Sport-Related Concussions

Symptom Recurrence After Return to Exercise

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Background: Current guidelines dictate a gradual exercise progression after a concussion; however, it is unclear what proportion of athletes experience a recurrence of symptoms once they are symptom free at rest. Estimating the proportion of athletes and predictors of symptom recurrence would help shape return-to-play protocols.

Purpose: To determine the proportion and associated risk factors of athletes who have a recurrence of concussion symptoms with exercise after being symptom free at rest.

Study Design: Case-control study; Level of evidence, 3.

Methods: Between October 1, 2009 and July 31, 2011, we studied patients from a sport concussion clinic located within a tertiary care regional children's hospital. Patients were queried at every visit using a standardized questionnaire. Our main outcome variable was recurrence of symptoms with exercise after being symptom free at rest at some point in their recovery. Cofactors included age, sex, loss of consciousness with injury, prior concussion (diagnosed and undiagnosed), Post-Concussion Symptom Scale (PCSS) score, time until clinical presentation, and duration of symptoms.

Results: Of the 217 patients included, 25 (12%) experienced a return of symptoms. Losing consciousness at the time of injury and a longer duration between injury and clinical presentation were associated with a decreased risk of symptoms recurring with exercise. Conversely, athletes who had sustained previously undiagnosed concussions and had suffered a longer duration of symptoms at rest were at an increased risk of symptom recurrence with exercise.

Conclusion: Relatively few athletes who are symptom free at rest after a concussion will have a recurrence of symptoms when they resume exercise. The risk of symptoms recurring with exercise may be greater among those athletes who sustained previously undiagnosed concussions and had a longer period of symptoms at rest. The early identification of athletes who may be at risk of symptom recurrence will help mold treatment guidelines and exercise progression protocols.

Keywords: sport-related concussion; exercise; return to play; symptoms

Sport-related concussions have garnered a lot of attention in the past several years, potentially because of increased awareness about the effects of the injury. The number of concussions diagnosed in young athletes has risen significantly recently.[17,22,25,32] The negative consequences of a concussion include potential academic performance deficits[33] or, in a small proportion of patients, recovery times that exceed 1 month.[27] While the overall incidence of concussions is difficult to estimate, many suspect that athletes continue to underreport the symptoms of a concussion.[26,29] The United States Centers for Disease Control and Prevention estimates that approximately 3.8 million traumatic brain injuries occur annually, with more than a quarter of these injuries occurring during athletics.[9]

Currently, each American state has legislation that requires the evaluation and clearance of any athlete suspected of having a concussion before returning to contact play.[6,35] Efforts to educate the general population on the importance of the recognition and proper treatment of concussions have been somewhat successful. Studies assessing coaching knowledge and behaviors have shown nearly universal willingness to sit a player out of play if a severe concussion is suspected, but the percentage of coaches restricting athletes from continued play when a concussion is felt to be "minor" is significantly lower.[2,9,30]

Most education campaigns and guidelines for managing concussions recommend rest, both physical and cognitive, until the athlete is symptom free, followed by a gradual return to physical activity. A gradual reintroduction to activity is recommended, as opposed to simply returning athletes to full participation once they are symptom free at rest, as a recurrence of symptoms with exercise may

The Orthopaedic Journal of Sports Medicine, 5(10), 2325967117732516
DOI: 10.1177/2325967117732516

indicate incomplete recovery from a concussion.[8,11,24] It is unclear, however, what proportion of athletes experience a recurrence of symptoms with the resumption of exercise once they are symptom free at rest. If such a recurrence of symptoms is rare, a gradual return to play might be unnecessary. Alternatively, if a substantial proportion of athletes have a recurrence of symptoms with return to activity, it will add support to current practice guidelines. Furthermore, little is known about what risk factors, if any, might be associated with symptom recurrence once athletes resume physical activity. Therefore, the purpose of this study was to identify factors that are independently associated with the recurrence of symptoms once postinjury exercise is initiated among those who are symptom free at rest.

METHODS

Participants and Design

We conducted an institutional review board–approved prospective cohort study of patients cared for in a sport concussion clinic of a tertiary care regional children's hospital between October 1, 2009 and July 31, 2011. This investigation represents a secondary analysis of these data. The approval process included an ethical review of the study. Patients who sustained concussions during organized or free-play sports, or with mechanisms similar to those in sports such as falling from a standing position, were included in the study. Exclusion criteria included injuries from more severe mechanisms such as motor vehicle collisions or patients with intracranial hemorrhage or skull fractures. A concussion was defined according to the definition provided by the Consensus Statement on Concussion in Sport[23] as a brain injury caused by a direct blow to the head, face, neck, or elsewhere on the body, resulting in the rapid onset of impaired neurological function.

A standardized questionnaire was completed at the initial clinic visit and at each subsequent visit until final discharge. Patients were queried as to their mechanism of injury, presence or absence of loss of consciousness (LOC) with injury, the type of activity played at the time of injury, the date of injury, and the date of symptom resolution. The questionnaire also documented patient sex, patient age, and the date(s) of previously diagnosed and undiagnosed concussions. Although estimating previously undiagnosed concussions in retrospect is difficult and nonspecific, for our purposes, in this study, we defined undiagnosed concussions as blows to the head with subsequent concussion-like symptoms that were not previously diagnosed as concussions.

On each visit, the patients' symptoms were measured using the Post-Concussion Symptom Scale (PCSS).[31] The PCSS contains a list of 22 symptoms typical for a concussion, and each symptom is scored by the patient using a Likert scale from 0 (absent) to 6 (severe). Symptoms in the PCSS are subjective and not specific to a concussion (ie, symptoms in the PCSS may come from causes other than a concussion). Therefore, as with other studies, in an effort to measure only those symptoms attributable to the injury, patients were instructed to rate only those symptoms that were not present before, or have been exacerbated since, the moment of injury, and were still ongoing within 24 hours of completing the questionnaire.[1,5,13,27] A score of 0 was recorded if the patient had full resolution of a particular symptom (or if the symptom was present before the injury and had returned to its preinjury level); a score of 1 through 6 was recorded if the symptom was new and persistent since the injury. Thus, scores ranged from 0 (symptom free) to a potential maximal possible score of 132 (22 symptoms $\times$ 6). When patients had a PCSS score of 0, they were considered to be symptom free at rest, and they were asked to record the date when their symptoms had resolved. After this point, as they resumed exercise, if there was a return of any symptoms included in the PCSS that were not part of their preinjury status, then we assumed that they had a recurrence of concussion symptoms caused by their physical activity and incomplete recovery from the concussion.

Full recovery, in clinical practice, has several components including a resolution of symptoms at rest and continued symptom-free status after physical exertion. We collected information on patients who reported being symptom free, returned to physical activity, and were seen by a physician for continued follow-up. These patients were then specifically queried as to whether their symptoms recurred when they resumed exercise. The average level of activity and type of physical activity to which the athlete was planning to return (noncontact, minimal-contact, or full-contact sports) were noted.

The levels of activity were adapted from the graduated return-to-play protocol found in the Consensus Statement on Concussion in Sport.[24] Minimal athletic activities include exercise such as vigorous walking or light stationary bicycling at a level of exertion where the athlete barely breaks a sweat. Moderate athletic activities include jogging or brisk bicycling, where the athlete breaks a sweat and breathes harder than with minimal activities but the level of exertion still allows the athlete to carry on a conversation. Sport-specific drills include changes of direction or ball-handling skills, plus a level of exertion where the

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The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.
Ethical approval for this study was obtained from Boston Children's Hospital (protocol No. IRB-P00012941).

TABLE 1
Univariate Comparisons for Patients With and Without Symptoms After Returning to Physical Activity[a]

Dichotomous Variable	Patients With Concussion Symptoms After Physical Activity, n/N (%)	Patients Without Concussion Symptoms After Physical Activity, n/N (%)	*P* Value
Male sex	13/25 (52.0)	122/192 (63.5)	.26
Loss of consciousness	1/23 (4.4)	34/175 (19.4)	.09
Amnesia	8/23 (34.8)	72/181 (39.8)	.64
Previously diagnosed concussion	6/21 (28.6)	79/174 (45.4)	.14
Previously undiagnosed concussion	14/25 (56.0)	51/174 (29.3)	.01
Continuous Variable	**Concussion Symptoms After Physical Activity, Median (IQR)**	**No Concussion Symptoms After Physical Activity, Median (IQR)**	***P* Value**
Age, y	14.8 (13.0-16.8)	14.7 (13.1-16.2)	.62
PCSS score at initial visit	20 (10-35)	9 (0-29)	.04
Time until presentation, d	17 (8-23)	18 (11-28)	.19
Time with concussion symptoms, d	63 (31-157)	27 (12-52)	<.01

[a]*P* values reflect the results from independent-samples *t* tests (for continuous variables) or from the Fisher exact test (for dichotomous variables). IQR, interquartile range; PCSS, Post-Concussion Symptom Scale.

athlete breaks a sweat and finds it difficult to carry on a conversation without interruption. Full-intensity activities include maximal effort, with full sprinting, change-of-direction skills, and ball- or stick-handling drills.

Per our usual clinical practice, some athletes who are symptom free at rest and have reachieved their baseline scores in all other clinical parameters assessed (eg, balance error score and computerized neurocognitive testing) may complete the return-to-play stages under the guidance of their athletic trainers. Thus, some athletes did not return to the clinic after they were found to be symptom free at rest.

Statistical Analysis

Continuous variables are presented as the mean ± SD and were compared using independent-samples *t* tests; categorical variables are presented as percentages and were compared using the Fisher exact test. To identify variables that might predict the recurrence of symptoms with exercise among those who were symptom free at rest, we first performed univariate comparisons of possible predictor variables between those who had a recurrence of their symptoms with exercise and those who did not. Candidate predictor variables included age, sex, duration of symptoms, total score on the initial PCSS, number of prior concussions (both diagnosed and undiagnosed), and time between injury and presentation to the clinic. Any variable that differed between the 2 groups with a statistical probability of $P < .2$ was identified as a potential predictor. All potential predictor variables were entered into a binary logistic regression model used to generate adjusted odds ratios. Any variable with an adjusted odds ratio that did not cross one was considered significantly different and, therefore, independently associated with the recurrence of symptoms with exercise. All analyses for the study were conducted with PASW Statistics 18.0 (SPSS) and Stata 10.1 (StataCorp).

RESULTS

We identified a total of 217 patients who returned to the sport concussion clinic after they had reported symptom resolution and subsequently returned to exercise. Athletes were most commonly injured during ice hockey, football, soccer, or basketball. The patients were predominantly male (62%), and 44% of patients reported a history of diagnosed concussions, while 33% of patients reported a history of undiagnosed concussions (Table 1).

Twenty-five (12%) athletes reported a recurrence of concussion symptoms while resuming physical activity after having been symptom free at rest (Table 1). While 25 patients were included in the analysis, data were unavailable for LOC and amnesia for 2 patients, as well as for previously diagnosed concussion for 4 patients. The highest proportion of athletes who experienced a recurrence of symptoms with activity did so during game play (Table 2) and while playing a contact sport (Table 3).

Among the 25 patients with a recurrence during physical activity progression, the majority had their recurrence during game play (n = 7) or during minimal noncontact activity (n = 6). During moderate noncontact exercise, 4 of 25 patients had a recurrence of symptoms. Sport-specific drills were associated with a recurrence of symptoms in 3 patients, and full-intensity noncontact activity was associated with a recurrence in 4 of the 25 patients. Only 1 of the 25 patients reported a recurrence of symptoms during full-intensity practice with contact.

Sex, LOC, a previously diagnosed concussion, a previously undiagnosed concussion, the initial PCSS score, the time from injury until initial clinical presentation, and the duration of time with concussion symptoms all met criteria for inclusion in the logistic regression model (Table 3). The odds of symptoms returning after physical activity were significantly greater among those who had a previous undiagnosed concussion, those who did not lose consciousness at the time of injury, those who reported to the clinic earlier

TABLE 2
Sport Type Played After Being Nonsymptomatic at Clinic[a]

Sport Type	Concussion Symptoms After Physical Activity, n/N (%)	No Concussion Symptoms After Physical Activity, n/N (%)
Noncontact sport	1/23 (4.4)	8/174 (4.6)
Limited-contact sport	5/23 (21.7)	13/174 (7.5)
Contact sport	17/23 (73.9)	153/174 (87.9)

[a]Sport type as defined by the American Academy of Pediatrics (Rice SG; American Academy of Pediatrics Council on Sports Medicine and Fitness. Medical conditions affecting sports participation. *Pediatrics.* 2008;121(4):841-848.). Twenty patients did not indicate a sport played.

TABLE 3
Statistics for Variables Included in Logistic Regression Model

Variable	β Estimate	Standard Error	Adjusted Odds Ratio[a]	95% CI
Male sex	–0.6842	0.5689	0.504	0.161-1.542
Loss of consciousness	–2.5421	1.2255	0.079	0.003-0.563[b]
Previously diagnosed concussion	–1.1368	0.7215	0.321	0.065-1.190
Previously undiagnosed concussion	1.6166	0.5873	5.036	1.634-16.829[b]
PCSS[c] score at initial visit	–0.0039	0.0112	0.996	0.973-1.017
Time until presentation	–0.0664	0.0294	0.936	0.877-0.984[b]
Time with concussion symptoms	0.0058	0.0022	1.006	1.002-1.010[b]

[a]Represents the difference in odds per point of the given variable.
[b]Does not include 1.
[c]The Post-Concussion Symptom Scale (PCSS) from the 3rd International Conference on Concussion in Sport.

after the injury, and those who had a longer duration of concussion symptoms (Table 3).

DISCUSSION

Approximately 12% of athletes who reported being symptom free at rest had a recurrence of their symptoms when they resumed exercise. This finding supports a graded return-to-play protocol, as is currently recommended, as opposed to simply clearing athletes for full play when they are symptom free at rest. Our data suggest that athletes who do not lose consciousness with their injury, who have a history of undiagnosed concussions, and who have a longer symptom duration have greater odds of experiencing symptom recurrence upon physical activity after a concussion.

Previously, best-practice guidelines for concussion management have centered on physical and cognitive rest,[24] followed by a gradual return to physical activity once symptoms resolve. One of the reasons for gradually returning to activity was to ensure that symptoms did not recur as exercise was resumed[11]; a return of symptoms has been considered to be a sign of incomplete recovery. There were, however, relatively little data showing how frequently symptoms recurred with exercise once an athlete was symptom free at rest.

Care must be taken to prevent the exacerbation of symptoms from excessive exercise intensity or recurrent collisions during the vulnerable recovery period.[36] However, excessive rest and prolonged inactivity have consequences as well, such as decreased school performance, psychological stress, or physical symptoms associated with deconditioning.[7,16] As more evidence is collected and protocols are changed in favor of early, sub-symptom threshold (noncontact) exercise as a form of treatment,[15,34] clinicians should be aware of the risk factors that may put a patient at an increased risk for a return of symptoms. While our specialty clinic's patient population may not necessarily represent the average primary care office, we observed that the odds of symptoms returning after exercise resumption were significantly greater among those who had a previous undiagnosed concussion, those who did not lose consciousness at the time of injury, those who reported to the clinic earlier after the injury, and those who had a longer duration of concussion symptoms.

Several prior studies have reported that a history of concussions is associated with negative outcomes soon after a subsequent concussion, such as more on-field signs and symptoms, heavier symptom burdens, altered gait patterns, and prolonged recovery.[10,12,18] In our study, it is interesting to note that while prior undiagnosed concussions were significantly associated with symptom recurrence, diagnosed concussions were not. This may be because of the characteristics of those who did not disclose their prior concussions, as they may also downplay their symptoms upon returning to play in an attempt to return sooner. Our study, however, could not directly assess this motivation, and future studies should seek to identify potential motivations for athletes to return to play before full recovery.

Athletes who did not lose consciousness at the time of injury were more likely to have a return of symptoms upon returning to physical activity than athletes who did lose consciousness. This is consistent with prior studies suggesting that LOC is not consistently associated with worse outcomes after a concussion and is often associated, perhaps surprisingly, with better outcomes.[3,4,14,19-21,27,28] While it is unclear why LOC might be associated with better outcomes after a concussion, it is possible that athletes with obvious on-field LOC are more likely to be removed from play and begin a treatment protocol right away. Thus, athletes with LOC may avoid recurrent collisions during the immediate vulnerable period. Furthermore, because of the objective nature of LOC, clinicians may be more

conservative when managing those who experience LOC at the time of injury.

As several studies have shown deficits in cognition, balance, and gait characteristics even after symptom resolution, it is possible that recovery remains incomplete for some athletes who report symptom resolution, and thus, some athletes may not have fully recovered before their resumption of physical activity. The recurrence of symptoms for these patients might be caused by incomplete recovery, despite the reporting of symptom resolution.

Limitations

The findings of our study should be interpreted in light of several limitations. The patients in this study were seen at a regional, specialty concussion clinic and the nature of their injuries or comorbidities may have been more severe and their recovery more complicated. Thus, our conclusions may not be generalizable to the overall population of athletes who sustain sport-related concussions. Furthermore, our main outcome, return of symptoms after initial symptom-free status, is nonspecific. The symptoms that recurred may have been caused by factors other than incomplete recovery from a concussion, such as physical deconditioning, anxiety, or other causes. Neurocognitive, balance, reaction time, or visual data may help to identify the course of complete physiological recovery after a concussion and to better understand the contributors of the exacerbation of concussion symptoms with the resumption of exercise.

In addition, several of our variables, including the time of symptom resolution at rest and history of undiagnosed concussions, were collected retrospectively and relied on patient recall. This is an imperfect system and has the inherent risk of recall bias. There is a wide range of causes that may produce posttraumatic symptoms that may be similar but not specifically due to a concussion, per se. In particular, the presence or absence of LOC can be difficult to ascertain. Athletes with any degree of anterograde amnesia may assume that they have had LOC, for instance.

CONCLUSION

In our review of patients treated in a specialty sport concussion clinic at a tertiary care hospital, approximately 12% of athletes who reported being symptom free at rest had a recurrence of their symptoms when they resumed exercise. Athletes who did not lose consciousness with their injury, who had a history of undiagnosed concussions, and who had a longer symptom duration were at a greater risk of symptom recurrence upon physical activity after a concussion. These risk factors may assist the treating clinician in determining the pace at which an athlete should progress through stepwise activity-resumption protocols.

REFERENCES

1. Babcock L, Byczkowski T, Wade SL, Ho M, Mookerjee S, Bazarian JJ. Predicting postconcussion syndrome after mild traumatic brain injury in children and adolescents who present to the emergency department. *JAMA Pediatr*. 2013;167(2):156-161.
2. Bramley H, Kroft C, Polk D, Newberry T, Silvis M. Do youth hockey coaches allow players with a known concussion to participate in a game? *Clin Pediatr (Phila)*. 2012;51(3):283-287.
3. Chrisman SP, Rivara FP, Schiff MA, Zhou C, Comstock RD. Risk factors for concussive symptoms 1 week or longer in high school athletes. *Brain Inj*. 2013;27(1):1-9.
4. Collins MW, Iverson GL, Lovell MR, McKeag DB, Norwig J, Maroon J. On-field predictors of neuropsychological and symptom deficit following sports-related concussion. *Clin J Sport Med*. 2003;13(4):222.
5. Gibson S, Nigrovic LE, O'Brien M, Meehan WP 3rd. The effect of recommending cognitive rest on recovery from sport-related concussion. *Brain Inj*. 2013;27(7-8):839-842.
6. Gibson TB, Herring SA, Kutcher JS, Broglio SP. Analyzing the effect of state legislation on health care utilization for children with concussion. *JAMA Pediatr*. 2015;169(2):163-168.
7. Gordon KE, Dooley JM, Wood EP. Is migraine a risk factor for the development of concussion? *Br J Sports Med*. 2006;40(2):184-185.
8. Griesbach GS. Exercise after traumatic brain injury: is it a double-edged sword? *PM R*. 2011;3(6 Suppl 1):S64-S72.
9. Guerriero RM, Proctor MR, Mannix R, Meehan WP. Epidemiology, trends, assessment and management of sport-related concussion in United States high schools. *Curr Opin Pediatr*. 2012;24(6):696-701.
10. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. *JAMA*. 2003;290(19):2549-2555.
11. Halstead ME, Walter KD; Council on Sports Medicine and Fitness. American Academy of Pediatrics. Clinical report: sport-related concussion in children and adolescents. *Pediatrics*. 2010;126(3):597-615.
12. Howell DR, Beasley M, Vopat L, Meehan W. The effect of prior concussion history on dual-task gait following a concussion. *J Neurotrauma*. 2017;34(4):838-844.
13. Howell DR, O'Brien MJ, Beasley MA, Mannix RC, Meehan WP. Initial somatic symptoms are associated with prolonged symptom duration following concussion in adolescents. *Acta Paediatr*. 2016;105(9):e426-e432.
14. Lau BC, Kontos AP, Collins MW, Mucha A, Lovell MR. Which on-field signs/symptoms predict protracted recovery from sport-related concussion among high school football players? *Am J Sports Med*. 2011;39(11):2311-2318.
15. Leddy JJ, Kozlowski K, Donnelly JP, Pendergast DR, Epstein LH, Willer B. A preliminary study of subsymptom threshold exercise training for refractory post-concussion syndrome. *Clin J Sport Med*. 2010;20(1):21-27.
16. Leddy MH, Lambert MJ, Ogles BM. Psychological consequences of athletic injury among high-level competitors. *Res Q Exerc Sport*. 1994;65(4):347-354.
17. Lincoln AE, Caswell SV, Almquist JL, Dunn RE, Norris JB, Hinton RY. Trends in concussion incidence in high school sports: a prospective 11-year study. *Am J Sports Med*. 2011;39(5):958-963.
18. Lovell MR, Collins MW, Iverson GL, et al. Recovery from mild concussion in high school athletes. *J Neurosurg*. 2003;98(2):296-301.
19. Lovell MR, Iverson GL, Collins MW, McKeag D, Maroon JC. Does loss of consciousness predict neuropsychological decrements after concussion? *Clin J Sport Med*. 1999;9(4):193-198.
20. Makdissi M, Darby D, Maruff P, Ugoni A, Brukner P, McCrory PR. Natural history of concussion in sport: markers of severity and implications for management. *Am J Sports Med*. 2010;38(3):464-471.
21. Makdissi M, Davis G, Jordan B, Patricios J, Purcell L, Putukian M. Revisiting the modifiers: how should the evaluation and management of acute concussions differ in specific groups? *Br J Sports Med*. 2013;47(5):314-320.
22. Marar M, McIlvain NM, Fields SK, Comstock RD. Epidemiology of concussions among United States high school athletes in 20 sports. *Am J Sports Med*. 2012;40(4):747-755.
23. McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on concussion in sport: the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. *J Ath Train*. 2009;44(4):434-448.
24. 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(5):250-258.

25. Meehan WP 3rd, d'Hemecourt P, Collins CL, Comstock RD. Assessment and management of sport-related concussions in United States high schools. *Am J Sports Med*. 2011;39(11):2304-2310.
26. Meehan WP, Bachur RG. Sport-related concussion. *Pediatrics*. 2009; 123(1):114-123.
27. Meehan WP, Mannix RC, Stracciolini A, Elbin RJ, Collins MW. Symptom severity predicts prolonged recovery after sport-related concussion, but age and amnesia do not. *J Pediatr*. 2013;163(3):721-725.
28. Meehan WP, O'Brien MJ, Geminiani E, Mannix R. Initial symptom burden predicts duration of symptoms after concussion. *J Sci Med Sport*. 2016;19(9):722-725.
29. Meier TB, Brummel BJ, Singh R, Nerio CJ, Polanski DW, Bellgowan PSF. The underreporting of self-reported symptoms following sports-related concussion. *J Sci Med Sport*. 2015;18(5): 507-511.
30. Mrazik M, Bawani F, Krol AL. Sport-related concussions: knowledge translation among minor hockey coaches. *Clin J Sport Med*. 2011; 21(4):315-319.
31. Pardini D, Stump J, Lovell M, Collins M, Moritz K, Fu F. The Post Concussion Symptom Scale (PCSS): a factor analysis. *Br J Sports Med*. 2004;38(5):661-662.
32. Powell JW, Barber-Foss KD. Traumatic brain injury in high school athletes. *JAMA*. 1999;282(10):958-963.
33. Ransom DM, Vaughan CG, Pratson L, Sady MD, McGill CA, Gioia GA. Academic effects of concussion in children and adolescents. *Pediatrics*. 2015;135(6):1043-1050.
34. Thomas DG, Apps JN, Hoffmann RG, McCrea M, Hammeke T. Benefits of strict rest after acute concussion: a randomized controlled trial. *Pediatrics*. 2015;135(2):213-223.
35. Tomei KL, 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.
36. Vagnozzi R, Signoretti S, Tavazzi B, et al. Temporal window of metabolic brain vulnerability to concussion: a pilot 1H-magnetic resonance spectroscopic study in concussed athletes, part III. *Neurosurgery*. 2008;62(6):1286-1295, discussion 1295-1296.