in most cases (79%), with a greater prevalence of knee valgus (88%, 97% of all identifiable cases) and externally rotated (70%) or neutral (19%) foot appearance. A significant increase in valgus appearance from IC to IF was apparent in most cases (68%). Additional details are reported in table 2.

Neurocognitive factors

Of 50 non-contact injuries, 39 (78%) were deemed to involve a neurocognitive error, with 30 (77%) injuries involving motor inhibitory response and 9 (23%) an attentional error. Of those classified as motor response inhibition, 20 (66%) involved a deceiving action, occurring at a median time of 240 ms before IC. For the pressing injuries (n=31), 26 (84%) involved a neurocognitive error, all being motor response inhibition (figure 3), with 18 involving a deceiving action from the opposing attacking player at a median of 240 ms before IC. The attentional errors (n=9) were present in regaining balance after kicking (n=3), landing from jump (n=2) (figure 3) and other (n=4).

Table 1 Details of injury mechanism according to a predefined checklist (n=115) for all injuries and across identified situational patterns for indirect contact and non-contact injuries (n=99)

		Non-contact and indirect contact situational patterns (n=100)				
Variables	**All injuries (n=115)**	**Pressing/ tackling (n=47)**	**Tackled (n=23)**	**Landing from jump (n=12)**	**Regaining balance after kicking (n=6)**	**Other (n=11)**
Playing phase before injury	Off (47), def (68)	Def (47)	Off (23)	Off (3), def (9)	Off (5), def (1)	Off (8), def (3)
Injury side	Right (68), left (47)	Right (27), left (20)	Right (11), left (12)	Right (6), left (6)	Right (2), left (4)	Right (7), left (4)
Dominant (kicking) leg injured	Yes (60), no (55)	Yes (24), no (23)	Yes (7), no (16)	Yes (7), no ()	Yes (4), no (2)	Yes (6), no (5)
Field location at injury						
Long axis of the field (zone)	Def third (34), middle third (48), off third (33)	Def third (14), middle third (21), off third (12)	Def third (5), middle third (10), off third (8)	Def third (5), middle third (5), off third (2)	Def third (1), middle third (2), off third (3)	Def third (5), middle third (4), off third (2)
Short axis of the field (corridor)	Left third (23), middle third (64), right third (28)	Left third (8), middle third (23), right third (16)	Left third (6), middle third (10), right third (7)	Left third (1), middle third (10), right third (1)	Middle third (5), right third (1)	Left third (4), middle third (7)
Player contact preceding injury	Yes (43), no (65), unsure (7)	Yes (16), no (29), unsure (2)	Yes (12), no (9), unsure (2)	Yes (10), no (2)	Yes (1), no (4), Unsure (1)	No (11)
If contact, where?	Upper body (35), injured leg (5), knee (2), foot (1)	Upper body (14), injured leg (1)	Upper body (10), foot (1), unsure (1)	Upper body (9), injured leg (1)	Upper body (1)	–
Player contact at injury frame	Yes (36), no (73), unsure (7)	Yes (11), no (34), unsure (2)	Yes (9), no (12), unsure (2)	Yes (2), no (10)	Yes (2), no (4)	No (11)
If contact, where?	Upper body (19), knee (10), injured leg (7)	Upper body (9), knee (2)	Upper body (7), injured leg (2)	Injured leg (1), upper body (1)	Injured leg (2)	–
Injury classification	Direct contact (16), indirect contact (49), non-contact (50)	Indirect contact (16), non-contact (31)	Indirect contact (23)	Indirect contact (8), non-contact (4)	Indirect contact (2), non-contact (4)	Non-contact (11)
Feet on ground at time of injury	One (83), two (26), unsure (6)	One (36), two (10), unsure (2)	One (19), two (2), unsure (2)	One (12)	One (5), two (1),	One (7), two (4)
Leg loading at IF	Injured leg (107), both (2), unsure (6)	Injured leg (45), both legs (1), unsure (2)	Injured leg (21), unsure (2)	Injured leg (12)	Injured leg (6)	Injured leg (11)
Horizontal speed	Zero (7), low (16), moderate (60), high (26), unsure (6)	low (4), moderate (31), high (10), unsure (2)	Low (4), moderate (10), high (7), unsure (2)	Zero (4), low (3), moderate (3), high (2)	low (3), moderate (2), high (1)	Zero (2), low (1), moderate (6), high (2)
Vertical speed	Zero (73), low (20), moderate (12), high (4), unsure (6)	Zero (36), low (6), moderate (3), unsure (2)	Zero (12), low (7), moderate (2), unsure (2)	Low (1), moderate (7), high (4)	Zero (4), low (2)	Zero (8), low (3)

def, defensive; IF, injury frame; off, offensive.

Seasonal, match and field distribution

Data for seasonal (n=167), match timing (n=123), position (n=123) and field distribution (n=123) were available. Seasonal distribution demonstrated a lower number of injuries in June and a similar number from July to January, but then with a peak in February, followed by a gradual decline until the end of the season (figure 4).

More injuries occurred during the first (n=73, 58%) than the second (n=50, 42%) half (p<0.01) (figure 5). When considering the minutes played correcting for

Figure 2 Visual representation of the main situational patterns. (A) Pressing (player in yellow jersey, right ACL injury): approaching/pressing the opponent (A1), initial contact of the right foot with the ground (A2), estimated injury frame of right ACL (A3), loss of balance (A4). (B) Tackling (player in white jersey, right ACL injury): approaching/pressing the opponent (B1), initial contact of the right foot with the ground and attempted tackle (B2), estimated injury frame of right ACL (B3), loss of balance (B4). (C) Being tackled (player in red jersey, right ACL injury): pressed by opposing player (C1), mechanical perturbation/contact from defending player (C2), estimated injury frame of right ACL (C3), loss of balance (C4). (D) Landing from a jump (goalkeeper, green kit, right ACL injury): jumping (D1), initial contact of both feet with the ground (D2), estimated injury frame of right ACL (D3), loss of balance (D4). ACL, anterior cruciate ligament.

substitutions, 50% of ACL injuries occurred in the first 30 min (figure 5). Injuries occurred in 8 goalkeepers, 45 defenders, 43 midfielders and 27 attackers. Injuries according to pitch location are detailed in online supplemental tables 3 and 4 and online supplemental figures 1–4.

DISCUSSION

The most important findings of the present study are: (1) most ACL injuries in professional Spanish male football occur without direct contact mechanism, with non-contact injuries being the most common injury mechanism; (2) four main situational patterns were identified, accounting for 89% of injuries; (3) ACL injuries involve multiplanar kinematics and (4) more injuries occur in the first half.

Injury mechanisms

More ACL injuries occurred while defending (59%), like previous research in football.[14 16] Our data again indicate that ACL injuries occur more commonly during high-velocity horizontal deceleration rather than vertical

Table 2 Sagittal, frontal and transverse plane metrics of non-contact or indirect contact anterior cruciate ligament injuries for all injuries and stratified (data on 81 cases)

Variables	Total	Pressing/ tackling	Tackled	Landing from jump	Regaining balance after kicking	Other
Sagittal plane metrics						
Flexion angle (°) (+ flexion, − extension)						
Trunk at IC	5 (−40, 35)	5 (−40, 35)	10 (0, 25)	20 (−25, 20)	−7.5 (−25, 0)	−5 (−15, 10)
Trunk at IF	5 (−40, 35)	5 (−45, 35)	10 (0, 35)	30 (−25, 30)	−5 (−20, 0)	2.5 (−10, 30)
Hip at IC	45 (0, 80)	50 (10, 60)	55 (10, 80)	40 (0, 55)	17.5 (10, 35)	42.5 (25, 50)
Hip at IF	45 (5, 85)	50 (5, 85)	60 (5, 80)	45 (15, 55)	25 (25, 35)	47.5 (15, 80)
Knee at IC	25 (5, 60)	30 (10, 60)	25 (5, 55)	20 (15, 40)	32.5 (15, 35)	27.5 (10, 30)
Knee at IF	55 (−40, 85)	55 (35, 85)	60 (−40, 85)	40 (40, 65)	37.5 (25, 60)	55 (0, 70)
Ankle at IC	−15 (−40, 30)	−15 (−35, 20)	−25 (−40, 0)	5 (−35, 15)	−7.5 (−25, 30)	−17.5 (−25, −10)
Ankle at IF	5 (−30, 35)	10 (−10, 30)	0 (−30, 35)	10 (−30, 25)	−2.5 (−20, 35)	0 (−20, 25)
Foot strike appearance IC						
Heel	42 (52%)	25 (69%)	11 (55%)	2 (18%)	1 (20%)	3 (33%)
Flat	26 (32%)	9 (25%)	5 (25%)	3 (27%)	3 (60%)	6 (67%)
Toe	8 (10%)	1 (3%)	1 (5%)	5 (45%)	1 (20%)	0 (0%)
Unsure	5 (6%)	1 (3%)	3 (15%)	1 (9%)	0 (0%)	0 (0%)
Foot strike appearance IF						
Heel	1 (1%)	0 (0%)	0 (0%)	1 (9%)	0 (0%)	0 (0%)
Flat	67 (83%)	29 (81%)	17 (85%)	8 (73%)	5 (100%)	8 (89%)
Toe	8 (10%)	6 (17%)	0 (0%)	1 (9%)	0 (0%)	1 (11%)
Unsure	5 (6%)	1 (3%)	3 (15%)	1 (9%)	0 (0%)	0 (0%)
Frontal and transverse plane metrics						
Trunk tilt IC (+ ipsilateral, − contralateral)	10 (−25, 40)	10 (10, 30)	10 (−5, 25)	17.5 (−20, 40)	−2.5 (−20, 30)	10 (−25, 25)
Trunk tilt IF (+ ipsilateral, − contralateral)	5 (−30, 50)	5 (5, 40)	10 (−10, 35)	15 (10, 50)	−5 (−30, 30)	10 (−20, 40)
Trunk rotation IC						
Towards injured	18 (22%)	10 (28%)	1 (5%)	3 (27%)	2 (40%)	2 (22%)
Neutral	17 (21%)	4 (11%)	8 (40%)	0 (0%)	2 (40%)	3 (33%)
Towards uninjured	38 (47%)	18 (50%)	10 (50%)	7 (64%)	0 (0%)	3 (33%)
Unsure	8 (10%)	4 (11%)	1 (5%)	1 (9%)	1 (20%)	1 (9%)
Trunk rotation IF						
Towards injured	19 (23%)	10 (28%)	2 (10%)	3 (27%)	2 (40%)	2 (22%)
Neutral	14 (17%)	4 (11%)	5 (25%)	2 (18%)	1 (20%)	2 (22%)
Towards uninjured	40 (49%)	18 (50%)	12 (60%)	5 (45%)	1 (20%)	4 (44%)
Unsure	8 (10%)	4 (11%)	1 (5%)	1 (9%)	1 20(%)	1 (11%)
Frontal plane hip alignment IC						
Abduction	70 (86%)	32 (89%)	18 (90%)	9 (82%)	4 (80%)	7 (78%)
Neutral	2 (2%)	0 (0%)	0 (0%)	1 (9%)	0 (0%)	1 (11%)
Adduction	1 (1%)	0 (0%)	1 (5%)	0 (0%)	0 (0%)	0 (0%)
Unsure	8 (10%)	4 (11%)	1 (5%)	1 (9%)	1 (20%)	1 (11%)
Frontal plane hip alignment IF						
Abduction	64 (79%)	30 (83%)	16 (80%)	10 (91%)	3 (60%)	5 (56%)
Neutral	6 (7%)	1 (3%)	1 (5%)	0 (0%)	1 (20%)	3 (33%)

Continued

Table 2 Continued

Variables	Total	Pressing/ tackling	Tackled	Landing from jump	Regaining balance after kicking	Other
Adduction	3 (4%)	1 (3%)	2 (10%)	0 (0%)	0 (0%)	0 (0%)
Unsure	8 (10%)	4 (11%)	1 (5%)	1 (9%)	1 (20%)	1 (11%)
Frontal plane knee alignment IC						
Valgus	29 (36%)	12 (33%)	7 (35%)	5 (45%)	2 (40%)	2 (22%)
Neutral	42 (52%)	18 (50%)	11 (55%)	5 (45%)	2 (40%)	6 (67%)
Varus	2 (2%)	2 (6%)	1 (5%)	0 (0%)	0 (0%)	0 (0%)
Unsure	8 (10%)	4 (11%)	1 (5%)	1 (9%)	1 (20%)	1 (11%)
Frontal plane knee alignment IF						
Valgus	71 (88%)	32 (89%)	17 (85%)	10 (91%)	4 (80%)	8 (89%)
Neutral	1 (1%)	0 (0%)	1 (5%)	0 (0%)	0 (0%)	0 (0%)
Varus	1 (1%)	0 (0%)	1 (5%)	0 (0%)	0 (0%)	0 (0%)
Unsure	8 (10%)	4 (11%)	1 (5%)	1 (9%)	1 (20%)	1 (11%)
Foot position IC						
External	48 (59%)	23 (64%)	13 (65%)	6 (54%)	2 (40%)	4 (44%)
Neutral	24 (30%)	9 (25%)	5 (25%)	4 (36%)	2 (40%)	4 (44%)
Internal	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Unsure	9 (11%)	4 (11%)	2 (10%)	1 (9%)	1 (20%)	1 (11%)
Foot position IF						
External	57 (70%)	29 (81%)	13 (65%)	7 (64%)	2 (40%)	6 (67%)
Neutral	15 (19%)	3 (8%)	5 (25%)	3 (27%)	2 (40%)	2 (22%)
Internal	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Unsure	9 (11%)	4 (11%)	2 (10%)	1 (9%)	1 (20%)	1 (11%)
Significant increase in valgus alignment from IC to IF						
Yes	55 (68%)	27 (75%)	11 (55%)	9 (82%)	2 (40%)	6 (67%)
No	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Unsure	26 (31%)	9 (25%)	9 (45%)	2 (18%)	3 (60%)	3 (33%)

ADD, adduction; IC, initial contact; IF, injury frame; IR, internal rotation.

deceleration tasks, like previous research in football[14] and other sports, including rugby[10] and basketball.[13] Injury risk mitigation programmes should emphasise the importance of horizontal deceleration training.

The low number of direct contact injuries (14%) is similar to previous research in European football (12%)[14 16] and suggests that most ACL injuries in elite male football may be preventable. We found a nearly identical proportion of non-contact (43%) and indirect contact (43%) to previous research on Italian football (n=44%).[14] This reiterates the importance of both non-contact and indirect contact mechanisms in ACL injury causation. Indirect contact injuries are highly prevalent for ACL injuries in other sports, such as rugby[10] and American football.[11] Most of these indirect contact injuries involved contact to the injured player's upper body at or before IF, which is thought to lead to mechanical perturbation resulting in loss of neuromuscular control and suboptimal kinematics.[23] Programme design should recognise the role of indirect contact in injury causation and include training to develop motor control when exposed to mechanical perturbation, particularly contact with the upper body.

Situational pattern of non-contact and indirect injuries

We identified four key situational patterns explaining 89% of non-contact and indirect contact ACL injuries: (1) pressing/tackling, (2) being tackled, (3) landing from a jump and (4) regaining balance after kicking, like our previous research on Italian football.[14]

The portion of pressing/tackling injuries (47% vs 47%) and tackled (23% vs 20%) injuries is nearly identical to previous research on Italian football players[14] and further emphasises these two patterns as the main situational patterns collectively explaining around two-thirds of indirect and non-contact ACL injuries. The proportion of injuries from landing from a jump was 12%, which was lower than early research from Waldén *et al*[16] (25%) but

Figure 3 Non-contact injury examples with neurocognitive error. Pressing situational pattern with opponent deceiving action: pressing (A), deceiving action (B), initial contact of the foot with the ground (also with a visual attentional shift to the ball) (C), estimated injury frame (D). Non-contact landing from a jump with attentional error: jumping to save the ball but with technical error (E), initial contact of the foot with vision/ selective attention away from the ground to the ball (F), estimated injury frame (G), loss of balance (H).

higher than our work on Italian football (7%).[14] While this may imply that vertical landing control is key, many of the landings from jump injuries involved landing from a combination of moderate or high vertical and horizontal speeds. Few landing injuries involved moderate or high vertical velocity only. Again, this has implications for neuromuscular training for injury risk mitigation and highlights a need to include both vertically (eg, single leg landings from box or standing headers) and horizontally (eg, hop and hold, broad jumps) orientated landing drills.

We found a low proportion of injuries from regaining balance after kicking (6%), which was previously highlighted as the third main situational pattern in Italian football (16%).[14] It is unsure why regaining balance after kicking was lower versus previous research. It may relate to playing styles across the leagues, potential injury risk mitigation processes and the anthropometrics of the players. Although the number of injuries occurring while regaining balance after kicking was low, we decided to include it as a main situational pattern for comparison to previous research.

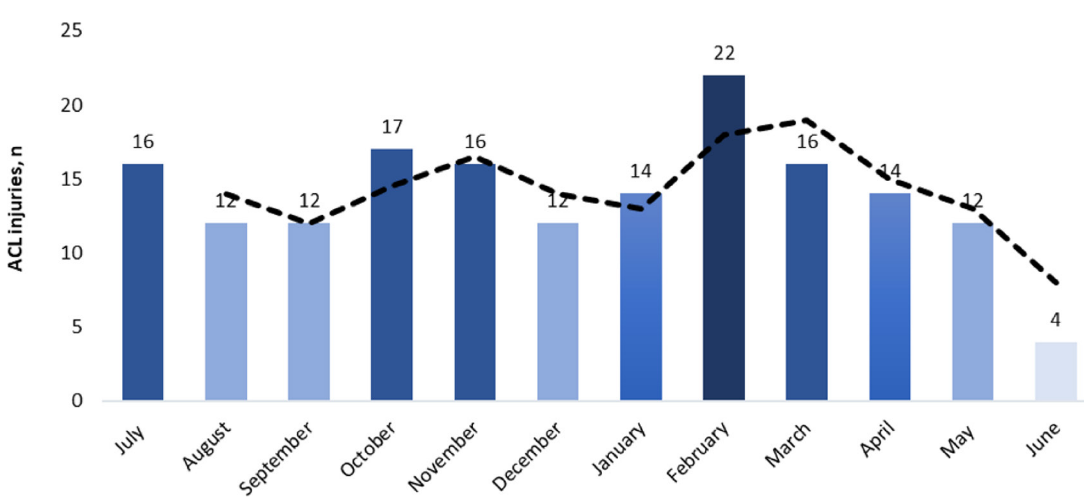

Figure 4 Distribution of ACL injuries (n=167) throughout the football season according to month of the year. The trend line displays the 2-month rolling average. ACL, anterior cruciate ligament.

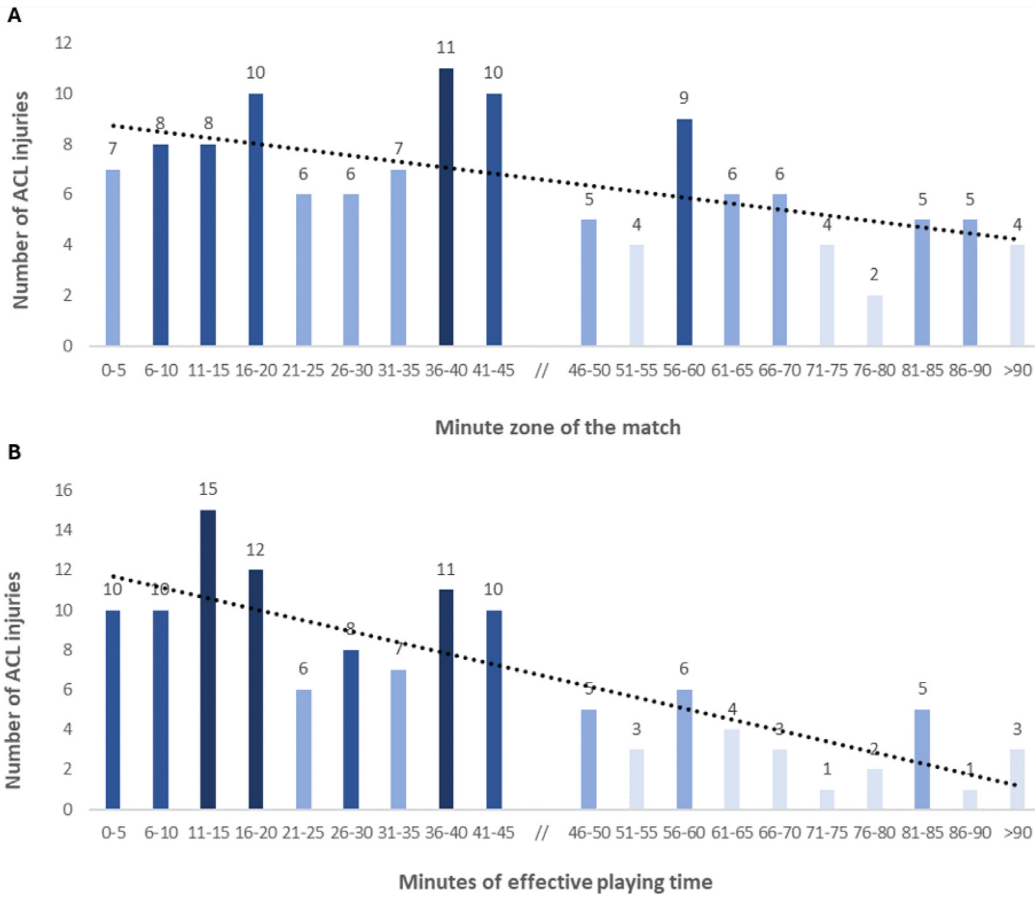

Figure 5 Distribution of ACL injuries throughout the match according to match minutes and specific time zone/period (A) (n=123) and minutes of effective playing time (B) (n=122). Dashed lines represent the linear trend line. ACL, anterior cruciate ligament.

Biomechanics (kinematics)

Our data again support the existing literature showing ACL injuries generally occur in early knee flexion, with dynamic knee valgus loading.[12–14 16 20] We reported a predominant knee loading movement pattern (knee dominant) in the sagittal plane. From IC to IF, there was no/minimal change in hip or trunk flexion, reduced ankle dorsi flexion, but a reasonably large increase in knee flexion (+30°). The 25° knee angle at IC corresponds to high ACL loading and a vulnerable position.[24] The increase in knee flexion from IC to IF (+30°) is slightly higher than the body of published research (15–25°).[14 16 20] The knee flexion angle at IF (55°) is also higher than previously reported in male football (30–40°)[8 16] and other published studies across other sports (30–53°) using video analysis[10 13 15] as well as model-based image matching approaches (47°).[20 25] The change in knee flexion from IC to IF was like that in movements, not resulting in injury (+30° vs +34°),[26] indicating that differences in injury pattern versus uninjured occurrences in this cohort were unlikely due to altered knee sagittal plane strategy (eg, not due to reduced knee flexion). This contrasts with previous research typically showing reduced knee flexion at the time of injury, indicative of knee avoidance in the sagittal plane.[10 14 16]

Injuries were estimated to occur in minimal dorsiflexion (5°) with typical increases in dorsiflexion of +20° from IC to IF. The dorsiflexion at IF is similar to previous research.[13 14 16] Still, the increase in dorsiflexion from IC to IF is higher than our previous research in male Italian (+10°),[14] as well as female football (+12.5°),[15] although identical to that in male basketball (+20°).[13] This ankle flexion increase from IC to IF is dramatically reduced compared with that reported in controls performing similar movements and not sustaining ACL injuries (+44°).[9 26] A flat-footed strike pattern (83% of cases at IF) and reduced ankle angular motion (+20° vs 44°) likely contributed to ankle stiffness and knee joint loading by hindering the calf muscle's ability to absorb external ground-reaction forces while decelerating, landing or cutting.[27] This, in combination with minimal trunk and hip motion, suggests preferential sagittal plane loading at the knee level. ACL injuries typically occur with around three to four times body mass (2000–3000 n) vertically directed ground reaction force.[12] In this sagittal plane scenario, these forces would likely be preferentially focused on the knee, predisposing it to injury.

The preferential knee loading at the time of injury on the sagittal plane was accompanied by altered frontal and transverse plane motions, which were considered crucial for ACL injury.[28] An increase in knee valgus suggestive of valgus-type loading from IC to IF was found, as in previous research.[12 14 16] Of note is that valgus appearance was apparent in nearly all observable (96%) cases, as in previous research.[14] It is unknown from our work if valgus caused or was the result of the ACL injury.

Similarly, hip abduction motion was common.[12 14 16] This common increase in frontal plane motion is likely due to the high external knee abduction moment, determined by hip abduction[29 30] on a laterally orientated and planted foot position outside the base of support.[29 31] A wide-foot stance is a major contributor to knee abduction moments in cutting tasks.[29]

We found a lateral trunk tilt towards the injured limb at IC (10°), like previous research in football[14] and other sports,[13] but larger than previous studies on male professional rugby players (5°).[10] From IC to IF, we found a reduction in trunk lean (−5°, from 10° to 5°), which differs from our work on Italian football,[14] which found an increase from IC to IF. The reduction in trunk lean for all injuries was largely due to a reduction in lateral trunk lean during pressing/tackling (from 10° to 5°). The identified trunk lean at IC for pressing/tackling injuries was the same as the previous study on Italian football players (10°),[14] although that study reported a 7.5° increase from IC to IF (17.5° at IF), while here we reported a 5° reduction in this cohort. A lateral-orientated trunk is thought to increase ACL loading due to a lateral shift of the centre of mass, achieving a resultant vector line lateral to the knee joint, thereby increasing the knee abduction moment.[30]

In summary, the kinematic analysis in our study confirms a knee-dominant strategy on the sagittal plane, with no flexion from IC to IF at the trunk/hip and reduced motion at the ankle, respectively, suggestive of reduced loading at these joints. This higher knee flexion strategy was nearly always accompanied by a wide foot stance, abducted hip at IC and dynamic valgus appearance at IF and lateral trunk lean at IC but not IF.

Neurocognitive errors

We reported a ‘neurocognitive error’ in four of every five (78%) non-contact ACL injuries. This provides further support that neurocognitive errors may have contributed to the events leading to a non-contact ACL injury.[17] Like previous research, we found pressing injuries to involve a deceiving action by the opposing attacking player (half of the injuries involving a neurocognitive error) while the ACL-injured player was defending. This has been termed ‘poor motor response inhibition’. Elite football players are true masters in making deceptive movements, and opponents must be able to predict the outcome of these deceptions. A defender must react quickly, inhibit an already initiated response and plan and execute a new movement within this short time window (~250 ms).[17] Giesche *et al*[32] reported that unplanned actions may result in at-risk knee biomechanics. Thus, it is possible the altered biomechanics were a result of a fast-initiated reactive movement task in response to a deceiving action of the opposing attacking player.

The non-contact injuries involving an attentional inhibition error (18% of all non-contact ACL injuries) are important in understanding injury causation of non-contact injuries. Unlike motor response inhibition, the externally directed attention away from the movement task (eg, impact landing) is thought to result in attention being taken away from temporospatial awareness of the player’s movement, thereby compromising motor control, leading to ACL injury. This attentional error may lead to altered neuromuscular activation before IC, compromising dynamic joint stability and leading to at-risk biomechanics and resulting in ACL injury. Of note, all landing from jump injuries involved the player’s attention external to the ground at the time of IC. ACL ruptures have been shown to occur within 50 ms of ground contact,[12 14 20] which is much longer than the ACL/hamstring reflex arc (85–110 ms).[33] Thus, optimal feedforward motor patterns with appropriate muscle pre-activation to develop tension and stabilise the joint before ground contact are essential in injury prevention.[34] Reduced hamstring pre-activation during cutting tasks has been identified as a prospective risk factor for ACL injuries in a female athlete cohort,[34] and it is possible the altered attention before IC leads to altered neuromuscular pre-activation of the muscles of the lower limb and resultant ACL injury.

Positional, seasonal, match and field distribution

We found a relatively consistent pattern of ACL injuries throughout the year in this cohort of elite Spanish matches, in contrast to previous research in Italian football.[14] Like previous research, the lower proportion of injuries in June and May likely relate to reduced match play during these months.[14] Previously, in Italian football,[14] a higher proportion of ACL injuries occurred during the first part of the season (September–October) and a secondary peak (March–May) compared with the winter months (January–February) was noted. It was speculated this could have been due to sunny/hot weather and hard/dry fields, which are thought to increase injury risk[35] and higher rainfall in those winter months. The current findings cannot support this conclusion. Differences in match incidence across months may more likely reflect ACL incidence in these months and player preparation, but further research is needed to corroborate this.

Although we found an increase in injuries towards the end of the first half, as there was a 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 ACL injuries, supporting previous research.[9 14] Other factors associated with the earlier periods of the match, such as lack of physical preparedness[14] and intense engagements,[36] maybe more important. The pattern of injuries according to effective match minutes follows a similar trend to previous research on Italian football.[20] We found nearly a quarter and a half of injuries occurring in the first 15 and nearly half in the first 30 min of effective match play minutes, respectively.

The field distribution showed a slightly higher prevalence of injury in the midfield third, in contrast to previous research in football,[14] which showed a higher number of injuries in the defensive third and fewer injuries in the middle of the pitch. Differences may relate to playing styles and divergence in situational patterns between leagues.

Practical implications

Understanding injury mechanisms is key to designing effective injury risk mitigation practices.[7 8] Our work collectively suggests that many ACL injuries in elite Spanish football may be preventable, with less than one in seven occurring because of direct contact and half being non-contact. Importantly, these non-contact ACL injuries typically involved a distraction or altered attentional focus at the time of injury, indicating a role of neurocognitive in injury causation,[17] which should be considered when designing injury risk screening and mitigation programmes. More than two in every five injuries were indirect contact, suggesting mechanical perturbation is an important factor in ACL causation. Our work suggests that improving neuromuscular control/kinematics during single-leg landing and horizontal deceleration (including landing tasks) and cutting actions in response to either mechanical or neurocognitive perturbation may be important to reduce ACL injury risk, as well as eccentrically strengthening the lower limb and quadriceps to develop the capacity to absorb high deceleration forces in the sagittal plane.[37] Previous research has shown that change of direction technique may be effectively trained to reduce external knee abduction moment,[30] and altered kinematics at the time of screening for change of direction kinematics is prospectively associated with ACL injury risk, at preliminarily in a small group of female football players.[38]

Methodological considerations

The main strengths of our study are (1) the sample size, alongside previous work in Italian football, it is the largest to date in systematic video-analysis study of ACL injuries; (2) the consecutive nature of the 116 injuries analysed; (3) the consistent biomechanical analysis with the use of measurement tools of three independent viewers and (4) the presentation of field, match and seasonal distribution data, only presented previously once on a group on Italian only football matches. The weaknesses of the study lie in the methodology used to identify ACL injuries, again different from the gold standard of prospective studies with frequent contact with the teams[39] and the use of video analysis with assessment of kinematics using video and tools, as opposed to the gold standard model-based image-matching technique.[40] However, the video analysis method is valid[40] and consistently adopted in many previous studies.[5 10–12 14 16] Another limitation of our study was the exclusion of training injuries, which could interfere with the overall presentation of ACL injuries in professional football. Furthermore, the inclusion of many injuries over multiple years (n=12 seasons) while being a strength due to the large sample size, it is possible there could be changes in mechanisms, situational patterns, biomechanics and/or neurocognitive errors over the course of the study, due to changes in the nature of football (eg, intensity increases) and further research to document ACL injury mechanisms, situational patterns, biomechanics and/or neurocognitive errors of current and recent seasons versus previous seasons may be warranted.

CONCLUSIONS

Our work provides further evidence that most ACL injuries occur without direct knee contact in professional football. In Spanish football, non-contact is the dominant injury mechanism, explaining nearly half of all injuries, while two in five occur with indirect contact. Four in five non-contact injuries involved a neurocognitive error. Pressing/tackling and being tackled represent more than two-thirds of all indirect contact and non-contact ACL injuries, with landing from the jump being the third and final dominant situational pattern. Injuries occur more during defensive and horizontal intense actions and more so in the first half. This information may be useful for better comprehending potential situations that may be considered in primary and secondary reduction (rehabilitation) settings.

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