REVIEW ARTICLE

Sport-Related Concussion

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The authors have indicated they have no financial relationships relevant to this article to disclose.

ABSTRACT

Sport-related concussion is a common injury in children and adolescents. Athletes seldom report concussive symptoms, which makes the diagnosis a challenge. The management of sport-related concussion has changed significantly over the last several years. The previously used grading systems and return-to-play guidelines have been abandoned in favor of more individualized assessment and management. Neuropsychological testing is being used more frequently to assist in management. After recovery, it is recommended that an athlete's return-to-play progress in a gradual, stepwise fashion while being monitored by a health care provider. Proper assessment and management of a sport-related concussion is crucial, because repeat concussions can result in decreased neurocognitive functioning, increased symptomatology, and, at times, catastrophic outcomes. *Pediatrics* 2009;123:114–123

www.pediatrics.org/cgi/doi/10.1542/peds.2008-0309

doi:10.1542/peds.2008-0309

Key Words
concussion, sport-related concussion, mild traumatic brain injury, closed head injury, athletic injuries, second-impact syndrome

Abbreviations
SRC—sport-related concussion
LOC—loss of consciousness

Accepted for publication Mar 31, 2008

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Since the year 776 BC, athletes have participated in organized sports, such as wrestling and fist-fighting, that place them at risk of concussion.[1] Symptoms of concussion have been observed at least since the time of Hippocrates.[1,2] Despite such a history, the management of sport-related concussion (SRC) is one of the most discussed and controversial topics in sports medicine[2–9] and has become an increasingly popular topic in the lay press.[10–15] SRCs differ from concussions sustained outside athletics because they typically result from low-velocity impact, causing disorientation and confusion more often than loss of consciousness (LOC), which is seen frequently with other mechanisms.[16] SRCs are a major issue in pediatrics, because the majority of at-risk athletes are children.[17,18] Moreover, children are particularly susceptible to SRCs.[9,19] Much of the research on SRC has been conducted in high school and college athletes.[9,20–46] In this article, we will review the literature on SRC.

DEFINITION

Although the terms "concussion" and "mild traumatic brain injury" are used synonymously in the literature, SRC can be a serious injury. The word "mild" is inaccurate in this context. Therefore, the term "concussion" will be used throughout this article.

A concussion results from a rotational acceleration or deceleration injury to the head that causes an alteration of mental status or various other symptoms such as headache or dizziness.[47–49] The precise definition of concussion has changed over time.[1] Universal agreement on a definition has been difficult to reach.[18,50,51] The following definition was developed by consensus among experts in SRC[49] and has subsequently been endorsed.[48]

Concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces. Several common features . . . include:

1. Concussion may be caused by a direct blow to the head, face, neck or elsewhere on the body with an "impulsive" force transmitted to the head.
2. Concussion typically results in the rapid onset of short lived impairment of neurologic function that resolves spontaneously.
3. Concussion may result in neuropathological changes but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury.
4. Concussion results in a graded set of clinical syndromes that may or may not involve loss of consciousness. Resolution of the clinical symptoms typically follows a sequential course.
5. Concussion is typically associated with grossly normal structural neuroimaging studies.[48,49]

For the practicing clinician, perhaps a more useful working definition is a trauma-induced alteration in mental status that may or may not involve LOC.[18,42,50,52–56]

BIOMECHANICS AND PATHOPHYSIOLOGY

Several theories exist regarding the biomechanics of concussion,[57] but none have been universally accepted. However, several characteristics have been well established. Concussion occurs when rotational or angular acceleration forces are applied to the brain, resulting in shear strain of the underlying neural elements.[58–62] This may be associated with a blow to the skull; however, direct impact to the head is not required.[60] In fact, in the laboratory setting, concussion can be achieved more effectively by nonimpact rotation of the head than by a blow to the head.[59,60] Linear acceleration-deceleration will usually produce focal effects, as opposed to concussion.[58,60,61]

On a molecular level, there seems to be an immediate disruption of neuronal membranes, resulting in a massive efflux of potassium into the extracellular space.[63,64] This results in the calcium-dependent release of excitatory amino acids, particularly glutamate, which stimulates further potassium efflux. As the concentration of extracellular potassium increases, it triggers neuronal depolarization, which is followed by neuronal suppression.[63–67] Sodium-potassium pumps work to restore homeostasis. Given the degree of the induced ion fluxes, a large amount of energy is expended, which increases glycolysis.[64,66,67] This results in local lactic acid accumulation.

To meet these increased metabolic demands and remove accumulated lactate, an increase in cerebral blood flow might be expected. However a decrease in cerebral blood flow has been observed.[64] After the initial increase in glycolysis, mitochondrial dysfunction with decreased oxidative metabolism and decreased cerebral glucose metabolism can be seen within 24 hours, persisting as long as 10 days in experimental models.[64,66]

EPIDEMIOLOGY

Twenty percent of traumatic brain injury resulting in an LOC occurs during sports activity.[68] Eighteen percent of head injuries reported to the National Head Injury Association are sustained during athletic competition.[53] Approximately 300 000 sport-related traumatic brain injuries resulting in an LOC occur each year.[68,69] The majority of these injuries are concussions. Because it has been well established that the vast majority of SRCs do not involve an LOC,[30,33,70] the actual number of SRCs occurring annually is much higher. Studies of children and adolescents have suggested that 26% of closed head injuries in children occur during athletics,[24] and this is likely to be an underestimate, because many children with SRCs do not seek medical attention.[34,40,71]

Concussion incidence has been studied most widely in American football, a sport in which 1.5 million Americans participate.[21,72] Several studies have estimated the incidence of SRC in high school and college football players to be between 4% and 5%.[33,41,70] In each of these studies, however, injuries were documented by athletic trainers. In most circumstances, for an athletic trainer to be aware that a concussion has occurred, it must be reported by the athlete. It has been well documented that athletes do not regularly report concussions to athletic trainers, coaches, parents, or others.[34,40,73,74] Therefore, studies conducted in this manner are likely to underestimate the true incidence of concussion. It is interesting to note that studies in which players have directly and confidentially reported their symptoms after a blow to the head have revealed much higher rates of concussion, ranging from 15% to 45%.[30,34,40,73]

Concussion accounts for ~8% to 11% of all injuries in American football.[39,44] Concussions are more likely to occur during games than practices[32,41,44,73] and are more common in high school athletes than college players.[19,33,44]

Although SRC has been studied most extensively in American football, it has been reported in all sports.[28,34,41,43,46,69,75–79] The incidence rates in ice hockey are even higher than in American football,[76,77] accounting for ~12% of total injuries.[39] In a survey of competitive college athletes engaged in all sports at a university in Ohio, 32% reported concussive symptoms after a blow to the head.[34] As with football, concussion in other sports occurs more commonly during games than practice.[22,29,41,43,78] Concussions are 6 times more likely to occur in organized sports than in leisure physical activity.[24]

UNDERREPORTING

Although SRC seems to be quite common, it is still not fully appreciated by athletes. More than one third of athletes do not recognize their symptoms as a result of concussion.[28,30,34,40,73] In a study of professional football players in the Canadian Football League, only 19% of concussed players realized that they had sustained a concussion.[73] Even those who experience LOC often fail to recognize the injury as a concussion or even as a serious injury.[30,73]

In addition, athletes do not regularly report their symptoms to trained personnel.[34,40,71] In American football, only 47% of players sustaining a concussion report their injury.[40] Most commonly, players fail to report a concussion because they feel the injury is not serious enough to warrant reporting.[40,74] Personal desire and outside pressure to continue playing, failure to recognize the symptoms of concussion, and jeopardizing future career or financial benefits are also commonly cited.[40,74]

Twenty-eight percent of athletes report continuing to play after a blow to the head that results in dizziness.[34] Athletes with a headache after a blow to the head continue to play at even higher rates, with 61% of American football players staying in the game.[34] In a study of high school football teams in Minnesota, 69% of the players who experienced an LOC and 81% of the players who sustained a concussion without an LOC returned to play on the same day.[30] Other studies have shown similar results.[73] These results are concerning, given the risks of recurrent concussions[30,32,33,45,73] and the potential for neurologic sequelae.[17,26,80,81]

ASSESSMENT

The recognition, assessment, and classification of an SRC can be challenging. Certainly, concussions that result in

TABLE 1 **List of Symptoms Reported in Athletes After Sustaining an SRC**

Signs of Concussion	Symptoms of Concussion
LOC	Headache
Amnesia, retrograde or antegrade	Dizziness
Disorientation	Nausea or vomiting
Appearing dazed	Difficulty balancing
Acting confused	Vision changes
Forgetting game rules or play assignments	Photophobia
Inability to recall score or opponent	Phonophobia
Inappropriate emotionality	Feeling "out of it"
Poor physical coordination	Difficulty concentrating
Imbalance	Tinnitus
Seizure	Drowsiness
Slow verbal responses	Sadness
Personality changes	Hallucinations

dramatic findings, such as prolonged LOC, will be readily detected. However, the majority of concussions result in more subtle findings.[33,34,38,39,43,73,82–85] Furthermore, LOC is not a reliable predictor of cerebral dysfunction or length of recovery.[38,39,86] Headache and dizziness are the most commonly reported symptoms of concussion.[32–34,82,83,87] Many other symptoms have been reported and are listed in Table 1.* It should be noted that although all of these various symptoms can be seen with concussion, not every athlete experiencing these symptoms has a concussion. Indeed, many of these symptoms can result from other etiologies such as dehydration, overtraining, and lack of sleep or can be seen with other illnesses such as anorexia nervosa, anemia, learning disabilities, and depression.[92,93] Given the nonspecific symptoms and lack of self-reporting,[34,40,71] the diagnosis can be difficult to make.

The on-field assessment of an acute SRC, similar to all medical assessments, should begin with the airway, breathing, and circulation.[18,56,72,94] Cervical spine injury should be considered[18,56,95]; the unconscious athlete should be treated as having a potential cervical spine injury.[72,90] Those with prolonged LOC should be transported rapidly to an appropriate medical facility.[72] For the conscious athlete suspected of having sustained a concussion, a thorough neurologic examination should be performed, including assessment of the athlete's orientation to person, place, and time.[72] This should be followed by questions to test recent memory (eg, "which quarter is it?" and "which team did we play last week?"), because these are the most sensitive in diagnosing SRC.[16,96] The ability to perform simple tasks should be assessed.[48,72,85] Postural stability should be assessed also.[97] Standardized methods of assessment are available in the literature and can help facilitate sideline examinations.[48,56,70,83,89,98–100]

Previously, >15 concussion-grading systems,[18,51,56] based mostly on the presence and duration of LOC and amnesia, have been used to categorize concussions. However, LOC and amnesia were found to be of minimal utility in predicting the severity or duration of concussion.[19,38,39,86] No grading scale had been universally accepted.[50,51] More recently, grading systems were abandoned.[8,38,39,48,83,101–103]

At the second International Conference on Concussion in Sport, the use of grading systems was abandoned explicitly in favor of classifying concussions as simple or complex. A simple concussion is one in which the injury resolves in 7 to 10 days. A concussion is categorized as complex when the athlete's symptoms persist, the athlete has sustained multiple concussions, or the athlete suffers sequelae such as convulsions, LOC of >1 minute, or prolonged cognitive impairment.[48] It should be noted that under this new classification system a concussion cannot be classified until all the signs and symptoms have resolved. Because the signs and symptoms of concussion can have a delayed onset,[39,88,104] up to several days after the time of injury,[104] this classification cannot be made in the acute setting.

MANAGEMENT

Once the diagnosis of an SRC is established and other significant injuries have been addressed, the clinician must decide when it is safe to return the athlete to play. Again, this is not as straightforward as it may seem.

Although return-to-play guidelines were intended to prevent catastrophic injury and cumulative effects of concussion, little scientific evidence exists to support them.[53,83,104,105] None of the guidelines have been adequately validated.[73] These guidelines, too, have been abandoned by experts in the management of SRC,[36,38,39,83,101,106,107] even by those who developed them.[48,102] In fact, the pursuit of a dependable, practical, universally accepted guideline has been described as "foolish and ill conceived."[103]

Because they were based on the previously mentioned grading scales, which emphasized LOC and amnesia and were found to be of minimal utility in predicting the severity or duration of concussion,[38,39,86] return-to-play decisions should not be based on these guidelines. Rather, each concussion should be managed individually by using multiple means of assessment.[8,48,49]

Generally accepted management principles have been proposed. No player should be returned to play until the symptoms of concussion have resolved completely, both at rest and during exercise.† Because younger athletes require longer recovery times, more conservative return-to-play decisions should be considered for younger athletes.‡ The American Academy of Pediatrics recommends conservative management of concussion.[113]

Studies have shown that concussed athletes score poorly on neuropsychological tests when compared with their own preinjury baseline scores and with uninjured athletes.[26,37,55,70,100,114,115] Such decreases in performance are not seen in uninjured controls who take preseason tests and subsequent tests during the season.[37,116] Experts in the management of SRC have endorsed the use of

*Refs 18, 19, 33, 34, 36, 56, 82, 83, and 88–91.

†Refs 18, 26, 48, 50, 51, 56, 72, 83, 93, 105, and 108–110.

‡Refs 9, 18, 19, 48, 56, 83, 111, and 112.

neuropsychological testing,[48,72,106,111] calling it "one of the cornerstones of concussion evaluation."[49,89]

Computerized neuropsychological testing is a recent development that is sensitive in diagnosing concussion.[25,104] In fact, it is more sensitive than traditional forms of neuropsychological testing,[117] likely because of more precise measurements of response time.[48,104,118] It has been shown to diagnose some concussions that would have been missed by symptom reporting alone.[9,35,38,104,115,119] In 1 such study of 834 athletes, Erlanger et al[104] used a computerized neuropsychological assessment instrument (HeadMinder CRI [New York, NY]) to compare postconcussion scores with baseline scores. Of the 26 athletes who sustained a concussion, 3 (12%) were noted to have neurocognitive deficits in the absence of self-reported symptoms. These athletes' conditions would not have been identified by symptoms reporting alone. This is of enormous value, because many athletes are reluctant to report concussion symptoms.[30,40,54,71,72] Computerized neuropsychological testing has been endorsed by experts in the field,[48,49] is mandatory for players in the National Hockey League, and is used by most teams in the National Football League.[35,83]

A lower score than that of a player's baseline signifies incomplete recovery.[120] Until recovery is complete, an athlete's reaction time is longer, ability to concentrate is diminished, and more time is required for thought processing,[92,121–124] thus increasing the risk of subsequent injury.[105,125] Reason suggests that returning to play would be safer for athletes whose symptoms have resolved and whose neuropsychological test results have returned to baseline. It should be stated, however, that the safety of returning an athlete to play on the basis of neuropsychological testing has not been explicitly studied.[105,126,127] However, given the association between returning to play before complete recovery and poor, even catastrophic outcomes,[23,72,128,129] it is recommended that return-to-play decisions be based, in part, on results of neuropsychological testing.§ Among experts in the field of SRC, this practice is recommended.‖

Neuropsychological testing is not meant to be used alone but, rather, as 1 of many aspects of evaluation.¶ Symptom reporting, medical history, concussion history, medication use, type of sport and position played, postural stability,[48,97,131,133] and other factors play a role in the decision to return an athlete to play. In young patients, the neuropsychological baseline may change often, because their cognition matures rapidly, requiring frequent baseline testing or changes in interpretation.[48,111]

Although recovery from an SRC will vary, symptoms, neuropsychological test scores, and postural stability usually will recover within 7 to 10 days.[35,38,39,102] Some patients will have a more prolonged recovery.[35,38,39,104] There is no reliable, predictable order in which recovery occurs.[39,86,104] During recovery, an athlete's academic performance may suffer, and intellectual activity may increase their symptoms. Thus, "cognitive rest" has been recommended for school-aged athletes.[48]

TABLE 2 **Return-to-Play Protocol Recommended by the Second International Conference on Concussion in Sport[48]**

Step	Level of Activity
1	No activity, complete rest; proceed to level 2 once symptoms resolve
2	Light aerobic exercise (eg, walking, stationary cycling)
3	Sport-specific exercise (eg, skating in hockey, running in soccer); addition of light resistance training
4	Noncontact training drills; progressively increased resistance training
5	Full-contact training after medical clearance
6	Game play

Once the decision is made to return an athlete to play, the return should be gradual, stepwise, and closely monitored, starting with light, aerobic activities that do not place the player at risk for subsequent concussion.[18,48,49,56,110] The steps recommended by the second International Conference on Concussion in Sport for returning to play an athlete who has recovered from a simple concussion are listed in Table 2.[48] Any occurrence of concussion symptoms during exertion should prompt the athlete to drop back to a previous asymptomatic level of activity for at least 24 hours before attempting to progress again.[48,49] For an athlete who has sustained a complex concussion, it is recommended that the injury and the athlete's return to play be managed by personnel with expertise in the management of SRC.[48]

SPECIAL CONSIDERATIONS

Repeat Concussions

After a first concussion, a player is at increased risk for additional concussions.[30,32,33,44,73] Those who experience an LOC are 6 times more likely to sustain another concussion than those who have never lost consciousness.[73] The risk of recurrent concussive injury may be greatest within 7 to 10 days of an acute concussive injury.[32] The reasons for this increased risk have not yet been elucidated, but possible explanations include (1) certain athletes' styles of play predispose them to concussion, (2) certain athletes are more susceptible to concussion, (3) the age and level of play may expose certain athletes to greater forces than those who do not sustain concussions,[43] (4) players who sustain multiple concussions may simply receive more play time,[43,73] and (5) it may be that once an athlete's brain has sustained a single concussion it becomes more susceptible to injury.[43]

Cerebral concussion reduces the ability to process information rapidly. This reduction is greater and lasts for a longer period of time after a second concussion than after a first.[17,27,80] Guskiewicz et al[32] showed that athletes who have a history of previous concussions require longer recovery times after an acute SRC than those with no previous history of concussion.

Although studies have suggested that concussions have long-term effects on an athlete's neurocognitive abilities, the number and severity of SRCs that lead to long-term effects have not been elucidated. Some studies have suggested that there is no detectable neurocog-

§Refs 18, 19, 35, 48, 49, 83, 86, 89, 119, 120, 130, and 131.
‖Refs 18, 19, 48, 49, 83, 86, 89, 119, 130, and 131.
¶Refs 19, 48, 49, 86, 88, 89, 105, 119, 131, and 132.

nitive deficits after 1 concussion[26] or even multiple concussions.[134–136] Others have shown that multiple SRCs result in deficits of neurocognitive abilities.[17,26,80,81] It is likely that SRCs have a cumulative effect on neurocognitive abilities but that 1 mild concussion results in small deficits that are not detectable by current means of analysis.

Recently, postmortem studies of athletes who sustained multiple SRCs during their careers, who had neurocognitive and psychiatric problems later in life, and who died at a young age have revealed findings similar to, but unique from, those seen with Alzheimer disease.[91,137] Although preliminary, these findings suggest that athletes who sustain multiple concussions are at risk for chronic traumatic encephalopathy.[138]

Education

Only 43% of athletes feel that they have some knowledge in the area of SRC.[34] Fewer than 50% of athletes understand the problems that occur as a result of concussion.[34] Most of them do not consider it to be a serious problem.[40] Many athletes who sustain an SRC fail to recognize their symptoms as being a result of concussion.[28,30,34,40,73] The problem of recognition is not limited to athletes. A recent survey of coaches revealed that 42% believed that an SRC only occurs when an athlete loses consciousness.[45] One in 4 of them would allow an athlete to return to play despite showing symptoms of a concussion.[45] This is concerning, because more players who sustain concussion are attended to by their coaches than by physicians.[30] Education of athletes, coaches, and medical personnel may lead to increased reporting and proper management of SRC.

Prevention

Preventing SRCs is difficult. Although helmets are often discussed as a means of preventing concussion, this is not the purpose of their design.[88] Current helmets have, at best, a limited effect.[51,72,139,140] Some evidence suggests that the design of certain football helmets may affect the risk of sustaining a concussion.[141,142] Research in this area is ongoing.

By bracing the neck muscles before impact, an athlete decreases the resulting acceleration that the head experiences.[143–145] Therefore, it has been suggested that strengthening the neck musculature may decrease the risk of concussion. Many concussions, however, occur when the athlete does not anticipate the impact, which makes increased musculature of questionable value.[51,88,89]

As noted earlier, sustaining a concussion increases the risk of subsequent concussions, especially before full recovery. Therefore, proper identification and management of SRCs in an attempt to prevent subsequent concussions may be the best prevention strategy currently available.

Second-Impact Syndrome

In 1984, Saunders and Harbaugh[129] described the case of a 19-year-old college athlete who was medically cleared to play football despite being symptomatic from a previous blow to the head. Although he sustained "no unusual head trauma" on the day he returned to football, he walked off of the field, collapsed, and later died despite the evacuation of a small subdural hematoma. An autopsy revealed widespread anoxic changes and transtentorial cerebral herniation. It was surmised that these effects were caused by an elevated intracranial pressure, secondary to minor sports trauma, before complete recovery from a previous concussion.

Since that time, there have been other similar cases described in the literature.[109,128,146] The term "second-impact syndrome" has come to describe such events. Typically, second-impact syndrome occurs after athletes have sustained a concussion from which they are still symptomatic and receive a second injury to the head. This second injury may be minor. Even a blow to the chest or trunk that transmits accelerative forces to the brain can result in second-impact syndrome.[109] After this second insult, the athlete rapidly decompensates, becoming unresponsive with dilated pupils and ultimately succumbs to respiratory failure.[109] It is thought that the autoregulatory control over cerebral blood flow is disrupted, leading to vascular engorgement and marked increase in intracranial pressure. This increase in pressure ultimately leads to uncal herniation or herniation of the cerebellar tonsils.[109,128]

Although its existence has been questioned,[6,16,108,125] most well-recognized authors in the area of SRC recognize this syndrome.# Even authors who question the existence of second-impact syndrome as defined in current literature recommend that athletes not return to play until after their symptoms and neuropsychological deficits have resolved.[108,125]

Concussion and Soccer

Recently, attention has been given to concussion and head injuries in soccer. In particular, some have asked whether heading the ball in soccer leads to concussion or to neurologic effects later in life.[16,148–150]

Concussions occur commonly in soccer,[22,28] accounting for ~2% to 4% of all acute injuries.[41,151] The rates are higher during game play.[22,29,41] In National Collegiate Athletic Association women's soccer, concussions account for 8.6% of all game-time injuries.

Although concussion is a common injury in soccer, it does not seem to occur as a result of purposeful heading of the ball.[22,88,149,151–154] In a 6-year prospective study of 20 Fédération Internationale de Football Association tournaments, none of the recorded concussions resulted from purposeful heading of the ball.[153] Rather, concussion is caused most commonly by collision with another player, a goal post, the ground, or other solid objects or being struck in the head unexpectedly by a ball kicked forcefully from close range.[22,29,41,149,151,153]

Studies have shown no neurocognitive deficits, symptoms, neurochemical changes, or MRI changes, either acute or chronic, from purposeful heading of the ball.[31,155–159] Some studies seem to have suggested such

#Refs 7, 47, 50, 53, 54, 72, 88, 95, 131, 146, and 147.

sequelae.[20,160–162] However, these studies have been criticized for having small numbers, using flawed methodology, and failing to control for potential confounders.[62,154,156,163]

Most experts agree that at this time, no conclusive evidence shows neurologic deficits caused by purposeful heading of the ball.** However, concussions sustained during soccer play may lead to neurologic sequelae.[22,42,154,156,158,162] Any potential effects resulting from frequent heading would be difficult to separate from those resulting from previous concussions, because those athletes who head the ball more frequently are at increased risk for concussion.[154,155]

Helmets have been proposed as a possible way of negating any potential effects of purposeful heading. However, no helmet has been shown to decrease the risk of concussion.[22,31,48,88,140,148,152] Headgear has been developed specifically for use in soccer but has not been shown to have any effect on decreasing head acceleration resulting from purposeful heading of the ball.[62] Headgear may have some efficacy in reducing the risk of concussion from head-to-head impacts.[62] One preliminary study has concluded that headgear decreases the risk of concussion in soccer players.[28] However, only a small number of athletes were included in the study; there were major differences between the headgear-wearing players and the control group; and the study did not properly control for potential confounders. Although the potential value of headgear in soccer should not be overlooked, it is unclear how much benefit headgear provides, what negative impact it will have on ball control, and whether players will accept it.

Some have recommended that players not be allowed to head the ball until they reach a certain age and the brain has reached a certain stage of development and is potentially protected against the possible effects of heading.[88] Others have argued that players should learn the skill of heading the ball properly[144] and develop neck musculature[143] before they are faced with the higher velocities generated during the play of older players.[31,88] At this point, we believe no definitive recommendation can be made.

Perhaps the most effective ways of decreasing the risk of concussion and other head injuries in soccer is to decrease the mass and air pressure of the ball used by smaller, younger players,[154,157,166,167] strictly enforce the rules,[151] and secure and pad goal posts properly.[150,164,165]

Genetic Predisposition

Several studies described in the adult literature have suggested that genetic factors may affect prognosis after brain injury. Specifically, possessing the apolipoprotein Eε4 allele has been associated with worse outcome.[168–170] However, these studies are preliminary, and most of them involved severe traumatic brain injury. Studies of concussion have not found such an association.[171,172] Some studies in athletes suggest that carriers of the apolipoprotein Eε4 allele who are exposed to subconcussive impacts or sustain concussions have more pronounced neurologic effects than controls.[173,174] We are not aware of any study that has made such an association in children. More research is needed in this area before apolipoprotein Eε4 allele status can be used clinically in athletes.

Concussion in Female Athletes

Although most of the publications regarding SRC involve male athletes, it also occurs commonly in female athletes.[29,78,175] In female soccer players, for example, concussion accounts for 3% to 5% of all injuries[29,175] and as much as 11% of all game-time injuries.[78] Some studies have suggested that concussion occurs more commonly in female athletes,[78,153] with women having more significant changes in their neuropsychological testing results than men.[82,176,177] Others studies have suggested that SRC is more common among male athletes.[22,149] Similarly, some evidence suggests that baseline performances on neuropsychological tests are different in the different genders,[177] although other studies have not detected such differences.[82,176] Postconcussion symptom reporting and neuropsychological test results may be different for male and female athletes.[82,149,176]

CONCLUSIONS

SRC is a common problem for children and adolescents. Because athletes are reluctant to report SRCs, proper sideline assessment and diagnosis is essential. SRCs should be classified as either simple or complex, mostly on the basis of the duration of signs and symptoms. This classification cannot be made acutely, because signs and symptoms may not be present initially and often take several days to resolve. Returning an athlete to play should not be considered until all signs and symptoms of concussion have resolved. The return to athletics should be monitored by medical personnel and should proceed in a stepwise fashion.

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