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11-1-2021

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Recommended Citation

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Factors Associated With the Mechanism of ACL Tears in the National Football League

A Video-Based Analysis

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Background: The factors associated with anterior cruciate ligament (ACL) injury mechanism in professional American football players are not well-understood.

Hypothesis: It was hypothesized that football-related and player-specific factors, such as position and body mass index (BMI), are associated with ACL injury mechanism in these athletes.

Study Design: Descriptive epidemiology study.

Methods: Videos of ACL tears occurring in National Football League (NFL) games over 6 consecutive seasons from 2014 to 2019 were reviewed by 2 orthopaedic surgeons who specialize in sports medicine. For each injury, the role of contact (*direct contact* [contact to the injured knee/lower extremity], *indirect contact* [contact not involving the injured knee/lower extremity], or *no contact*) as well as playing situation and lower extremity position were recorded. Additional player characteristics, timing of injury, and surface information were obtained from NFL game-day and injury database statistics.

Results: Of the 140 ACL tears, a minority occurred via direct contact to the injured lower extremity (30%), although this varied by position. Just over two-thirds (70%) of ACL tears in offensive linemen occurred via direct contact to the injured lower extremity, while wide receivers had no direct contact ACL tears. Elevated BMI was associated with a greater likelihood of ACL tears occurring via direct contact (53% in players with BMI $\geq$35 kg/m^2 vs 24% in players with BMI <35 kg/m^2; $P = $ <.01). Rookies had the lowest percentage of direct contact ACL tears (18%; $P = $ .22). ACL tears that occurred during the middle 8 weeks of the regular season resulted more often from direct contact (38%; $P = $ .06). ACL tears that occurred in the third quarter were the most likely to occur via direct contact (44%), while those that occurred in the fourth quarter were the least likely to occur via direct contact (13%; $P < $ .01).

Conclusion: Although most NFL players sustained ACL tears via a noncontact mechanism (ie, through indirect or no contact), players with an elevated BMI, especially on the offensive line, were more likely to injure their ACL through direct contact. Position-dependent variance in injury mechanism may help guide injury prevention efforts in these athletes.

Keywords: anterior cruciate ligament; noncontact injury; American football

The anterior cruciate ligament (ACL) of the knee is at risk for injury during sports involving cutting, jumping, and pivoting motions such as in American football. Prior studies based on publicly available data have reported that less than two-thirds of these athletes get back to professional football[21] and those who do return perform at a lower level[4] and have a shorter career.[20] As a result, there is considerable interest in reducing the ACL injury burden in these athletes.

Preventing these injuries requires a detailed understanding of when and how they occur. In other sports such as soccer, basketball, and Australian football, a majority of ACL injuries has been shown to occur via a noncontact

mechanism.[1,2,5,10-12,17,24] A previous study[25] of injuries in collegiate American football and rugby reported that the majority of injuries occurred via contact; although, this was based on injury reports rather than video review and there were no data on mechanism of injury for ACL tears. It is important to understand that ACL tears are defined as noncontact if there is no direct contact to the injured knee or lower extremity. If an ACL tear occurs after contact elsewhere on the body (ie, the upper body collision of 2 linemen), the injury is still defined as a noncontact ACL tear. In a previous study[10] based on 69 publicly available videos of ACL tears in the National Football League (NFL), 73% occurred via a noncontact mechanism. This included ACL tears without any contact to the injured player (24%) and tears after contact to the injured player not involving the injured lower extremity (49%). The purpose of the current

study was to conduct a thorough video analysis of ACL injuries using data obtained from the NFL's centralized electronic health record (EHR) to test the hypothesis that football-related and player-specific factors, such as position and body mass index (BMI), are associated with ACL injury mechanism in these athletes. As there is a higher rate of lower extremity injury on synthetic surfaces in the NFL,[15] we also compared the distribution of injury mechanism on natural surfaces to synthetic surfaces.

METHODS

The study protocol received institutional review board approval and complied with the NFL medical research protocol approval process procedures.[14] The NFL's centralized EHR[6] was used to identify all ACL injuries that occurred in regular season and postseason games over 6 consecutive seasons from 2014 to 2019. Film archives were reviewed to identify which injuries were captured and available on tape. Multiple video clips presenting different angles of each play involving an injury were then created for review.

A total of 142 videos were reviewed by 2 academic orthopaedic surgeons (R.H.B. and B.D.O.) with fellowship training in sports medicine. For each injury, the reviewers watched the available videos and recorded their objective impression of the role of contact in the injury as (1) *direct contact* (contact to the injured knee/lower extremity) (2) *indirect contact* (contact not involving the injured knee/lower extremity), or (3) *no contact*. If contact occurred, it was further characterized as with player, surface, or other. Indirect contact and no contact were considered noncontact mechanisms. Additional abstraction fields, regardless of mechanism, included the following: (1) if another player was within 1 to 2 yards of the injured player at the time of injury; (2) if the injured player was engaged with another player (ie, blocking/tackling) at the time of injury; (3) the position and orientation of the foot, ankle, knee, and hip of the injured extremity; and (4) if contact occurred to the foot, leg, knee, thigh, and hip of the injured lower extremity. Reviewers also assessed whether the injured player's cleat was engaged with the turf at the time of injury. The full abstraction tool is available in Appendix Table A1.

Additional characteristics of interest were obtained from the NFL's centralized EHR[6] (BMI, player years of service, timing during season, and timing during game) and NFL Game Statistics and Information System (surface type, surface conditions, and roster position).

All statistical analyses were performed using SAS (SAS Enterprise Guide Version 7.13). Interrater reliability was evaluated by random selection of 20% of ACL tear cases per year (n = 31 total across the 6-year study) for review by both reviewers. The Cohen kappa statistic was calculated using PROC FREQ capabilities to assess interrater reliability for contact mechanism. Assumptions required by this method were met as follows: (1) the variable of interest was measured on a nominal scale, (2) the categories were mutually exclusive, (3) both reviewers had the same number of categories in their assessment, (4) both reviewers conducted their analyses independently, (5) both reviewers assessed the same videos, and (6) the same reviewers assessed all videos. Resolution in absence of agreement was done through discussion of the 2 parties with potential for a third reviewer "tiebreaker" in the case of disagreement. Differences in distribution of ACL injury characteristics were compared using Fisher exact chi-square tests. Results were considered statistically significant at $P < .05$.

RESULTS

Videos were available for 142 (90%) regular season and postseason game-related ACL injuries during the 6 NFL seasons under review (Table 1). Injuries that were documented in the EHR but did not have available video (n = 12 for regular season, n=3 for postseason) were excluded from analyses. For 2 videos, the incident event was not evident in the video and therefore they were excluded from the analysis, resulting in a final sample size of 140 injuries (89%) included in the analysis.

The calculated kappa statistic for interrater reliability on injury mechanism was 0.80 (95% CI, 0.61-0.98), suggesting "substantial" agreement between the 2 reviewers.[13] When type of contact was added with injury mechanism, the calculated kappa statistic was 0.84 (95% CI, 0.64-1.00) suggesting "almost perfect" agreement. Only 4 injuries were adjudicated by discussion in terms of mechanism or other details.

Of the 140 ACL injuries reviewed, only 30% of ACL tears occurred as a result of direct contact to the knee, while 70% occurred via a noncontact mechanism (44% via indirect contact, 26% via no contact) (Table 1). All ACL tears resulting

TABLE 1
Characteristics of 2014-2019 NFL Game ACL Injuries by
Injury Mechanism[a]

| | Direct Contact With Player | Noncontact Mechanism | |
		Indirect Contact With Player	No Contact
Total	42 (30)	61 (44)	37 (26)
BMI, kg/m^2			
<25	0 (0)	0 (0)	3 (100)
25 to <30	14 (23)	26 (43)	20 (33)
30 to <35	12 (26)	22 (47)	13 (28)
≥35	16 (53)	13 (43)	1 (3)
Years of service			
Rookie year (0 years)	4 (18)	10 (45)	8 (36)
1 year	8 (31)	12 (46)	6 (23)
2 years	6 (26)	12 (52)	5 (22)
3 years	9 (45)	8 (40)	3 (15)
4 years	4 (31)	3 (23)	6 (46)
≥5 years	11 (31)	16 (44)	9 (25)
Timing during season			
Weeks 1-4	7 (20)	15 (43)	13 (37)
Weeks 5-8	16 (40)	13 (33)	11 (28)
Weeks 9-12	9 (35)	12 (46)	5 (19)
Weeks 13-17	9 (24)	21 (57)	7 (19)
Postseason	1 (50)	0 (0)	1 (50)
Timing during game			
First quarter	11 (35)	12 (39)	8 (26)
Second quarter	8 (29)	13 (46)	7 (25)
Third quarter	17 (44)	13 (33)	9 (23)
Fourth quarter	5 (13)	22 (56)	12 (31)
Not applicable	0 (0)	1 (50)	1 (50)
Missing	1 (100)	0 (0)	0 (0)
Surface type			
Synthetic	14 (28)	21 (42)	15 (30)
Natural	28 (31)	40 (44)	22 (24)
Surface conditions			
Wet field, outdoor stadium	1 (17)	3 (50)	2 (33)
Dry field, outdoor stadium	30 (32)	39 (42)	24 (26)
Dry field, indoor stadium[b]	10 (29)	15 (43)	10 (29)
Dry field, unknown stadium type	1 (17)	4 (67)	1 (17)

[a]n=31 injuries were double-reviewed as part of the agreement analysis. In the case of n=4 injuries for which the 2 reviewers disagreed on the injury mechanism, the primary reviewer's decision was used for analyses, as decided through discussion between the 2 parties. Data are reported as n (% of all injuries). ACL, anterior cruciate ligament; BMI, body mass index; NFL, National Football League.
[b]Includes dome roof and retractable roof.

from direct or indirect contact were due to contact with another player. Classified by roster position, a majority of injuries (70%) sustained by offensive linemen were due to direct contact to the knee while wide receivers had no direct contact injuries (Figure 1). Of 16 offensive lineman injuries resulting from direct contact, 15 were due to contact of the injured lower extremity with an opponent and 1 was due to contact with a teammate.
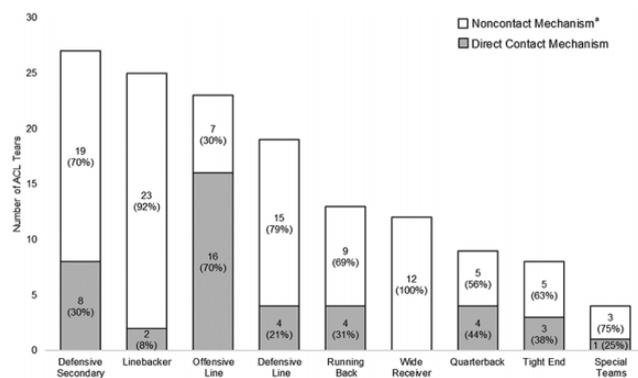

Figure 1. Number of anterior cruciate ligament (ACL) tears by contact mechanism and roster position. [a]Includes injuries occurring via indirect contact with another player as well as via no contact.

Noncontact injuries were more likely to occur in athletes with a lower BMI, whereas direct contact injuries were more likely to occur in athletes with a higher BMI. For athletes with a BMI <35 kg/m^2 and ≥35 kg/m^2, 24% and 53% of ACL injuries occurred via direct contact, respectively ($P < .01$). Rookies had the lowest percentage of direct contact ACL tears (18% vs. 32% for nonrookies; $P = .22$).

Injury mechanism varied based on timing during the game and timing during the season. Direct contact injuries made up the largest percentage of ACL tears that occurred in the third quarter (44%) and the lowest percentage of tears that occurred in the fourth quarter (13%) ($P < .01$ for third vs fourth quarter) (Table 1). ACL tears in the middle 8 weeks of the regular season (weeks 5-12) had an elevated likelihood of resulting from direct contact to the knee (38%) compared with the first and last 4 weeks of the regular season (22%; $P = .06$).

The unadjusted (crude) proportion of ACL tears due to a noncontact mechanism did not differ by surface type; 72% (n = 36) of ACL tears on synthetic fields occurred via noncontact compared with 69% (n = 62) on natural grass.

DISCUSSION

Approximately one-third (30%) of ACL injuries in professional American football athletes that were reviewed occurred via direct contact to the injured knee. Factors associated with the mechanism of injury, such as position, BMI, and timing of injury during the game and season, are important for guiding injury prevention for these athletes in particular and their sports in general.

Position clearly plays an important role in ACL injury mechanism. Similar to the findings of Johnston et al,[10] offensive linemen had a majority of ACL injuries occurring via direct contact to the knee. This is not necessarily surprising, as they are often engaged with an opponent at the line of scrimmage, when they were vulnerable to contact from teammates and opponents alike, often without direct visual awareness of impact forces. In our series, all but 1 of

these injuries to the offensive linemen resulted from contact to the injured lower extremity by an opponent. They typically appeared to be inadvertent, as the opponents were almost always getting blocked by 1 or more of the injured player's teammate(s) just before or at the time of contact. On the other end of the spectrum, wide receivers had no direct contact ACL tears. This suggests that prevention programs for these athletes should focus on functional movement and strength screening as well as training targeted on optimal movement and muscle balance that may mitigate noncontact injury risk, perhaps similar but most likely not identical to previously published programs for athletes in other sports.[3,7-9,16]

ACL tears occurring in athletes with a BMI $\geq$35 kg/m^2 were very likely to occur via direct contact to the knee. This finding is confounded by the aforementioned predominance of contact injuries in offensive linemen, who are likely to have an elevated BMI. We reviewed the 9 ACL tears that occurred in athletes with a BMI $\geq$35 kg/m^2 who were not offensive linemen, and only 1 occurred via direct contact, suggesting that player position is more relevant than BMI. More research is needed to confirm and better understand the implication of this finding for developing prevention programs for these athletes.

ACL tears are more likely to occur via direct contact to the knee in the third quarter of games and the middle half of the season, and very unlikely to occur via direct contact in the fourth quarter. The reasons for these findings are not immediately clear. The variance during games may be more easily explained. For example, teams may tend to have a relatively conservative game plan in the third quarter, resulting in more play at the line of scrimmage, which could explain a higher proportion of direct contact injuries, for example, to offensive linemen. Conversely, more aggressive play calling in the fourth quarter could lessen exposure at the line and put more receivers and defenders in the secondary at risk. Conditioning may be another factor, as fatigue could contribute to non-contact injuries in the fourth quarter. There is no immediately obvious explanation for why a greater proportion of ACL tears occur via direct contact to the knee in the middle 8 weeks of the regular season.

These findings may help identify opportunities for preventing ACL injuries in these athletes. For example, offensive linemen are a subset that might benefit from bracing, whereas wide receivers could be more likely to benefit from interventions targeted to minimize noncontact ACL tears similar to the FIFA 11+ program.[19,22] This variation in the proportion of contact and noncontact ACL tears by position across professional football players is similar to the variation across different sports. One recent study[23] of collegiate and high school athletes based on a review of injury databases reported that 48% of ACL tears in American football were noncontact injuries, compared with a higher percentage in soccer (60%), basketball (65%), and lacrosse (81%). It is unclear why this study reported a lower rate of noncontact injuries in American football players than that reported in our present study. While it could represent a different risk profile for athletes at lower levels of American football compared with professionals, it could also be a

result of different methodology, as their study did not review injury videos and it is unclear how their data accounted for injuries resulting from indirect contact. Much more research is needed to determine if and how the findings of the current study can guide interventions to reduce the occurrence of these injuries in American football.

This study has several limitations. First, this study represents a subset of ACL tears that occurred in the NFL, excluding all tears that occurred in nongame team activities (n=132) and preseason games (n=81), in addition to tears that occurred in regular or postseason games that were not captured or could not be visualized on video. While the latter was a relatively small proportion (11%) and we did not observe any systematic bias among game injuries, findings from this review may not be generalizable to injuries that were not captured on video, particularly practice and preseason game injuries. In general, while several ACL injuries occur in practice, game-related ACLs are more common than practice-related injuries, with >60% of injuries occurring each year in games.[18] Associations are not necessarily evidence of causation; more research is needed to better understand the implications of these findings, particularly for injury prevention. Despite the high level of interrater reliability, it was not possible to determine with complete certainty the exact moment of each injury.

In addition, the small sample size was underpowered to draw definitive conclusions. For example, the association of injury mechanism with BMI was undoubtedly affected by the fact that linemen tend to have higher BMIs than other positions, but a rigorous analysis to determine which variable was more significant was not possible in the current study. Finally, it is important to emphasize the descriptive nature of this study, as it reported the relative distribution of injury mechanism but did not report relative injury rates or risks. It was not possible to calculate exposures, and associations were not evaluated by statistical hypothesis testing due to small sample sizes. In particular, in this descriptive study, player characteristics at the time of the injury could not account for the varying number of players in the NFL that fall into each category, and descriptions of surface type and field condition at the time of injury could not account for the varying number of games played on each field type; these factors have been analyzed in more depth elsewhere.[15]

Despite these limitations, this study confirmed that a majority of in-game ACL tears in the NFL do not result from direct contact to the injured lower extremity. Perhaps more importantly, this study identified several factors, including position and timing of injury, associated with ACL injury mechanism in American football. Further investigation is needed to confirm these findings and explore their potential to guide injury prevention efforts for these athletes in particular and their sport in general.

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APPENDIX

TABLE A1
ACL Tears in NFL Players: Video Abstraction Tool[a]

Abstraction Tool Variable	Variable Description
Player and play information	
Player on offense, defense, or special teams	Offense, defense, special teams
Player position	Description of player position (free text)
Player activity	Tackled, tackling, blocked, blocking, diving/leaping, other
Play type	Pass, rush, kickoff, punt, field goal/extra point
Video information	
Visualization of event in video	1-10 (1 is least clear, 10 is most clear)
Best video source/view	Network, sideline, endzone
Replay available	Yes/no
Injury information	
Injury identification confidence	Confident, likely, possible, unsure
General player activity at time of injury	Description of player activity (free text)
Contact mechanism	Direct contact with player, indirect contact with player, noncontact, no injury evident

(continued)

Table A1 (continued)

Abstraction Tool Variable	Variable Description
Proximal player	Yes/no
Additional comments	Additional comments
Detailed biomechanical parameters	
Ankle flexion	Description of ankle flexion
Ankle eversion/inversion	Description of ankle eversion or inversion
Ankle rotation	Description of ankle rotation
Knee flexion	Description of knee flexion (free text)
Direct blow to ipsilateral foot	Yes/no
Direct blow to ipsilateral leg	Yes/no
Direct blow to ipsilateral knee	Yes/no
Direct blow to ipsilateral thigh	Yes/no
Direct blow to ipsilateral hip	Yes/no
Player engaged/engaging with another player	Yes/no
Cleat engaged with turf	Yes/no
General direction of ground-reaction force	Description of general direction of ground-reaction force (free text)
Turf engagement contributory mechanism	Yes/no
Excessive shoe flexion contributory mechanism	Yes/no

[a]ACL, anterior cruciate ligament; NFL, National Football League.