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Three distinct mechanisms predominate in non-contact anterior cruciate ligament injuries in male professional football players: a systematic video analysis of 39 cases

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ABSTRACT

Background Current knowledge on anterior cruciate ligament (ACL) injury mechanisms in male football players is limited.

Aim To describe ACL injury mechanisms in male professional football players using systematic video analysis.

Methods We assessed videos from 39 complete ACL tears recorded via prospective professional football injury surveillance between 2001 and 2011. Five analysts independently reviewed all videos to estimate the time of initial foot contact with the ground and the time of ACL tear. We then analysed all videos according to a structured format describing the injury circumstances and lower limb joint biomechanics.

Results Twenty-five injuries were non-contact, eight indirect contact and six direct contact injuries. We identified three main categories of non-contact and indirect contact injury situations: (1) pressing (n=11), (2) re-gaining balance after kicking (n=5) and (3) landing after heading (n=5). The fourth main injury situation was direct contact with the injured leg or knee (n=6). Knee valgus was frequently seen in the main categories of non-contact and indirect contact playing situations (n=11), but a dynamic valgus collapse was infrequent (n=3). This was in contrast to the tackling-induced direct contact situations where a knee valgus collapse occurred in all cases (n=3).

Conclusions Eighty-five per cent of the ACL injuries in male professional football players resulted from non-contact or indirect contact mechanisms. The most common playing situation leading to injury was pressing followed by kicking and heading. Knee valgus was frequently seen regardless of the playing situation, but a dynamic valgus collapse was rare.

INTRODUCTION

Anterior cruciate ligament (ACL) injury in professional athletes can cause long lay-off from sports,[1–3] and may be career threatening.[1][2][4] On average, one player will suffer an ACL injury every second season in a professional men's football team squad.[3] Serious injuries have not dropped in men's professional football in the past decade,[5] and prevention of ACL injury is a priority area within sports medicine/sports physiotherapy research.[6]

Understanding the injury mechanisms is a key factor in injury prevention research[7] and systematic video analysis has advantages for analysing complex injury mechanisms.[8] During the past decade, several video studies have been published on ACL injuries in team sports such as basketball,[9][10] handball[9][11] and Australian Rules football.[12] Although a few football-related ACL injuries were included in two studies analysing injury sequences from several sports,[13][14] the specific ACL injury mechanisms in football were not established. Recently, a study on football players was published,[15] but that study had a retrospective design and included a heterogeneous sample of youth, amateur and professional football players of both sexes. It is also unclear from that study how the time of the tear was determined and information on the quality of the video sequences is also lacking. Additionally, the study used only two analysts for visual estimations, and there was limited data on biomechanics and playing situations.

The objective of this study was, therefore, to describe the ACL injury mechanisms, in particular the playing situation, player-opponent behaviour and biomechanics in male professional football players based on systematic video analysis.

MATERIALS AND METHODS

Injury inclusion and video recording

The ACL injuries included for video analysis were obtained from long-term prospective injury surveillance studies on three different cohorts of male professional football players in Europe carried out by our research groups: the Union of European Football Associations (UEFA) Elite Club Injury Study since 2001,[16][17] the Swedish professional league since 2001[18][19] and the Norwegian professional league since 2000.[20][21] All ACL injury situations eligible for inclusion occurred during first team match play at club level competition (national league, national cup and international cup matches). We only included complete ACL tears confirmed by surgery or MRI. We excluded ACL injuries occurring during training, in first team friendly matches, reserve or youth team matches and in national team matches. We excluded ipsilateral re-injuries after previous ACL reconstruction.

In total, 55 complete ACL tears were reported in the three cohorts during the inclusion period for this study and video sequences from 40 (73%) of these were obtained (figure 1). This included 28 injuries from the UEFA Elite Club Injury Study, where video sequences from national league and cup matches (n=20) were collected from the club's medical staff, and UEFA Champions League video
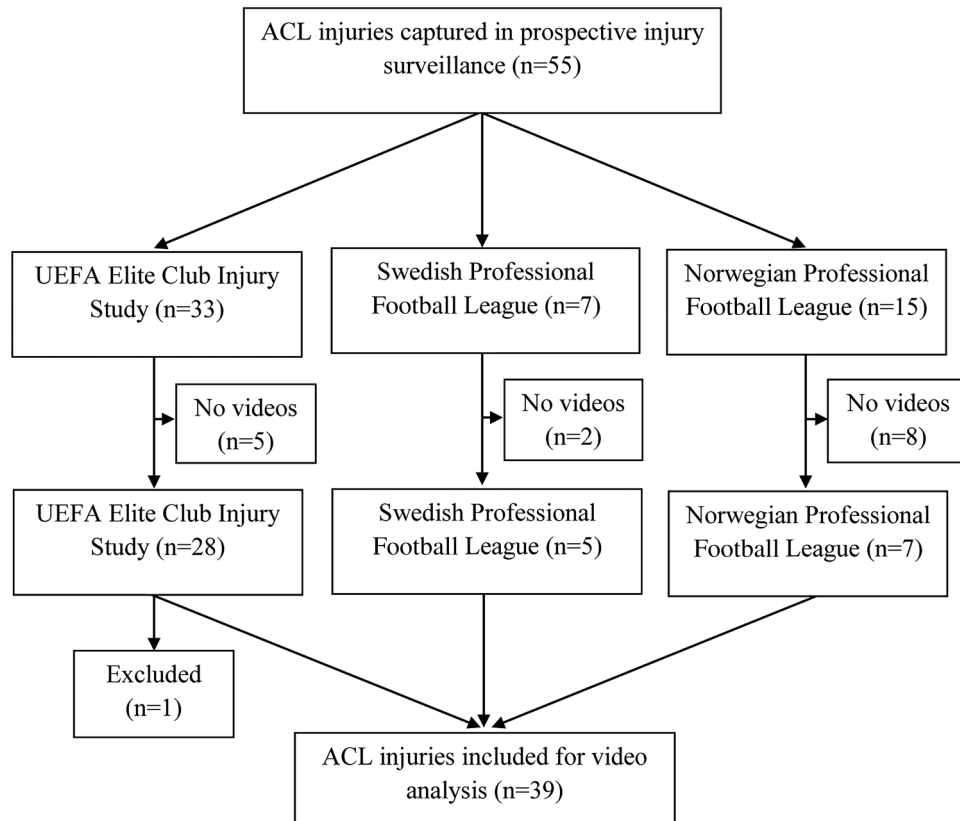
Figure 1 Flow chart showing the process to obtain video sequences of anterior cruciate ligament injuries in prospective injury surveillance of men's professional football players (January 2001–June 2011).

sequences (n=8) were obtained from Viasat Sport, Modern Times Group MTG AB (Stockholm, Sweden). The Swedish professional league sequences (n=5) were obtained from Onside TV Production AB (Sundbyberg, Stockholm), and the Norwegian professional league sequences (n=7) were obtained from Football Media AS (Oslo, Norway). In total, 16 of the injury situations were captured from 1 camera angle, 10 from two, 12 from three, 1 from four, and 1 from five camera angles, respectively. The majority of videos had a standard PAL resolution (typically 768×576 pixels), but eight videos had a lower resolution (typically 352×288 pixels); one video was recorded in High Definition (1440×1080 pixels). We excluded one video (case #31) from all analyses as it had insufficient resolution (176×100 pixels).

Video processing
The injury sequences were digitised and cut using a video editing programme (Final Cut Pro, V.6.0.5, Apple, Cupertino, California, USA). All files were converted to QuickTime (.mov) files, which enabled easy frame-by-frame navigation in the video sequences using QuickTime Player (V.7, Apple, Cupertino, California, USA). Two different versions were made for each injury case. First, we cut a longer sequence containing approximately the 10 s before the injury situation and 2–3 s sequence after the injury to assess the specific match situation and the injury circumstances. Second, we cut another sequence containing the 1–2 s prior to the injury to 2–3 s after the injury for analysis of the biomechanical variables. Where possible (n=23), these sequences were de-interlaced to increase the effective frame rate from 25 to 50 Hz. For cases where two or more camera views were available, we made one single video with all

sequences synchronised side by side using Adobe AfterEffects (V. CS4, Adobe System Inc, San Jose, California, USA). We conducted the synchronisation manually by using, for example, foot onset to the ground or ball impact as visual cues.

Video analysis
Five analysts (all researchers with expertise in sports medicine, football, biomechanics) assessed all videos in real time and in slow motion. In the first step, the analysts reviewed and documented all sequences independently to estimate the time of initial contact (IC) between the foot and the ground as well as the assumed moment of the ACL tear, referred to as the index frame (IF). Next, all injuries were reviewed in a group session during a 1-day meeting to obtain a consensus on the IC and IF. Thereafter, all videos were analysed independently by the analysts again according to an analysis form based on protocols previously used for Football Incident Analysis,[22] and for systematic video analysis in basketball and alpine skiing.[10 23]

The analysis form included tick-box alternatives for categorical variables on injury circumstance and biomechanics (table 1). Additionally, joint flexion angles for the hip, knee and ankle were visually quantified to the nearest 5° for the following frames: IC, IC+40 ms, IC+80 ms and IF for each injury case (40 ms corresponds to two frames for de-interlaced sequences and 1 frame for interlaced sequences). We defined a non-contact injury as one occurring with no bodily contact with another player in the IF. Contact to any other body region other than the injured leg was referred to as indirect, while contact to the injured leg was defined as direct.[11 12 15] The player's speed was categorised into 'high, low, zero, and unsure' in the vertical and horizontal directions. As we did not have the possibility to

Table 1 Variables and categories used to describe the ACL injury circumstances and biomechanics

Variable	Categories
Weather condition	
Precipitation preceding injury	Yes, no, unsure
Football-specific variables	
Playing situation preceding injury	Offensive, defensive, set play, other, unsure
Field location at injury*	Defensive third, midfield zone 1, midfield zone 2, offensive third, unsure
Player action preceding injury	Heading, dribbling, receiving, screening, turning, kicking (passing, shooting or clearing), blocking, other (e.g. goalkeeping), unsure, no ball possession
If kicking, which leg	Right, left, unsure
Duel type preceding injury	Collision (unintentional), tackling (other player), tackled (by other player), heading, screening, pressing, running, blocking, other, unsure, no duel
If tackled, from what direction	Front, behind, side, unsure
If tackled, what type	One-footed, two-footed, unsure
If tackled, what movement	Sliding, standing, unsure
If pressing, what type	Tackling, intention to tackle, no intention to tackle, unsure
Player contact preceding injury	Yes, no, unsure
If contact, what type	Direct contact (to injured knee or injured leg), indirect contact (to uninjured leg, trunk, head/neck or arm), unsure
Player contact at injury	Yes, no, unsure
If contact, what type	Direct contact (to injured knee or injured leg), indirect contact (to uninjured leg, trunk, head/neck or arm), unsure
Biomechanical variables	
In balance at IC	Yes, no, unsure
If out of balance, what direction	Forward, backward, sideways, combined directions, unsure
Player movement at IC	Forward, backward, sideways, upward, downward, combined directions, unsure
Cutting angle at IC	Intended change of direction 0–30°, intended change of direction 30–90°, intended stopping or change of direction >90°, unsure
Leg loading at IF	One leg, two legs with equal load, two legs with main load on injured leg, two legs with main load on uninjured leg, unsure
Horizontal speed at IC	High, low, zero, unsure
Vertical speed at IC	High, low, zero, unsure
Trunk rotation at IF†	Toward injured leg, toward uninjured leg, neutral, unsure
Foot rotation at IC‡	Internal 0–45°, internal >45°, external, neutral, unsure
Foot strike at IC	Heel, toe, flat, unsure

*Midfield zones 1 and 2 denote the first and second halves of the middle third of the playing field.
†Trunk rotation denotes the position in relation to the foot position.
‡Foot rotation denotes the position in relation to the player movement direction.
ACL, anterior cruciate ligament; IC, initial contact; IF, index frame.

quantify their velocity through any measurements, we were limited to assess speed based on the movement type they executed. Walking and jogging would typically be characterised as 'low horizontal speed', whereas running and sprinting would be categorised as 'high horizontal speed'; a distinct jump with a vertical component would be classified as having 'high vertical speed', whereas running, stopping or cutting would have a 'low vertical speed' component.

The analysts also reported if there was substantial hip abduction (>20°), knee valgus, and ankle eversion for the non-contact and indirect contact injuries during the sequence: IC, IC+40 ms and IC+80 ms (and IF if this frame deviated from the previous three). We defined a valgus collapse as a substantial medial knee displacement that could result from hip adduction, hip internal rotation, knee valgus and external tibial rotation.[10 24] Finally, we held a 1-day consensus meeting where we examined each video as many times as was needed to obtain a consensus for the categorical variables.

Statistical analysis

We used a Microsoft Excel spreadsheet from Windows (Microsoft Excel 2007, Redmond, Washington, USA) to store and analyse data.

To obtain a consensus for each categorical variable, at least three of the five analysts had to agree on the category.[10] Flexion angles are reported as the median of the individual estimates, along with the mean absolute deviation from the median,[23] for the main categories of injury situations identified (at least five assessable cases per category). A median joint flexion angle was reported for each case only if at least four of the analysts were able to estimate a joint angle for the actual frame; otherwise, the flexion angle was reported as 'unsure'. We reported the median joint flexion angle with a corresponding IQR for each of the three main injury situation categories. Joint flexion angles are shown as positive values. As a measure of the accuracy of the IC and IF estimates, the mean absolute deviation (in ms) of the initial individual estimates determined in the consensus meeting was calculated. We required at least three of the analysts to have made sure initial estimations of the IC and IF frames in order to report the mean absolute deviation for that particular case.

In addition to the video that was excluded because of insufficient resolution, another three videos were excluded from the frame accuracy calculation, joint flexion angle estimations and the visual estimations of hip abduction, knee valgus and ankle eversion for various reasons: player hidden by opponent, poor picture quality and uncertainty of injury identification. All these excluded videos were filmed from one camera angle only. Biomechanical variables and joint flexion angles were not assessed for injuries resulting from contact to the injured knee or lower leg.[10] Five cases were excluded from the IC and IF accuracy calculations because there were more than two unsure estimations from the analysts, and owing to a technical error

during data computerisation, another case was excluded from the IF accuracy calculation. The mean absolute deviation of the initial individual estimates of IC and IF were 7 and 11 ms, respectively.

RESULTS

A total of 39 ACL injuries were included in the study, 27 from the UEFA Elite Club Injury Study (2003–2011), and 5 and 7 from the professional leagues in Sweden (2002–2008) and Norway (2006–2011), respectively. There were 20 and 19 injuries to the right and left knees, respectively. We were able to describe the injury circumstances for all 39 cases included (see online supplementary table S1). We classified 25 injuries as non-contact injuries, 8 as indirect contact injuries and 6 injuries as direct contact injuries. A majority of the ACL injuries (n=30) occurred in a player who was involved in a defensive playing action. No injury occurred during set play. Twenty players had no ball possession at the time of injury. Most injuries (n=34) occurred to a one-legged loaded knee, and in all five two-legged loaded cases, the main load was on the injured leg (see online supplementary table S2). The vast majority of the injuries (n=37) occurred during seemingly dry weather conditions; in only one case we observed precipitation at the time of injury. Six injuries were the result of foul play according to the decision of the referee.

Injury situations

We identified three main categories of non-contact and indirect contact injury situations: (1) pressing (n=11), (2) re-gaining balance after kicking (n=5) and (3) landing after heading (n=5). Additionally, direct contact to the injured leg or knee (n=6) was another main category. The remaining cases (n=12), all representing non-contact or indirect injury situations, were distinctly different from the categories described above (see online supplementary tables S1 and S2).

Non-contact and indirect contact injury mechanisms

The most frequent injury situation was pressing, 10 of 11 being the result of non-contact mechanisms (table 2). In a pressing situation, the defending player typically made a sidestep cut in order to reach the ball or to tackle an opponent (figure 2 and online supplementary video 1). In six cases, the injured player was intending to tackle or was tackling, but did not achieve any contact with the opponent. The pressing player was typically moving forward at high speed with an intended cutting angle between 30° and 90° (table 3). The individual flexion angles at IC were in all cases 40° or less for the hip, and 20° or less for the knee (see online supplementary table S3), with the median flexion angles 25° for the hip and 5° for the knee (table 4). We identified substantial hip abduction in eight cases and knee valgus in six cases (four unsure), one of which was a clear dynamic valgus collapse. Estimates of ankle eversion showed no clear trend: four 'yes', three 'no' and three 'unsure'.

Re-gaining balance after kicking (n=5) was another common injury situation, all owing to non-contact or indirect injury mechanisms (table 2). The most frequent kicking situation was clearing the ball (figure 3 and online supplementary video 2). The kicking player was typically moving at high horizontal speed while being out of balance (table 3). The individual flexion angles at IC were lower than 30° and 20° in all estimated cases for the hip and knee joints, respectively (see online supplementary table S3), with the median flexion angles 10° for both the hip and knee joints (table 4). Substantial hip abduction was seen in three cases and knee valgus in three cases (one unsure), but no dynamic valgus collapse was identified. Estimates of ankle eversion showed no clear trend: two 'yes', two 'no' and one 'unsure'.

Table 2 Football-specific variables recorded for 33 non-contact and indirect contact ACL injury cases analysed using systematic video analysis

	Playing situation	Field location	Player action	Duel type	Player contact preceding injury	Player contact at injury
Pressing 11 cases	Defense (n=11)	Defensive third (n=2) Midfield zone 1 (n=3) Midfield zone 2 (n=4) Offensive third (n=2)	No ball possession (n=11)	Pressing (n=11)	No (n=11)	No (n=10) Indirect, to trunk/arm (n=1)
Kicking 5 cases	Offense (n=2) Defense (n=3)	Defensive third (n=1) Midfield zone 1 (n=2) Offensive third (n=2)	Passing (n=1) Shooting (n=1) Clearing (n=3)	No duel (n=2) Tackled by other player (n=2) Other (n=1)	No (n=2) Direct, to injured leg (n=1) Indirect, to uninjured leg (n=1) Indirect, to trunk/arm (n=1)	No (n=3) Indirect, to trunk/arm (n=2)
Heading 5 cases	Offense (n=1) Defense (n=4)	Defensive third (n=2) Midfield zone 1 (n=2) Offensive third (n=1)	Heading (n=5)	No duel (n=3) Heading duel (n=2)	No (n=3) Indirect, to trunk/arm (n=2)	No (n=5)
Other 12 cases	Offense (n=4) Defense (n=8)	Defensive third (n=6) Midfield zone 1 (n=3) Offensive third (n=3)	Dribbling (n=1) Receiving (n=2) Screening (n=1) No ball possession (n=8)	No duel (n=5) Collision (n=1) Tackled by other player (n=1) Screening (n=1) Running (n=4)	No (n=5) Direct, to injured leg (n=1) Indirect, to uninjured leg (n=1) Indirect, to trunk/arm (n=4) Combined* (n=1)	No (n=7) Indirect, to trunk/arm (n=5)

*Player contact both to the trunk/arm and injured leg.
ACL, anterior cruciate ligament.
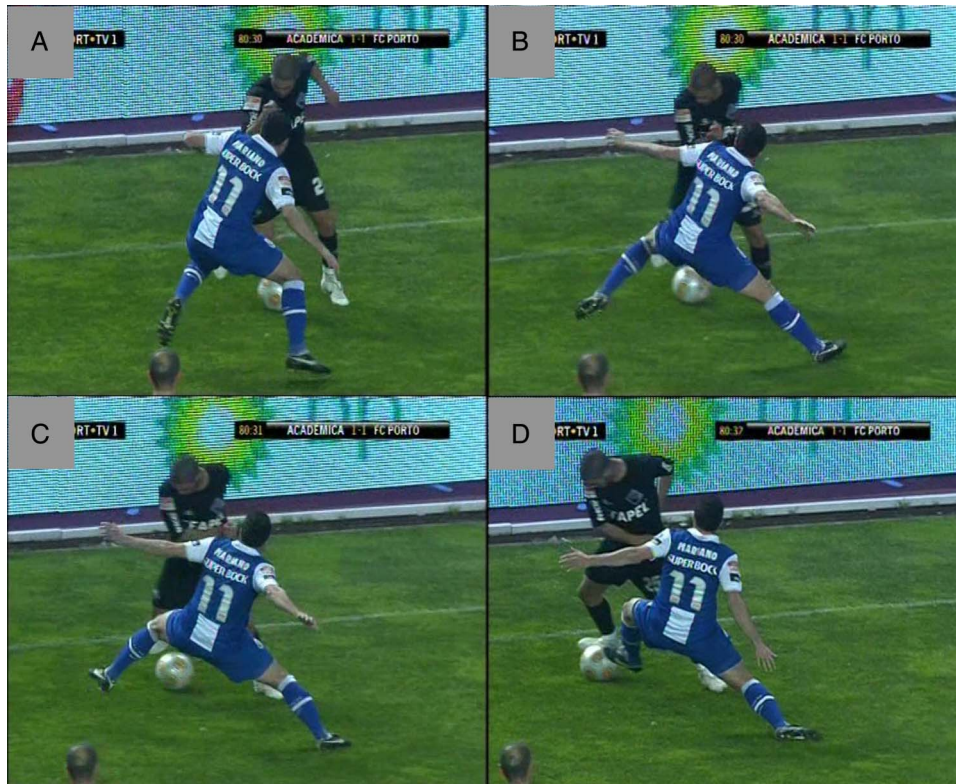
Figure 2 Non-contact pressing mechanism (right knee). (A) At−160 ms, the defending player is running forward at high speed towards the opponent in possession of the ball. (B) At initial contact, he strikes the pitch with his right heel and makes a sidestep cut in an effort to reach the ball or to tackle the opponent, but no player contact. (C) At 80 ms, he rotates the trunk towards his left leg and puts the entire load on his right leg. (D) At 240 ms the right hip and knee joints are in abducted positions and the ankle joint is in eversion (dynamic valgus without collapse).

All injuries occurring during landing after having headed the ball (n=5) were the result of non-contact injury mechanisms (table 2). The injured players landed mainly on one leg only (table 3). In all one-legged landing situations, the injured player landed on his forefoot (figure 4 and online supplementary video 3). The individual flexion angles at IC was 10° or less in all estimated cases for the knee, but showed greater variation for the hip (see online supplementary table S3). The median flexion angles were 10° for the hip and 5° for the knee at IC (table 4). Substantial hip abduction was seen in one case and knee valgus was seen in two cases (one unsure), and both of these were dynamic valgus collapses. Estimates of ankle eversion showed no clear trend: one 'yes', one 'no' and two 'unsure'.

Direct contact injuries

The six direct contact injuries occurred as a result of tackling or collision duels (see online supplementary table S1). In all three cases resulting from direct tackling to the injured knee, the tackle was from behind with lateral impact to the knee joint leading to forceful valgus collapse (figure 5 and online supplementary video 4). In the three unintentional collision injuries, the injury situations varied: front-to-front contact with anterolateral impact to the lower leg leading to valgus and hyperextension of the injured knee, knee-to-knee contact with posterolateral impact leading to varus and anterior translation of the injured knee, and knee-to-knee contact with anteromedial impact leading to valgus and hyperextension of the injured knee.

DISCUSSION

Eighty-five per cent of the ACL injuries resulted from non-contact or indirect contact mechanisms. We identified three main playing situations for these injuries: (1) pressing, (2) re-gaining balance after kicking and (3) landing after heading. Regardless of the playing situation, we frequently observed knee valgus, but we rarely saw an overt dynamic valgus collapse. In contrast, a dynamic valgus collapse was obvious in all three tackling-induced direct contact ACL injuries.

Injury circumstances

Previous football studies using player interviews reported that ACL injuries occur infrequently in contact situations (16–22%).[25][26] The proportion of direct contact ACL injuries in this study (15%) was consistent with these data and lower than that in previous studies on handball and Australian Rules football (30–32%) that used classification identical to ours.[11][12] Our proportion of direct and indirect contact injuries (36%) was, however, in line with other video studies on different sports where between 28% and 35% were reported as contact injuries (but not further specified as being direct or indirect).[10][13][14]

In contrast, more than half (53%) of the ACL injuries in male football players in a recently published video study, using the same classification as in our study, were categorised as contact injuries.[15] Even if it occasionally is difficult to categorise player-contact based on circumstances preceding the injury, for example, if a player was pushed in the back or held by his shirt,[8] this cannot probably explain this apparent discrepancy. It is, in our opinion, more likely that differences in video collection procedures and study samples could explain this discrepancy between studies.

Playing situations associated with ACL injury

We found that 77% of the ACL injuries occurred during defending, which corresponds to recent findings from another recent

Table 3 Biomechanical variables recorded for 33 non-contact and indirect contact ACL injury cases analysed using systematic video analysis

	In balance	Player movement	Cutting angle	Leg loading	Horizontal speed at IC	Vertical speed at IC	Trunk rotation at IF	Foot rotation at IC	Foot strike
Pressing									
11 cases	No (n=2) Yes (n=9)	Forward (n=10) Sideways (n=1)	0–30° (n=1) 30–90° (n=9) Stopping/>90° (n=1)	One leg (n=11)	High (n=8) Low (n=3)	Zero (n=11)	Toward uninjured leg (n=6) Neutral (n=4) Unsure (n=1)	Internal >45° (n=1) External (n=3) Neutral (n=6) Unsure (n=1)	Heel (n=7) Toe (n=1) Flat (n=1) Unsure (n=2)
Kicking									
5 cases	No (n=5)	Forward (n=1) Backward (n=2) Sideways (n=2)	Stopping/>90° (n=2) NA (n=3)	One leg (n=4) Two legs* (n=1)	High (n=1) Low (n=4)	Zero (n=5)	Toward uninjured leg (n=2) Neutral (n=2) Unsure (n=1)	Internal >45° (n=2) External (n=1) NA (n=2)	Toe (n=3) Flat (n=1) Unsure (n=2)
Heading									
5 cases	No (n=3) Yes (n=2)	Forward (n=1) Backward (n=1) Sideways (n=1) Downward (n=2)	30–90° (n=1) Stopping/>90° (n=2) NA (n=2)	One leg (n=4) Two legs* (n=1)	Low (n=3) Zero (n=2)	High (n=3) Low (n=2)	Toward uninjured leg (n=2) Neutral (n=3)	Internal >45° (n=1) Neutral (n=2) NA (n=2)	Toe (n=4) Flat (n=1)
Other									
12 cases	No (n=6) Yes (n=4) Unsure (n=2)	Forward (n=8) Sideways (n=3) Combined† (n=1)	0–30° (n=3) 30–90° (n=3) Stopping/>90° (n=6)	One leg (n=8) Two legs* (n=3) Unsure (n=1)	High (n=8) Low (n=4)	Low (n=1) Zero (n=11)	Toward uninjured leg (n=6) Toward injured leg (n=2) Neutral (n=3) Unsure (n=1)	Internal 0–45° (n=2) Internal >45° (n=2) External (n=2) Neutral (n=3) Unsure (n=3)	Heel (n=4) Toe (n=1) Flat (n=4) Unsure (n=3)

*Main load on injured leg.
†Player movement both forward and sideways.
ACL, anterior cruciate ligament; IC, initial contact; IF, index frame; NA, not applicable.

study where 73% of the ACL injuries occurred during this phase of play.[15] Importantly, we identified three main non-contact and indirect contact situations comprising 54% of all situations leading to ACL injury. Pressing was most frequent (28%) followed by re-gaining balance after kicking and landing after heading (13% each). Interestingly, all players getting injured while kicking were clearly out of balance and most players being injured after heading landed out of balance on one leg. Thus, our findings suggest that ACL injury preventive exercises in male footballers, similar to what has been shown for female players,[27 28] should target neuromuscular and postural control in out-of-balance situations, including footwork and running technique training during changes of direction as well as jumping and landing technique training.

ACL injuries also occurred occasionally as a result of direct contact to the injured knee or leg (15%). The pattern of associated injuries found in the tackling-induced cases suggests a valgus-driven injury mechanism, since all three had concomitant injury to the medial collateral ligament and two had lateral meniscus injury (data not shown).

Lower limb biomechanics

In the video analysis on Australian Rules football,[12] all indirect and all but one non-contact ACL injury had a shallow knee flexion (less than 30°) at IC which tallies with our findings (maximum 20° knee flexion). The most reliable data to date are likely those reported in a study utilising a model-based image matching (MBIM) technique to estimate joint kinematics in ACL injury situations of 10 basketball and handball players. The mean knee flexion angle at IC was 23°, and this increased by 24° within the following 40 ms where the injury was assumed to occur.[29] Thus, it seems that a majority of ACL injured

**Table 4** Joint flexion angles for the main non-contact and indirect contact ACL injury mechanisms

	Hip flexion angle (°)*		Knee flexion angle (°)*		Ankle flexion angle (°)*	
Case	IC	IF	IC	IF	IC	IF
Pressing†						
10 cases	25 (12.5)	30 (7.5)	5 (5)	30 (13.75)	10 (12.5)	−2.5 (12.5)
Kicking						
5 cases	10 (8.75)	20 (5)	10 (5)	27.5 (10)	0 (7.5)	2.5 (7.5)
Heading‡						
4 cases	10 (25)	25 (22.5)	5 (5)	30 (18.75)	30 (22.5)	−10 (11.25)

*Flexion angles are reported as median with the IQR. Positive values mean flexion and negative values mean extension.
†Case #11 excluded.
‡Case #14 excluded.
ACL, anterior cruciate ligament; IC, initial contact; IF, index frame.
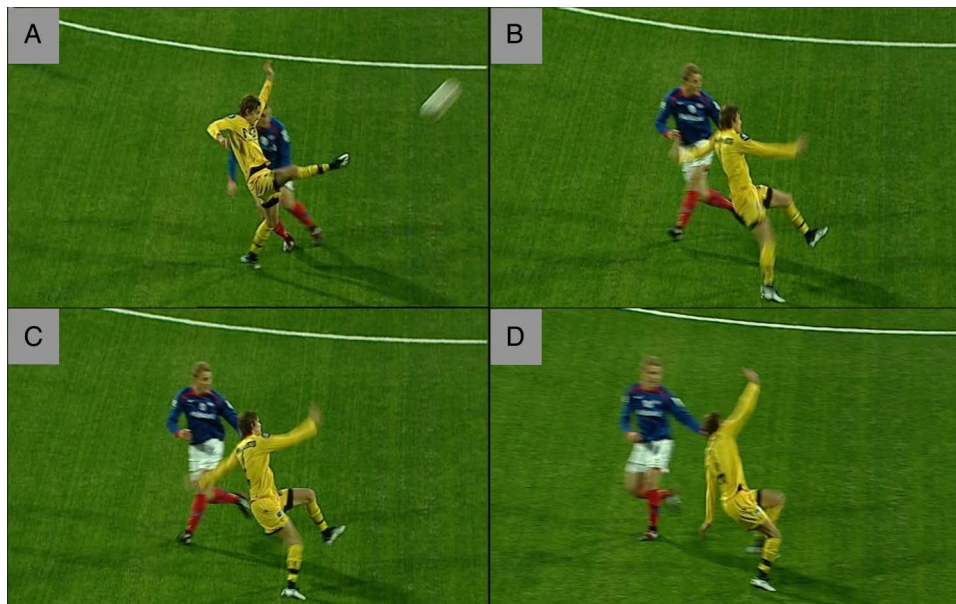
Figure 3 Non-contact kicking mechanism (right knee). (A) At−220 ms, the player is clearing the ball with his right foot. (B) At initial contact, he strikes the pitch with the forefoot and rotates the trunk to the left. (C) At 40 ms, being out of balance backwards, he puts the entire load on his right leg. (D) At 140 ms, his right knee joint is abducted and the ankle joint is in eversion (dynamic valgus without collapse).

athletes are likely to have a relatively straight knee at the time of injury. Vertical compression at a straight knee has previously been shown to load the ACL through anterior tibial drawer and internal rotation.[30]

Although the classification of knee valgus was uncertain as determined by visual inspection in 11 cases in our study, we observed valgus in 15 of the 19 remaining cases. This finding is in line with previous research from several other sports,[10–13 29]

Figure 4 Non-contact heading mechanism (right knee). (A) At−306 ms, the player wins a heading duel while having trunk-to trunk contact in the air with his opponent. (B) At initial contact, he lands at high vertical speed on his right leg striking the pitch with the forefoot. (C) At 80 ms, being out of balance both backwards and sideways, he puts the entire load on his right leg. (D) At 186 ms, his right knee joint clearly give way in substantial abduction (dynamic valgus collapse).

Figure 5 Direct contact mechanism (right knee). (A) At−60 ms, the player is jogging forward at slow speed towards the sideline trying to screen the ball from the opponent. (B) At initial contact, he strikes the pitch with his right heel and holds the trunk in a neutral position. (C) At 140 ms, having the entire load on his right leg, he is tackled from behind with forceful lateral impact to the knee joint. (D) At 440 ms, he falls backwards and his right knee clearly give way in substantial abduction (dynamic valgus collapse).

and suggests that knee valgus is also an important component in football. A sudden knee valgus increase was also reported in a non-contact ACL injury in a male professional football player, where the MBIM technique was employed.[31]

Interestingly, there were no sex-related differences in knee valgus at IC in a study of 39 ACL injuries in female and male basketball players, but the valgus angle was significantly higher in females at assumed time of injury 33–50 ms later.[10] Similar findings were reported in a study on a mixed sample of athletes where knee valgus was significantly more pronounced in female athletes' five frames after IC compared with males.[14] Additionally, a valgus collapse was reported to be five times more common in female than in male basketball players.[10] It has been argued that the dynamic valgus collapse might be a sex-specific knee motion occurring predominately in females.[24] Our data seem to support this hypothesis, since an overt valgus collapse was identified in only a minority of the non-contact and indirect contact cases. However, given that we observed knee valgus in three-quarter of the cases where assessment was possible, one can speculate whether the overt valgus collapse often seen in females is a sex-specific consequence after the injury (eg, due to lower muscle strength and higher joint laxity) rather than a mechanism leading to the injury.

Methodological considerations

The major strength of our study is that it includes a relatively large and homogenous sample of professional male football players for whom we captured all injuries prospectively through ongoing injury surveillance. We, therefore, believe that our sample is representative, particularly since the major findings were consistent. Additionally, we used the same methodology as

has been used in the majority of previous systematic video analysis studies on ACL injury mechanisms in other sports,[10 11 23] and the number of analysed videos were also similar compared with previous studies (20–55 cases).[10–15] Moreover, all ACL injuries eligible for analysis were verified with MRI or surgery. Finally, we used as many as five analysts to make the estimations individually, and there was also a high degree of agreement between them in, for example, the IC and IF estimations.

However, some limitations should be acknowledged. First, video analysis studies are dependent on the quality and resolution of the images, and the number of camera views available. Owing to poor quality of the video recordings, one case was excluded from all analyses and another three cases from the biomechanical analyses. Additionally, the number of camera views available was varying (range 1–5), and 15 of the 39 injuries were captured with one camera view only (five excluded from main analyses). Second, video analysis is also limited by difficulties to, by visual inspection only, estimate the exact moment of injury (illustrated by five cases being excluded from the accuracy calculation).[8] Additionally, it has previously been shown that visual inspection may underestimate joint flexion angles during different running and side-step cutting manoeuvres compared with a three-dimensional motion analysis system.[32] Consequently, the reported joint flexion angles and body motions might not be the actual mechanisms leading to the ACL injury, but rather a consequence of the injury.[29] Third, given that we only studied competitive match injuries in professional male football players, it is unknown whether the injury mechanisms and playing situations differ from training injuries and as compared with injuries sustained by amateur, female or youth football players. Fourth, although weather and surface

conditions are known to interact with footwear at the inciting injury event,[33] it was not possible to accurately assess the surface conditions by visual inspection. However, we observed precipitation in only one case suggesting that a vast majority of injuries occurred during dry weather conditions. This might be of interest from a prevention perspective since it has previously been hypothesised that warm and dry conditions, giving higher shoe-surface traction, are associated with an increased rate of non-contact ACL injury.[34 35]

What are the new findings?

▸ The most common playing situations associated with non-contact and indirect contact anterior cruciate ligament (ACL) injuries was pressing followed by re-gaining balance after kicking and landing after heading.
▸ Knee valgus was frequently seen regardless of the playing situation, but a dynamic valgus collapse was rarely identified.
▸ The injured knee was relatively straight both at the initial ground contact and at the assumed time of tear for all non-contact and indirect contact ACL injuries.

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

▸ Our findings in this systematic video analysis study on ACL injury mechanisms in male professional football players suggest that ACL injury preventive interventions, similar to what has previously been shown for female athletes, should focus on:
  – General postural and neuromuscular control of the core and lower extremities;
  – Footwork and running technique during changes of direction in defensive playing actions, mimicking the pressing situation;
  – Maintaining balance during shooting, passing and ball clearing;
  – Jumping and landing technique during heading duels;
  – Promoting fair play in order to avoid fierce tackling from behind.

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