TITLE
Systematic Video Analysis of ACL injuries in Male Basketball Players: Injury Mechanisms, Situational patterns, and Biomechanics Study on 36 Consecutive Cases

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Video Analysis of Anterior Cruciate Ligament Injuries in Male Professional Basketball Players

Injury Mechanisms, Situational Patterns, and Biomechanics

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Background: Improving our understanding of the situations and biomechanics that result in an anterior cruciate ligament (ACL) injury in basketball players may support the design of more effective programs to mitigate the risk of injury.

Purpose: To (1) describe the mechanisms, situational patterns, and gross biomechanics (kinematics) of ACL injuries in professional basketball matches using video analysis and (2) document the distribution of ACL injuries according to player position, phase of the match, and location on the court.

Study Design: Case series; Level of evidence, 4.

Methods: A total of 38 ACL injuries in professional male European basketball leagues from the 2013-2014 to 2019-2020 seasons were identified. There were 36 (95%) injury videos analyzed for injury mechanisms and situational patterns, while biomechanical analysis was possible in 32 cases. Overall, 3 independent reviewers evaluated each video. Data according to player position (n = 38), phase of the match (n = 38), and location on the court (n = 36) were evaluated.

Results: More injuries occurred while attacking (n = 25 [69%]) than defending (n = 11 [31%]). There was 1 (3%) direct contact injury, 21 (58%) indirect contact injuries, and 14 (39%) noncontact injuries. Most injuries (83%) occurred during 3 main situations: offensive cut (n = 17 [47%]), landing from a jump (n = 8 [22%]), and defensive cut (n = 5 [14%]). Injuries generally involved knee flexion (with minimal hip/trunk flexion and reduced plantarflexion) in the sagittal plane and knee valgus loading in most cases (75%). A similar number of injuries occurred during the first (53%) and second (47%) halves of the match, with a higher prevalence in the second (37%) and fourth (34%) quarters. Half of the injuries occurred during the first 10 minutes of effective playing time. More injuries occurred in guards (58%), and 73% of all injuries occurred in the scoring zone.

Conclusion: Indirect contact was the main injury mechanism found in male professional basketball players. The offensive cut was the most common situational pattern. Biomechanical analysis confirmed a multiplanar mechanism, with knee loading in the sagittal plane accompanied by dynamic valgus. More injuries occurred in the first 10 minutes of a player's effective playing time, within the scoring zone, and among guards.

Keywords: injury prevention; ACL injury; injury mechanism; biomechanics

An anterior cruciate ligament (ACL) injury is a severe and concerning health issue for professional basketball players, causing a long layoff time (~10 months).[28,34] While return-to-play rates are high in elite basketball players (84%-89%),[17,20,26,28] the risk of early-onset knee osteoarthritis[19,29] and reduced career length and performance[20] are serious concerns.

Understanding the mechanisms and situations that lead to ACL injuries is key for the effective design of

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specific exercise programs that reduce the incidence of ACL injuries.[3,35] Although many approaches are available to support an increased understanding of ACL injury mechanisms,[5] video analysis is a frequently used and valid tool to investigate injury mechanisms, playing situations, and gross biomechanics preceding and during actual injuries.[5] Several video analysis studies of ACL injuries have been performed across different sports.[7,11,13,18,24,37] Regarding elite male basketball, only 1 article has been published to date,[23] more than 15 years ago. While a valuable study in the discipline, there were limitations and biases in the study design, such as a lack of systematic assessments, the inclusion of different playing levels, and mixed sexes. There is a need for further research in a larger cohort to better understand ACL injury causation in basketball. A clear definition of the differences between indirect and noncontact injuries is needed, given the importance of mechanical perturbation in ACL injuries, recently reported in other team sports.[11,13,18] In addition, there is a need to better understand injuries according to timing within the match, location on the court, and team positional role as well as kinematics immediately before and at the time of the injury.

The primary purpose of this study was to describe the mechanisms, situational patterns, and gross biomechanics of ACL injuries in male professional basketball players. The secondary purpose was to document the distribution of ACL injuries across the match and location on the court and according to team positional role. In doing so, we aimed to support practitioners in creating more effective designs of programs that mitigate the risk of primary and secondary ACL injuries.

METHODS

Identification of Injuries

All of the videos we accessed for this study were publicly available, data were anonymized, and no personal player information was accessed and published. Therefore, ethical approval was not required. We performed a systematic search of online databases across 7 consecutive seasons (from 2013-2014 to 2019-2020) to identify ACL injuries occurring during matches in players of Italian first league (Lega Basket Serie A) and second league (Serie A2), Spanish first league (Liga ACB), EuroLeague, and EuroCup professional basketball teams.

To identify ACL injuries, each season and team roster were extracted from online databases (legabasket.it, legapallacanestro.com/a2, acb.com, euroleague.net, and eurocupbasketball.com). Then, each player's name was searched on Google, matching it with the English, Italian, and Spanish keywords "anterior cruciate ligament injury," "lesione del legamento crociato anteriore," and "lesion de ligamento cruzado anterior." When a result related to a likely episode of an ACL injury in a professional male basketball player was detected, a new and more targeted search was performed in national and local media to find details on the specific episode. Finally, injuries were included only when we were able to track an official publicly available communication from the medical staff of the team, stating the nature of the injury (complete ACL injury) sustained by the player. Through similar methods (publicly available sources), ACL reconstruction procedures undergone by all players were also tracked.

Video Extraction and Processing

Videos of matches were obtained from an online digital platform (synergysportstech.com). Videos were then downloaded to a personal computer and cut using video editing software (Dartfish Pro S; Dartfish). Each video was cut to 10 to 12 seconds before and 3 to 5 seconds after the estimated ACL injury frame (IF) to accurately evaluate the playing situation that preceded the injury as well as the injury mechanism. Additionally, all available replays from the television broadcast (in slow motion and from different angles) were added to the video.

Video Evaluation

The video evaluation was performed independently by 3 reviewers (F.T., M.B., F.D.V.) with experience in sports medicine and orthopaedic rehabilitation as well as research in team sports injury video analysis. The video evaluation was conducted according to a predetermined checklist (Appendix Table A1). Each ACL injury video was downloaded onto a personal computer, opened using open-source software (Kinovea), and analyzed using an evaluation flow adapted to basketball from previous research.[11-13,24] In brief, each reviewer evaluated the original video to define the playing phase of the injury (defensive or offensive), which was categorized based on ball possession and the specific playing situation. The injured

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Ethical approval was not sought for the present study.

leg was determined based on injury history and video data. Leg loading in the IF was classified as injured, uninjured, or both limbs. Subsequently, the intensity of action was determined based on estimated horizontal and vertical speeds (zero, low, moderate, or high). Then, a series of views were used to determine the injury mechanism and situational pattern. Overall, 3 categories of the injury mechanism were used according to our previous research[11]: (1) noncontact, defined as an injury occurring without any contact (at the knee or any other level) before or in the 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. When estimating the interval between initial contact (IC) and the estimated IF, reviewers based the decision on current knowledge and previous work.[21] The time between IC and the estimated IF in our analysis was a median of 67 milliseconds (interquartile range, 40-80 milliseconds).

After independent analysis, all reviewers met for a 1-day comprehensive discussion about the main injury mechanism and situational pattern to establish a consensus. If complete agreement was not reached between the reviewers, issues were solved through a collegial decision, as in previous research.[11,13] A consensus on all the items, including IC and IF, was reached during the meeting. Before the meeting, the intraclass correlation coefficient for IC between the reviewers was 0.99.

Biomechanical Analysis (Kinematics)

Biomechanical/kinematic analysis was performed on indirect and noncontact injuries when a frontal and/or sagittal view of sufficient quality was available. Analysis was conducted to estimate the intersegmental relationship and joint angles according to frontal- and sagittal-plane alignment at IC and in the IF. When more than one view was available, composite videos were created by manual synchronization using visual clues (eg, IC).[11,27] Overall, 4 videos had 4 camera views, 7 videos had 3 camera views, 15 videos had 2 camera views, and 10 videos had 1 camera view.

Evaluated biomechanical variables are listed in Appendix Table A2. Sagittal- and frontal (trunk tilt)-plane angles were estimated to the nearest 5° using custom-made software (GPEM Screen Editor; GPEM) at IC and in the IF. The remaining frontal- and coronal-plane estimated joint positions were categorized according to their appearance at IC and in the IF. Foot strike was evaluated according to previous methodology[11] at IC and in the IF.

Distribution of Match Phases and Court Locations

For each available injury video, data regarding the match phase and location on the court were gathered through a systematic web search and analysis of videos in relation to the position of the injured player. We considered the (1) phase of the match when the ACL injury occurred (according to minute and a half as well as minutes played after correcting for substitutions) and (2) location on the court. The court location was categorized into 6 zones, with dimensions in square meters, calculated according to the official Fédération Internationale de Basketball court dimension (28 × 15 m) (Figure 1).

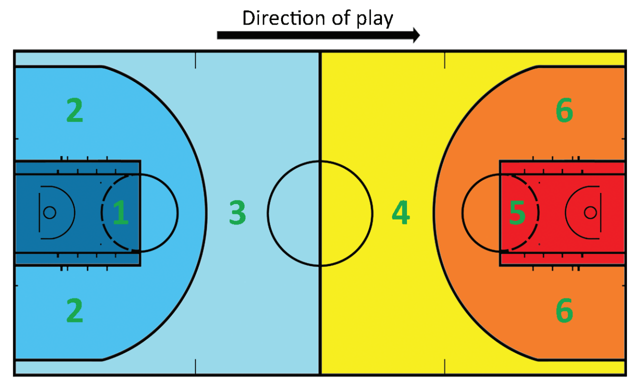

Figure 1. Division of the basketball court into zones. Zones 1 and 5 (28.4 m^2 each) represent the 3-second zones, often referred to as the paint zone in the back and front court, respectively; zones 2 and 6 (63.7 m^2 each) are inside the semicircle and 2-point scoring zone of the back and front court, respectively; and zones 3 and 4 (117.9 m^2 each) are the 3-point scoring zones up to the midcourt line in the back and front court, respectively.

Statistical Analysis

Continuous variables were reported as means with standard deviations or medians with interquartile ranges as appropriate. Discrete variables were reported as absolute numbers with percentages of the total number. The chi-square test was used to assess the statistical difference in the ACL injury distribution (2 × 4 contingency table). Excel (Version 2016; Microsoft) and Stata (Version 12; StataCorp) were used for these analyses.

RESULTS

A total of 38 ACL injuries were tracked and analyzed in this study. Of these, 10 each occurred in Italian Serie A and A2 matches, 3 in Spanish Liga ACB matches, 11 in international competitions (EuroLeague, EuroCup, and Basketball Champions League), 2 during friendly national matches, and 1 each during the Turkish Basketball Cup and the Acropolis International Basketball Tournament. The mean age of the injured players was 26.2 ± 4.4 years. All ACL injuries were primary injuries, with 23 injuries (61%) to the right ACL and 15 injuries (39%) to the left ACL.

Of the 38 ACL injuries included, video footage was available and identifiable for analysis of injury mechanisms and situational patterns in 36 cases (95%), and

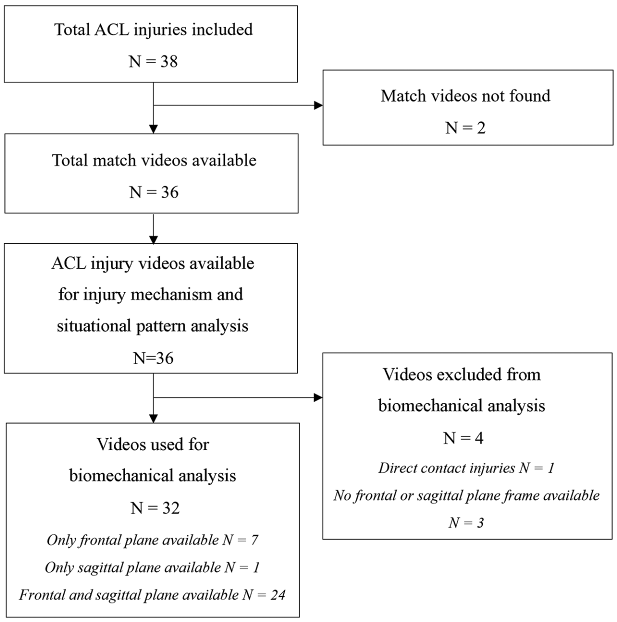

Figure 2. Detailed flowchart of the study. ACL, anterior cruciate ligament.

biomechanical analysis was possible in 32 cases. A detailed study flowchart is shown in Figure 2.

Injury Mechanisms

In the 36 cases analyzed, more injuries occurred while attacking (n = 25 [69%]) than defending (n = 11 [31%]). Most injuries (n = 35 [97%]) involved loading of the injured leg, with single-limb loading on the ground frequently observed (n = 29 [81%]). There were 1 (3%) direct contact, 21 (58%) indirect contact, and 14 (39%) noncontact injuries. A large proportion of injuries involved high or moderate horizontal speeds (72%), while few (22%) involved high or moderate vertical speeds at the time of the injury (Table 1).

Situational Patterns of Indirect and Noncontact ACL Injuries

We identified 3 main situational patterns that accounted for 83% of injuries. Offensive cut injuries were the most common, accounting for nearly half of all injuries (n = 17 [47%]). These injuries involved ball possession, with the injured player typically trying to overcome an opponent with the intention to drive toward the basket. In addition, 7 (41%) of these injuries occurred without any contact (Figure 3, A-D), while 10 (59%) involved indirect contact to the upper body before or in the estimated IF (Figure 3, E-H), generally resulting in an ipsilateral trunk tilt at IC.

Landing from a jump was the second most common situation, accounting for more than 1 in 5 injuries (n = 8 [22%]). These typically occurred after rebounding, blocking, boxing out, or a layup. Most involved indirect contact

TABLE 1
Mechanisms of ACL Injuries (n = 36)[a]

	No.
Playing phase before injury	
Offensive	25
Defensive	11
Court location at time of injury	
Zone 1	3
Zone 2	3
Zone 3	5
Zone 4	4
Zone 5	18
Zone 6	3
Player contact before injury	
Yes	20
Upper body	20
No	16
Player contact in IF	
Yes	14
Upper body	13
No	22
Injury mechanism	
Direct contact	1
Indirect contact	21
Noncontact	14
No. of feet on ground	
One	29
Both	7
Leg loading in IF	
Injured leg	35
Both legs	1
Horizontal speed	
Zero	5
Low	5
Moderate	12
High	14
Vertical speed	
Zero	26
Low	2
Moderate	1
High	7
Distance from ball, m	
0-0.99	30
1-1.99	4
2-3	2

[a]ACL, anterior cruciate ligament; IF, injury frame.

(88%) and single-leg landing (88%) (Figure 4, A-D). A defensive cut was the third situational pattern identified, accounting for 1 in 7 injuries (n = 5 [14%]), and involved a defensive pressing (Figure 4, E-H). The other 6 injuries involved dribbling, pivoting, rebounding, or during a duel for the ball. See Table 2 for additional details.

Biomechanical Findings

Of the 32 cases for which biomechanical analysis was possible, 22 cases had both frontal- and sagittal-plane images, 9 cases had frontal-plane images only, and 1 case had sagittal-plane images only (foot-strike analysis was

Figure 3. Two examples of the offensive cut situational pattern for anterior cruciate ligament (ACL) injuries in basketball. (A-D) Noncontact injury of a player in a white jersey (right ACL) during ball possession: (A) player about to cut, (B) initial contact, (C) estimated injury frame, and (D) after the injury. (E-G) Indirect contact injury of a player in a blue-and-red striped jersey (right ACL) during ball possession: (E) mechanical perturbation at the upper body, (F) initial contact, (G) estimated injury frame, and (H) complete knee valgus collapse.

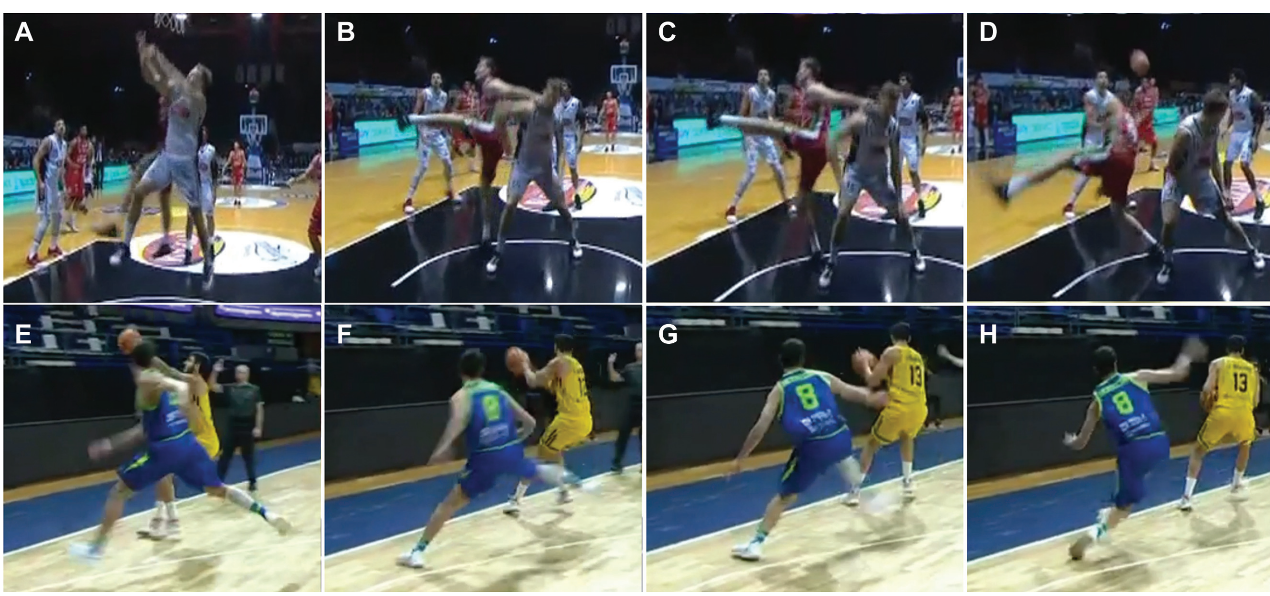

Figure 4. Examples of the landing from a jump and defensive cut situational patterns. (A-D) Landing from a jump in a player in a red jersey (right anterior cruciate ligament [ACL]): (A) duel for the ball, (B) initial contact, (C) estimated injury frame, and (D) loss of balance after the injury. (E-G) Defensive cut in a player in a blue jersey (left ACL): (E) neurocognitive perturbation, (F) initial contact, (G) estimated injury frame, and (H) loss of balance after the injury.

possible for 32 injury videos). Tables 3 and 4 show the results of biomechanical analysis.

At IC in the sagittal plane, players displayed a minimally flexed trunk (median, 6°), moderately flexed hip (median, 32°), shallow flexed knee (median, 24°), plantarflexed ankle (median, 13°), and flat foot (47% of cases). In the frontal plane at IC, the trunk was tilted ipsilaterally (median, 11°) and was either neutral (44% of cases) or rotated toward the injured leg (25% of cases), with the hip generally abducted (75% of the cases), the

TABLE 2
Situational Patterns of ACL Injuries (n = 36)[a]

	Total	Playing Phase	Injury Mechanism	Horizontal Speed	Vertical Speed	Court Location
Offensive cut	17 (47)	Offensive: 17 (100)	Indirect contact: 10 (59); noncontact: 7 (41)	Zero: 1 (6); moderate: 6 (35); high: 10 (59)	Zero: 17 (100)	Zone 4: 2 (12); zone 5: 10 (59); zone 6: 5 (29)
Landing from jump	8 (22): 1 bilateral, 7 unilateral	Offensive: 5 (63); defensive: 3 (37)	Indirect contact: 7 (88); noncontact: 1 (12)	Zero: 2 (25); moderate: 3 (38); high: 3 (38)	Moderate: 1 (12); high: 7 (88)	Zone 1: 2 (25); zone 2: 1 (12); zone 5: 5 (62)
Defensive cut	5 (14)	Defensive: 5 (100)	Indirect contact: 1 (20); noncontact: 4 (80)	Zero: 1 (20); moderate: 2 (40); high: 2 (40)	Low: 2 (40); moderate: 2 (40); high: 1 (20)	Zone 2:1 (20); zone 3: 4 (80)
Other	6 (17): 2 dribbling, 1 pivoting, 2 rebounding, 1 duel for ball	Offensive: 3 (50); defensive: 3 (50)	Direct contact: 1 (17); indirect contact: 3 (50); noncontact: 2 (33)	Zero: 2 (33); low: 3 (50); moderate: 1 (17)	Zero: 6 (100)	Zone 1: 2 (33); zone 2: 1 (17); zone 3: 1 (17); zone 4: 2 (33)

[a]Data are reported as n (%). ACL, anterior cruciate ligament.

TABLE 3
Sagittal-Plane Biomechanical Variables of ACL Injuries[a]

	Total (n = 32)	Offensive Cut (n = 16)	Landing From Jump (n = 7)	Defensive Cut (n = 5)	Other (n = 4)
Flexion angle, deg					
Trunk at IC[b]	6 (–20 to 30)	9 (–7 to 23)	–1 (–16 to 20)	8 (0 to 30)	–10 (–20 to 0)
Trunk in IF[b]	4 (–22 to 26)	11 (2 to 24)	1 (–22 to 23)	9 (–5 to 26)	–8 (–16 to 0)
Hip at IC[b]	32 (2 to 59)	49 (32 to 59)	7 (2 to 20)	22 (12 to 32)	34 (18 to 49)
Hip in IF[b]	30 (8 to 66)	52 (29 to 66)	22 (8 to 29)	27 (17 to 40)	36 (29 to 43)
Knee at IC[b]	24 (10 to 55)	25 (10 to 55)	17 (10 to 24)	36 (23 to 42)	43 (35 to 50)
Knee in IF[b]	46 (–19 to 88)	45 (–19 to 88)	45 (27 to 53)	55 (40 to 70)	57 (53 to 60)
Ankle at IC[c]	–13 (–45 to 28)	–13 (–30 to 28)	–25 (–32 to 5)	–5 (–10 to 15)	–29 (–45 to −12)
Ankle in IF[c]	7 (–50 to 40)	5 (–50 to 30)	20 (–16 to 25)	15 (2 to 40)	20 (8 to 32)
Foot strike at IC					
Heel	9 (28)	7 (44)	0 (0)	2 (40)	0 (0)
Flat	15 (47)	8 (50)	2 (29)	3 (60)	2 (50)
Toe	7 (22)	1 (6)	5 (71)	0 (0)	1 (25)
Unsure	1 (3)	0 (0)	0 (0)	0 (0)	1 (25)
Foot strike in IF					
Heel	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Flat	30 (94)	16 (100)	6 (86)	5 (100)	3 (75)
Toe	1 (3)	0 (0)	1 (14)	0 (0)	0 (0)
Unsure	1 (3)	0 (0)	0 (0)	0 (0)	1 (25)

[a]Data are reported as median (interquartile range) or n (%). ACL, anterior cruciate ligament; IC, initial contact; IF, injury frame.
[b]Positive values indicate flexion, and negative values indicate extension.
[c]Positive values indicate dorsiflexion, and negative values indicate plantarflexion.

knee typically neutral (50% of cases) or in valgus (22% of cases), and the foot often externally rotated (44% of cases).

In the estimated IF in the sagittal plane, the trunk remained minimally flexed (median, 4°), the hip similarly flexed (median, 30°), the knee more flexed (+22°; median, 46°), and the ankle slightly dorsiflexed (+20°; median, 7°), with the foot predominantly planted flat (94% of cases). In the frontal plane in the IF, the trunk remained tilted ipsilaterally (median, 13°) with a prevalence of trunk rotation toward the uninjured side (44% of cases). The hip remained abducted in most cases (64% of cases), with a greater prevalence of knee valgus (75% of cases) and an externally rotated foot (50% of cases).

Knee valgus was frequently observed, and a significant increase in hip internal rotation and/or adduction from IC to the IF was seen in most cases (75%), while valgus collapse occurred in 22% of cases. The most common intersegmental body positions in the 2 most common situational patterns, offensive cut and landing from a jump, are shown in Figure 5.

Injury Distribution by Player Position, Match Phase, and Court Location

Data according to player position (n = 38), phase of the match (n = 38), and court location (n = 36) were analyzed.

TABLE 4
Frontal- and Transverse-Plane Biomechanical Variables of ACL Injuries[a]

	Total (n = 36)	Offensive Cut (n = 17)	Landing From Jump (n = 8)	Defensive Cut (n = 5)	Other (n = 4)
Trunk tilt,[b] deg					
At IC	11 (3-27)	11 (4-27)	17 (8-21)	12 (10-20)	10 (3-16)
In IF	13 (1-33)	12 (1-22)	21 (10-30)	15 (10-16)	33 (2-33)
Trunk rotation at IC					
Toward injured leg	9 (25)	5 (29)	1 (13)	2 (40)	1 (25)
Neutral	16 (44)	7 (41)	5 (63)	1 (20)	3 (75)
Toward uninjured leg	6 (17)	4 (24)	0 (0)	2 (40)	0 (0)
Unsure	5 (14)	1 (6)	2 (25)	0 (0)	0 (0)
Trunk rotation in IF					
Toward injured leg	7 (19)	3 (18)	3 (38)	0 (0)	1 (25)
Neutral	8 (22)	5 (29)	1 (13)	1 (20)	1 (25)
Toward uninjured leg	16 (44)	8 (47)	2 (25)	4 (80)	2 (50)
Unsure	5 (14)	1 (6)	2 (25)	0 (0)	0 (0)
Frontal-plane hip alignment at IC					
Abduction	27 (75)	13 (76)	6 (75)	5 (100)	3 (75)
Neutral	2 (6)	2 (12)	0 (0)	0 (0)	0 (0)
Adduction	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Unsure	7 (19)	2 (12)	2 (25)	0 (0)	1 (25)
Frontal-plane hip alignment in IF					
Abduction	23 (64)	9 (53)	6 (75)	5 (100)	3 (75)
Neutral	4 (11)	4 (24)	0 (0)	0 (0)	0 (0)
Adduction	4 (11)	3 (18)	0 (0)	0 (0)	1 (25)
Unsure	5 (14)	1 (6)	2 (25)	0 (0)	0 (0)
Frontal-plane knee alignment at IC					
Valgus	8 (22)	3 (18)	1 (13)	4 (80)	0 (0)
Neutral	18 (50)	9 (53)	5 (63)	1 (20)	3 (75)
Varus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Unsure	10 (28)	5 (29)	2 (25)	0 (0)	1 (25)
Frontal-plane knee alignment in IF					
Valgus	27 (75)	15 (88)	5 (63)	5 (100)	2 (50)
Neutral	3 (8)	0 (0)	1 (13)	0 (0)	2 (50)
Varus/hyperextended	1 (3)	1 (6)	0 (0)	0 (0)	0 (0)
Unsure	5 (14)	1 (6)	2 (25)	0 (0)	0 (0)
Foot position at IC					
Externally rotated	16 (44)	7 (41)	4 (50)	2 (40)	3 (75)
Neutral	8 (22)	5 (29)	1 (13)	2 (40)	0 (0)
Internally rotated	5 (14)	4 (24)	1 (13)	0 (0)	0 (0)
Unsure	7 (19)	1 (6)	2 (25)	1 (20)	1 (25)
Foot position in IF					
Externally rotated	18 (50)	8 (47)	5 (63)	2 (40)	3 (75)
Neutral	4 (11)	2 (12)	0 (0)	2 (40)	0 (0)
Internally rotated	7 (19)	6 (35)	1 (13)	0 (0)	0 (0)
Unsure	7 (19)	1 (6)	2 (25)	1 (20)	1 (25)
Significant hip internal rotation/adduction from IC to IF					
Yes	27 (75)	14 (82)	6 (75)	5 (100)	2 (50)
No	4 (11)	2 (12)	0 (0)	0 (0)	2 (50)
Unsure	5 (14)	1 (6)	2 (25)	0 (0)	0 (0)
Valgus collapse					
Yes	8 (22)	5 (29)	1 (13)	1 (20)	1 (25)
No	22 (61)	11 (65)	5 (63)	4 (80)	2 (50)
Unsure	6 (17)	1 (6)	2 (25)	0 (0)	1 (25)

[a]Data are reported as median (interquartile range) or n (%). ACL, anterior cruciate ligament; IC, initial contract; IF, injury frame.
[b]Positive values indicate ipsilateral, and negative values indicate contralateral.

Overall, 11 injuries each occurred to point guards (29%) and shooting guards (29%), 9 to small forwards (24%), 4 to centers (10%), and 3 to power forwards (8%). Regarding match phases, a similar number of injuries occurred in the first (n = 20 [53%]) and second (n = 18 [47%]) halves of matches. More injuries occurred in the second (n = 14

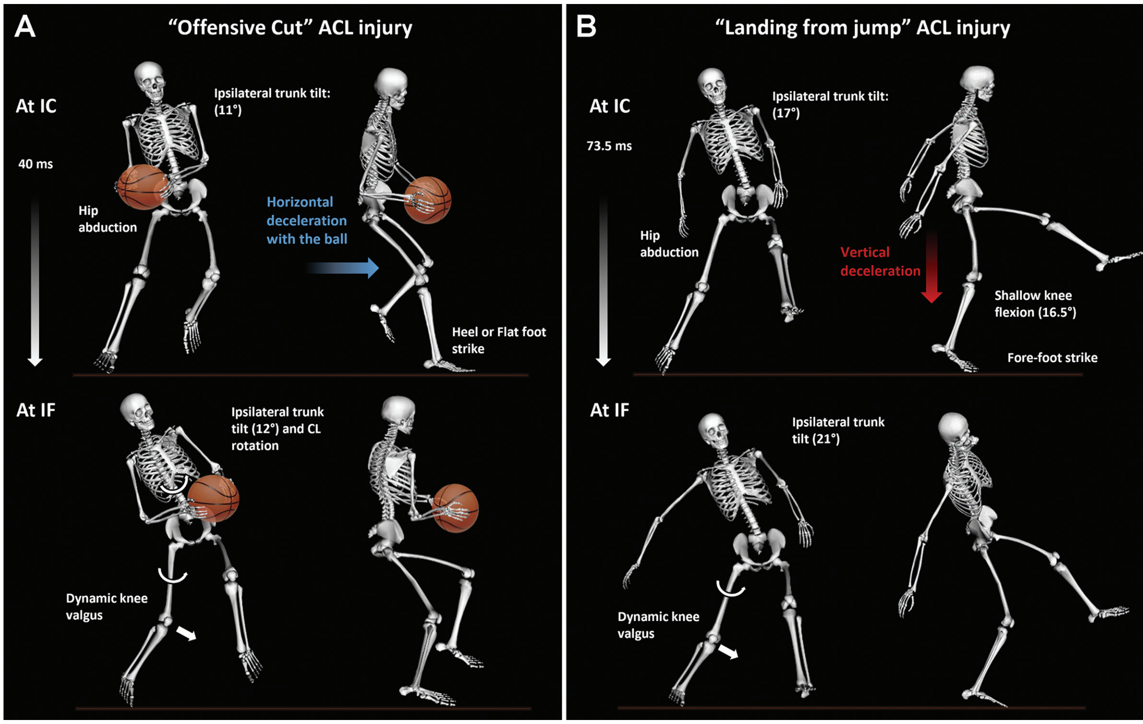

Figure 5. Biomechanics (kinematics) of the 2 most frequent situational patterns for anterior cruciate ligament injuries in male professional basketball players: (A) offensive cut and (B) landing from a jump. IC, initial contact; IF, injury frame.

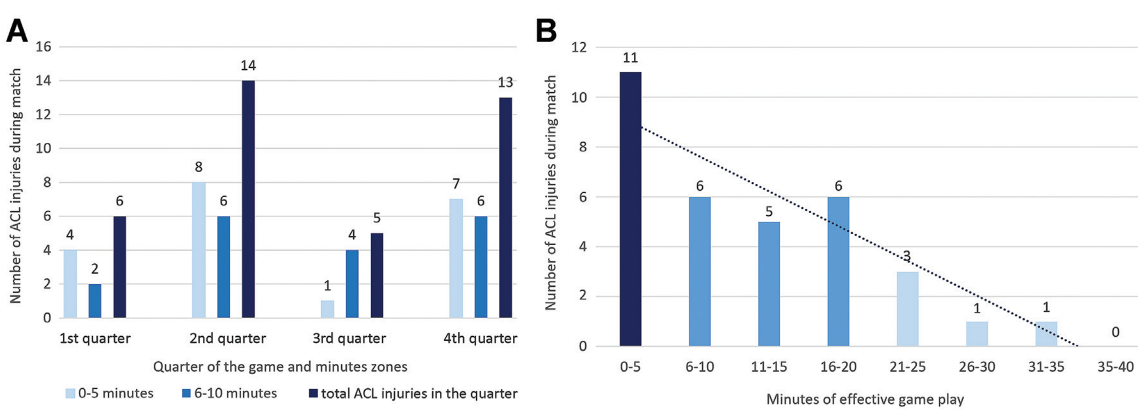

Figure 6. Distribution of anterior cruciate ligament injuries during a match: (A) distribution across half and quarter phases and (B) distribution according to minutes of effective playing time. The dotted line indicates the linear trend.

[37%]) and fourth (n = 13 [34%]) quarters than in the first (n = 6 [16%]) and third (n = 5 [13%]) quarters (P = .028) (Figure 6A). Analysis of players' actual playing time when correcting for substitutions was possible in 33 cases; one-third of injuries (n = 11 [33%]) occurred in the first 5 minutes of a player's actual playing time and half (n = 17 [52%]) within the first 10 minutes of actual playing time (Figure 6B). Regarding locations on the court, nearly three-fourths (73%) of injuries occurred in zone 5 (Figure 7 and Appendix Figure A1).

DISCUSSION

The main findings of our study were that (1) virtually all ACL injuries (97%) in elite basketball occurred without direct contact to the knee, with more injuries occurring with an indirect than noncontact mechanism; (2) there were 3 main situational patterns, with offensive cutting being the dominant pattern; (3) kinematic changes from IC to the IF were multiplanar, with differences between situational patterns; and (4) there were differences in

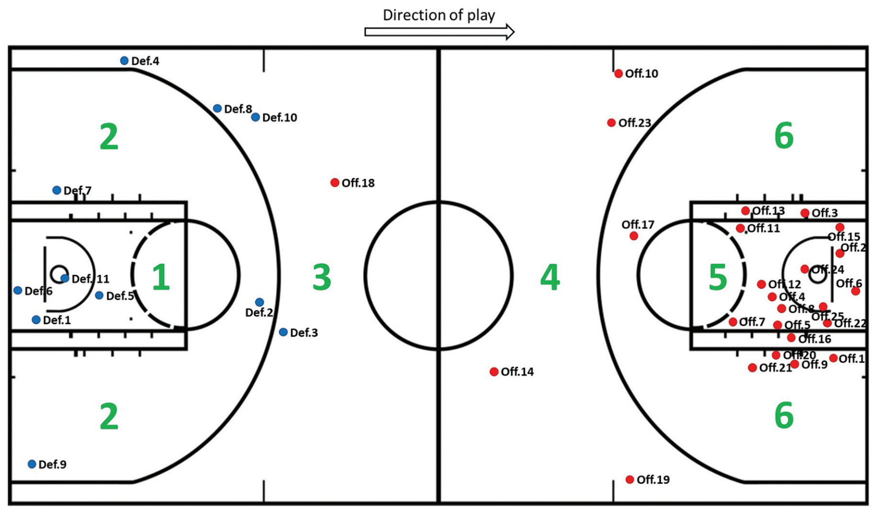

Figure 7. Distribution of anterior cruciate ligament injuries on the basketball court according to zones. Blue dots represent defensive (Def) injuries, and red dots represent offensive (Off) injuries.

injuries between phases of the match, court locations, and player positions.

Injury Mechanisms

Most ACL injuries occurred while attacking (69%), similar to findings in previous research on basketball injuries (74%).[23] This is much higher than that in other sports such as soccer, which typically has noted more injuries, almost 70%, while defending[7,11,37] but is very similar to another ball-carrying sport: rugby (72% while attacking).[13] This suggests a higher risk of ACL injuries in ball-carrying sports while attacking. Additionally, according to our data, ACL injuries in male basketball players were more commonly the result of horizontal deceleration (eg, cutting) rather than vertical deceleration (eg, landing from a jump). Injury prevention programs should emphasize the importance of horizontal deceleration tasks.

We found a much lower number of direct contact injuries (3%) than previously reported in male basketball players (24%),[23] although similar to that in female players.[23] Basketball is considered a noncontact sport (although a large amount of contact does occur), and thus, lower numbers of direct contact injuries versus other more contact-based sports such as soccer (12%)[11,37] and collision sports such as rugby (32%)[13] are expected. This highlights the great potential for strategies mitigating the risk of ACL injuries in basketball.

We found indirect contact (58%) as opposed to noncontact (39%) to be the dominant injury mechanism. This is very different from previous research on male basketball players, which indicated few indirect contact injuries (12%), with most injuries being noncontact (65%).[23] The importance of indirect contact in ACL injury causation has recently been reported in other sports such as soccer,[11] rugby,[13] and football[18] as well as in other injuries in soccer, including the medial collateral ligament.[8] Our research highlights the importance of indirect contact injuries in ACL injury causation. Most of these indirect contact injuries involved contact to the injured player's upper body in or before the IF, which is thought to lead to mechanical perturbation, resulting in the loss of neuromuscular control and suboptimal kinematics.

As with previous studies in basketball,[6,23] injuries typically occurred with the ball or an opposing player in proximity. The role of neurocognitive errors and distraction has been highlighted as important in the mechanics of injuries in soccer[16] and should not be neglected. However, in the case of ACL injuries in basketball, these aspects may be less relevant, as these injuries are more frequently offensive in nature, with the player potentially in control of the playing situation. Mechanical perturbation during these offensive actions as opposed to "neurocognitive perturbation" may be more relevant and should be considered in the design of programs that mitigate the injury risk.

Situational Patterns

Most injuries occurred according to 3 main situational patterns: (1) offensive cut (47%), (2) landing from a jump (22%), and (3) defensive cut (14%). We found more injuries during cutting (61% vs 12%, respectively) and less during landing (22% vs 59%, respectively) than previous research in basketball.[23] Previous research has not distinguished between offensive and defensive cutting. Of the landing injuries, we found these to be predominantly indirect contact single-leg injuries, which differs from previous research that reported noncontact single- and double-leg landing injuries.[23] ACL injuries during offensive cutting were the most represented and therefore critical to be addressed. In our cohort, most of these injuries were indirect contact (~60%), with mechanical perturbation at the upper body, suggesting a key role of player-to-player interactions. On the other hand, nearly 40% were noncontact, even in this cohort of very selected male professional players. A potential approach to mitigate these injuries could be to address the cutting technique[14] while eccentrically strengthening the lower limbs, thus building the capacity to absorb high deceleration forces.[38] The defensive cut is a new situational pattern, which has not previously been mentioned in basketball, and was apparent in 14% of injuries. This is similar to the pressing-type pattern identified by our group and others in soccer[11,24,37] and rugby.[13] It often involves neurocognitive perturbation[11,16] in which the player must change directions in an attempt to make a tackle/block. Pattern-specific injury reduction principles are suggested.

Biomechanical Findings

Data from our kinematic analysis largely confirm existing knowledge of ACL injuries: that they occur because of multiplanar loading.[6,11,13,23,25,31,37] In the sagittal plane, our results support a "knee-dominant" pattern at the time of the injury,[11,13,24] although with some differences between situational patterns. At IC, considering all injuries, we found an upright trunk, early flexed hip and knee, and plantarflexed ankle. From IC to the IF, there was a minimal change in trunk or hip flexion but a moderate increase in knee flexion (+22°) and ankle dorsiflexion (+20°). The 24° knee angle at IC is thought to correspond to high ACL loading and a vulnerable position.[9,40] The knee flexion angle in the IF (46°) is higher than that previously found in basketball (18°-23°)[23] but more aligned with more recent video analysis research (30°-53°)[11,13,24] and studies using model-based image-matching approaches (47°).[21] While we report a "knee-dominant" pattern in the sagittal plane (eg, preferential flexion at the knee, minimal hip/trunk flexion, and reduced ankle plantarflexion), the change in knee flexion from IC to the IF was still less than that found in similar movements, not resulting in an injury (+22° vs +34°, respectively).[6] The increase in ankle dorsiflexion from IC to the IF (+20°) was greater than previously found for ACL injuries in other sports (+0°-16°)[6,11,13,24,37] but still less than half that reported in controls performing similar movements and not sustaining ACL injuries (44°).[6] The increase in ankle dorsiflexion from IC to the IF was less during cutting (+18°-20°) than landing (+45°), suggesting that reduced ankle acceptance during cutting but not landing may be associated with an ACL injury. Interestingly, we also found the difference between IC and the IF to be nearly twice as long for landing injuries (74 milliseconds) versus cutting injuries (40 milliseconds). A flat-footed strike pattern (~95% of cases in the IF during cutting) and reduced ankle angular motion (18°-20° vs 44°, respectively) likely contributed to ankle stiffness and knee joint loading by hindering the calf muscle's ability to absorb external ground-reaction forces during cutting.[10,39] This, in combination with minimal trunk and hip motion, suggests preferential sagittal-plane loading at the knee level, specifically during offensive cutting.

We also found altered frontal- and transverse-plane movements, thought to be essential for ACL injuries.[25,31] Knee valgus and valgus-type loading from IC to the IF were common, as in previous research.[11,13,21,37] Also similar to previous studies,[11,13,37] hip abduction motion was common, with a significant increase in hip internal rotation and/or adduction (medial thigh motion) from IC to the IF in most cases.

We found a lateral trunk tilt toward the injured limb at IC and in the IF (11°-13°), similar to that in other sports but larger than in male professional soccer and rugby players (5°),[11,13] suggesting lower control of the upper body. The lateral trunk tilt was particularly high for landing injuries (21°). A laterally orientated trunk is thought to increase ACL loading because of a lateral shift in the center of mass, thus increasing the knee abduction moment.[30]

Complete valgus collapse occurred in 22% of cases, which is similar to that found previously in male basketball players (17%) but substantially lower than reported in female basketball players (53%).[23] Compared to other sports, it is slightly higher than that found for elite male soccer players (8%-13%),[11,37] identical to elite female soccer players,[24] and substantially lower than that reported in elite male rugby players (34%).[13] It is likely a mix of task demands, the player's weight, and neuromuscular control/function, as well as sex-specific differences, that account for the variability in complete valgus collapse across sports, sexes, and situational patterns.

Distribution of Injuries by Player Position, Match Phase, and Court Location

We found differences in the injury incidence according to player position, suggesting a greater risk of ACL injuries for guards (58% of injuries, including point guards and shooting guards [29% each]) and a lower risk among centers (10%). Previous research on positional differences found fewer injuries for guards than our study (42%-45%) and a higher incidence for centers (19%-22%) than we found,[17] with minimal differences between positions.

Three-quarters of all ACL injuries occurred within the scoring zone (zone 5). Schultz et al[33] found that National Basketball Association players with higher drive tendencies with the ball toward the basket had a significantly higher rate of ACL injuries (5.2%) than those with lower drive tendencies (3.8%). They suggested that players with a high drive tendency more likely rely on quick lateral movements and acceleration/deceleration movements, shown here to be components of ACL injuries.

We found a similar number of injuries across the first (53%) and second (47%) halves of the match. Previous research reported more injuries in the second half (62%)[17] and suggested the role of fatigue as a mechanism of injury, which our work somewhat contradicts. Interestingly, we found more injuries in the second (37%) and fourth (34%) quarters compared to the first (16%) and third (13%) quarters. The higher rate in the fourth quarter (34%)

is similar to that found in previous research (40%),[17] but the high incidence in the second quarter (37%) contradicts previous research (13%).[17] While higher numbers in the second and fourth quarters could indicate the role of fatigue within each half (as opposed to cumulative fatigue over the course of the match), one-third of injuries occurred in the first 5 minutes and more than 50% in the first 10 minutes of a player's effective playing time (when correcting for substitutions), with a strong trend showing fewer injuries as the minutes of the match increased. It is not clear why there were higher numbers of injuries in the second and fourth quarters. Typically, there is either similar workloads (total distance, distance per minute, accelerations and/or decelerations performed) across quarters[1,2] or a gradual decline throughout the match.[32,36] It is possible that the use of substitutions during these quarters (second and fourth), with players entering the match with a lack of neuromuscular/neurocognitive preparation when coming from the bench, may be responsible. Equally, given the complexity of ACL injury causation,[4] we cannot rule out fatigue as a risk factor in some players. It is likely that injuries are caused by multiple factors, including neuromuscular readiness, match intensity, and still possibly acute and cumulative (over the course of match play) fatigue in some cases, among others.

Practical Implications

Our work collectively suggests that many ACL injuries in male basketball players may be preventable, with few direct contact injuries found. Most injuries were indirect contact, suggesting mechanical perturbation as an important factor in ACL injury causation. While approximately 40% were noncontact injuries, these typically involved the ball or an opposing player close by, potentially indicating a role of neurocognitive errors and/or distraction in injury causation. Understanding injury mechanisms is considered important for prevention.[3,35] Our work suggests that improving neuromuscular control/kinematics during single-leg landing and cutting actions, in response to either mechanical or neurocognitive perturbation, may be important to reduce the ACL injury risk. Previous research has shown that changes in the direction technique may be effectively learned to reduce external knee abduction moments,[14] and altered kinematics at the time of screening for changes in direction has been shown to be prospectively associated with the ACL injury risk in a small group of female soccer players.[15]

Methodological Considerations

The main strengths of our study are (1) the sample size, with ours being the largest systematic video analysis of ACL injuries to date in elite male basketball players (the only other study on video analysis in basketball had 39 players, which was split across male [n = 17] and female [n = 22] players); (2) the consecutive nature of the injuries analyzed; (3) consistent biomechanical (kinematic) analysis using measurement tools and 3 independent viewers; and (4) the inclusion of data on the distribution of injuries by court location and match phase. The weaknesses of the study lie in the methodology used to identify ACL injuries, which is different from the gold standard of prospective studies with frequent contact with teams. This limits information concerning concomitant injuries of the players. We determined the kinematics before and at the time of the injury using video analysis as opposed to the gold standard of a model-based image-matching technique.[21] Video analysis, however, is valid[22] and has been consistently adopted in similar studies.[8,11,13,37] We have a male-only, elite-level sample, and thus, this may not be generalizable to female players and players at lower levels. Further work to elucidate the injury mechanisms in these samples is warranted.

CONCLUSION

Indirect contact as opposed to noncontact was the main injury mechanism in male professional basketball players. There were 3 main situational patterns described, with offensive cut being the most prevalent. Biomechanical analysis confirmed a multiplanar mechanism, with knee loading in the sagittal plane accompanied by dynamic valgus. More injuries occurred in the first 10 minutes of a player's effective playing time, within the scoring zone, and among guards.

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APPENDIX

TABLE A1
Checklist for Video Evaluation[a]

Variable	Category
Playing phase before injury	Defensive/offensive
Court location at time of injury	According to division of basketball court into 6 zones[b]
Player contact before injury[c]	Yes/no
If contact, where?	Upper body/pelvis/injured leg/uninjured leg
Player contact in IF	Direct contact/indirect contact/noncontact
If indirect contact, where?	Upper body/pelvis/injured leg/uninjured leg
Injury mechanism	Direct contact/indirect contact/noncontact
No. of feet on ground	One/both/unsure
Leg loading in IF	Injured leg/uninjured leg/unsure
Horizontal speed	Zero/low/moderate/high
Vertical speed	Zero/low/moderate/high

[a]IF, injury frame.
[b]See Figure 1 for a description of the zones.
[c]In the frames before the IF/initial contact.

TABLE A2
Checklist for Biomechanical Evaluation[a]

Variable	Measurement/Category
Trunk flexion (+flexion, –extension)[b]	Estimation to nearest 5°
Hip flexion (+flexion, –extension)[b]	Estimation to nearest 5°
Knee flexion (+flexion, –extension)[b]	Estimation to nearest 5°
Ankle flexion (+dorsiflexion, –plantarflexion)[b]	Estimation to nearest 5°
Foot strike[b]	Heel/flat/toe/unsure
Trunk tilt (+ipsilateral, –contralateral)[b]	Estimation to nearest 5°
Trunk rotation[b]	Toward injured leg/neutral/toward uninjured leg/unsure
Frontal-plane hip alignment[b]	Abduction/neutral/adduction/unsure
Frontal-plane knee alignment[b]	Valgus/neutral/varus/unsure
Foot position[b]	Externally rotated/neutral/internally rotated
Significant hip internal rotation/adduction from IC to IF	Yes/no/unsure
Valgus collapse	Yes/no/unsure

[a]IC, initial contact; IF, injury frame.
[b]Measured at IC and in the IF.

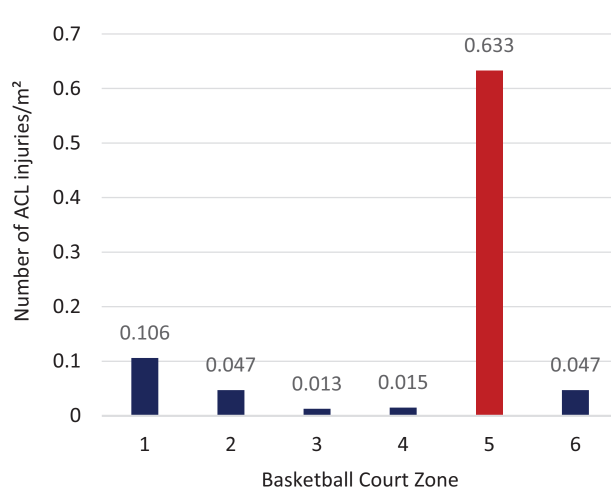

Figure A1. Distribution of anterior cruciate ligament injuries (per m^2) according to basketball court location.