Original Article

Concussion Is Associated With Increased Odds of Acute Lower-Extremity Musculoskeletal Injury Among National Basketball Association Players

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Purpose: To determine the odds of sustaining an acute lower-extremity (LE) musculoskeletal injury during the 90-day period after return-to-play (RTP) from concussion in National Basketball Association (NBA) athletes. **Methods:** Concussion data for NBA players were collected from the 1999-2000 to 2017-2018 seasons, from publicly available sources. Age, position, injury, time to RTP, and demographic factors were collected. The 90-day period after each case of concussion was reviewed for acute noncontact LE musculoskeletal injury. Control athletes without a documented history of concussion were matched to concussed athletes by age, body mass index, position, and experience. Conditional logistic regression with a calculated odds ratio and a 95% confidence interval were used to assess the association between concussion and subsequent risk of LE injury. **Results:** In total, 189 concussions were documented in 153 athletes. Of these, 140 cases were the first recorded instance of concussion in players with publicly available data. Thirty-six (25.7%) athletes sustained a LE injury within 90 days of concussion; 26 (20.2%) were non–season-ending and included in RTP analysis. The odds of sustaining an acute LE musculoskeletal injury within the 90-day period after concussion was 4.69 times greater in concussed players compared with controls (95% confidence interval 1.96-11.23, $P < .001$). There was no significant difference in games (4.2 ± 5.0 vs 4.7 ± 4.7 games, $P = .566$) or days (18.5 ± 39.1 days vs 10.9 ± 10.6 days, $P = .912$) missed between concussed players with LE injury and nonconcussed controls. The most common LE injuries in concussed athletes were ligament sprains/tears (65%). **Conclusions:** Concussed NBA athletes have increased odds for sustaining an acute LE musculoskeletal injury within 90 days of RTP compared with nonconcussed controls. The most common injuries were ligament strains or tears. Changes in neuromotor control and proprioception following a concussion should be evaluated in high-level basketball players returning to sport. **Level of Evidence:** Level III, Case-Control Study.

Our understanding of the immediate and long-term consequences of sustaining a sports-related concussion has increased in recent years. Mainstream media attention has contributed toward greater awareness of this once poorly understood injury. The incidence of concussion, both sport-related or recreational, is estimated to be just more than 3 million in the United States per year.[1] Concussions comprise roughly 8.9% of all high school athletic injuries.[2] Seventy percent of the time, these injuries occur as a result of player–player contact.[3] Understandably, athletes participating in high-impact/contact sports are at greater risk for concussion. Although deliberate forceful contact is penalized in basketball, and concussion rates are lower than in the aforementioned sports, concussions still occur at a rate of about 5.5 per 10,000 athletic

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exposures (defined as both practice and competition).[3] Relatively little is known about the impact of concussions in professional basketball athletes; it has been previously demonstrated that concussions at the professional level in the National Basketball Association (NBA) occur at a rate of about 15 per season.[4]

Initial traumatic injury to the brain often results in headache, amnesia, cognitive deficits, and balance instability. Typically, the majority of these symptoms resolve in days to weeks with adequate cognitive rest and graduated recovery protocols. However, persistence of the symptomatology can occur and is often termed postconcussive syndrome. It is postulated that many of the acute mechanisms of concussion pathophysiology (neurotransmitter dysregulation, metabolic derangements, neuroinflammation, cerebral blood flow changes, axonal injury, etc.) also may be responsible for chronic, persistent symptomology.[5] As brain trauma becomes repetitive, these initial derangements can progress to permanent changes in cognition, behavior, and neuromuscular function.[6] Moreover, there is well-established research that indicates athletes have changes in gait pattern, reaction time, and postural stability following concussion.[7-10] Recent literature also illustrates that this neuromuscular impairment can lead to increased risk for musculoskeletal injury, and more specifically lower-extremity (LE) injury.[11-13]

Certainly, the concussive clinical scenario can have severe implications on the performance, safety, and well-being of athletes. The propensity for LE injury found in athletes is troubling, but it is unknown to what extent concussions affect professional basketball players' risk for LE injury. The purpose of this study was to determine the odds of sustaining an acute LE musculoskeletal injury during the 90-day period after return-to-play (RTP) from concussion in NBA athletes. We hypothesize that individuals who have sustained a concussion would be at greater risk of subsequent LE injury.

Methods

All concussions sustained by professional athletes in the NBA from the 1999-2000 season to the 2017-2018 season were collected from publicly available injury reports, press releases, personal websites, and game summaries. If a player sustained multiple concussions, only the first recorded concussion and subsequent 90-day period was included in the analysis, to avoid confounding variables such as "second impact syndrome" and residual postconcussive deficits from the primary concussion. Players without adequate, publicly available data (i.e., insufficient/conflicting injury reports, insufficient RTP data, etc.) were not included. Specific online sources for data acquisition included the official website of the NBA (NBA.com), as well as multiple sports websites. Specific online sources for data acquisition included official sports websites of ESPN (ESPN.com), CBS (CBSsports.com), NBC (NBCsports.com), Fox (FoxSports.com), a professional analysis and statistics website (basketball-reference.com), and a transactional sports database (prosportstransactions.com). Team websites, local game reports, and media guides were then used to further cross reference and verify each concussion. To further verify each athletes' date of injury, we cross-referenced each player's reported injury with a gap in statistics. These methods were validated by previous studies.[14-20] For each instance of confirmed concussive event, the following information was collected and reviewed by 2 of the authors: primary position, date of injury, season of injury, age at injury, LE injury within 90-day period, location of LE injury, type of injury, and date of RTP. One author collected the player's information, followed by a confirmation by the second author. Location of LE injury was classified as hip, groin, thigh, knee, shin, ankle, and foot. The type of injury was classified as fracture, muscle strain and/or tear, and ligament sprain and/or tear. It also was recorded if a player sustained multiple LE injuries within the 90-day period. LE injuries were confirmed as noncontact via game film and press releases. The date of RTP was identified as the date of first competitive exposure (i.e., game) after injury. The basis of selecting a 90-day period after concussion was based on previous studies that have found that the 90-day period after concussion is associated with increased injury risk.[11,12]

Any player who was able to return to regular season NBA competition for a least 1 play in a basketball game during the same season met RTP criteria. The number of games missed and time to RTP was calculated from initial injury date to the date of the first game played. Players whose concussion was sustained at the end of the season, who required time during the offseason to RTP, were excluded from RTP analysis as they uniformly returned the following season. (Fig 1)

A matched-case-control analysis was constructed to compare the odds of LE injury between individuals who sustained a concussion and those who did not sustain a concussion. To select the control cohort, an age-, body mass index-, position-, and experience-matched control group consisting of 140 NBA players who did not sustain a documented concussion in their NBA career from the 1999-2000 to 2017-2018 seasons was compiled via blinded matching methodology.[17,21-23] All previously described data that were tabulated for concussed players also were collected for the control cohort using similar methods and sources. This control group was used to compare odds of LE injury during the same time frame between those athletes who sustained a concussion and those who did not. Players who sustained a season-ending injury that affected accurate RTP data were removed from the RTP analysis similar

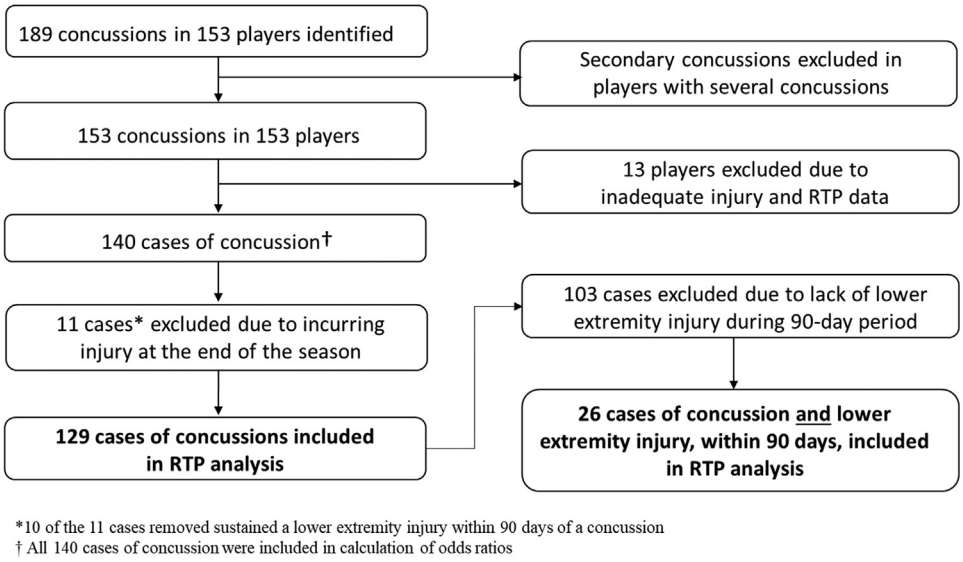

Fig 1. Selection of concussion cases with lower-extremity injury for RTP analysis. †All 140 cases of concussion were included in calculation of odds ratios. (RTP, return to play.)

to the concussion cohort. Therefore, 137 NBA control athletes were included in the RTP analysis.

Statistical Analysis

Univariate 2-group comparisons were performed using independent 2-sample *t* tests if the variables were normally distributed, and a Wilcoxon signed-rank tests if the variables were non-normally distributed. For categorical variables, univariate 2-group comparisons were performed using χ^2 tests when expected cell counts were >5 and using Fisher exact tests when expected cell counts were <5. Statistical significance was set at $P < .05$. All analyses were performed using SAS, 9.4 (SAS Institute Inc., Cary, NC).

Results

A total of 189 concussions were documented in 153 athletes. Of these, 140 cases were the first recorded instance of concussion in 140 unique players with adequate publicly available data. The average age at the time of concussion for all concussed players was 26.2 ± 5.4 years. Among those athletes who sustained a LE injury after concussion, the most commonly injured position was point guard (33%), followed by power forward (19%) (Table 1). Further data on injury characteristics can be found in Table 1. In the RTP analysis, nonconcussed athletes were able to RTP on average 10.9 ± 10.6 days (4.2 ± 5.0 games) following their LE injury. Meanwhile, concussed individuals RTP at an average of 22.6 ± 46.9 days after concussion and concussed individuals with subsequent LE injury RTP at an average of 18.5 ± 39.1 days after their LE injury (Table 2). These findings were not statistically significant.

A total of 36 players sustained an LE injury within 90 days of returning from a concussion. The odds of acute noncontact LE musculoskeletal injury during the 90-day period after concussion was greater in concussed athletes compared with controls (26% vs 7%, $P < .001$). The odds of sustaining an LE musculoskeletal injury in the acute 90-day period was 4.69 (95% confidence interval 1.96-11.23, $P < .001$) times greater in concussed athletes than in controls.

There was no significant difference in time/games required for RTP after LE injury among athletes who sustained a concussion as compared with those who did not (18.5 ± 39.1 days vs 10.9 ± 10.6 days, $P = .912$; 4.2 ± 5.0 games vs 4.7 ± 4.7 games, $P = .566$). A subcohort analysis examining RTP timing after the concussive event among athletes with a subsequent LE injury and without, showed no statistical difference in days missed (7.5 ± 8.1 vs 8.9 ± 9.5, $P = .183$) or games missed (3.1 ± 3.6 vs 4.3 ± 4.6, $P = .059$). The most common location of LE injury for concussed athletes was the ankle (43%), followed by the knee (20%) or foot (18%). A preponderance of athletes sustained ligament strains or tears (64%).

Discussion

Our study found increased odds of sustaining an acute LE musculoskeletal injury within 90 days of RTP following a concussion in NBA athletes. RTP timing after a concussion was not found to influence rate of subsequent LE injury. These findings suggest that despite clearance for RTP, high-level basketball players may still exhibit neuromotor and proprioceptive deficits that increase their odds of early LE injury after a concussion event.

Table 1. Demographics and Injury Characteristics for All Concussed NBA Athletes + Lower-Extremity Injuries and All Nonconcussed Control NBA Athletes

	Nonconcussed Control (N = 140)	Concussed with LE Injury Within 90 Days (N = 36)	*P* Value
Age, y, mean ± SD	25.5 ± 4.5	26.1 ± 3.71	.479
Primary position			
Point guard	29 (21%)	12 (33%)	.354
Shooting guard	28 (20%)	5 (14%)	
Small forward	25 (18%)	8 (22%)	
Power forward	28 (20%)	7 (20%)	
Center	30 (21%)	4 (11%)	
Location of LE injury			
Hip	1 (6%)	1 (3%)	.207
Groin	0 (0%)	3 (8%)	
Thigh	0 (0%)	2 (6%)	
Knee	7 (44%)	7 (19%)	
Shin	1 (6%)	0 (0%)	
Ankle	6 (38%)	16 (44%)	
Foot	1 (6%)	7 (19%)	
Injury type			
Acute fracture	1 (6%)	3 (8%)	.885
Muscle strain/tear	3 (19%)	10 (28%)	
Ligament sprain/tear	12 (75%)	23 (64%)	
Multiple LE injuries	5	14	.723

NOTE. Univariate 2-group comparisons between nonconcussed controls and concussed with LE injury are shown. Bold *P* values denote significant value. Significance set at $P < .05$.

LE, lower extremity; SD, standard deviation.

There is increasing evidence supporting the notion that sustaining a concussion may increase the risk for LE musculoskeletal injury following return to sport. Brooks et al.[11] conducted a retrospective review of 75 athletes with concussions participating in NCAA Division I sports at a single institution from 2011 to 2014. The authors found an increased odds of acute LE musculoskeletal injury among concussed athletes as compared with controls.[11] Similarly, Herman et al.[12] performed a retrospective review of 73 NCAA Division I men's football and women's basketball, soccer, and lacrosse athletes from 2006 to 2013 and found a greater rate of LE musculoskeletal injuries in the concussed athletes as compared with nonconcussed athletes. This pattern was also demonstrated in soldiers returning from a concussive event.[24] Similarly, the present study found a greater rate of LE injury in the acute period among concussed NBA athletes as compared with controls (26% vs 7%, $P < .001$), correlating to an odds ratio of 4.69 (95% confidence interval 1.96-11.23, $P < .001$). This phenomenon is thought to be due to changes in gait pattern, reaction time, and postural stability following concussion even after clinical resolution.[7-10] Previous studies have

Table 2. Return-to-Play* Data of Concussed NBA Athletes + Lower-Extremity Injuries and Nonconcussed Control NBA Athletes

	Non-Concussed Control (N= 137)	Concussed with LE Injury within 90 Days (N=26)	*P* Value
Age, y, mean ± SD	25.5 ± 4.5	26.1 ± 4.2	.513
Primary			
Point guard	29 (21%)	11 (42%)	.171
position			
Shooting guard	28 (20%)	4 (15%)	
Small forward	24 (18%)	4 (15%)	
Power forward	27 (20%)	5 (19%)	
Center	29 (21%)	2 (8%)	
Number of days missed, mean ± SD	10.9 ± 10.6	18.5 ± 39.1	.925
Number of games missed, mean ± SD	4.2 ± 5.0	4.7 ± 4.7	.580

Univariate 2-group comparisons between nonconcussed controls and concussed with LE injury are shown. Bold *P* values denote significant value. Significance set at $P < .05$.

Days/games missed are after LE injury.

LE, lower extremity; SD, standard deviation.

*Players in the return-to-play analysis excluding players with season-ending injuries.

shown changes in neuromuscular function, such as reduced maximal muscle activation, motor-evoked potential amplitude, and intra-cortical facilitation, inhibition, and motor-evoked potential latencies, that lasts well beyond symptomatic resolution.[25-28] These changes may be the driving factor toward increased odds for LE musculoskeletal injury in the acute period and should be evaluated objectively in future studies.[11-13] The current study adds to this growing body of knowledge, but further investigation comparing various RTP protocols that may include measures and rehabilitation of neuromotor control and proprioception are needed. Such modifications may be helpful for identifying players at increased risk for subsequent LE injury.

Herman et al.[12] hypothesized that concussed Division I collegiate athletes would have a greater severity of LE injury, resulting in greater time before RTP. In their study, they ultimately found that median time lost after a LE musculoskeletal injury did not differ significantly between concussed and nonconcussed athletes. The authors attributed these findings to an underpowered study and a low incidence of severe injuries. Among NBA players sustaining a LE injury after concussion, the present study also found no significant difference in number of games or days missed between concussed players sustaining a noncontact LE injury and nonconcussed controls sustaining LE injury, echoing previous findings. While the exact mechanism behind this phenomenon is unknown, however, this finding is likely due to the heterogeneity of injuries presented, and the fact that neither study was adequately powered for RTP times. More work must be done to better elucidate the epidemiology and RTP following concussion among professional athletes.

In a prospective cohort study of 66 elite European soccer players sustaining concussions, Nordstrom et al.[29] found that within the 90-day period after concussions, there were increased odds for sudden LE injuries, such as ligament sprains and muscular strains, as compared with gradual-onset LE injuries, such as stress fractures or tendinopathy. Similarly, Herman et al.[12] found a 3.39 times greater risk of ligament sprains/ruptures or muscle sprains/tears within 90 days of concussion. In the present study, most LE injuries following concussion were ligament sprains or tears (64%). In a prospective study of 76 Division I NCAA football players, Wilkerson and Mokha[30] administered the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) to athletes who sustained a concussion. This assessment is computerized concussion test used to assess an athlete's neurocognitive performance at baseline and readiness to RTP post-concussion. They found that poor reaction time was predictive of LE strains and sprains (74% sensitivity and 51% specificity). A decrement in motor cortex excitability has been noted in those with LE injury such as ankle instability and ACL injury.[31-33] It has been postulated that the elevated risk of strains and tears may be due to alterations in motor cortex function, and differential activation of musculature, thus predisposing athletes to these types of injuries.[12] It should be noted that in the present study, there was no difference in RTP times in concussed athletes with and without a LE injury, suggesting an appropriate RTP interval. Ligament injuries are substantial in basketball athletes and lead to long recovery times.[34] Awareness of risk factors for these injuries is important and allows teams and physicians to tailor treatment plans accordingly.

Limitations

This study is not without limitations. Player injury and statistical information were collected from the Internet and are subject to potential inaccuracies. Furthermore, other limitations with data collection include lack of official diagnosis or use of unknown diagnostic criteria for each case. However, the NBA mandates all information concerning player injuries, illnesses, and rest for all NBA games be reported each game day. Therefore, a reasonable amount of accuracy can be inferred but not confirmed since medical records were not analyzed. In addition, the data in this study were cross-referenced by multiple sources (publicly available injury reports, player profiles, and game summaries) to ensure the highest quality and most accurate data. Despite that, a history of LE injury or severity of LE injury was not accounted for and also may be a confounder in this study. These methods have been used in several previous studies using publicly available injury data.[14-16] Although this study found significant results with regards to increased odds of LE injury for concussed players, the RTP analysis did not prove to be significant. This may be partly due to inadequate power and relative heterogeneity in the injury types. A post-hoc power analysis demonstrated $<20\%$ power for these secondary outcomes. Next, it was not possible to control for athlete exposure and thus risk of LE injury during the measured 90-day period. Athletes playing more minutes and/or at a greater level have an inherently higher risk of LE injury as compared with those who have less exposure. This was a study of the effect of concussion on elite, male athletes in the NBA, and the results may not therefore be broadly generalizable. However, there is a growing body of literature reflecting this phenomenon in other demographics.[11,12,29] Lastly, concussion reporting is partly reliant on athlete self-reporting and organizational standards. Neglecting to self-report symptoms to remain playing has been a documented problem and differential organization standards may lead to underreporting of concussions in the NBA.[35]

Conclusions

Concussed NBA athletes have increased odds for sustaining an acute LE musculoskeletal injury within 90 days of RTP compared with nonconcussed controls. The most common injuries were ligament strain or tears. Changes in neuromotor control and proprioception following a concussion should be evaluated in high-level basketball players returning to sport.

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