Video Analysis of Anterior Cruciate Ligament Tears in Professional American Football Athletes

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Background: Anterior cruciate ligament (ACL) injuries are prevalent in contact sports that feature cutting and pivoting, such as American football. These injuries typically require surgical treatment, can result in significant missed time from competition, and may have deleterious long-term effects on an athlete's playing career and health. While the majority of ACL tears in other sports have been shown to occur from a noncontact mechanism, it stands to reason that a significant number of ACL tears in American football would occur after contact, given the nature of the sport.

Hypothesis/Purpose: The purpose was to describe the mechanism, playing situation, and lower extremity limb position associated with ACL injuries in professional American football players through video analysis to test the hypothesis that a majority of injuries occur via a contact mechanism.

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

Methods: A retrospective cohort of National Football League (NFL) players with ACL injuries from 3 consecutive seasons (2013-2016) was populated by searching publicly available online databases and other traditional media sources. Of 156 ACL injuries identified, 77 occurred during the regular season and playoffs, with video analysis available for 69 injuries. The video of each injury was independently viewed by 2 reviewers to determine the nature of the injury (ie, whether it occurred via a noncontact mechanism), the position of the lower extremity, and the football activity at the time of injury. Playing surface, player position, and time that the injury occurred were also recorded.

Results: Contrary to our hypothesis, the majority of ACL injuries occurred via a noncontact mechanism (50 of 69, 72.5%), with the exception of injury to offensive linemen, who had a noncontact mechanism in only 20% of injuries. For noncontact injuries, the most common football activity at the time of injury was pivoting/cutting, and the most common position of the injured extremity included hip abduction/flexion, early knee flexion/abduction, and foot abduction/external rotation. There was no association between injury mechanism and time of injury or playing surface in this cohort.

Conclusion: In this study of players in the NFL, the majority of ACL tears involved a noncontact mechanism, with the lower extremity exhibiting a dynamic valgus moment at the knee. These findings suggest that ACL injury prevention programs may reduce the risk of noncontact ACL tears in American football players.

Keywords: football; anterior cruciate ligament; ACL tear; injury mechanism

Anterior cruciate ligament (ACL) injuries are common, often devastating, injuries in athletes. This can be particularly true among professional athletes, whose livelihood depends on the ability to compete. There has been increased public awareness and media coverage of ACL injuries in the National Football League (NFL) over the past several years. A recent study identified >200 ACL injuries in NFL players over a 4-season period (2010-2013).[15] These injuries are season ending and can have serious implications on the remainder of the athlete's career and ability to return to play.[8,11] Furthermore, they can increase the likelihood of chronic knee pain and osteoarthritis after the player's career has ended.[44]

There is a significant body of evidence suggesting that the majority of ACL injuries during sports occur via a noncontact mechanism.[‡‡] This research includes biomechanical, clinical, and, more recently, video analysis in team

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handball, basketball, soccer, Australian football, and alpine skiing.[4-6,9,14,24,28,29,37,45] To our knowledge, no study has analyzed video of ACL injuries in the NFL to describe the mechanism, playing situation, and lower extremity position at the time of injury. Given that American football is a collision sport in which tackling and blocking occur at a high rate of speed with significant force, it stands to reason that a majority of ACL tears sustained by these athletes may actually occur via a contact mechanism. The current study was designed to test the hypothesis that a majority of injuries in this population occur via a contact mechanism.

METHODS

We reviewed ACL injuries over 3 consecutive NFL seasons from publicly available sources: 2013-2014 (2013), 2014-2015 (2014), and 2015-2016 (2015). First, a comprehensive list of all ACL injuries (practice and game related) from each season was compiled by performing an online search of publicly available Internet sources. The Twitter account "ACL Recovery Club" has kept a running count of ACL injuries that occur in the NFL over the past several years. This includes complete listings by year and time of season (preseason or regular season). This list was then cross-referenced via Google Search to confirm the injury. A player list was compiled according to year of injury and whether the injury was sustained during the preseason, regular season, or postseason. Data regarding player, position, team, week of season, quarter of game, and playing surface (artificial or grass) were then organized via a Microsoft Excel spreadsheet and analyzed in SPSS Statistics for Mac (v 24.0; IBM).

To obtain the video clips for review, we utilized NFL Game Pass, a service available through NFL.com that allows complete viewing of all NFL games in their entirety from 2009 to the present. We used the data obtained via Google Search to determine the game number for each injury; that game was then reviewed and the ACL injury identified. A short clip was then created via the iPhone 6 (Apple Computer Inc) video function to record footage obtained shortly before, during, and after the injury. When possible, multiple video clips for 1 injury were created to view all possible angles that were captured on camera at the original telecast; this was repeated for all identified injuries. The number of viewing angles varied depending on the significance and anticipated viewership of each game. Therefore, there was not a specific minimum number of viewing angles used for each injury. We recorded the number of views available for each injury.

A 10-question survey was developed and utilized to analyze each video clip (Appendix, available in the online version of this article). These questions were divided into 3 categories: (1) contact or noncontact mechanism, (2) type of football activity at the time of injury, and (3) position of the involved lower extremity at the time of injury. We also recorded whether the athletes were wearing a lower extremity brace. Injury mechanism was described as noncontact in the open field, contact involving the injured lower extremity, and contact not involving the injured lower extremity. For purposes of analyzing ACL injuries, only contact involving the injured lower extremity is considered a "contact" injury mechanism, whereas contact not involving the injured lower extremity is considered a "noncontact" injury mechanism. Owing to the difficulty of making precision angle measurements on videos with varying clarity, the position of the lower extremity was grouped into broad categories for the hip, knee, and foot. Two orthopaedic surgeons with fellowship training in sports medicine (R.H.B. and J.T.J.) analyzed the videos individually and completed the 10-question survey. The surveys were compared and differing answers resolved via consensus review. To assess interrater reliability between the independent raters, a Cohen's kappa statistic (κ) was generated for each question (SPSS, v 24.0). The formula for Cohen's κ is $Pr(a) - Pr(e) / 1 - Pr(e)$, where $Pr(a)$ is the observed percentage of agreement (accuracy) and $Pr(e)$ is the expected percentage of agreement (chance).

Answers were tabulated to determine what percentage of the videos depicted noncontact injury versus contact injury. Player position, game quarter, week of season, and type of playing surface (grass vs artificial turf) were

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TABLE 1
Number of ACL Injuries by Year[a]

Year	Total ACL Injuries	Preseason	Videos	Regular Season and Playoffs	Videos
2013	63	32	4	31	28
2014	45	22	8	23	21
2015	48	25	9	23	20
Total	156	79	21	77	69

[a]ACL, anterior cruciate ligament.

analyzed to determine if there were significant differences among these demographics in terms of ACL injury frequency and/or mechanism.

RESULTS

Over 3 NFL seasons, 156 ACL injuries were identified (Table 1). There was substantial agreement between the raters; interrater reliability measures yielded an overall κ of 0.63 for all data and κ of 0.76 for the question regarding injury mechanism. The range of κ scores for all questions was 0.478 to 0.914 (see the Appendix, available online). Any discrepancies were resolved by consensus for final analysis.

Among these injuries, 79 (51%) occurred in the preseason and 77 (49%) in the regular season, including the playoffs and Super Bowl. Video clips were available for 69 of the 77 (90%) regular season ACL injuries. Of the 8 injuries for which there was no video available, 6 occurred during practice, 1 during a game but not captured on video, and 1 outside of football activity. For 39 injuries, only 1 video clip was available; 28 had 2 views; and 2 had 3 views. Video clips were available for only 21 of 79 (27%) ACL injuries from the preseason. Fifteen injuries had 1 view available, and 6 had 2 views. A large number of preseason injuries occurred during practice or games with limited television broadcasting.

The distribution of ACL injury by player position, playing surface, quarter of the game, and week of season was tabulated (Tables 2-5).

Of the 69 videos analyzed, 50 (72.5%) were noncontact in nature: 16 in the open field and 34 with contact not involving the injured extremity. The remaining 19 (27.5%) injuries involved direct contact to the injured extremity (Table 6).

Of the 50 noncontact injuries, the most common athletic activity at time of injury was lateral movement (pivoting or cutting), which occurred in 30 injuries (60%) (Table 7).

The most common football-related activity at the time of injury was pursuing an opponent in the open field (13 of 50, 26%) (Table 8).

The most common position of the knee (Table 9) in the sagittal plane was early flexion (0°-45°), which accounted for 41 of 50 injuries (82%). In the coronal plane, the most common knee position relative to the hip was abduction (46 of 50, 92%).

TABLE 2
Injuries by Week of Season

Week	Injuries	
	n	%
1	4	5.8
2	0	0.0
3	3	4.4
4	3	4.4
5	10	14.5
6	8	11.6
7	5	7.3
8	4	5.8
9	2	2.9
10	3	4.4
11	6	8.7
12	1	1.5
13	1	1.5
14	6	8.7
15	4	5.8
16	2	2.9
17	3	4.4
Wild Card	0	0.0
Divisional	2	2.9
Championship	1	1.5
Super Bowl	1	1.5
Total	69	100.0

TABLE 3
Injuries by Quarter of Game

	Injuries, n
1	17
2	13
3	24
4	15

TABLE 4
Player Position

	Injuries		
	n	%	Noncontact, n (%)
Quarterback	5	7.3	4 (80)
Running back, fullback	7	10.1	5 (71)
Wide receiver, tight end	8	11.6	6 (75)
Offensive lineman	12	17.4	3 (25)
Defensive lineman	10	14.5	9 (90)
Linebacker	5	7.3	3 (60)
Defensive back	12	17.4	10 (83)
Special	10	14.5	10 (100)
Kicker/punter	0	0.0	—
Total	69	100.0	50 (73)

Foot position (Table 10) in the coronal plane relative to the knee most commonly involved abduction (45 of 50, 90%). In the axial plane, the most common foot position relative to the knee was external rotation (45 of 50, 90%).

TABLE 5
Injury by Playing Surface

	Injuries, n (%)		
Field Type	Overall	Noncontact	Contact
Natural	36 (52.2)	27 (39.1)	9 (13.0)
Artificial	33 (47.8)	23 (33.3)	10 (14.5)
Total	69 (100)	50 (72.5)	19 (27.5)

TABLE 6
Mechanism of Injury

Presence or Lack of Contact	n	%
Noncontact in the open field	16	23.2
Noncontact with perturbation not involving the injured extremity	34	49.3
Direct contact to the injured extremity	19	27.5

TABLE 7
Activity at the Time of Noncontact Injury

	n	%
Landing from jump	6	12
Beginning jump	0	0
Lateral movement (pivot/cut)	30	60
Running	5	10
Decelerating	5	10
Backwards	3	6
Stationary/still	1	2

TABLE 8
Football-Related Activity for Noncontact Injuries

Football Activity	n	%
Running with ball	10	20
Offense running without ball	4	8
Blocking	5	10
Defense rushing at line of scrimmage	9	18
Pursuing as defender, open field	13	26
Landing from jump	5	10
Ball carrier being tackled	4	8
Open field blocked	0	0

TABLE 9
Knee Position at Time of Noncontact Injury

	n	%
Sagittal position		
Full extension	0	0
Early flexion (0°-45°)	41	82
Mid-flexion (45°-90°)	8	16
Hyperflexion (>90°)	1	2
Coronal position relative to hip		
Adducted	2	4
Abducted	46	92
Neutral	2	4

TABLE 10
Foot Position at Time of Noncontact Injury

	n	%
Position relative to knee (coronal)		
Adducted	2	4
Abducted	45	90
Neutral	3	6
Rotation relative to knee		
External	45	90
Neutral	5	10
Internal	0	0

TABLE 11
Hip Position at Time of Noncontact Injury

	n	%
Coronal position		
Adducted	2	4
Abducted	43	86
Neutral	5	10
Sagittal position		
Extended	0	0
Flexed	48	96
Neutral	2	4

Regarding the hip (Table 11), the most common position in the coronal plane was abduction (43 of 50, 86%). In the sagittal plane, the hip was most commonly flexed (48 of 50, 96%).

Breakdown of ACL injuries by week of season, quarter of game, position, and field type was performed (Tables 2-5). Interesting findings included a very low rate of noncontact injuries among offensive linemen (25%) and a slightly higher rate of noncontact injuries on natural grass fields (75%) than on artificial playing surfaces (70%).

It was not always obvious whether an athlete was wearing a brace, as it can be worn inside or outside of the uniform. Brace use could be confirmed in only 2 injuries (3%), whereas the majority of athletes (n = 44, 64%) were not wearing a brace. The remaining 23 injuries (33%) did not have adequate visualization to definitively determine if athletes were wearing a brace.

ACL tears in the preseason had similar findings to the regular season. Of the 21 ACL injuries captured on video, 12 were noncontact in open field or noncontact with perturbation not involving the injured extremity (57%). More injuries occurred on artificial surfaces (n = 13, 62%) than on grass (n = 8, 38%). Of the noncontact preseason injuries, the most common activity at time of injury was lateral movement (pivot/cut), occurring in 6 of 12 (50%). Running with the ball or pursuing in open field as a defender were most common football activities, accounting for 25% each. The most common position of the knee in the sagittal plane was early flexion (75%). The most common foot position relative to the knee in the coronal plane was abduction (83%). The most common foot rotation relative to the knee was external rotation (75%). The most common coronal position

of the knee in relation to the hip was abduction (92%). The most common position of the hip was abduction (58%). The most common position of the hip in the sagittal plane was flexion (92%).

DISCUSSION

Despite the fact that professional American football is a collision sport, the majority of ACL injuries in these athletes occur via a noncontact mechanism, similar to other sports, with the exception of offensive linemen. The noncontact injuries most often occur with the lower extremity in a position of risk, with the hip flexed and abducted, the knee in early flexion, and the foot abducted and externally rotated. This suggests that prevention programs designed to reduce the incidence of noncontact ACL injuries could benefit athletes in American football as they have for other athletes.[§§]

The general public has become increasingly aware of ACL injuries in NFL athletes over the past several years. This is due in part to the around-the-clock coverage on sports news networks and websites, as well as the media documentation of several high-profile NFL players who have sustained ACL injuries. ACL injuries have been occurring in professional football for years. Bradley et al[7] reported 203 ACL injuries in the NFL over a 5-year period from 1994 to 1998. Dodson et al[15] documented 219 ACL injuries in the NFL over a 4-year period from 2010 to 2013. Interestingly, 18.3% of these were retears or tears in the contralateral knee of a player who had a previous ACL injury. The authors also found that 21% to 37% of these athletes never returned to play and that those who did return performed at a lower level than before injury. Shah et al[41] showed a similar return-to-play rate of 63% for NFL athletes who sustained an ACL tear. Return to play may be related to position, as Erickson et al[19] recently reported a 92% rate of return to play among NFL quarterbacks after ACL reconstruction.

In our study, we identified 156 ACL injuries over 3 seasons (52 injuries per season), which is a similar rate to those in the aforementioned studies. We focused on injury mechanism and did not consider treatment or return to play. Unfortunately, these previous studies showed that return to play may not be as high as once thought and that those who do return to play may do so at a lower level. Sustaining an ACL injury also affects length of career, and in general, these injuries place those who sustain them at a higher risk of eventual osteoarthritis and the potential need for knee replacement.[8,44]

Roughly half of the ACL injuries in the NFL occurred during the preseason. Considering that each team plays only 4 preseason games per year, compared with 16 regular season games, this suggests that the rate of ACL injury is higher in the preseason than the regular season. However, since this observational study lacks exposure data, no definitive conclusion can be drawn, particularly since the preseason includes a higher incidence of practices with contact and game-type situations. If the rate of ACL injury is higher in the preseason, several factors could contribute. First, athletes may be at higher risk for injury as they get back into shape and reacclimate to the rigors of professional football. Second, the preseason roster is significantly larger than the regular season roster, as rookies and free agents attempt to earn a spot on the team. These individuals may be competing with heightened intensity to try to make the roster, and some may be less athletically gifted than the NFL regulars, perhaps putting them at more risk for injury. For these reasons, as well as the relatively low rate of video availability, we reported preseason findings separately from regular season findings.

ACL injuries are not isolated to professional football. Numerous recent studies at the collegiate[16,17,27] and high school[32] level also reported on ACL injuries in football players. Given the effect of these injuries at all levels of play, prevention is a worthwhile goal. The first step toward prevention is understanding the mechanism by which these injuries occur in football.

Our study is in agreement with the findings of previous video analyses of other sports in that the majority (72.5%) of ACL injuries in the NFL involve a noncontact or indirect contact mechanism. This is significant as one could hypothesize that direct contact would lead to the majority of ACL injuries in a collision sport where players have direct contact to their lower extremities on nearly every play. Note that 50% of injuries involved contact to the body that did not directly involve the injured lower extremity. We categorized such contact as a "perturbation." Previous studies used video analysis to analyze ACL injury mechanisms in other populations.[4-6,9,14,24,28,29,37,45] Boden et al[5] examined video clips of 27 ACL injuries and identified 72% to be of a noncontact mechanism. In a 2004 video study of female team handball players, 19 of 20 ACL injuries were noncontact.[37] In a 2007 study of basketball players, 72% of 29 ACL injuries were also from a noncontact mechanism. Interestingly, despite the high number of noncontact injuries, the authors did observe that opponents were almost always in close proximity to the injured player. Thus, there was likely an element of perturbation, similar to what we document here in NFL athletes. Given this, the researchers suggested that preventive programs include "distracting elements" similar to those encountered in competition to enhance knee control.[29] In the same year, Cochrane et al[14] conducted video analysis of 34 ACL injuries in Australian football players, and 58% were of a noncontact mechanism (68% if indirect contact, or perturbation, is included). The majority of these occurred during decelerating and/or cutting maneuvers with the knee in near-full extension. The authors concluded that training programs should focus on specific muscle activation strategies to stabilize knee valgus motion and rotation and increase hamstring activation to oppose the quadriceps, which strains the ACL in greater degrees of knee extension. A recent video study of ACL injury mechanisms in rugby players reported that just over half (57%) were of a contact nature and that the knee was typically in limited flexion (10°) at the time of noncontact injuries.[33] A video study of ACL tears in 39 male soccer players found that 85% involved a noncontact or indirect contact mechanism.[45]

[§§]References 2, 10, 12, 13, 18, 20-23, 25, 26, 30, 31, 34, 35, 38-40, 42, 43, 47.

Also in agreement with other video studies was our finding of a common lower extremity position at the time of injury.[6,9,29,32,35] When we analyzed the lower extremity position in the injury videos, the most common knee position involved early flexion and abduction, with the foot in abduction and external rotation and the hip in flexion and abduction. These positions all place a valgus load on the knee, which can lead to ACL injury.[2,5]

In light of these findings, these athletes may benefit from preventive training to reduce ACL injuries. Prevention programs focusing on neuromuscular training have shown varying degrees of efficacy in decreasing ACL injuries and in modifying biomechanical risk factors in athletes.[||||] In a 2009 review of prevention programs aimed at modifying risk factors and reducing injury rates, Alentorn-Geli et al[2] concluded that neuromuscular training appears to be effective in reducing noncontact ACL risk factors and injuries in male and female soccer players. To our knowledge, the application of ACL prevention programs to American football has not been reported in the literature. Future research is warranted to develop a program for football athletes that focuses on similar principles, with sport-specific and perhaps position-specific modifications.

The 1 position with a very different distribution of injury mechanism was the offensive line. The majority (80%) of its ACL injuries occurred via contact. When blocking an opponent, an offensive lineman often gets locked up with him, and it is at this time when another athlete—opponent or teammate—may fall onto or roll into his lower extremity. Further study is warranted to confirm this finding, as alternative injury prevention strategies such as bracing could be indicated.

There are several limitations to this study. Since we used publicly available data in compiling a list of ACL injuries over the period analyzed, some injuries could have been omitted. Although we were able to obtain video clips for a high percentage of the regular season injuries that occurred over the study period (69 of 77, 90%), they were not of equal quality. In some videos, the injured player was partially obstructed by other players, or the angle at which the injured extremity is viewed was not ideal to determine knee position. However, the majority of videos clearly depicted the position of the lower extremity, and essentially all videos showed whether contact occurred to the injured extremity. Despite these technical challenges, there was substantial interobserver agreement, particularly with regard to injury mechanism. Finally, statistical analysis of injuries was limited by the lack of total athlete exposure data, as we did not have access to that information. Therefore, we were unable to conclude whether the variables that we studied—including but not limited to player position, timing of the injury, or field surface—are associated with the incidence or mechanism of ACL injury.

In conclusion, contrary to our initial hypothesis, the majority (72.5%) of ACL tears in the NFL over the 3 consecutive seasons examined in this study involved a noncontact mechanism, with the lower extremity exhibiting a dynamic valgus moment at the knee. Given the apparent similarity of the ACL injury mechanism in football athletes to the injury mechanism in other sports where specially targeted intervention programs have been shown to decrease risk of injury, future study should be aimed at developing and testing the efficacy of similar injury prevention programs for football athletes.

[||||]References 10, 12, 13, 18, 20-23, 25, 26, 30, 31, 34, 35, 38-40, 42, 43, 47.

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