Concussion Increases Odds of Sustaining a Lower Extremity Musculoskeletal Injury After Return to Play Among Collegiate Athletes

M. Alison Brooks, Kaitlin Peterson, Kevin Biese, Jennifer Sanfilippo, Bryan C. Heiderscheit and David R. Bell

Am J Sports Med published online January 19, 2016

DOI: 10.1177/0363546515622387

AJSM PreView, published on January 19, 2016 as doi:10.1177/0363546515622387

Concussion Increases Odds of Sustaining a Lower Extremity Musculoskeletal Injury After Return to Play Among Collegiate Athletes

M. Alison Brooks,*†‡ MD, MPH, Kaitlin Peterson,§ BS, Kevin Biese,|| BS,
Jennifer Sanfilippo,‡¶ MS, ATC, Bryan C. Heiderscheit,†‡ PT, PhD,
and David R. Bell,†‡|| PhD, ATC
Investigation performed at University of Wisconsin–Madison, Madison, Wisconsin, USA

Background: Previous studies have identified abnormalities in brain and motor functioning after concussion that persist well beyond observed clinical recovery. Recent work suggests subtle deficits in neurocognition may impair neuromuscular control and thus potentially increase risk of lower extremity musculoskeletal injury after concussion.

Purpose: To determine the odds of sustaining an acute lower extremity musculoskeletal injury during the 90-day period after return to play from concussion in a cohort of National Collegiate Athletic Association (NCAA) Division I collegiate athletes.

Study Design: Cohort study; Level of evidence, 3.

Methods: Included in this study were 87 cases of concussion among 75 athletes (58 men; 17 women) participating in NCAA Division I football, soccer, hockey, softball, basketball, wrestling, or volleyball at a single institution from 2011 to 2014. The 90-day period after return to play for each case of concussion was reviewed for acute noncontact lower extremity musculoskeletal injury. Each 90-day period after return to play was matched to the same 90-day period in up to 3 controls. Control athletes without a history of concussion in the previous year were matched to concussed athletes by sport team/sex, games played, and position. A total of 182 control (136 men; 46 women) 90-day periods were reviewed for acute injury. Conditional logistic regression was used to assess the association between concussion and subsequent risk of acute lower extremity musculoskeletal injury.

Results: The incidence of acute lower extremity musculoskeletal injury was higher among recently concussed athletes (15/87; 17%) compared with matched controls (17/182; 9%). The odds of sustaining an acute lower extremity musculoskeletal injury during the 90-day period after return to play were 2.48 times higher in concussed athletes than controls during the same 90-day period (odds ratio, 2.48; 95% CI, 1.04-5.91; $P = .04$).

Conclusion: Concussed athletes have increased odds of sustaining an acute lower extremity musculoskeletal injury after return to play than their nonconcussed teammates. The study results suggest further investigation of neurocognitive and motor control deficits may be warranted beyond the acute injury phase to decrease risk for subsequent injury.

Keywords: sports-related concussion; mild traumatic brain injury

Sport-related concussion is a growing public health concern. According to the Centers for Disease Control and Prevention, an estimated 1.6 to 3.8 million sport-related concussions occur in the United States annually.[13] Recent attention in the media and scientific community has led to rule changes and legislation in many states to protect athletes from repeat injury.[25] However, because of limited empirical-based guidelines, concussion continues to be one of the most difficult athletic injuries to diagnose and manage.

The American Journal of Sports Medicine, Vol. XX, No. X
DOI: 10.1177/0363546515622387

After a single athletic concussion, the probability of a second concussion increases 3-fold.[3] Neurophysiological studies have suggested that after a concussion, there is a window of vulnerability during which a second concussive episode may lead to more severe traumatic brain injury.[26] Furthermore, recurrent concussion has been associated with an increased risk of late-life mild cognitive impairment, clinical depression, and earlier onset and higher risk of neurodegenerative disorders.[9,10,14] Thus, understanding the time course of recovery and establishing criteria for safe return to play is critical to preventing the risk of both acute and long-term deficits after concussion.

Sports concussion is commonly assessed using a clinical battery of tests that evaluate self-reported symptoms, neurocognitive functioning, and postural control. Numerous reports have demonstrated that most athletes exhibit full clinical recovery of symptoms, cognitive dysfunction, and balance impairments by 7 to 10 days after injury.[4,11,16] However, emerging evidence suggests that abnormalities in brain and motor functioning after concussion persist well beyond the typical time course of observed clinical recovery.[1,2,4-7,15,17,20,23,26] Over the past decade, study of brain functioning using event-related potentials has provided new insight into specific aspects of cognition that may be affected by concussion. Several studies have identified deficits in mental performance and attention in the absence of symptoms and overt cognitive deficits.[6,7,19] Similarly, concussion history has been associated with altered motor control and adoption of a conservative gait strategy in clinically asymptomatic athletes.[2,15,23] In addition, it has been suggested that deficits in cerebral performance, including reaction time, processing speed, and verbal and visual memory, may indicate impaired neuromuscular control.[24] Such findings suggest athletes may demonstrate ongoing cognitive and neuromuscular impairments and a decreased capacity for motor planning after concussive injury. However, it is unclear to what extent these impairments may increase the risk of subsequent musculoskeletal injury during continued sports participation.

Therefore, the primary aim of this study was to determine if collegiate athletes are at increased odds of sustaining an acute lower extremity musculoskeletal injury during the 90-day period after return to play from concussion. We hypothesize that concussed individuals will have greater odds of sustaining a noncontact acute lower extremity musculoskeletal injury in the 90 days after return to sport compared with matched controls.

METHODS

Participants

A retrospective cohort study was conducted to examine the risk of lower extremity musculoskeletal injury after return to play from concussion. Injury data for all men and women participating in National Collegiate Athletic Association (NCAA) Division I football, soccer, hockey, basketball, wrestling, volleyball, and softball were reviewed for the 2011-2012, 2012-2013, and 2013-2014 competitive seasons. The 90-day period after return to play was chosen for evaluation in accordance with similar time periods in which previous studies have identified deficits in cognitive functioning, postural stability, and increased injury risk after concussion.[12,16,20] This study was approved by the University of Wisconsin Institutional Review Board.

Injury records obtained from the university's Sports Injury Monitoring System (SIMS) database identified 106 cases of concussion among 84 athletes (62 men; 22 women). Cases of concussion used for analysis were selected from this pool based on strict inclusion criteria, which included the following: (1) all athletes suspected of having sustained a concussion during practice or competition were examined by a certified athletic trainer and subsequently diagnosed with concussion by a team physician as a part of standard procedure. Concussive subjects were identified according to criteria established by the American Academy of Neurology[21] (*concussion* was defined as a direct or indirect blow to the head resulting in altered mental status and one or more of the following symptoms: headache, nausea, vomiting, fatigue, dizziness, balance impairment, difficulty sleeping, sensitivity to light or noise, drowsiness, blurred vision, memory impairment, and difficulty concentrating). Other criteria included the following: (2) athletes who participated in games and practices for a minimum of 72 days (80%) of the 90-day period after return to play (this applied to controls as well, as they were matched to the same 90-day period) and (3) athletes with complete medical records regarding diagnosis and return-to-play date. All concussed athletes were evaluated and cleared by a team physician before returning to play. After resolution of clinical symptoms and signs, athletes gradually increased activity under supervision of a team physician. Athletes who remained asymptomatic throughout rehabilitation were cleared for return to play.

Cases of concussion were excluded if the athlete sustained a second concussion within the 90-day period after return to play. Cases and controls were also excluded if a nonmusculoskeletal injury, upper extremity injury, or illness was sustained that limited their sport participation for greater than 18 days (20%) of the 90-day period. Of the original 106 cases identified, a total of 19 cases of concussion were excluded, leaving 87 cases of concussion among 75 athletes (58 men; 17 women) for analysis. Figure 1 depicts the flow diagram outlining the rationale for each case removal.

Potential control participants without a history of concussion within the previous year were identified and randomly matched to concussed athletes. Matching criteria included the following: (1) sport team/sex and (2) exposure, matched to the number of games/matches in which the athlete played during the 90-day period. For instances in which concussed athletes could not be matched to controls of similar game play, we attempted to match to controls with greater participation. In rare circumstances, we matched controls with 1 less game exposure (9 of the 182 controls). The third criterion was position, as evaluated

*Address correspondence to M. Alison Brooks, MD, MPH, Department of Orthopedics and Rehabilitation, University of Wisconsin–Madison, 1685 Highland Avenue, Madison, WI 53705, USA (email: brooks@ortho.wisc.edu).
†Department of Orthopedics and Rehabilitation, University of Wisconsin–Madison, Madison, Wisconsin, USA.
‡Badger Athletic Performance, University of Wisconsin–Madison, Madison, Wisconsin, USA.
§School of Medicine and Public Health, University of Wisconsin–Madison, Madison, Wisconsin, USA.
||Department of Kinesiology, University of Wisconsin–Madison, Madison, Wisconsin, USA.
¶Division of Intercollegiate Athletics, University of Wisconsin–Madison, Madison, Wisconsin, USA.
The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

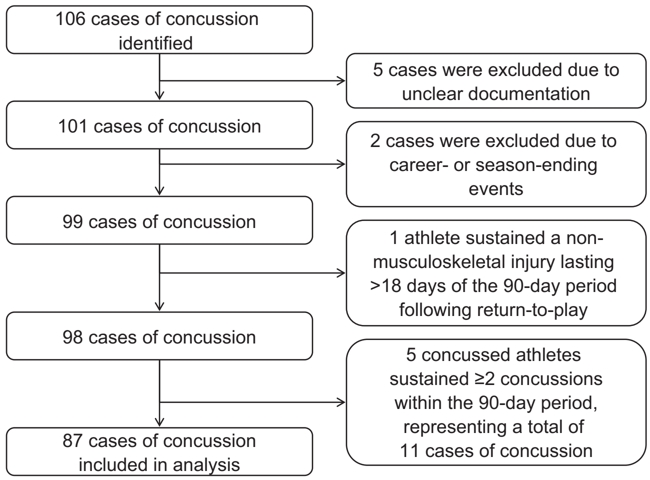

Figure 1. Selection of concussion cases and reasons for exclusion.

independently for each sport with consideration of the unique demands and challenges specific athletes face on the field. Football athletes were matched by skilled (running backs, fullbacks, tight ends, wide receivers, defensive backs, linebackers) and nonskilled (offensive/defensive linemen) positions. Hockey athletes were matched by forwards and defenders. Soccer players were matched by forwards/midfielders, defenders, and goalkeepers. Softball athletes were matched by infielders, outfielders, and utility players. Volleyball athletes were matched by hitters/setters and libero/defensive specialists. Basketball players were matched by forwards/guards and centers. And last, concussed wrestlers were matched with control subjects within 3 weight classes above or below competition weight. If no controls in a given position had comparable or greater game play, controls from the next most similar position were evaluated. A pool of possible controls matched on the stated variables was identified for each case of concussion. Up to 3 controls were then randomly selected for each case from the pool of potential controls that met all criteria (30 cases of concussion matched with 3 controls; 35 cases of concussion matched with 2 controls; 22 cases of concussion matched with 1 control). A total of 182 controls (136 men; 46 women) were identified.

Concussion diagnosis, onset, and return-to-play date, as well as musculoskeletal injury diagnosis and onset, were collected through the SIMS database. Per clinical standard of care, athletic trainers assessed and documented injury type, location, and pertinent recovery information in SIMS for all cases of concussion and musculoskeletal injuries. The 90-day period after return to play for each case of concussion was reviewed for lower extremity musculoskeletal injury as well as the year before enrollment to account for previous injury history. Each 90-day period after return to play from concussion was compared with the same 90-day period in up to 3 control athletes. Lower extremity musculoskeletal injuries were defined as noncontact acute fractures, muscle strains/tears, or ligament sprains/ruptures of the hip, groin, thigh, knee, shin, ankle, or foot. Contusions, stress fractures, abrasions, overuse injuries, and other nonmusculoskeletal injuries were excluded.

TABLE 1
Demographic Information of Concussed Athletes and Controls

	Concussion	Controls
Sex, n		
Male	69	136
Female	18	46
Age, y, mean ± SD	19.8 ± 1.3	19.9 ± 1.3
Year of eligibility, mean ± SD	2.4 ± 1.3	2.4 ± 1.2
Body mass index, mean ± SD	27.7 ± 4.3	28.1 ± 4.8
Injury location, n		
Hip	1	0
Groin	1	3
Thigh	2	2
Knee	4	2
Shin	0	1
Ankle	5	7
Foot	2	2
Injury type, n		
Acute fracture	0	0
Muscle strain/tear	5	6
Ligament sprain/rupture	10	11
Game exposures, mean ± SD	5.1 ± 6.4	5.9 ± 6.5
Total game exposures, n	448	1084

Statistical Analysis

Conditional logistic regression was used to assess the association between concussion and subsequent risk of acute lower extremity musculoskeletal injury, independent of potential differences in sport/sex, games played, and position. We also controlled for history of previous time-loss lower extremity injury. Time to injury was further examined using the Mann-Whitney *U* test to compare time (days) to lower extremity injury only for those who sustained a lower extremity injury. SPSS was used for all analyses ($P \leq .05$).

RESULTS

Demographic information of the concussed and control athletes is presented in Table 1. Concussed athletes averaged a return-to-play time of 21.0 days (median, 9.0; interquartile range [IQR], 5.0-15.0) after their concussive injury. The incidence of acute, noncontact lower extremity musculoskeletal injury during the 90-day period after return to play was higher in concussed athletes (17%) compared with matched controls (9%) (Table 2). The odds of sustaining a lower extremity musculoskeletal injury were 2.48 times higher in concussed athletes than in controls matched by sport/sex, game play, and position after controlling for history of lower extremity injury (odds ratio [OR], 2.48; 95% CI, 1.04-5.91; P = .04). However, in patients who sustained a lower extremity injury, there

TABLE 2
Acute Lower Extremity Musculoskeletal Injury Occurrence in Concussed and Control Athletes

	Lower Extremity Musculoskeletal Injury, n		
Concussion	Yes	No	Total
Yes	15	72	87
No	17	165	182
Total	32	237	269

was no difference in time to lower extremity injury (P = .97) in controls (mean, 33.1 days; 25th percentile, 7.5 days; 50th percentile, 29 days; 75th percentile, 51 days) and concussed athletes (mean, 32.1 days; 25th percentile, 12 days; 50th percentile, 22 days; 75th percentile, 53 days). Figure 2 demonstrates the number of lower extremity injuries sustained each week during the 90-day follow-up period.

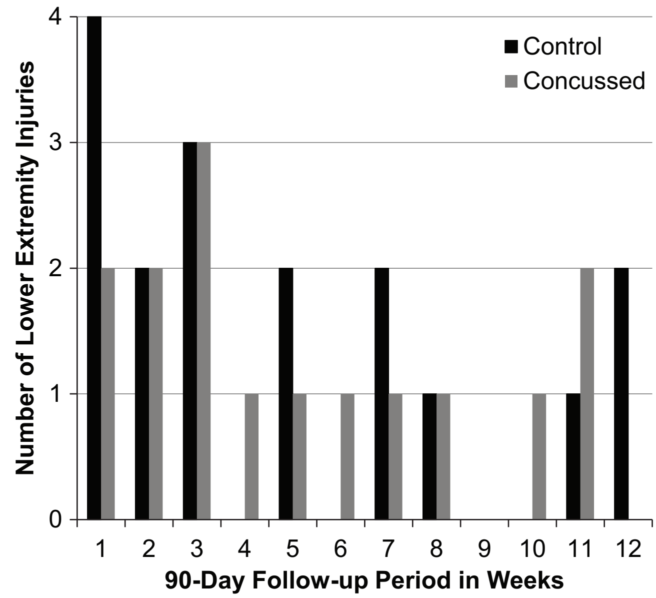

Figure 2. Number of lower extremity injuries during the 90-day follow-up period in weeks.

DISCUSSION

The most important finding of this study is that concussed collegiate athletes were at increased odds compared with controls of sustaining an acute, noncontact lower extremity musculoskeletal injury during the 90-day period after return to play. These findings support previous reports of subclinical deficits that extend beyond the acute stage of injury.[1,2,4-7,15,17,20,23,26] Furthermore, these results highlight the need for additional research focused on screening of concussed athletes to assess for subtle impairments in neuromuscular control that may affect future musculoskeletal injury risk.

Comparison With Previous Studies

In 2013, Herman et al[12] reported that concussion may increase the risk but not the severity of lower extremity musculoskeletal injury in the 90-day period after return to play in Division I collegiate athletes. A total of 61 cases of concussion in 49 athletes participating in collegiate men's football and women's basketball, soccer, and lacrosse were matched to controls of similar sport, starting status, and position. Overall, concussed athletes in this cohort had a 3.79 times greater risk of muscle strains/tears or ligament sprains/ruptures in the 90-day period after return to play. While this estimate is higher than that found in our study, the limited number of male sports other than football and matching based on starting status rather than game play may explain this difference. Nonetheless, our findings in an independent collegiate cohort support the work by Herman et al, suggesting a significantly increased risk of acute lower extremity injury after concussion in this athletic population.

Consistent with our findings that concussed collegiate athletes are at an increased risk of acute lower extremity injury after concussion, a recent study by Nordstrom et al[18] reported that concussed athletes from a cohort of professional male soccer players (mean age, 26 ± 1 years) were 2.2 times more likely to sustain an injury in the subsequent year. Interestingly, analysis of 3 separate time frames (0-3 months, 3-6 months, and 6-12 months) found that the risk of all types of injury progressively increased in the year after concussion, with an approximately 4-fold greater risk at 6 to 12 months. While the reasons for this are unclear, increased risk may be attributed to increased level of exposure and return to competitive play in the following season. In addition, subset analysis, adjusting for the number of injuries in the year before and after concussion, found that concussion was associated with an increased risk of sudden onset (ie, ligament sprains and muscle strains) but not gradual onset (ie, tendinopathy, stress fracture) injury.

Possible Explanations for Increased Injury Risk

Although once considered a transient injury, concussion is now recognized as a complex injury with both acute and chronic effects. Most research surrounding concussion has focused on changes in neurocognitive and motor functioning in the days and weeks after injury. However, while gross changes in symptoms, neurocognitive dysfunction, and balance impairments generally resolve 1 week after injury, it is unclear if standard clinical tests have the sensitivity to detect more subtle deficits in function that may explain this possible increased risk of injury.

One possible explanation for the increased risk of injury we observed after concussion is detraining due to missed time to recover from concussion. However, this is an unlikely explanation for our findings given that no difference was observed in days to lower extremity injury between groups. In fact, the average time from return to play to lower extremity injury was equal between the concussed group (32 days) and the control group (33 days). In addition, the histogram (Figure 2) of the number of injuries each week of the follow-up period shows no discernable pattern. We would expect injuries associated with deconditioning to occur during the first few weeks of play until athletes are able to recover previous levels of aerobic and muscular fitness. Therefore, we believe alternative mechanisms underlie the cause of increased musculoskeletal injury in this cohort.

Several investigations have identified abnormal indices of brain and motor functioning after concussion in the presence of normal clinical findings. Specifically, studies of event-related potentials have provided new insight into precise aspects of cognition that may be affected by concussion. Gaetz and Weinberg[6] found that athletes with a history of concussion had smaller P3 amplitude and longer P3 latency on both visual and auditory oddball tasks relative to nonconcussed controls. Furthermore, Gosselin et al[7] found similar impairments in brain functioning in both symptomatic and asymptomatic concussed athletes. Based on current understanding of P3, these findings suggest that deficits in attentional resource allocation (smaller P3 amplitude) and cognitive processing speed (longer P3 latency) may persist even in the absence of symptoms and overt cognitive deficits.[19]

Similarly, several gait studies have identified differences in motor functioning that persist well beyond the acute stage of injury. In comparison with simple clinical tests, challenging and dynamic postural tasks (ie, dual-task, obstacle avoidance) have demonstrated lasting balance impairments in concussed individuals.[8] Likewise, Buckley et al[2] detected lingering alterations in motor control strategy that persisted at least 10 days after injury despite all individuals returning to baseline values on standard concussion assessments. Thus, changes in cerebral functioning that affect postural control may persist beyond the acute injury phase.[23] Furthermore, Martini et al[15] found that those with a history of concussion (average of 6.32 years after injury) had slower gait velocity and spent significantly more time in a double-leg stance and less time in a single-leg stance than nonconcussed controls. Together, these results suggest that concussed athletes adopt a more conservative gait strategy after injury. While the reasons for this are not entirely clear, it has been proposed that these changes may reflect a decreased capacity for motor planning.[2,15] Alternatively, adoption of an altered movement strategy could possibly help concussed athletes maintain stability and decrease their risk for further injury.

Collectively, these studies, along with the present findings, provide evidence for a postacute period during which motor dysfunction persists despite presumed clinical recovery. We acknowledge this study was not designed to investigate the underlying mechanisms responsible for the observed increased risk of injury. However, as suggested in previous studies, our findings warrant further study to assess if subclinical neurocognitive deficits, loss of neuromuscular control, and/or impaired motor functioning are associated with subsequent musculoskeletal injury. Given the demanding environment in which athletes are required to execute complex maneuvers, it is possible that mild neurocognitive deficits may result in judgment errors and loss of coordination during play. Interestingly, a study conducted by Swanik et al[24] found that athletes who performed worse on a neurocognitive test battery (designated by slower reaction time and processing speed and worse visual and verbal memory scores) were more likely to sustain a noncontact anterior cruciate ligament injury. Thus, neurocognitive differences may indeed denote a diminished capacity for neuromuscular control and thereby predispose certain athletes to injury.

We acknowledge that this study has limitations. Perhaps the most significant is that it is possible that the groups were not exposed to the same risk of lower extremity injury during the 90-day period. We used matching criteria to control for sport differences, game exposure, and different practice frequencies between teams. However, within a game, better athletes may play more minutes and attract more attention from opposing players, which could increase exposure and risk. Given the smaller sample size of concussed athletes, there may have been unmeasured modifiers or confounding factors associated with previous concussion that could not be distinguished in the present study. We were unable to include balance or neurocognitive scores in this analysis. In addition, this study only included collegiate athletes who had a sport-related concussion and may not be generalizable to other populations. Therefore, future studies are needed to see if the observed results are applicable to younger age groups and additional types of injury (eg, upper extremity, back strain/tear). Last, this was a retrospective study. Longitudinal studies are needed to prospectively follow athletes over a longer time frame to further elucidate specific factors that may alter injury risk.

CONCLUSION

Although previous studies had suggested specific deficits may put concussed athletes at an increased risk of injury, few data were available regarding the actual risk of injury associated with concussion. Our study aimed to help fill this knowledge gap and demonstrated that collegiate athletes were at increased odds of sustaining an acute, noncontact lower extremity musculoskeletal injury within 3 months after return to play from concussion. Our findings suggest that the well-established effects of concussion on neurocognitive and motor control may extend well beyond apparent clinical resolution of the acute injury phase. These findings warrant further exploration of the underlying mechanisms responsible for subsequent increased risk of injury after an athlete sustains a concussion. Future studies that investigate the potential relationship between injury risk and proposed deficits persistent after concussion may help sports medicine staff recommend specific therapy (ie, vestibular or oculomotor rehabilitation) or neuromuscular training programs that can facilitate functional recovery and decrease injury risk.[22] As more advanced concussion studies are conducted and our knowledge of the natural course of recovery grows, clinicians should be aware of the potential for lower extremity musculoskeletal injury as it concerns management and return-to-play decisions and closely monitor concussed athletes throughout recovery even after they exhibit improvement on standard clinical tests.

ACKNOWLEDGMENT

The authors acknowledge the Sports Medicine staff at the University of Wisconsin–Madison Division of Athletics for their commitment to the welfare of the student athletes and for their contributions to the Badger Athletic Performance Program.

REFERENCES

1. Broglio SP, Moore RD, Hillman CH. A history of sport-related concussion on event-related brain potential correlates of cognition. *Int J Psychophysiol*. 2011;82:16-23.
2. Buckley T, Munkasy B, Tapia-Lovier TG, Wikstrom EA. Altered gait termination strategies following a concussion. *Gait Posture*. 2013;38:549-551.
3. Cantu RC. Recurrent athletic head injury: risks and when to retire. *Clin Sports Med*. 2003;22:593-603.
4. Ellemberg D, Henry LC, Macciocchi SN, Guskiewicz KM, Broglio SP. Advances in sport concussion assessment: from behavioral to brain imaging measures. *J Neurotrauma*. 2009;26:2365-2382.
5. Ellemberg D, Leclerc S, Couture S, Daigle C. Prolonged neuropsychological impairments following a first concussion in female university soccer athletes. *Clin J Sport Med*. 2007;17:369-374.
6. Gaetz M, Weinberg H. Electrophysiological indices of persistent post-concussion symptoms. *Brain Inj*. 2000;14:815-832.
7. Gosselin N, Theriault M, Leclerc S, Montplaisir J, Lassonde M. Neurophysiological anomalies in symptomatic and asymptomatic concussed athletes. *Neurosurgery*. 2006;58:1151-1161.
8. Guskiewicz KM. Balance assessment in the management of sport-related concussion. *Clin Sports Med*. 2001;30:89-102.
9. Guskiewicz KM, Marshall SW, Bailes J, et al. Association between recurrent concussion and late-life cognitive impairment in retired professional football players. *Neurosurgery*. 2005;57:719-726.
10. Guskiewicz KM, Marshall SW, Bailes J, et al. Recurrent concussion and risk of depression in retired professional football players. *Med Sci Sports Exerc*. 2007;39(6):903-909.
11. Guskiewicz KM, Ross SE, Marshall SW. Postural stability and neuropsychological deficits after concussion in collegiate athletes. *J Athl Train*. 2001;36(3):263-273.
12. Herman D, Jones D, Harrison A, et al. Concussion increases the risk of subsequent lower extremity musculoskeletal injury in collegiate athletes. *Clin J Sport Med*. 2013;23(2):124.
13. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. *J Head Trauma Rehabil*. 2006;21:375-378.
14. Lehman EJ, Hein MJ, Baron SL, Gersic CM. Neurodegenerative causes of death among retired National Football League players. *Neurology*. 2012;79:1970-1974.
15. Martini DN, Sabin MJ, DePasa SA, et al. The chronic effects of concussion on gait. *Arch Phys Med Rehabil*. 2011;92:585-589.
16. McCrea M, Guskiewicz KM, Marshall SW, et al. Acute effects and recovery time following concussion in collegiate football players: the NCAA concussion study. *JAMA*. 2003;290:2556-2563.
17. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med*. 2013;47:250-258.
18. Nordstrom A, Nordstrom P, Ekstrand J. Sports-related concussion increases the risk of subsequent injury by about 50% in elite male football players. *Br J Sports Med*. 2014;48(19):1447-1450.
19. Polich J. Updating p300: an integrative theory of P3a and P3b. *Clin Neurophysiol*. 2007;118:2128-2148.
20. Prichep LS, McCrea M, Barr W, Powell M, Chabot RJ. Time course of clinical and electrophysiological recovery after sport-related concussion. *J Head Trauma Rehabil*. 2013;28(4):266-273.
21. Report of the quality standard subcommittee. Practice parameter: the management of concussion in sports (summary statement). *Neurology*. 1997;48:581-585.
22. Schneider KJ, Meeuwisse WH, Nettel-Aguirre A, et al. Cervicovestibular rehabilitation in sport-related concussion: a randomized controlled trial. *Br J Sports Med*. 2014;48(17):1294-1298.
23. Sosnoff JJ, Broglio SP, Shin S, Ferrara MS. Previous mild traumatic brain injury and postural-control dynamics. *J Athl Train*. 2011;46(1):85-91.
24. Swanik CB, Covassin T, Stearne DJ, Schatz P. The relationship between neurocognitive function and noncontact anterior cruciate ligament injuries. *Am J Sports Med*. 2007;35(6):943-948.
25. Tomei K, Doe C, Prestigiacomo CJ, Gandhi CD. Comparative analysis of state-level concussion legislation and review of current practices in concussion. *Neurosurg Focus*. 2012;33(6):E11:1-9.
26. Vagnozzi R, Signoretti S, Cristofori L, et al. Assessment of metabolic brain damage and recovery following mild traumatic brain injury: a multicentre, proton magnetic resonance spectroscopic study in concussed patients. *Brain*. 2010;133(11):3232-3242.