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Mechanisms of Anterior Cruciate Ligament Injury in Basketball

Video Analysis of 39 Cases

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Background: The mechanisms of anterior cruciate ligament injury in basketball are not well defined.

Purpose: To describe the mechanisms of anterior cruciate ligament injury in basketball based on videos of injury situations.

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

Methods: Six international experts performed visual inspection analyses of 39 videos (17 male and 22 female players) of anterior cruciate ligament injury situations from high school, college, and professional basketball games. Two predefined time points were analyzed: initial ground contact and 50 milliseconds later. The analysts were asked to assess the playing situation, player behavior, and joint kinematics.

Results: There was contact at the assumed time of injury in 11 of the 39 cases (5 male and 6 female players). Four of these cases were direct blows to the knee, all in men. Eleven of the 22 female cases were collisions, or the player was pushed by an opponent before the time of injury. The estimated time of injury, based on the group median, ranged from 17 to 50 milliseconds after initial ground contact. The mean knee flexion angle was higher in female than in male players, both at initial contact (15° vs 9°, $P = .034$) and at 50 milliseconds later (27° vs 19°, $P = .042$). Valgus knee collapse occurred more frequently in female players than in male players (relative risk, 5.3; $P = .002$).

Conclusion: Female players landed with significantly more knee and hip flexion and had a 5.3 times higher relative risk of sustaining a valgus collapse than did male players. Movement patterns were frequently perturbed by opponents.

Clinical Relevance: Preventive programs to enhance knee control should focus on avoiding valgus motion and include distractions resembling those seen in match situations.

Keywords: athletic injuries; anterior cruciate ligament (ACL); biomechanics; perception

Although much attention has been focused on noncontact ACL injuries in team sports, the exact mechanism of these injuries remains unclear.^{7,28} Understanding the joint kinematics and loading patterns that lead to injury is essential.

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However, if the aim is to prevent injuries from occurring, it may also prove useful to explore the nature of the injury situations in a wider context.⁴ Important information would include what kind of player actions are involved, whether the joint kinematics is different during injury situations, and, if so, what factors cause the abnormal behavior. One such factor could be a perturbation occurring before the injury, for example, by being pushed off balance. In other words, it may be helpful to describe the injury mechanism in terms of not only the involved biomechanics but also the playing situation and player behavior.⁴

Video footage of injury situations represents objective sources of information on the kinematics involved in the injury mechanism. The accuracy of this method ultimately depends on the methods used to extract the data. In contrast, athlete interviews are subjective reporting of the injury, are laden with inaccuracies of remembering the event, and are often biased by others' input into what might have happened. Mathematical, laboratory, or cadaveric simulation studies can also provide accurate data, but they cannot provide information from actual injuries. Hence, video analysis may represent a valuable research tool to describe the mechanisms of injury. Previous studies that used video analysis to describe the mechanisms of noncontact ACL injuries seem to agree that in most cases, the injury occurred early after initial contact (IC) in landings or cutting maneuvers with the knee near full extension.^{5,34,40} Also, many situations resulted in a "valgus collapse," that is, a situation in which the knee collapses medially from excessive valgus and/or internal-external rotation. However, with the exception of the study of Olsen et al,³⁴ who attempted to quantify the joint kinematics, most descriptions were qualitative, and the results are difficult to compare across studies. Furthermore, apart from 1 study on team handball,³⁴ previous video analyses have only investigated a limited number of cases from mixed sports.

Therefore, the purpose of this study was to describe the mechanisms of ACL injury in basketball in terms of the playing situation, player behavior, and joint kinematics based on 39 videotapes of real injury situations.

MATERIALS AND METHODS

Video Analysis

Six international experts, several with extensive experience in visual video analysis of injury tapes, participated as analysts in this study. A total of 39 videos of ACL injury situations were analyzed (17 male and 22 female players). Twenty-eight of the tapes were collected by sending out questionnaires to college trainers and team doctors around the United States asking for videotapes of ACL injuries. Of these 28 videos, 23 were from the high school and college level (22 match and 1 training injury), and 5 were from National Basketball Association (NBA)/Women's National Basketball Association (WNBA) games. The remaining 11 cases were match injuries obtained from NBA Entertainment Inc (NBA and WNBA games). No medical information was available other than the diagnoses.

Eight situations were filmed from 2 different views, and 2 situations were filmed from 4 different views. The remainder of the videotapes contained only 1 camera view. When more than 1 camera recording was included, composite videos were created by manual synchronization, using the IC of the foot in each camera view as the synchronization frame. If the foot could not be seen in both camera views, we used another player's foot contact instead.

The video quality, as judged by the picture quality, resolution of the subject, number of cameras, the camera angle(s), and degree of occlusion, was excellent in 2 cases, good in 4 cases (see Figure 1 for an example), average in 16 cases, poor in 11 cases (see Figure 2), and impossible to judge in 6 cases.

The cases that were impossible to judge were excluded for the kinematic variables but were included in the analysis of playing situation, although no consensus could be the result for several variables. All the injuries occurred on finished wood basketball court flooring.

The video recordings were processed using Final Cut Pro HD (version 4.5, Apple, Cupertino, Calif), deinterlaced to achieve a 60-Hz effective frame rate, and stored using either the DV or the DVCPRO50 coded in NTSC format. Each video was composed in 2 versions, 1 in real time and 1 in slow motion (50% of normal speed). Each of the analysts used a Macintosh computer (Apple) with a 20-in or 21-in LCD monitor, and the analyses were done independently, with the analyst blinded to the results of the other analysts. QuickTime (version 7.0, Apple) was used to play the videos, and the analysts could move the video sequence back and forth, frame by frame, using the keyboard arrows.

For each situation, 2 distinct time points were analyzed: IC and 50 milliseconds after IC. We decided to analyze a predetermined time point instead of allowing for separate time points to enable an intertester reliability analysis. Previous video analysis studies,³⁴ as well as simulation studies^{29,32} and laboratory motion analysis studies,³¹ have indicated that such injuries are likely to occur immediately after IC. Thus, we assumed that by analyzing these 2 time points, it was probable that the injury would occur within this narrow interval. However, the analysts were free to suggest a point of rupture outside this interval.

In 4 of the 39 cases, it was not possible to deinterlace the footage, thus making the effective frame rate only 30 Hz. In these cases, we chose to do the analyses at IC and at 33 milliseconds, which corresponds to 1 frame after IC.

The analysts were asked to judge if there was contact at and before the injury and to separate between situations in which another player was close (within 1 m) or not. Contact was classified into the following: direct blow to the knee, collision of other kind, pushing, foot-foot contact, holding, or other. Player action was categorized into the following: 1-legged landing, 2-legged landing, 1-legged stopping, 2-legged stopping, pivoting, cutting, and other. Player attention was classified according to where the player appeared to have directed his or her attention at the time of injury: the basket rim, the player from whom he or she received the ball, the player who received the ball, opponent, ball, and other. Ball possession was classified as follows: yes, no, have passed, and have shot. Game phase was classified as follows: offense, defense, rebound, and turnover. Foot placement was classified as follows: narrow, normal, wide, and very wide.

The analysts were also asked to provide estimates of several continuous variables. At the predefined frames marked in each of the videos (IC and 50/33 milliseconds after IC), they assessed knee flexion-extension, knee varus-valgus, hip flexion-extension, hip adduction-abduction, approach velocity, and vertical velocity. No measurement tools were used to aid the visual inspection estimates of the experts. Approach speed was the instantaneous horizontal velocity of the center of mass at IC. Similarly, vertical speed was the downward-directed instantaneous velocity of the center of mass at IC.

In addition, 4 analysts assessed if the knee joint experienced a "valgus collapse" in the injury.

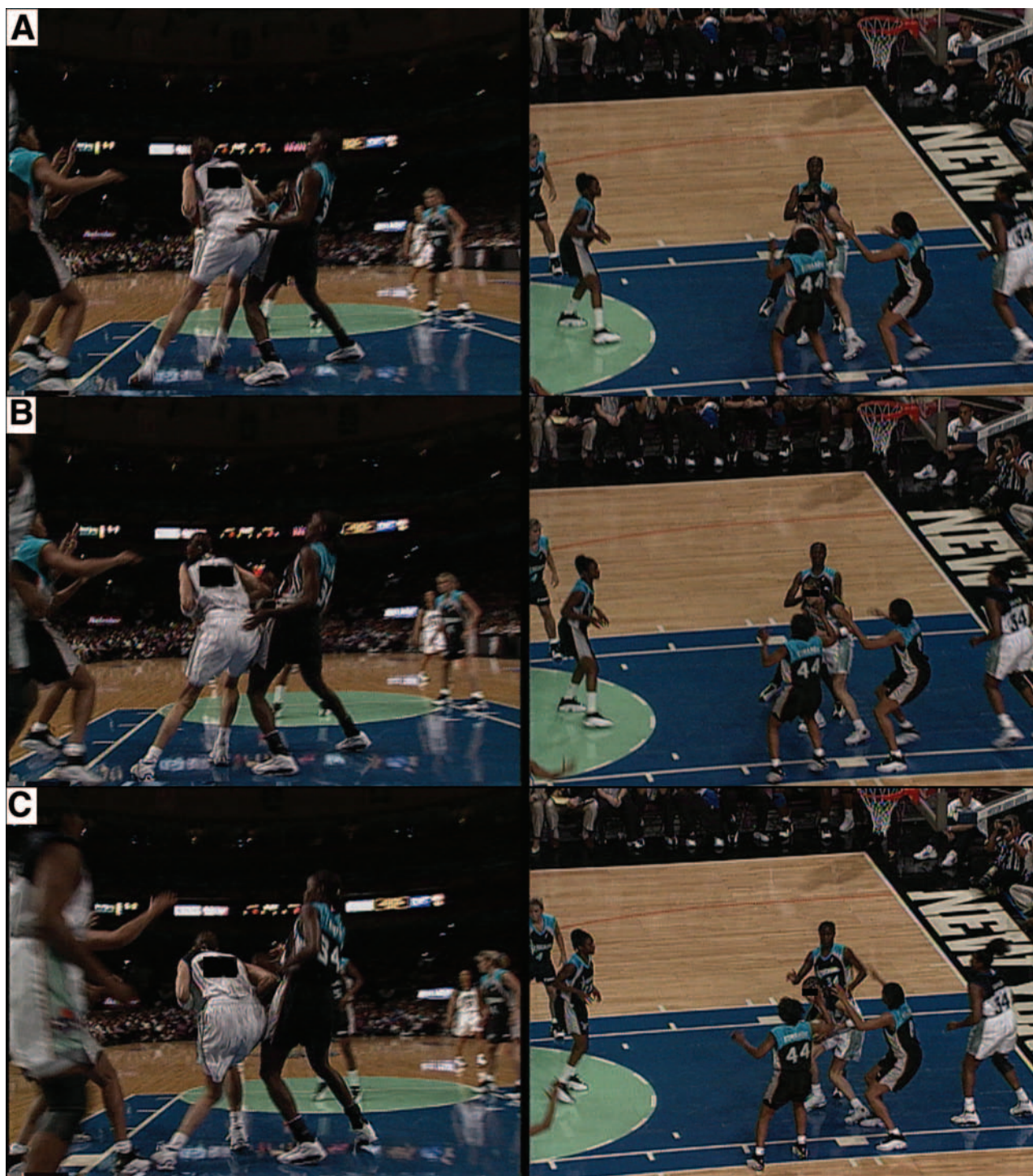


Figure 1. Synchronized video images from a 2-camera sequence with good quality. The injured player is seen in white shorts in the middle of the images at initial contact (A); 33 milliseconds after initial contact, corresponding to the approximate estimated time of rupture (B); and 133 milliseconds after initial contact (C). This situation was classified as a “valgus knee collapse.”

Data Reporting and Statistical Methods

The data from the analysts' forms were entered into a custom-made database using Microsoft Access (version 2003, Microsoft Corporation, Redmond, Wash). Descriptive

statistics were calculated using SPSS (version 13, SPSS Inc, Chicago, Ill). Knee flexion and valgus as well as hip flexion and abduction angles are shown as positive values. For all the continuous variables, except time of injury, we calculated the mean value between analysts for each case. For the time



Figure 2. Video image from a single-camera sequence with poor quality. The right leg (partly hidden) of the player to the left, holding the ball, is injured. The video frame is captured at initial contact of the right foot.

of injury, we used the median instead of the mean because 1 analyst in several cases estimated the injury to occur much later than did the rest of the group. Results are reported as the means with SDs and ranges across cases. Finally, the SDs across analysts are reported as a measure of intertester reliability for each variable.

To obtain a consensus on each of the categorical variables, at least 3 of the analysts had to agree on the category. If fewer than 3 analysts agreed on a category, or if the analysts' opinions were split in 2 groups of 3, the decision was "no consensus."

We used an independent-samples *t* test to determine if there were differences between genders. An independent-samples *t* test was also used to determine if there were differences in vertical speed between cutting maneuvers and landings. Pearson χ^2 test was used to examine if there was a difference in relative risk for sustaining a valgus collapse between genders. For all analyses, an α level of $<.05$ was used to denote statistical significance.

RESULTS

Playing Situation and Player Behavior

In 29 of the 39 cases, the injury occurred when attacking, 5 while defending, 2 after rebounds, and 1 injury occurred during a turnover. In 2 cases, there was no consensus. In 28 cases (10 male and 18 female players), the injured player was in possession of the ball when the injury occurred. In 3 cases, the injured player had just shot, whereas in 7 cases, the player did not have the ball at all. In 1 case, there was no consensus on ball involvement. The attention of the injured player was most commonly focused at the basket rim (15 cases), followed by an opponent (11 cases). In 9 cases, analysts reported that the focus was on the ball and in 1 case on the player who received a pass. In 3 cases, there was no consensus.

There was contact at the assumed time of injury in 11 of the 39 cases (5 male and 6 female players). Four of these

TABLE 1
Player Action at the Time of Injury (N = 39)

Action	Male Players	Female Players
1-legged landing	6	4
2-legged landing	4	9
Cutting	2	2
No consensus	1	2
Direct blow to the knee	4	0
Impossible to judge	0	5

cases were direct blows to the knee, all in men. Three of the 11 contact cases were classified as "collision of other kind," all in female players. In the 4 remaining contact cases, there was no consensus. However, in 22 of the remaining 28 cases (9 male and 13 female players), another player was within 1 m at the assumed time of injury. Only 2 injuries occurred with no other players within 1 m. In the 4 remaining cases, there was no consensus. Although contact at the time of injury was only registered in 6 cases in female players, in as many as 11 of the 22 female cases, there was a collision or the player was pushed by an opponent before the injury. Only 1 male player was perturbed in this way before the time of injury. Most of the player maneuvers were landings (Table 1). There were no cases classified as 1-legged stopping, 2-legged stopping, or other.

Knee and Hip Motion

For the joint motion description, we excluded direct blows to the knee (4 cases). In addition, there were 5 cases in which the video quality was too poor to allow further analyses. This meant that 30 videos were available to assess knee and hip motion during noncontact ACL injuries (13 male and 17 female players).

The mean knee flexion angle was higher in female players than in male players at IC (15° vs 9° , $P = .034$) and at 50/33 milliseconds after IC (27° vs 19° , $P = .042$). This was the case for hip flexion as well, both at IC (27° vs 19° , $P = .043$) and at 50/33 milliseconds after IC (33° vs 22° , $P = .020$).

The estimated time of injury ranged between 17 and 50 milliseconds after IC (Table 2). At IC, the mean knee flexion ranged between 8° and 15° across player actions and genders (Table 3). At 50/33 milliseconds after IC, the knee flexion angles were about twice as high as at IC.

No significant gender differences for female and male players were found at IC for knee valgus (4° vs 3° , $P = .071$), but at 50/33 milliseconds after IC, female players had larger valgus angles (8° vs 4° , $P = .018$). Knee collapse occurred in 9 of the 17 cases in female players. All of the collapses were cases that one could term *valgus collapse*; that is, the knee collapsed medially, in what appeared to be a combination of hip internal rotation, knee valgus, and external rotation of the tibia. No collapse was found in 2 cases, and 4 situations were impossible to judge. In addition, there were 2 cases of no consensus. Knee collapse occurred in only 2 cases in male players, whereas no collapse was found in 10 cases. One case

TABLE 2
Mean Time Point of Rupture (ms) and SDs With Range (n = 27)^a

Action	Male Players		Female Players	
	Mean ± SD	Range	Mean ± SD	Range
1-legged landing	37 ± 9	25-50	37 ± 5	33-42
2-legged landing	33 ± 7	25-42	39 ± 10	25-50
Cutting	46 ± 6	42-50	25 ± 12	17-33

^aThe 3 cases of no consensus in player action are not included in the table.

was impossible to judge. The relative risk for sustaining a valgus collapse was 5.3 times greater in female players than in male players ($P = .002$).

Mean hip abduction angles were consistent across genders and player actions, ranging from 8° to 19° (Table 4) at IC as well as at 50/33 milliseconds after IC. However, for individual cases, hip abduction angles ranging from -7° (ie, adduction) to 48° were reported.

Intertester Reliability

The mean SD for rupture time between analysts was 31 milliseconds, but values up to 105 milliseconds were seen (Table 5). The mean SD between analysts was higher for hip flexion compared with knee flexion, with a maximal SD of 32° observed for hip flexion. Relatively low SDs were observed for knee valgus angles, whereas for hip abduction angles, they were substantially higher. There were only small differences in SD between analysts between the video sequences rated as excellent, good, average, or poor. Similarly, there was no difference in intertester reliability for knee and hip flexion estimates whether a sagittal-plane view was present or not.

DISCUSSION

Playing Situation and Player Behavior

The results showed that 72% of the injuries did not involve contact with other players at the assumed time of injury. This agrees well with the findings of Boden et al,⁵ in which 72% noncontact injuries were registered among 100 cases. Arendt and Dick² found 80% noncontact injuries in female players and 65% in male players. Opponents were close by in nearly all of the injury situations. This is not unexpected because a competitive game like basketball implies close proximity between players most of the time. However, as many as half of the injured female players were pushed or collided before the time of injury, which indicates that such perturbations may have influenced the movement patterns. These findings support statements by Boden et al,⁵ Ebstrup and Bojsen-Moller,⁹ and Olsen et al,³⁴ who suggested that although there was no body contact at the time of injury, the movement patterns may have been perturbed by an opponent. This view is supported by experimental studies, which show that the introduction of a static defender in cutting maneuvers³¹ or

using an overhead goal¹² in vertical jumps alters the knee biomechanics significantly. Thus, it seems reasonable to suggest that preventive programs^{14,33} should include “distracting elements” resembling those seen in match situations to enhance knee control. Furthermore, there is an obvious need to continue the development of laboratory protocols that more effectively simulate actual game play by including elements forcing subjects to focus their attention elsewhere.

Joint Kinematics

Previous studies have concluded that ACL injuries occur shortly after foot strike with the knee near full extension.^{5,34,40} By interpolation between the estimates at IC and 50/33 milliseconds after IC, the analysts' knee flexion estimates at the assumed time of injury were 18° and 24° in male and female players, respectively. However, because of the systematic underestimation discussed below, the true knee flexion angles may be twice as high as the visual estimates.²²

Numerous recent studies have investigated if the gender difference in ACL injury incidence is caused by differences in knee and hip flexion in landings, with the rationale that women are more extended during landing, perhaps because of weaker musculature, than are men.^{10,11,31,36,38} Boden et al⁵ hypothesized that a vigorous quadriceps contraction on an extended knee was the main cause of the excessive ACL force. However, although several laboratory studies have supported this theory,^{31,38} some studies also found no differences,³⁶ and several studies have even reported larger flexion angles in women.^{10,11} Huston et al¹⁸ showed significantly less knee flexion at IC during a drop landing from a 60-cm height but not from a 20-cm height, indicating that such a difference may be task specific if it exists at all. In the present study, in which actual ACL injury situations were analyzed, female players were found to have significantly higher knee and hip flexion angles than men at IC, at 50/33 milliseconds after IC, and at the assumed point of injury. These results suggest that women are likely not more prone to the quadriceps drawer mechanism than are men. In theory, it may even be possible that the larger knee flexion angles will increase the risk of noncontact ACL injury. Nevertheless, caution must be taken because, for example, hamstrings muscle coactivation could be different.

The question still remains to what degree the quadriceps drawer mechanism is a likely cause of injury in the situations studied here, considering that the knee flexion angles at the time of injury may be substantially higher than what

TABLE 3
Mean Knee and Hip Flexion (deg) and SDs With Range (n = 27)^a

Action	Knee Flexion						Hip Flexion									
	Men (n = 12)			Women (n = 15)			Men (n = 12)			Women (n = 15)						
	IC	50/33 ms After IC	Range	IC	50/33 ms After IC	Range	IC	50/33 ms After IC	Range	IC	50/33 ms After IC	Range				
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range				
1-legged landing (n = 10)	8 ± 6	3-16	18 ± 6	10-28	10 ± 4	5-14	18 ± 4	13-23	16 ± 8	5-27	22 ± 7	17-31	20 ± 10	5-27	20 ± 7	14-30
2-legged landing (n = 13)	9 ± 7	3-19	17 ± 6	11-23	15 ± 4	10-22	27 ± 7	18-40	18 ± 4	13-22	18 ± 5	14-26	25 ± 8	17-44	32 ± 11	21-54
Cutting (n = 4)	12 ± 2	11-13	23 ± 7	18-28	14 ± 11	7-22	27 ± 4	24-29	29 ± 6	25-33	22 ± 1	21-22	37 ± 7	32-42	45 ± 6	41-49

^aIC, initial contact. The 3 cases of no consensus in player action are not included in the table.

TABLE 4
Mean Knee Valgus and Hip Abduction (deg) and SDs With Range (n = 27)^a

Action	Knee Valgus						Hip Abduction									
	Men (n = 12)			Women (n = 15)			Men (n = 12)			Women (n = 15)						
	IC	50/33 ms After IC	Range	IC	50/33 ms After IC	Range	IC	50/33 ms After IC	Range	IC	50/33 ms After IC	Range				
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range				
1-legged landing (n = 10)	3 ± 1	0-5	6 ± 3	2-10	4 ± 1	3-5	8 ± 0	8-9	12 ± 5	6-20	12 ± 3	9-16	15 ± 21	1-46	15 ± 22	-1-48
2-legged landing (n = 13)	2 ± 1	1-4	5 ± 2	3-8	3 ± 2	1-7	7 ± 3	4-14	19 ± 13	9-38	17 ± 16	6-41	15 ± 9	6-33	14 ± 10	5-36
Cutting (n = 4)	2 ± 2	1-4	-2 ± 12	-11-7	6 ± 0	5-6	10 ± 3	9-12	11 ± 20	-3-25	8 ± 21	-7-23	19 ± 6	14-23	14 ± 6	10-19

^aIC, initial contact. The 3 cases of no consensus in player action are not included in the table.

TABLE 5
Intertester Reliability for Continuous Variables Reported as the SD Between Analysts^a

Variable	Intertester Reliability		
	SD	Minimum Value	Maximum Value
Rupture time, ms	31	13	105
Knee flexion, deg	7	2	20
Hip flexion, deg	12	3	32
Valgus, deg	4	1	18
Hip abduction, deg	10	3	25
Approach speed, m/s	1.0	0.5	1.9
Vertical speed, m/s	1.1	0.4	2.0
Foot-pelvis rotation, deg	8	1	19

^aData are shown as the mean SD across cases with minimum and maximum values.

have been assumed previously. Although it has been shown that isolated ACL rupture from the quadriceps mechanism is possible,⁷ the relationship between flexion angle and ACL strain induced by quadriceps contraction, and how it is affected by ground reaction forces, is still unclear.^{8,17,26,37} Although some cadaveric studies have suggested that this mechanism requires flexion angles of less than 30° to be effective,^{8,26} others have shown that quadriceps activity can induce significant ACL strain³⁷ and anterior tibial translation¹⁷ even at 45°. In a recent cadaveric study,⁴¹ ACL strain was reported to be proportional to the increase in quadriceps force, with maximal strain occurring at approximately 30°. However, mathematical simulation studies have concluded that sagittal-plane loading alone cannot produce ACL ruptures,^{29,35} although these authors acknowledged that this mechanism may still contribute to the injury. In light of these findings, it is difficult to interpret the flexion angle results from the present study. If the strain produced from the quadriceps drawer mechanism is not the primary cause of the loading and injury, it is possible that an anterior drawer before the time of rupture could place the knee joint in a vulnerable position. If anterior drawer is combined with valgus and rotational loading, these combined forces may lead to ACL failure. However, investigation is required to delineate the role of the quadriceps drawer in the ACL injury mechanism.

Olsen et al³⁴ stated that the injury could be owing to valgus loading in combination with external or internal knee rotation. This would support the hypothesis of Ebstrup and Bojsen-Moller,⁹ who proposed notch impingement as the cause of injury. Hewett et al¹⁵ showed in a prospective study that a landing pattern with valgus loading predicted ACL injury, indicating that this was likely to be an important element in the noncontact ACL mechanism. In support of this, Speer et al³⁹ concluded that valgus loading must have been part of the injury mechanism, based on the bone bruise pattern on magnetic resonance imaging (MRI). Arnold et al³ suggested internal rotation as a probable injury mechanism from athlete interviews. The internal rotation hypothesis is supported by cadaveric studies that have shown that internal rotation will put high stress on the ACL, especially at low flexion angles.²⁵

These hypotheses cannot be evaluated by video analysis alone because it is not possible from such gross kinematic

estimates to determine the relationship between external loads, muscle loads, and ACL force. For instance, as discussed, we know that a small anterior displacement of the tibia may cause large ACL forces, but estimation of such skeletal motions from ordinary television recordings is simply not possible. Still, the valgus collapses seen in many cases indicate that valgus loading was likely present before the rupture, although it is also possible that the valgus loads lead to collapse after ACL failure. The noncontact valgus collapses appeared strikingly similar to the collapses seen in situations with direct blows to the lateral knee.

A possible implication of the higher proportion of valgus collapses in female players is that the knee-loading patterns in noncontact ACL injuries may be different between men and women. This hypothesis is supported by laboratory motion analysis studies in which men demonstrated internal rotation combined with varus motion, whereas women demonstrated the combination of valgus-external rotation.^{6,31} It is generally agreed that lumbopelvic (or core) stability plays an important role in controlling the knee.^{24,27,30,33} Furthermore, Kraemer et al¹⁹ found that the neuromuscular performance was lower in women, and several studies have shown a "ligament dominance" in women, implying that the ligaments rather than muscles absorb the impact forces.^{1,16} Insufficient lumbopelvic strength or lack of neuromuscular control might therefore be the reason for the uncontrolled valgus collapses. Interestingly, Hewett et al¹⁶ reported that this unfortunate joint-loading pattern can be drastically reduced through neuromuscular training. On the other hand, an alternative explanation could be that the loading patterns are not different between genders but that valgus collapses are more apparent after injury in female players because of reduced joint stiffness.^{13,42,43} In support of this theory, some degree of valgus was estimated in all cases in the present study. However, the relatively poor accuracy and precision of these estimates²² do not allow firm conclusions to be made. Likewise, the poor reliability in rotational variables²² makes it difficult to assess the internal rotation hypothesis, although some situations displayed rotational motions similar to what was illustrated in Arnold et al.³ Similar to what was reported in the study of Boden et al⁵ and Olsen et al,³⁴ we did not find any injuries involving hyperextension or varus.

Study Limitations

The study was not based on a systematic, prospective collection of videos from a defined athlete population but represented a convenience sample obtained from athletic trainers, team physicians, and the NBA. Thus, we do not know whether these are representative. Also, because we do not have access to the medical records, we do not know how the ACL tears were confirmed, nor do we know if the athlete had a history of previous knee injury. Nevertheless, it seems reasonable to assume that the diagnoses are reliable because an ACL rupture is a major injury usually requiring surgical intervention in this population of athletes. Furthermore, it required an effort to submit cases, which was not rewarded financially or in other ways.

From the video analysis, it is not possible to verify the exact moment when the ACL injury occurred. In fact, in many situations, it was not even easy to detect that an injury had occurred until the athlete took his or her weight off the injured leg. However, in other situations, obvious abnormal joint configurations (Figure 1) were seen soon after IC. Although the analysts most often agreed that the injury occurred within 50 milliseconds after IC, there were 6 situations in which 1 of the analysts estimated the time of rupture to be more than 100 milliseconds after IC, demonstrating the difficulty in performing such analyses. Still, the relatively consistent overall judgment from the group does indicate that there is a high probability that many of the injuries occurred shortly after IC, a conclusion that also agrees with previous studies.^{5,34,40}

The reliability of the visual-inspection approach was assessed in a recent study in which the same group of analysts examined a series of noninjury cutting and planting video situations.²² The results showed that the group consistently underestimated knee and hip flexion, although the differences were smaller near full extension. For instance, an estimated flexion angle of 20° corresponded to a true angle of approximately 40°. The results also showed that estimates for other variables, such as knee valgus or rotation angles, may not be reliable. Therefore, the results in the present study must be interpreted with caution.

Future Perspectives

Future studies should aim to improve methods for analyzing noncontact ACL injury situations from video, preferably using more sophisticated methods that can produce continuous estimates of the kinematics leading up to the point of rupture, for example, model-based image-matching techniques.^{21,23} The introduction of high-definition television broadcasts will be helpful for such analyses. In sports such as basketball, in which play is confined in a relatively small capture volume, an increased number of camera views and possibly even introduction of high-speed imaging equipment suitable for conducting 3D motion analysis can be considered. Even so, it will be necessary to combine different research approaches to evaluate the hypotheses proposed in the literature,²⁰ for example, to develop cadaveric models or mathematical simulation models that will produce the kinematics and MRI results seen in real injury situations.

CONCLUSION

The knee flexion angles at the assumed point of injury were higher in male players than in female players, and female players had a 5.3 times higher relative risk of sustaining a valgus collapse than did male players. The injuries occurred predominantly during landing. Although the majority of the injuries did not involve contact at the assumed point of injury, the movement patterns were likely perturbed by an opponent, for example, by pushing before the injury.

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