Original Article

Concussions Increase the Odds of Lower-Extremity Injuries in National Football League Players: Four-Year Review of Publicly Available Data

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Objective: To investigate the effect of multiple concussions on the risk of lower-extremity injuries in National Football League (NFL) players. **Methods:** All active NFL players from September 2016 to January 2017 through September 2019 to January 2020 regular seasons were eligible for inclusion. All players who sustained multiple concussions during the study period were identified using publicly available data and included in the multiple concussion (MC) cohort. Players who sustained a single concussion (SC) as well as controls were age and position matched to the MC cohort using MEDCALC case-control. Lower-extremity injuries were then documented for the players included in all 3 cohorts. **Results:** The odds of sustaining a lower-extremity injury were significantly greater in the MC as well as the SC cohort when compared with the no concussion (NC)-matched cohort (odds ratio 2.92, standard deviation [SD] 1.7-4.9) and 2.28 (SD 1.5-3.6), respectively. However, we found no significant difference in the odds of sustaining a lower-extremity injury when comparing the SC with the MC cohort (odds ratio 1.00, SD 0.7-1.3). The time to lower-extremity injury after return to play from a concussion was significantly shorter in the SC group when compared with the MC group, within 1 year following a concussion injury ($P = .01$). **Conclusions:** There was a significant increase in the odds of suffering a lower-extremity injury after return to play in NFL players exposed to SC or MC when compared with age- and position-matched controls who did not sustain a concussion within the study period. There was no significant difference in the odds of suffering a lower-extremity injury after return to play for NFL players exposed to MC when compared with players exposed to a SC during our study period. Our findings suggest a potential need for injury-prevention protocols following concussion injuries. **Level of Evidence:** Level III, retrospective comparative prognostic trial.

Multiple studies suggest that current return to play (RTP) progression following concussive injury is limited in its ability to predict complete resolution of postconcussive symptoms and puts athletes at increased risk of injury.[1] Brooks et al.[2] and Herman et al.[3] both demonstrated that athletes with concussion had greater odds of sustaining a lower-extremity injury in the 90 days after RTP following an sport related concussion. Expanding on these findings, Harada et al.[1] demonstrated that collegiate athletes with multiple concussions (MCs) were more likely to sustain a lower-extremity injury when compared with age-matched controls who sustained a single concussion (SC). Postconcussion athletes have been found to have measurable deficits in balance and gait long after documented RTP, which may explain the increased incidence in lower-extremity injuries noted in these athletes.[4-6]

Given the findings of Harada et al.,[1] special consideration should be given to athletes who experience MCs during their career. Thus, the purpose of this study was to investigate the effect of MCs on the risk of lower-extremity injuries in NFL players. We hypothesized that the risk of lower-extremity injuries would be significantly greater in athletes who sustained MCs compared with control groups of those with a SC or no concussions (NCs) during the study period.

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Methods

Data Collection

This study was a retrospective review of National Football League (NFL) injury reports including 4 seasons. The data were compiled using publicly available injury reports (Appendix Table 1, available at www.arthroscopyjournal.org). The sources used publish weekly injury reports detailing the name of the players injured, their corresponding teams, and a brief description of each injury. At least 2 different sources (NFL.com and pro-football-reference.com) were used to cross-reference injury information. To verify each player's date of injury, we confirmed each player's reported injury date corresponded to an absence of statistics from the respective games for which they were ruled out. These methods of collecting publicly available injury data are in accordance with previously published investigations.[7-16]

All active NFL players from September 2016 to January 2017 through September 2019 to January 2020 regular seasons (6,784 athletes) were eligible for inclusion. All players who sustained multiple concussions during the study period were included in the MC cohort (55 athletes). For the purposes of this study, athletes who sustained a SC injury during the study period were eligible for inclusion in the SC cohort (352 athletes). We understand that players included in the SC cohort may have sustained a concussion during their football career outside of the study period. However, athlete records while playing at the high school and collegiate level are not publicly available; thus, our data are limited and should be interpreted as such. Athletes who sustained a concussion during the season 1 year before the beginning of the study period were excluded to control for recent past concussions. We then age- and position-matched players in the SC cohort to the MC cohort. A control cohort also was established by age and position matching NFL players who did not sustain a concussion throughout the study period to the MC cohort. Lower-extremity injuries were then documented for players included in all 3 cohorts. As mentioned previously, Brooks et al.[2] and Herman et al.[3] both demonstrated that athletes had greater odds of sustaining a lower-extremity injury in the 90 days after RTP following concussion. It is unclear how long the risk of sustaining a lower-extremity injury persists after concussion. Given the NFL regular season is approximately 5 months in length, we choose to include all lower-extremity injuries that occurred during the remainder of the season following sport related concussion.

Team records available on individual team websites were used to document demographic information. Our dataset included each player's name, position, team, pathology, age at injury, date of injury, season, number of weeks missed due to injury, and date of RTP.

Definitions

Reportable injuries were based on the criteria that the injury necessitated a team physician referral or emergent care and resulted in a missed game. Players were assessed by their respective team medical staff, which typically includes an athletic trainer, as well as team physician (M.D. or D.O.), and neurologist (M.D. or D.O.). Preseason games were excluded from investigation to account for the potentially different level of competition during this time period, as starters typically do not play as many minutes during the preseason compared with the regular season, as well as for the inability to track players lost to follow-up due to being cut from the team before the regular season. However, we did confirm that athletes included in the study did not sustain a lower-extremity injury or concussion during the preseason. In addition, postseason play was excluded so that all teams had equal representation throughout the study period to eliminate potential confounding of injury rates due to team-specific playing style. Concussions were diagnosed in accordance with the NFL Head, Neck and Spine Committee's Concussion Diagnosis and Management Protocol.[17] An athlete-exposure was defined as one athlete's participation in one game in which they were exposed to potential injury.

Age- and Position-Matched Controls

All active male professional football players participating in the 2016-2017 through 2019-2020 NFL regular seasons were eligible for inclusion as age- and position-matched controls. Football players included in the SC or MC injury cohort were excluded from the control group. An online search was performed to determine whether any football players in the control group had sustained a concussion during the study period. The primary sources used to gather this information is listed in Appendix Table 1. Football players who were identified to have sustained a concussion injury were excluded from the age-matched control group. The MEDCALC case-control matching procedure was used to randomly match cases and controls with a 1:1 allocation ratio, respectively, based on age and position (MedCalc Software Ltd., Ostend, Belgium). We chose to age- and position- match controls in order to minimize selection bias. By position-matching controls, we attempted to control for positions that sustained lower-extremity injuries at a greater rate.

Data and Statistical Analysis

Data analysis was conducted using SPSS 25 (IBM Corp., Armonk, NY). Baseline characteristics were compared using a combination of 1-way analysis of variance and χ^2 tests. Average number of games missed, and number of players placed on injury reserve

Table 1. Demographics

	Multiple Concussions (n = 55)	Single Concussion (n = 54)	No Concussion (n = 55)	*P* Value
Age, y (SD)	26.8 (2.8)	26.5 (2.6)	26.9 (2.9)	.66
Position				
Cornerback	10	10	10	.99
Defensive end	2	2	2	
Defensive tackle	1	1	1	
Guard	6	6	6	
Linebacker	5	5	5	
Offensive tackle	5	4	5	
Quarterback	2	2	2	
Running back	2	2	2	
Safety	5	5	5	
Tight end	8	8	8	
Wide receiver	9	9	9	

SD, standard deviation.

(IR) per year were also calculated. Binary logistic regression was used to calculate odds ratio (OR) associated with number of concussions (continuous predictor variable) and presence of lower-extremity injury (binary dependent variable). Kaplan−Meier and log rank test analysis were used to compare time-to-event for lower-extremity injury occurrence following concussion in the SC and MC cohorts. Participation of a given player for more than one season was handled in the following manner: players who sustained MC throughout the study period were included only within a MC cohort, there was no crossover between groups. Survival curves were generated and censored to 90 days, 1 year, and the study duration for each athlete. Statistical significance was set at $P \leq .05$ and associated 95% confidence interval.

Table 2. Type, Location, and Games Missed due to Lower-Extremity Injury

	Multiple Concussions (n = 55)	Single Concussion (n = 54)	No Concussion (n = 55)
Total lower-extremity injuries	86	84	29
Lower-extremity injury type			
Contusion	20	22	5
Fracture	3	6	3
Sprain/strain	58	51	18
Stress	0	1	1
Ligament tear	5	4	2
Lower-extremity injury location			
Hip	10	8	4
Thigh	8	21	9
Knee	24	21	5
Leg	7	2	1
Ankle	24	18	8
Foot	13	14	2
Games missed due to lower-extremity injury	165	159	102
Players placed on IR	9	15	19
Games missed on IR	55	77	83

IR, injury reserve.

Table 3. Odds of Lower-Extremity Injury

	OR (95% CI)	*P* Value
SC vs NC	2.28 (1.5-3.6)	.001
MC vs NC	2.92 (1.7-4.9)	.001
SC vs MC	1.00 (0.7-1.3)	.97

CI, confidence interval; MC, multiple concussions; NC, no concussions; OR, odds ratio; SC, single concussion.

Results

We identified 55 athletes with multiple documented concussions and 352 athletes with isolated cases during the study period. All 55 athletes were determined to be eligible for the MC group (39/55 with 2 concussions, 16/55 with 3 concussions). From the athletes with SCs, 352 were eligible for inclusion, from whom 54 were chosen for the SC group, based on age and position matching. The NC group was selected from active NFL players during the study period through age and position matching. The final cohort included 55 athletes in the MC and NC cohorts and 54 athletes in the SC cohort (Table 1).

A total of 199 lower-extremity injuries were identified across the 3 cohorts (Table 2). The majority of the lower-extremity injuries occurred in the MC cohort (86/199 [43%]), followed by the SC (84/199 [42%]), and NC cohorts (29/199 [15%]). In total, 426 NFL games were missed due to lower-extremity injuries. Players in the MC cohort missed the most games secondary to a lower-extremity injury (165/426 [39%]). There were 43 players placed on the IR for a lower-extremity injury. The majority of the players placed on the IR for a lower-extremity injury (19/43 [44%]) were from the NC cohort. Average games missed per lower-extremity injury were 3 in the MC, 2.9 in the SC, and 1.8 in the NC cohort.

The odds of sustaining a lower-extremity injury were significantly greater in the MC as well as the SC cohort when compared with the NC matched cohort OR 2.92 (1.7-4.9) and 2.28 (1.5-3.6), respectively (Table 3). However, we found no significant difference in the odds of sustaining a lower-extremity injury when comparing the SC with the MC cohort (OR 1.00 [0.7-1.3]).

The time to lower-extremity injury after RTP from a concussion was significantly shorter in the SC group when compared with the MC group, within 1 year following a concussive injury ($P = .01$). However, there was no significant difference in time to lower-extremity injury after RTP from concussion in the first 90 days following a concussion injury ($P = .62$) (Figs 1 and 2).

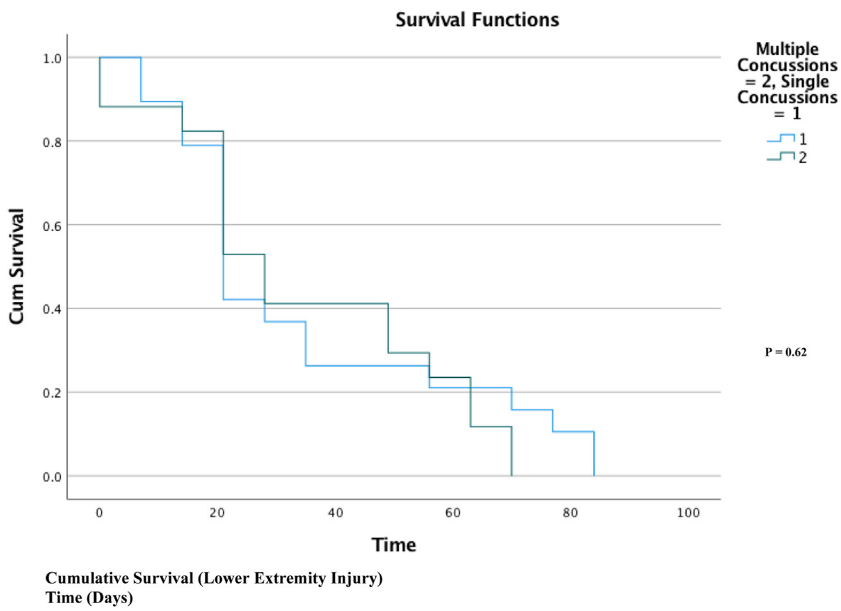

Fig 1. Time to lower-extremity injury (90 days).

Discussion

The most important finding of the current study was that there was no significant difference in the odds of suffering a lower-extremity injury after RTP for NFL players exposed to MC when compared with players exposed to a SC during our study period. However, there was a significant increase in the odds of suffering a lower-extremity injury after RTP in NFL players exposed to single or multiple concussions when compared with age- and position-matched controls. Our findings support the multiple previous studies, which demonstrated concussions to increase the odds of acute lower-extremity injuries in athletes.[1-3,18] The findings of our study add to the body of evidence that suggests that subclinical deficits in athletes with concussion extend beyond the acute stage of injury.[19-23]

Few studies have investigated how multiple concussions may affect future risk of injury. Guskiewicz et al.[5] proposed that concussion injuries place the brain in a

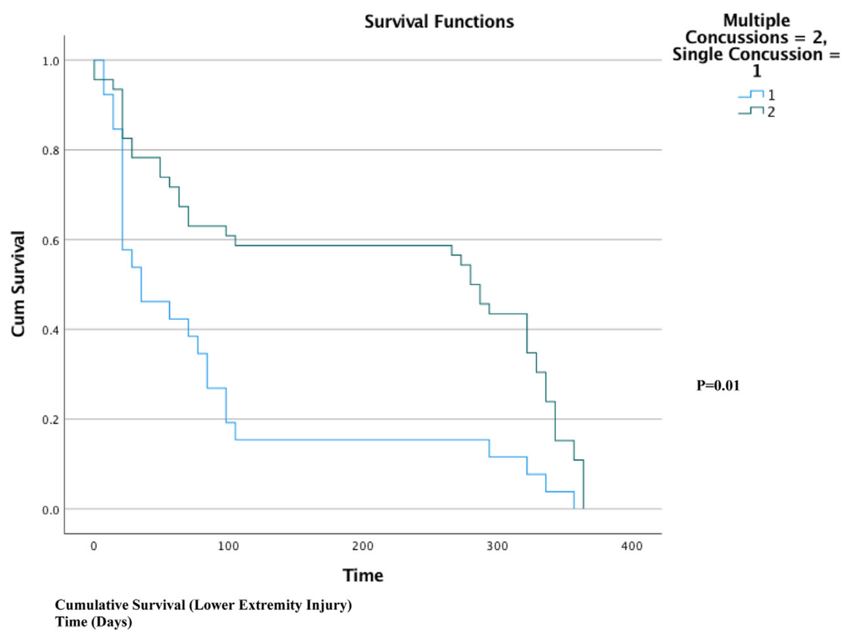

Fig 2. Time to lower-extremity injury (365 days).

state of "neuronal vulnerability," and that such neurologic changes slow down recovery time and increase the risk of injury. In another article by Guskiewicz et al.,[5] the authors describe how the vestibular system is commonly affected by concussion, hypothesizing that such altered sensory cues can affect players' motor responses, predisposing them to injury after RTP.[24] The findings of more recent studies evaluating gait and proprioception in athletes with concussion support the hypotheses of Guskiewicz et al in that athletes with concussion were found to have measurable differences in neuromuscular control.[4] Thus, there is evidence to suggest that altered neuromuscular control in athletes with concussion may contribute to the observed increase in associated lower-extremity injuries.

Harada et al.,[1] in a similar study investigating the relationship between multiple concussions and lower-extremity injuries in collegiate athletes, demonstrated that players exposed to multiple concussions were found to have both increased odds of lower-extremity injury and a shorter time to lower-extremity injury following RTP. In contrast to this study, their findings did not suggest a significant difference between odds of lower-extremity injury in players sustaining a SC versus no concussion. However, their study population included all collegiate athletes at a single National Collegiate Athletic Association Division I institution across multiple sports. Thus, their findings may not have external validity when applied only to NFL players. Jildeh et al.[25] investigated the risk of acute, noncontact lower-extremity injuries after concussion in NFL offensive players. The authors demonstrated that the odds of acute noncontact, lower-extremity injury were not increased in athletes who sustained a concussion when compared with controls, contradicting our results. Like the current study Jildeh et al.[25] used publicly available data to perform their investigation. The difference in our findings could be explained by Jildeh et al.[25] excluding defensive players who made up a significant portion of the players included in the current study. Jildeh et al.[25] also excluded contact-related lower-extremity injuries, which also could explain the difference in results. Concussed athletes have been shown to have measurable differences in neuromuscular control,[4] possibly increasing their risk of sustaining contact injuries, which is why we choose to include contact injuries in the current study.

Limitations

This study, as well as other similar publications using the well-established multistep protocol to identify injuries in professional athletes through review of public records, is associated with several well-recognized limitations. Details regarding injury diagnosis and management, including injury severity, exact pathology, imaging reports, and exact medical clearance, were not available for all players. Because injured players were identified using public records, the possibility of reporting errors, and omissions exist. We attempted to minimize this limitation by further describing the injuries in our results when further details were provided on the injury report. However, there may be underreporting of specific injuries in our data. Our results should be interpreted with this in mind. Exclusion of preseason injuries is a major limitation, given the short timeframe of the study with a small number of cases; however, we choose to exclude these injuries as the level of competition during the preseason is variable as starters typically do not play the whole game, and players are often lost to follow-up due to being cut from the team prior to the regular season (37 players cut during the preseason on each team, each year). We also are unable to capture subconcussive injuries that are not formally diagnosed or concussions sustained by players during their football career outside of the study period. Athlete records while playing at the high school and collegiate level are not publicly available, which limits our ability to capture these injuries. In an attempt to control for recent past concussions, we did exclude athletes who sustained a concussion during the season 1 year before the beginning of the study period. Selection bias may have influenced our results in that the more players see the field, the more likely they are to sustain a concussion injury, as well as a lower-extremity injury. Finally, there remains the possibility of selection bias in the injured group in which only "newsworthy" players injured were reported on. We attempted to control for this selection bias by only including regular-season games to account for the inability to track players lost to follow-up due to being cut from the team before the regular season. Further, an attempt to minimize this bias was made by corroborating reported injuries with 2 additional resources, but the data is limited by what is publicly available. The short study timeline is a significant limitation, spanning only 4 NFL seasons, and the biggest difference between our study and Harada et al.[1] This is a significant limitation because, given how common concussions are in football players, it is likely that a majority of the players included in this study sustained a concussion at some point during their high school, college, or NFL career that was not captured by our data. Unfortunately, it is impossible to longitudinally follow NFL players for their whole football careers to get a more accurate assessment of their career concussions. However, the average NFL career, as reported by NFL.com is 3.3 years. Thus, our dataset is similar in length to the average player's career, which we felt was adequate.

Conclusions

There was a significant increase in the odds of suffering a lower-extremity injury after RTP in NFL players exposed to single or multiple concussions when compared with age- and position-matched controls who did not sustain a concussion within the study period. There was no significant difference in the odds of suffering a lower-extremity injury after RTP for NFL players exposed to multiple concussions when compared with players exposed to a SC during our study period. Our findings suggest a potential need for injury-prevention protocols following concussion injuries.

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Appendix Table 1. Data Sources Used

http://www.nfl.com/injuries
https://www.espn.com/nfl/injuries
https://www.cbssports.com/nfl/injuries/
https://www.pro-football-reference.com/players/injuries.htm
https://bleacherreport.com/nfl-injuries