



Sport-Related Concussion in Children and Adolescents

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Sport-related concussion is an important topic in nearly all sports and at all levels of sport for children and adolescents. Concussion knowledge and approaches to management have progressed since the American Academy of Pediatrics published its first clinical report on the subject in 2010. Concussion's definition, signs, and symptoms must be understood to diagnose it and rule out more severe intracranial injury. Pediatric health care providers should have a good understanding of diagnostic evaluation and initial management strategies. Effective management can aid recovery and potentially reduce the risk of long-term symptoms and complications. Because concussion symptoms often interfere with school, social life, family relationships, and athletics, a concussion may affect the emotional well-being of the injured athlete. Because every concussion has its own unique spectrum and severity of symptoms, individualized management is appropriate. The reduction, not necessarily elimination, of physical and cognitive activity is the mainstay of treatment. A full return to activity and/or sport is accomplished by using a stepwise program while evaluating for a return of symptoms. An understanding of prolonged symptoms and complications will help the pediatric health care provider know when to refer to a specialist. Additional research is needed in nearly all aspects of concussion in the young athlete. This report provides education on the current state of sport-related concussion knowledge, diagnosis, and management in children and adolescents.

abstract

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INTRODUCTION

Over the last several decades, sport-related concussions (SRCs) have been recognized as a major health concern in young athletes. Exposure to contact sports at younger ages, long-term exposure to repetitive head trauma, and consequences of the immediate effect on an athlete's daily life are continued concerns among parents, athletes, and health care providers.^{1,2} Research about SRCs is being published at a robust pace with the hope of identifying the best ways to diagnose, treat, and (ideally) prevent SRCs.

Many organizations have published position statements or clinical reports on SRCs, including the American Academy of Pediatrics (AAP), National Athletic Trainers' Association, American Medical Society for Sports Medicine, American College of Sports Medicine, American Academy of Neurology, and National Academy of Medicine (formerly Institute of Medicine).^{3–8} Despite these publications as well as existing legislation throughout the United States mandating education about concussions, knowledge of concussions by athletes, parents, coaches, and health care providers can be improved.^{9–17} This report serves as an update the 2010 AAP clinical report for pediatric health care providers on the current state of knowledge and guidance for the diagnosis and management of pediatric and adolescent SRC.

DEFINITION

There is currently no universally accepted definition of SRC. A universally accepted definition is important when discussing the injury with patients and their parents, for health care providers in making the diagnosis correctly, and for researchers to have uniform standards when conducting studies about SRCs. Debate still exists as to whether the term concussion or mild traumatic brain injury (mTBI) should be used to describe the injury. Often, concussion is considered to be a subset of mTBI and will be considered as such for this report.

Several international symposia on concussion in sport have been held since 2001.^{18,19} In the Concussion in Sport Group, a consensus of experts defined SRC as “a traumatic brain injury induced by biomechanical forces.” This consensus statement also includes 5 common features of concussive head injury:

1. SRC 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. SRC typically results in the rapid onset of short-lived impairment of neurologic function that resolves spontaneously. However, in some cases, signs and symptoms may evolve over a number of minutes to hours.
3. SRC may result in neuropathologic changes, but the acute clinical signs and symptoms largely reflect a functional disturbance rather than a structural injury, and as such, no abnormality is seen on standard neuroimaging studies.
4. SRC results in a range of clinical signs and symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course. However, in some cases, symptoms may be prolonged.
5. The clinical signs and symptoms cannot be explained by drug, alcohol, or medication use; other injuries (such as cervical injuries, peripheral vestibular dysfunction, etc); or other comorbidities (eg, psychological factors or coexisting medical conditions).

In 2014, a systematic review was published by an expert panel attempting to develop an evidence-based definition of concussion.²⁰ This study found the following prevalent and consistent indicators of a concussion:

- observed and documented disorientation or confusion immediately after the event;
- impaired balance within 1 day after injury;
- slower reaction time within 2 days after injury; and/or
- impaired verbal learning and memory within 2 days after injury.

GRADING SCALES

More than 25 grading scales for SRC and mTBI have been published.²¹ Because these grading scales are based on expert opinion alone, the 2001 Vienna Concussion in Sport Group recommended the discontinuation of their use in describing SRC or guiding return to play. Current recommendations are to diagnose the SRC without labels such as mild, moderate, or severe or as simple versus complex and to use current consensus protocols to guide return to play.

PATHOPHYSIOLOGY

The biokinetics that induce SRC consist of forces of acceleration, deceleration, and rotation of the head.^{22–24} SRCs are usually caused by a direct blow to the head; however, SRCs may also be caused by a blow elsewhere on the body with a secondary force transmitted to the head.^{18,19} Weaker neck muscles, which are more frequently seen in the pediatric population, may impair the attenuation of force to the head and increase SRC risk.^{25,26}

Neurologic signs and symptoms of SRCs are not related to macroscopic neural damage; they are believed to be a functional or microstructural injury.^{18,19,27} The pathophysiology of concussion, as described in animal models and some recent human studies, involves a neurometabolic cascade of events.^{27–29}

After the biomechanical injury to the brain, there is potassium efflux from the neurons and a dramatic increase in extracellular glutamate.^{29,30} Glutamate, an excitatory neurotransmitter, activates the N-methyl-D-aspartate receptor. This leads to neuronal depolarization with further potassium efflux and calcium and sodium influx, which depresses neuronal activity.^{27,29} In an attempt to restore homeostasis, there is upregulation of the

sodium-potassium ion pumps, which depletes intracellular energy reserves as a result of the increased use of adenosine triphosphate and hyperglycolysis.^{27,30} Pediatric and adolescent studies have revealed reduced cerebral blood flow after SRC, which, when coupled with the increased energy demand, leads to a proposed “energy crisis.”^{27,30–32} In an attempt to normalize increased intracellular calcium levels, neurons sequester calcium into mitochondria, leading to mitochondrial dysfunction and impaired oxidative metabolism, worsening the energy crisis.²⁷ After the increase in glucose metabolism, there is an ensuing hypometabolic state that may persist for up to 4 weeks.^{33,34}

Structurally, the intracellular calcium flux can damage the cytoskeleton and also cause axonal injury; however, axonal injury primarily occurs from shear and tensile forces of trauma.^{27,30} This damage can reduce conductive velocity through the neuron and could be correlated with the cognitive impairments seen in SRC. Findings suggest that the young brain may be more vulnerable to axonal injury because myelination is an ongoing maturational change throughout brain development.^{27,35–37} Although all the postinjury changes can lead to cell death, there appears to be little cell death after a concussion.^{27–30} Currently, it is unclear how chronic structural changes and cognitive dysfunction may evolve over time.

EPIDEMIOLOGY

Historically, it is reported that up to 3.8 million recreational and SRCs occur annually at all ages in the United States.^{38–42} Because of the large number of participants in youth and high school sports, concussions in the pediatric and adolescent age groups account for the majority of SRCs. A recent study that evaluated 3 national injury databases

estimated that 1.1 million to 1.9 million recreational concussions and SRCs occur annually in the United States in children 18 years of age or younger.⁴³ This large range highlights the challenges of understanding the true epidemiology of SRCs: variable definitions used in research, the lack of a widespread injury surveillance system, different entry points for athletes with concussion into the health care system, and underreporting of the injury.^{8,44–46} Many epidemiologic studies are based on emergency department visits, but a recent study showed that 75% of 5- to 17-year-old patients with SRCs entered the health care system through their primary care provider.⁴⁷ To further complicate finding the true epidemiology, some patients may never seek medical care for their injuries. A pediatric study estimated that between 511 590 and 1 240 972 (45%–65%) patients with concussion were not seen in health care settings, and an adult-based study revealed that 42% of patients with an mTBI did not seek medical care.^{43,48}

Concussion incidence and reporting have increased over the last 2 decades. Many studies report SRC rates using athletic exposures (AEs). An AE means that an athlete has participated in some or all of 1 practice or 1 game. Studies of high school athletes show an overall increase in SRCs from 0.12 in 1000 AEs in 1997–1998 to 0.51 in 1000 AEs in 2011–2012.^{40,49} Studies have also demonstrated increased emergency department visits over the last decade for recreational concussions and SRCs ranging from increases of 57% to more than 200% in the 8- to 19-year-old age group.^{50,51} This increasing rate is likely explained by increased overall awareness because of medical, coaching, and lay public education and increased media exposure, leading to improved reporting and diagnosis. There may also be

an increase in the true incidence with more opportunity for sport participation, leading to increased injury exposure risk, and with the increasing size, strength, and speed of young athletes over the years.^{40,49,51,52}

Underreporting by athletes with SRCs remains a large concern, especially because in most cases, SRC is not a visible injury to an observer, so identification relies on self-reporting. When surveyed in 2013, 70.6% of high school athletes indicated they would report their SRC, which is an increase from 2002 data indicating that only 47.3% indicated they would report their injury.^{44,45} Unfortunately, athletes still attempt to hide their injury.¹⁶ A recent study of high school athletes found only 40% to 45% of high school athletes reported their SRC.⁵³ A study of youth rugby players revealed that 80% of athletes either did not report a concussion or returned to play before full recovery.⁵⁴ Other surveys indicate that 66% of high school athletes would play through their SRC, with the primary reasons being that they did not want to be removed from play and that they were fearful of approaching their coach, in addition to a lack of recognition by coaches, athletes, and parents.^{55,56} There is evidence that female high school athletes are more likely than male athletes to report concussive symptoms to an authority figure despite having similar knowledge about SRC symptoms.⁵⁷

On the basis of a compilation of several large epidemiologic studies, the high school sport with the highest risk of concussion remains American tackle football (Table 1).^{49,58–60} The high-contact boys' sports of lacrosse, ice hockey, and wrestling also carry high concussion risk. In girls' sports, soccer carries the highest risk of concussion, followed by lacrosse, field hockey, and basketball.

In comparable sports played by those of both sexes, such as basketball and

TABLE 1 Concussion Rates in High School Sports

| Sport | Concussions per 1000 AEs |
|---|--------------------------|
| Boys' tackle football | 0.54–0.94 |
| Girls' soccer | 0.30–0.73 |
| Boys' lacrosse | 0.30–0.67 |
| Boys' ice hockey | 0.54–0.62 |
| Boys' wrestling | 0.17–0.58 |
| Girls' lacrosse | 0.20–0.55 |
| Girls' field hockey | 0.10–0.44 |
| Girls' basketball | 0.16–0.44 |
| Boys' soccer | 0.17–0.44 |
| Girls' softball | 0.10–0.36 |
| Boys' basketball | 0.07–0.25 |
| Girls' volleyball | 0.05–0.25 |
| Cheerleading | 0.06–0.22 |
| Boys' baseball | 0.04–0.14 |
| Girls' gymnastics | 0.07 |
| Boys' and girls' track and/or field | 0.02 |
| Boys' and girls' swimming and/or diving | 0.01–0.02 |

Data compiled from Gessel et al,³⁹ Lincoln et al,⁴⁰ Rosenthal et al,⁴⁹ Marar et al,⁵⁸ Meehan et al,⁵⁹ O'Connor et al,⁶⁰ Currie et al,⁶¹ and Castile et al.⁶²

soccer, girls have a higher concussion risk when compared with boys.^{49,58–60} Girls' ice hockey data specific to high school are limited, but in college-aged female ice hockey players, the concussion rate is higher than in male ice hockey players and is similar to football rates.^{8,63} The reason behind the sex differences in concussion rates remains unclear, although some have theorized that female athletes have weaker neck musculature or that estrogen may play a role.²⁵ It has also been suggested that female athletes may report symptoms more frequently than male athletes.⁶⁴

Most studies classify youth athletes as anyone younger than 18 years, but the majority of these include only high school athletes. Recent research has shown that middle school tackle football has the highest concussion rate (2.6–2.9 in 1000 AEs), followed by girls' soccer (1.2–2.2 in 1000 AEs).^{65–67} Cheerleading (0.68–1.1 in 1000 AEs) and girls' basketball (0.88 in 1000 AEs) had the next-highest rates. A study of youth tackle football players 8 to 12 years of age revealed concussion rates that were

higher (1.76 in 1000 AEs) than in high school athletes, with a nearly 2.5 times higher concussion risk in 11- to 12-year-olds when compared with 8- to 10-year-olds.⁶⁸ A study of youth ice hockey players 12 to 18 years of age revealed a similar concussion rate to that in the tackle football study (1.58 in 1000 AEs), but in contrast to the pattern seen in other contact sports, the younger athletes (12–14 years) had a 2.4 times higher concussion risk than the older athletes (15–18 years).⁶⁹ No studies of young children that reported SRC incidence by AE were identified; however, a study evaluating athletes ages 4 to 13 years seen in the emergency department revealed tackle football to be the most likely sport to cause athletes to sustain a concussion, followed by basketball, soccer, and baseball.⁷⁰ The youngest athletes in this study, 4- to 7-year-olds, were also found to be more likely to sustain SRC from player-to-other-object contact than were their older counterparts.⁷⁰

In general, the concussion incidence is higher in competition than practice for both male and female athletes across nearly all sports.^{8,58,60} For boys, the concussion rate in competition when compared with practice is more than 7 times higher in lacrosse and soccer, about 3 times higher in tackle football, and over twice as high in wrestling.^{60,71} In girls, the concussion rate in competition when compared with practice is about 5 times higher in lacrosse, soccer, and basketball.^{60,71} The exception to this is cheerleading, which showed a higher concussion rate in practice (0.14 in 1000 AEs) than in competition and/or performance (0.12 in 1000 AEs).^{58,61}

SIGNS AND SYMPTOMS

Signs and symptoms of SRCs can be classified into 5 categories, including somatic, vestibular, oculomotor, cognitive, and emotional and sleep (Table 2). Headache (86%

TABLE 2 Signs and Symptoms of a Concussion

| Category | Symptoms |
|------------------------------|----------------------------------|
| Somatic | Headache |
| | Nausea and/or vomiting |
| | Neck pain |
| | Light sensitivity |
| Vestibular and/or oculomotor | Noise sensitivity |
| | Vision problems |
| | Hearing problems and/or tinnitus |
| | Balance problems |
| Cognitive | Dizziness |
| | Confusion |
| | Feeling mentally “foggy” |
| | Difficulty concentrating |
| Emotional | Difficulty remembering |
| | Answers questions slowly |
| | Repeats questions |
| | Loss of consciousness |
| Sleep | Irritable |
| | More emotional than usual |
| | Sadness |
| | Nervous and/or anxious |
| Sleep | Drowsiness and/or fatigue |
| | Feeling slowed down |
| | Trouble falling asleep |
| | Sleeping too much |
| Sleep | Sleeping too little |

to 96%) is the most frequently reported SRC symptom, followed by dizziness (65% to 75%), difficulty concentrating (48% to 61%), and confusion (40% to 46%).^{60,62,72} Loss of consciousness is not a requirement to diagnose concussion and is reported to occur in less than 5% of SRCs.^{62,72} Recent studies have also demonstrated high rates of vestibular and oculomotor dysfunction in athletes after SRC, including accommodative disorders, convergence insufficiency, and saccadic dysfunction.^{73,74}

It is important for the clinician to recognize that symptoms of a concussion are not specific to that diagnosis and may mimic preexisting problems of an athlete. Specific attention to athletes with migraine and/or headache disorders, learning disorders, attention-deficit/hyperactivity disorder (ADHD), mental health conditions (such as depression or anxiety), and sleep disorders is critical to not

falsely attributing those symptoms to the concussion, although it is important to realize that an SRC may temporarily worsen the symptoms the athlete experiences with these conditions.

A postconcussion symptom checklist is useful in assessing an athlete after an SRC and often is a component of sideline assessment tools (Table 3). Several variations are available, and it is helpful to use an age-appropriate symptom questionnaire in athletes younger than 12 years (Table 4). These tools typically use a 7-point Likert scale graded from 0 (no symptoms) to 6 (severe symptoms) for athletes older than 12 years, although tools for athletes 5 to 12 years of age often use 4-point Likert scales. A graded scale permits the assessment of the severity of symptom burden and may minimize the reluctance of an athlete to admit symptoms if asked verbally about the presence or absence of specific symptoms. Parental questionnaires may also be of benefit.^{19,75,76} Athletes have been found to report a greater number and severity of symptoms than their parents, with better agreement observed if they are asked within 1 week of the injury.⁷⁵

Multiple studies have found that girls typically report a higher symptom burden than boys.^{77–79} The presence of a higher overall initial symptom burden, and especially a higher burden of somatic symptoms, has been found to be the most consistent predictor of a prolonged (>28 days) recovery after a concussion.^{80–83} This underscores the importance of symptom monitoring with a postconcussion symptoms checklist. The presence of ADHD, female sex, a high cognitive symptom load, loss of consciousness, dizziness, and early pubertal stage have been suggested to increase the risk for a prolonged recovery after SRC in some studies; however, other studies have revealed no increased risk.^{81,82,84–87}

TABLE 3 Postconcussion Symptom Scale (Ages 13 and Older)

| Symptoms | No Symptoms | Mild | Moderate | Severe |
|---------------------------|-------------|------|----------|--------|
| Headache | 0 | 1 | 2 | 3 |
| “Pressure in head” | 0 | 1 | 2 | 3 |
| Neck pain | 0 | 1 | 2 | 3 |
| Nausea or vomiting | 0 | 1 | 2 | 3 |
| Dizziness | 0 | 1 | 2 | 3 |
| Blurred vision | 0 | 1 | 2 | 3 |
| Balance problems | 0 | 1 | 2 | 3 |
| Sensitivity to light | 0 | 1 | 2 | 3 |
| Sensitivity to noise | 0 | 1 | 2 | 3 |
| Feeling slowed down | 0 | 1 | 2 | 3 |
| Feeling “in a fog” | 0 | 1 | 2 | 3 |
| “Don’t feel right” | 0 | 1 | 2 | 3 |
| Difficulty concentrating | 0 | 1 | 2 | 3 |
| Difficulty remembering | 0 | 1 | 2 | 3 |
| Fatigue and/or low energy | 0 | 1 | 2 | 3 |
| Confusion | 0 | 1 | 2 | 3 |
| Drowsiness | 0 | 1 | 2 | 3 |
| More emotional | 0 | 1 | 2 | 3 |
| Irritability | 0 | 1 | 2 | 3 |
| Sadness | 0 | 1 | 2 | 3 |
| Nervous or anxious | 0 | 1 | 2 | 3 |
| Trouble falling asleep | 0 | 1 | 2 | 3 |

Use of the Postconcussion Symptom Scale: The athlete should fill out the form, on his or her own, to give a subjective value for each symptom. This form can be used with each encounter to track the athlete’s progress toward the resolution of symptoms. Many athletes may have some of these reported symptoms at baseline, such as concentration difficulties in a patient with ADHD or sadness in an athlete with underlying depression, and this must be taken into consideration when interpreting the score. Athletes do not have to be at a total score of 0 to return to play if they had similar symptoms before the concussion. There are currently no guidelines that determine the severity of a concussion on the basis of these scores.

TABLE 4 Postconcussion Symptom Scale (Ages 5–12 Years)

| | Not at All or Never | A Little or Rarely | Somewhat or Sometimes | A Lot or Often |
|---|---------------------|--------------------|-----------------------|----------------|
| I have headaches | 0 | 1 | 2 | 3 |
| I feel dizzy | 0 | 1 | 2 | 3 |
| I feel like the room is spinning | 0 | 1 | 2 | 3 |
| I feel like I’m going to faint | 0 | 1 | 2 | 3 |
| Things are blurry when I look at them | 0 | 1 | 2 | 3 |
| I see double | 0 | 1 | 2 | 3 |
| I feel sick to my stomach | 0 | 1 | 2 | 3 |
| My neck hurts | 0 | 1 | 2 | 3 |
| I get tired a lot | 0 | 1 | 2 | 3 |
| I get tired easily | 0 | 1 | 2 | 3 |
| I have trouble paying attention | 0 | 1 | 2 | 3 |
| I get distracted easily | 0 | 1 | 2 | 3 |
| I have a hard time concentrating | 0 | 1 | 2 | 3 |
| I have problems remembering what people tell me | 0 | 1 | 2 | 3 |
| I have problems following directions | 0 | 1 | 2 | 3 |
| I daydream too much | 0 | 1 | 2 | 3 |
| I get confused | 0 | 1 | 2 | 3 |
| I forget things | 0 | 1 | 2 | 3 |
| I have problems finishing things | 0 | 1 | 2 | 3 |
| I have trouble figuring things out | 0 | 1 | 2 | 3 |
| It’s hard for me to learn new things | 0 | 1 | 2 | 3 |

ACUTE ASSESSMENT

On the Field and/or Sideline

Ideally, initial evaluation of a conscious athlete who is suspected of

having an SRC involves a neurologic examination and an assessment of current symptoms, cognition, balance, and vision. It is highly preferred that this assessment is

performed by a health care provider who is knowledgeable in the assessment of SRC. It would also be ideal if this assessment is conducted by a health care provider who already knows the athlete because he or she may be better suited to identify subtle changes in his or her function or demeanor. If available, a quiet area (such as a locker room) would be a preferable place to assess the athlete instead of on a field and/or sideline or in a loud gymnasium.

If an athlete is unconscious after a head injury, initial assessment includes the “ABCs”: airway, breathing, and circulation. If the athlete remains unconscious, the athlete must be assumed to have an associated cervical spine injury, and appropriate measures of stabilizing the cervical spine and transportation to an emergency facility should occur. If the athlete regains consciousness, the cervical spine can be adequately assessed, and if there is normal function and sensation in all 4 extremities, further assessment may be conducted on the sideline or, preferably, in a quiet location.

Various sideline assessment tools are readily available. The most frequently used concussion assessment tool is the Sport Concussion Assessment Tool (SCAT), which is available in both child (ages 5–12 years; Child SCAT 5) and adolescent and/or adult (13 years and older; SCAT 5) versions.^{76,88} These tools are updated with each Concussion in Sport Group meeting on the basis of research published in previous versions between meetings.^{19,76,88} To complete a full assessment using the entire tool requires a minimum of 10 minutes. The Acute Concussion Evaluation is an additional history-taking and assessment tool produced by the Centers for Disease Control and Prevention that may be useful to pediatricians.⁸⁹

The SCAT 5 begins with the observable signs of SRC, which include lying motionless on the playing surface, balance and/or gait abnormalities or stumbling movements, inability to appropriately respond to questions or disorientation, blank and/or vacant look, and facial injury. Memory is assessed regarding the current event through the use of the Maddocks questions. The Child SCAT 5 no longer includes the Maddocks questions because they have not yet been determined to be valid in children younger than 13 years.⁷⁶ The SCAT 5 and Child SCAT 5 also include the Glasgow Coma Scale (GCS), a cervical spine assessment, and demographic and symptom assessments. The Child SCAT 5 also includes parental assessment of the child. The Standardized Assessment of Concussion (which assesses cognition), a brief neurologic examination, and a modified version of the Balance Error Scoring System (BESS) are also components of the SCAT 5 and Child SCAT 5.

Studies of previous versions of the SCAT revealed significant differences in performance on testing between younger and older athletes, which led to the development of the Child SCAT 3 in 2013 with revision to the SCAT 5 in 2017.^{90–92} Younger athletes perform worse on components of the Standardized Assessment of Concussion, including ability to perform months of the year in reverse and digits in reverse, as well as the BESS.^{91,93} Female athletes, in general, perform better than their male counterparts on most components of the SCAT.^{90,93–95} Several studies have published normative data and reliability assessments for the BESS in young athletes, although the BESS has not been demonstrated to consistently reveal balance deficits greater than 3 days after SRC.^{93,96–99}

The assessment of visual deficits after SRC is drawing more interest. Tools

such as the King-Devick Test and vestibular/ocular motor screening have demonstrated some usefulness in the evaluation of SRC.^{100–103} At this time, there are not enough studies of adequate quality to recommend their inclusion in the SCAT.^{76,88}

Sideline assessment tools can assist health care providers in the evaluation of SRC but are not intended to be used in isolation for making the diagnosis of SRC. These tools can provide additional information, along with the clinical judgement of the assessor, in making the diagnosis of SRC. However, these tools, particularly in younger athletes, have not been studied adequately to recommend widespread use. Despite the availability of limited normative data on the SCAT and Child SCAT, it is preferable to be able to compare an athlete’s performance with his or her own preinjury status. It is noted that preinjury assessments are often not obtained or are not available at the time of assessment immediately after injury.

Because an athlete may not always present immediately with symptoms or deficits on his or her cognitive or balance assessments, repeat assessments are crucial for the athlete after head trauma. If an assessment for a concussion has been initiated, it is better to err on the side of caution and keep an athlete from returning to play on that day, while continuing serial assessments, unless the assessor is confident that SRC has not occurred.

When evaluating an athlete after suspected head trauma, there are several red flags that warrant urgent referral to an emergency department. These red flags include weakness or tingling in the arms or legs, severe or progressively increasing headache, loss of consciousness, deteriorating level of consciousness, repeated episodes of vomiting, a combative state, and seizures or convulsions. These findings may indicate that a more serious and potentially

life-threatening head injury has occurred and may require further evaluation with neuroimaging. Tonic posturing and convulsive movements may immediately follow a concussion. Fortunately, these are often benign and self-limited and do not portend long-term deficits and generally can be addressed through routine SRC management. If seizure or seizure-like activity has occurred minutes to hours following head trauma, further evaluation in an emergency department is warranted.¹⁰⁴

In-Office and/or Emergency Department Assessment

When assessing a patient in the office after an SRC, obtaining a history of the injury as well as relevant past history, including previous head injuries and any preexisting conditions (eg, ADHD, depression, anxiety, migraine headaches, and learning disabilities), is important.⁸⁹ The use of a postconcussion symptom checklist is helpful in facilitating the history taking and reminding the health care provider to ask about all relevant symptoms. A physical examination may include a neurologic examination, a head-and-neck evaluation, an ocular evaluation (such as the vestibular and/or ocular motor screening assessment), a balance assessment (which may include the BESS, Romberg test, and/or tandem gait), and an assessment of cognitive function. It is currently unclear whether the use of sideline tools, such as the SCAT, are as useful after SRC when assessed multiple days after the original injury.¹⁹ If evaluation occurs immediately after the injury, monitoring the athlete for deterioration may be needed. It is important to also assess for findings on the history or physical examination that may be concerning for a structural injury (eg, cervical spine injury, skull fracture, or intracranial hemorrhage) that would require further evaluation with neuroimaging. Even if an

athlete becomes symptom free or is minimally symptomatic after his or her injury, return to play on the day of injury is not permissible if the diagnosis of SRC has been made. All 50 states and the District of Columbia have enacted laws requiring an individual who is suspected of sustaining a concussion to be removed from play and evaluated by a medical provider before returning to play.

NEUROIMAGING

Results of conventional neuroimaging are typically normal in SRC. Computed tomography (CT) or MRI of the brain contribute little to concussion evaluation and management except when there is suspicion of a more severe intracranial injury or structural lesion (eg, skull fracture or hemorrhage).^{19,105,106} Despite a decrease in reported injury severity and conventional neuroimaging often yielding normal results, emergency department head CT use for concussions increased 36% from 2006 to 2011.¹⁰⁷

Concussion may be associated with a significant cervical spine injury, skull fracture, or any of the 4 types of intracranial hemorrhage (subdural, epidural, intracerebral, or subarachnoid).¹⁰⁶ Signs and symptoms that increase the index of suspicion for more serious intracranial injury include severe headache, seizures, focal neurologic deficits, loss of consciousness for over 30 seconds, significant mental status impairment, repeated emesis, significant irritability, and worsening symptoms.^{19,108} Normal neuroimaging in the acute phase of injury may not absolutely rule out a chronic subdural hematoma, nor does it help predict subsequent neurobehavioral dysfunction or recovery time.¹⁰⁹

Recent literature has shown that the likelihood of finding clinically

significant intracranial hemorrhaging after 6 hours without deterioration in level of consciousness is extremely rare: 0.03% of patients.¹¹⁰ Therefore, CT for delayed diagnosis of intracranial hemorrhage in patients without deterioration in level of consciousness after 6 hours is unlikely to be helpful, although past studies have recommended CT to be performed in the first 48 hours after injury.^{105,111} CT is easier to perform and more cost-effective to obtain when compared with MRI. However, CT exposes children to the potentially harmful effects of ionizing radiation, which increases the risk for benign and malignant neoplasm.^{112–115} Therefore, criteria to guide neuroimaging decisions have been developed, but none are sensitive enough to diagnose all intracranial pathology.^{116–119}

In a 2009 prospective study, more than 42 000 patients were evaluated regarding who may be at high risk of structural brain injury and had a CT scan performed through the emergency department.¹¹⁸ In patients older than 2 years, approximately 7% of the injuries were sport related. Patients with a GCS score less than 15, signs of basilar skull fracture, or signs of altered mental status (agitation, somnolence, repetitive questioning, slow response to verbal communication) were found to be at the highest risk for structural brain injury, and CT scanning was recommended. Patients with a GCS of 15 in the emergency department but with a history of loss of consciousness, history of vomiting, severe headache, or severe mechanism of injury (falls >3 feet, motor vehicle or bicycle crash, or head struck by high-impact object) carried a 0.9% risk of structural brain injury, and the authors recommended CT instead of observation. In this study population, 58% did not fall into those categories, and CT was not recommended because the structural brain injury risk was less than

0.05%. A 2010 Canadian study came to similar conclusions and found that acutely worsening headaches elevated the risk of structural brain injury, and CT was recommended.¹¹⁹

MRI is superior to CT in the detection of cerebral contusion, petechial hemorrhage, and white matter injury.¹²⁰ MRI is believed to be the test of choice if neuroimaging is needed outside of the emergency period. Patients who are clinically worsening or not improving over time may benefit from MRI to assess for other structural problems that may cause a similar symptom profile (eg, Chiari malformation or tumor). These findings may have implications for long-term outcomes and return-to-play decisions. However, only 0.5% of pediatric patients with persistent symptoms after SRC had findings on an MRI that were compatible with traumatic injury, whereas another 14.3% were found to have abnormal findings unrelated to trauma, with the majority of those findings being benign.¹²¹

Emerging neuroimaging modalities hold promise for identifying imaging biomarkers that may improve diagnosis, management, and prognosis; however, further research is needed before these modalities can be recommended for clinical care.^{105,122,123} These modalities include diffusion tensor imaging with tractography, magnetic resonance spectroscopy, functional MRI, positron emission tomography, and single-photon emission CT. Research has shown postinjury changes using these modalities.^{32,122–124} The identification of biomarkers through neuroimaging and the measurement of metabolic and hemodynamic changes in the brain through functional imaging will likely provide a more accurate picture of the injury and provide a biologic basis for concussion symptoms while potentially improving management strategies and recovery predictions.^{8,122} Currently, these modalities are best

used for research purposes to expand knowledge about concussion and validate management strategies.

NEUROCOGNITIVE TESTING

Neurocognitive testing may be performed in the assessment of an athlete with SRC to help provide objective information about recovery from the injury. Traditional pencil-and-paper neurocognitive testing often takes several hours to administer and requires interpretation by a neuropsychologist. Several computerized neurocognitive tests (CNTs) are available that allow for rapid and uniform testing of large numbers of athletes. There have been numerous studies evaluating the reliability of various CNT platforms; however, studies conducted independently of the developers of the tests have questioned the overall reliability of testing from year to year.^{125–138} The reliability of pencil-and-paper testing has also been questioned.¹³⁹

It is important for the individual interpreting the results of baseline and postinjury CNTs to be knowledgeable about the modifiers that may affect performance on the test. Sleep has frequently been cited as a modifier for performance on baseline and postinjury CNTs.^{140–143} History of concussion, regardless of sex, did not affect performance on CNTs.^{144,145} Individuals with ADHD tend to have lower baseline scores on CNTs than those without and perform worse on CNTs if they do not take their medication before testing.^{146,147} Athletes with musculoskeletal injuries were found to have impaired CNT results similar to those of athletes with concussion.¹⁴⁸ The mechanism of the hit that produces an SRC has not been shown to alter performance on CNTs.¹⁴⁹ Athletes found to be more severely depressed performed worse than those who were considered mildly depressed.¹⁵⁰

To be efficient when baseline testing multiple teams at a school, many schools use a group setting. It has been demonstrated that performance in a group setting will result in lower baseline scores than performance in those tested individually, although 1 study revealed an elimination of these differences when standardized test instructions were used and a trained administrator was present.^{151–153} A baseline CNT is ideally performed in a quiet environment, free of distractions, before the athlete's season, while the athlete is well rested, and following the recommendations of the test manufacturers. Repeating invalid baseline tests more than once has been shown not to be beneficial because the individual has a low likelihood of obtaining a valid test result.¹⁵⁴

Concerns have been raised about athletes "sandbagging" their baseline CNTs, which means intentionally performing poorly to be able to have an easier goal to reach on their testing after an SRC. Although there was initial concern about this possibility, the majority of these sandbagging results can be detected.^{155–157} Studies have demonstrated that 11% to 35% of athletes could successfully avoid detection when intentionally performing poorly on CNTs, but experience in test interpretation can help identify those who may be sandbagging.^{155–157}

It must be acknowledged that when using a group setting for baseline testing, most schools and organizations will have great difficulty in creating the proper testing environment with administrators who have the time and are appropriately trained to review all baseline results individually. The ideal methodology for baseline and postinjury testing may be impractical for most schools and organizations. Careful consideration is necessary

when schools or organizations are considering using CNTs as part of their concussion program. Providing baseline and postinjury CNT results in isolation for athletes is not considered to be an adequate concussion program for the school or organization seeking to use these tools. If a school chooses to implement CNTs as part of its concussion program, a plan should be in place to include proper administration and interpretation of the baseline and postinjury test results.

There is no agreed-on time at which to conduct CNTs after SRCs. Given that CNTs cannot be used to predict the length of recovery, it is likely prudent to perform postinjury testing on an athlete when he or she is free of concussion symptoms. Ideally, comparison is with an athlete's own baseline because several studies demonstrate improved identification of cognitive impairment when an athlete's own baseline is used for comparison rather than population-based norms.^{158,159}

Ideally, neurocognitive testing is performed and interpreted by a neuropsychologist. However, given the large number of athletes participating in sports and the relative scarcity of and limited access to neuropsychologists, a widespread CNT program would not be practical or possible.¹⁶⁰ Ideally, if a nonneuropsychologist is using CNTs, collaboration with a neuropsychologist to aid in test administration and interpretation may be beneficial.¹⁶¹

Currently, it is not recommended that routine mandatory baseline and postinjury CNTs be conducted.¹⁹ CNTs, when used, should be conducted by individuals with appropriate training in the administration, interpretation, and limitations of the specific test. Ideally, the tests should be interpreted against a patient's individual baseline. These tests should not be

used as the sole determining factor in return-to-play decisions. If an athlete is suffering from prolonged symptoms over several months or has had multiple concussions with cognitive or emotional concerns believed to be related to the concussion, a formal assessment by a neuropsychologist may be beneficial.

ACUTE MANAGEMENT

The management of an athlete with concussion involves the education of the athlete and his or her family about concussions and expectations for recovery, assessing for injuries or deficits that may benefit from rehabilitation, and guiding the athlete back to school and physical activity. Because each patient and concussion is unique, it is important to proceed with an individualized approach to managing the athlete.

Athletes who are suspected to have a concussion should be removed from play and not be allowed to return the same day. Athletes who continued to play immediately after a SRC were found to have worse symptoms and CNT scores than those who were removed immediately from play.¹⁶² The athletes who continued to play were also 8.8 times more likely to have a recovery longer than 21 days.¹⁶² Another study demonstrated that athletes who sustained an additional head impact within 24 hours of the first had a greater symptom burden and a longer recovery time (52.3 vs 36.9 days) than those who did not sustain an additional head injury.¹⁶³ These studies reinforce the importance of immediate removal from play to reduce the likelihood of a longer recovery and worse symptoms or exposure to additional head trauma.

The previous clinical report emphasized the role of physical and cognitive rest.³ Although there is a role for reducing physical and cognitive activity after an SRC, recent research has revealed that

there may be negative consequences of extremes of rest in an athlete's recovery from SRC. Several recent studies have demonstrated that athletes who are recommended periods of strict rest, regardless of symptom severity, typically take longer to recover and often continue to report higher symptom burdens than athletes who rest for only a few days.^{164–169} A study of the role of cognitive rest after an SRC demonstrated that athletes who did not reduce their cognitive load at all after injury did take the longest to improve, but even mild reductions in their cognitive load resulted in similar recovery times as in those who had extreme rest.¹⁷⁰

In light of recent research, a reasonable approach to physical rest includes immediate removal from play and, while the athlete is having consistent symptoms, limiting physical exertion to brisk walking but avoiding complete inactivity. Allowing some light cardiovascular activity, such as brisk walking, although not allowing a return to full sports participation, seems prudent and is supported by recent research.¹⁷¹ This exercise is intended to be subsymptom exercise, meaning the intensity of the exercise is limited to a level that does not increase or provoke symptoms. This may be self-monitored or through a formal physical therapy program. Further research is needed to determine the optimal time to initiate this type of exercise after an SRC as well as the most beneficial type and duration of exercise.

When returning an athlete to school after a concussion, it is beneficial for the student to receive academic adjustments to reduce his or her workload and environmental triggers that may exacerbate symptoms. Communication with teachers and working with school staff who will be implementing these adjustments is important for a smooth transition back into school. Prolonged school

removal or absence is discouraged. A more detailed discussion of returning to learning after a concussion can be found in the AAP clinical report “Returning to Learning Following a Concussion.”¹⁷²

Because many young athletes are highly socially connected through their electronics and social media, blanket recommendations to have athletes with SRCs completely avoid the use of electronics, computers, television, video games, and texting is discouraged. To date, no research has documented any detrimental effect of electronic use in SRC recovery. Individuals with light sensitivity or oculomotor dysfunction may find their symptoms worsen while using electronics and may need to limit their overall screen time, adjust brightness levels, or increase font sizes to reduce episodes of symptom worsening. A complete elimination of electronics may result in feeling socially isolated from friends, which may lead to depressive or anxious symptoms.⁸

Several studies have demonstrated deficits in the reaction time to and judgment of road hazards in adults with concussion attempting a driving simulator in the first 24 hours after injury.^{173,174} Similar deficits likely exist in adolescent athletes after an SRC, so it is worthwhile to avoid driving for the first few days after an SRC.

Reported recommendations for the use of medications after a concussion are common among primary care, emergency department, and sports medicine physicians.^{175–177} Acetaminophen and nonsteroidal anti-inflammatory medications were the most commonly used.^{175–177} Emergency department physicians reported high rates of use of ondansetron.¹⁷⁶ Primary care physicians also report a frequent recommendation of melatonin and amitriptyline.^{175,177} The chronic use of acetaminophen or nonsteroidal anti-inflammatory medications

is discouraged because they may contribute to medication overuse headaches.¹⁷⁸ There are currently no medications that are specific to treat concussion. Despite the widespread prescription of medications by physicians caring for patients with SRCs, there is no evidence-based research to support their use in the management of SRCs.

Because many SRCs occur through a whiplash-type mechanism, cervical strains are commonly associated with a concussion. A cervical strain may also lead to cervicogenic headaches. If a cervical strain is diagnosed, physical therapy can be considered to help facilitate recovery.¹⁷⁹

Athletes may also experience vestibular injuries or oculomotor dysfunction after an SRC. Rehabilitation of these injuries may also be of benefit, although it is unclear when the appropriate time is to initiate therapy for these problems because many cases are mild and may resolve spontaneously. Persistent symptoms of dizziness and balance problems may benefit from vestibular rehabilitation by appropriately trained physical therapists.¹⁷⁹

It is important to counsel patients regarding their expected recovery and provide reassurance that they are expected to improve. Each concussion is unique, and there are currently no diagnostic tests, physical examination findings, or historical elements that can definitively predict how long it will take for a patient to recover. Studies on recovery time have reported that the majority of pediatric and adolescent athletes with SRCs recover between 1 and 4 weeks.^{180–186} Not all athletes with SRCs will recover within that time frame, however. Athletes who sustain a second concussion within 1 year after recovery from the first concussion were not found to have a longer recovery time than that of the initial concussion.¹⁸⁰

RETURN TO SPORT AND/OR PLAY

Determining when an athlete returns to play after a concussion should follow an individualized course, because each athlete recovers at a different pace. Return to sport after an SRC is best accomplished by following a graduated stepwise program updated by the Berlin Concussion in Sport Group (Table 5).¹⁹ Return-to-sport recommendations for children have been extrapolated from adult consensus guidelines, and further research is required to refine a pediatric- and adolescent-specific program. Studies reveal a longer recovery period for adolescents and younger athletes compared with college-aged athletes; therefore, a more conservative approach to deciding when pediatric and adolescent athletes can return to full sport is warranted.^{181–186}

No athlete should be allowed to return to play on the same day as the injury.^{162,163} The phrase, “When in doubt, sit them out!” is paramount in the management of pediatric and adolescent concussion.¹⁸ Despite the existence of state laws and the AAP, American Medical Society for Sports Medicine, American Academy of Neurology, and Concussion in Sport Group all having published statements recommending not returning to play on the same day of the injury, literature reveals that 10% to 38% of young athletes reported returning to play on the same day as the injury.^{187,188} Additional education of all stakeholders in SRCs remains an important task.

Athletes should not be allowed to return to contact, collision, or high-risk activities until symptoms of the concussion have resolved and a return-to-sport progression has been completed. Premature return to contact increases the risk of more severe injury, repeat injury, and prolonged recovery.^{189,190} Cognitive and noncontact physical exertion might increase symptoms, but it

TABLE 5 Graduated Return-to-Sport Program

| Stage | Aim | Activity | Goal of Step |
|-------|----------------------------|---|---|
| 1 | Symptom-limited activity | Daily activities that do not provoke symptoms | Gradual reintroduction of work and/or school activities |
| 2 | Light aerobic exercise | Walking or stationary cycling at slow-to-medium pace; no resistance training | Increase heart rate |
| 3 | Sport-specific exercise | Running or skating drills; no activities with risk of head impact | Add movement |
| 4 | Noncontact training drills | Harder drills (eg, passing drills and team drills); may begin progressive resistance training | Exercise, coordination, and increased thinking during sport |
| 5 | Full-contact practice | After medical clearance, participate in full, normal training activities | Restore confidence and allow coaching staff to assess functional skills |
| 6 | Return to sport | Normal game play | Full clearance/participation |

Recommend 48 h of relative physical and cognitive rest before beginning the program. No more than 1 step should be completed per day. If any symptoms worsen during exercise, the athlete should return to the previous step. Consider prolonging and/or altering the return-to-sport program for any pediatric and/or adolescent patient with symptoms over 4 wk.

is unlikely to worsen the injury or outcomes, whereas prolonged inactivity is known to result in a higher symptom level and prolonged recovery.^{164,168,191} Although beginning symptom-limited aerobic activity may be appropriate in some young athletes with a concussion, children and adolescents should not fully return to sports until they have also successfully returned to full academics.

The graded return-to-sports program was initially proposed by the Canadian Academy of Sport and Exercise Medicine in 2000 and endorsed by the first meeting of the Vienna Concussion in Sport Group in 2001.^{18,192} Children and adolescents should not advance beyond step 2 until they return to their preinjury symptom levels and are fully participating in school. Ideally, the progression is monitored by a licensed health care professional who is knowledgeable in concussion management; however, a parent or coach may monitor the progression through the return-to-sport program if he or she is given proper instructions and can monitor for the return of symptoms. Athletic trainers are also licensed health care professionals who can supervise a return-to-sport program once they are instructed to do so. Each step should take at least 24 hours, and it may take the athlete just under a week to resume full game participation, provided that

symptoms do not return. A return of symptoms may indicate incomplete recovery from the concussion. If symptoms return while the athlete is in the program, the athlete should wait 24 hours, and if the symptoms have resolved, he or she may then attempt the previous step that was completed without symptoms and continue the progression if symptoms do not recur. Reevaluation by a health care provider is indicated for any athlete who has a continued return of symptoms with exertion. An athlete who has a history of multiple concussions or who had a prolonged recovery (over 4 weeks) may need a longer period of time to progress through each step of the program. A specialist with experience in concussion management may be needed to create an appropriate return-to-activity program.

LEGISLATION

By 2014, every state and the District of Columbia had passed youth sports concussion laws.¹⁹³ Most laws consist of the 3 key components found in Washington state's 2009 Zackery Lystedt Act¹⁹³:

1. Organizations operating sports programs for athletes younger than 18 years, both schools and youth sports organizations, must provide educational materials and/or programs to inform coaches, athletes, and parents about the nature and risks of

concussion. These materials should be provided on an annual basis, and all stakeholders should sign the forms acknowledging their participation and understanding.

2. Any athlete suspected of sustaining a concussion should be immediately removed from play and cannot return to play on the same day.
3. Any athlete with a suspected concussion cannot return to participation until written medical clearance is received from a health care provider who is trained in the evaluation and management of concussion.

States may vary on the type of education, frequency of signed certification, return-to-play content, and type of health care provider who can provide written clearance.^{194,195} Every health care provider should understand his or her state's law and how it affects the patients and practice.

Research indicates that concussion laws have had a positive impact by increasing the reporting of symptoms by athletes and decreasing instances in which coaches allow athletes who are symptomatic to return to play.^{195–197} Before all states passed concussion legislation, states that had laws had a 10% higher concussion-related health care use rate compared with states that did not have laws, indicating a positive

effect.¹⁹⁸ However, education does not seem to be spread evenly across the athletic community. A study performed 3 years after the passage of the Washington state law revealed that although nearly all high school football and soccer coaches received education through 2 or more modalities (written, in-person, video, and slide presentation), only 34.7% of the athletes and 16.2% of parents were exposed to that much education.¹⁹⁹ In addition, a recent study in Illinois showed that although pediatricians had good knowledge about concussion diagnosis and initial management, only 26.6% were “somewhat familiar” or “very familiar” with a recently passed state law.¹² A pediatric health care provider can have a positive impact by incorporating concussion education for both parents and athletes into the young athlete annual examination.

PROLONGED SYMPTOMS AND/OR LONG-TERM ISSUES

Although the vast majority of young athletes will have a resolution of their symptoms within 4 weeks, some will have symptoms that linger beyond that time. In athletes with persistent symptoms, it is important to evaluate for associated injuries that may benefit from rehabilitation or other treatments, including cervical strains; vestibular injuries; oculomotor disorders; sleep cycle disturbances; and developing depression, anxiety, or problems with attention.⁸ Because the majority of these possible coexisting conditions can mimic symptoms of concussion, providers may attribute persistent symptoms to the concussive injury itself and miss an opportunity to potentially improve a treatable problem. Several studies have also demonstrated young athletes with prolonged symptoms have a higher likelihood of high preinjury somatization.^{87,200} It is reasonable to consider referral of patients with prolonged symptoms

to a concussion specialist for further evaluation.

There is still no consensus agreement on the definition of postconcussion syndrome (PCS). The World Health Organization’s definition of PCS includes the presence of 3 or more of the following symptoms after a head injury: headache; dizziness; fatigue; irritability; difficulty with concentrating and performing mental tasks; impairment of memory; insomnia; and reduced tolerance to stress, emotional excitement, or alcohol.²⁰¹ There was no minimum time frame for these symptoms provided by the World Health Organization to diagnose PCS. The *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition* included a definition of PCS, but this was removed in the fifth edition because of confusion and a lack of consensus regarding the disorder.²⁰²

Long-term Effects

Significant attention in the medical community and media has been given to the concern of potential long-term effects of SRC and repetitive head trauma. The most emphasis is on the condition known as chronic traumatic encephalopathy (CTE). There is currently not a way to conclusively diagnose CTE in a living individual; this is exclusively a postmortem pathologic diagnosis. In a recent convenience sample study of former football players who donated their brains for evaluation after their deaths, 3 of 14 high school (21%) and 0 of 2 pre-high school players were found to have CTE on analysis.²⁰³ The 3 athletes who only played in high school were noted to have stage 1, the mildest form of CTE. Nearly all of the professional athletes were found to have evidence of CTE, the majority of them with evidence of severe pathology. Further research is necessary to correlate pathologic findings with clinical manifestations, including larger-scale evaluations of the brains of contact-sport athletes

with no clinical problems to reduce the bias of convenience samples. Two studies revealed no increased risk of dementia, Parkinson disease, amyotrophic lateral sclerosis, or cognitive or depressive problems in former high school football players compared with classmates who did not play football.^{204,205}

Second-impact syndrome is a condition that is still contested in the medical community.²⁰⁶ This injury is believed to be the result of an individual sustaining a second head injury before fully recovering from the first, which can result in cerebral vascular congestion, progressing to diffuse cerebral edema and death.²⁰⁷ Particular attention to this condition in the young athlete is important because the vast majority of cases have been reported in individuals of high school age and younger.²⁰⁸ Fortunately, this is believed to be a rare phenomenon but lends support to the recommendation to immediately remove an athlete from play after a suspected SRC and to not allow premature return to play, particularly while symptomatic.

Retirement

The decision to retire an athlete from a particular sport or sports after an SRC is often a difficult decision. No evidence-based criteria exist to help guide the clinician in making a decision concerning the appropriate time to retire. Several expert opinion publications have offered some considerations for retirement.^{209,210} It is likely prudent to refer an athlete to a specialist with expertise in SRC if a clinician is contemplating retiring an athlete from a particular sport. There is no “magic number” of concussions that an individual has sustained that can be used to determine when an athlete should no longer be allowed to participate in a particular sport.

PREVENTION

The prevention of all concussions is highly unlikely, and expectations should be focused on efforts to reduce the risk and minimize any potential long-term outcomes. Concussion prevention efforts have historically been focused on protective equipment, educational efforts, rule changes, evaluating for increased risk, and dietary supplements.

Mouth Guards

The use of mouth guards in sports has been described since 1930.²¹¹ The potential for mouth guards to prevent concussion was initially suggested in 1954, with data supporting this notion being published a decade later.^{212,213} Since then, several larger studies with varying designs have refuted this assertion.^{214–218} Evidence of an advantage in concussion prevention between athletes wearing custom-made versus noncustom-made mouth guards remains inconclusive.^{215,216,219–221} However, the use of mouth guards is paramount in reducing maxillofacial and dental trauma.^{214,217,222}

Helmets

Football helmets have evolved significantly over the past 50 years. Current football helmets are larger, heavier, and designed to absorb and dissipate impact forces to a greater extent than earlier models.²²³ Since the 1970s, football helmets have been designed to reduce severe injuries, such as skull fractures, subdural hematomas, and brainstem contusion or hemorrhage.²²⁴ The current goal of reducing concussions through helmet design remains elusive. Several studies have not demonstrated a difference in concussion symptom severity, time to recovery, or incidence of concussion among various brands and models of football helmets, whether new or refurbished.^{220,225}

In terms of concussion prevention, football helmet improvements may be reaching a point of diminishing returns and are not likely to be the solution to the issue of concussions.²²⁶ Properly fitted football helmets may decrease the likelihood of sustaining more significant intracranial injury and are recommended.^{227,228} Helmet fit is best assessed by individuals with proper training in this area, such as athletic trainers.

There are several after-market helmet attachments, such as bumpers, pads, and sensors. No studies demonstrate that helmets or third-party attachments prevent or reduce the severity of concussions. These attachments have not been tested by the National Operating Committee on Standards for Athletic Equipment and may void the helmet certification and manufacturer's warranty. Data suggesting an impact threshold for injury are not supported, and the use of helmet impact indicators has a low positive predictive value and may generate unnecessary evaluations.^{229,230} The use of these sensors does not appear to have a role in clinical decision-making but may have a role in research regarding rule changes or improved helmet design.^{229–231} The use of helmet-based or other sensor systems to clinically diagnose or assess SRC cannot be supported at this time.¹⁹

Studies in the sports of skiing, snowboarding, lacrosse, equestrianism, rodeo, and recreational bicycling have demonstrated a protective effect of helmet use in limiting impact forces causing head injury overall but none regarding concussion specifically.^{232–241} Hockey helmets have been shown to reduce the impact force from elbow collisions and low-velocity puck impacts but not from shoulder collisions, falls, or high-velocity puck impacts.²⁴²

Headgear

Soccer headgear has been marketed to help reduce the impact associated with heading and head hits and ultimately the risk for concussion. Headgear has not been demonstrated to have a benefit for head-to-ball impact or neurocognitive performance.^{243–245} Soccer headgear may increase the risk of injury attributable to possibly increased rotational forces to the head and an increased risk for a more aggressive style of play.^{246–248} Headgear has also not been found to provide significant protection from SRC in rugby.^{249–251} Given the lack of evidence-based research conclusively demonstrating benefit, the use or mandating of headgear for reducing concussion risk cannot be supported at this time.

Education

Education and awareness of concussion are also important when trying to reduce SRC as well as improve diagnosis and management. Several studies have demonstrated the benefit of education efforts in improving concussion knowledge, reducing referrals for neuroimaging, and increasing the likelihood of reporting SRCs.^{252–255} Although these particular education efforts may not directly reduce SRCs alone, understanding how concussions occur through education may result in rule changes as well as changes in behaviors and attitudes toward SRC.

Biomarkers

Several different biomarkers have been investigated as playing a potential role in concussion evaluation, including S100 β , glial fibrillary acidic protein, neuron-specific enolase, τ , neurofilament light protein, amyloid β , brain-derived neurotrophic factor, creatine kinase and heart-type fatty acid binding protein, prolactin, cortisol, and albumin.²⁵⁶ Additionally, apolipoprotein E ϵ 4, apolipoprotein E ϵ 4 promoter G-219T-TT genotype,

and $\tau^{Ser53Pro}$ polymorphism have been suggested as possible risk factors for a predisposition to concussion, potential delayed recovery, or increased risk for catastrophic injury.^{257,258} These investigations are preliminary, and none of these potential biomarkers have advanced to use in the clinical setting.²⁵⁹

Supplements

Similar to biomarkers, numerous nutritional supplements have been investigated as having potential preventive and/or therapeutic roles in concussion management, including Ω -3 fatty acids, eicosapentaenoic acid, docosahexaenoic acid, curcumin, resveratrol, melatonin, creatine, *Scutellaria baicalensis*, green tea, caffeine, and vitamins C, D, and E.^{260,261} There are some animal studies to support their possible benefit, but there is currently no evidence that these supplements can help in the prevention or treatment of concussions in humans.^{260–263}

Neck Strengthening

A simple and somewhat promising form of prevention may come from a cervical muscle strengthening program. Poor neck strength was found to be a predictor of concussion, and for each additional pound of strength a player had, the overall risk of SRC was reduced by 5%.²⁵ Improved neck strength, as well as the ability to anticipate and activate the neck muscles, was found to mitigate the kinematic forces from head impact.²⁶⁴

Rule Changes

Rule changes and a proper enforcement of rules by officials may help reduce the likelihood of concussion. The AAP has addressed the benefits of reducing concussion risk by eliminating body checking in youth hockey.²⁶⁵ The AAP policy statement on tackling in youth football reviewed the

literature regarding rule changes in American football and provided recommendations for reducing SRC risk.²⁶⁶ Increasing the age at which heading is initiated may provide some reductions in SRCs in soccer in younger age groups, although greater reductions may be achieved through limiting player-to-player contact.²⁶⁷ There is likely a benefit of encouraging athletes to play by the rules and discouraging aggressive playing styles, which may be influenced by coaching.

FUTURE DIRECTIONS

Since the original clinical report in 2010, there has been an exponential increase in the amount of published research on SRCs. This research has advanced the knowledge base and understanding of the injury and has helped guide the evolution in evaluation and management of SRC. There continue to be large gaps in research, particularly in the middle school and younger-aged populations. The need exists for furthering our knowledge in the area of diagnosis, especially in terms of finding tests or imaging studies to help increase sensitivity and specificity in truly determining what is and is not an SRC. Agreement on a definition of SRC would also further the field. Refining our approaches to the management of the injury will only benefit athletes as they recover. Much work is needed to clarify the confusing information the general public receives regarding the absolute risk of CTE, what the pathologic findings mean in relation to the clinical picture, what dose response may exist, and what modifying factors may also contribute to the development of CTE. Continuing to make and enforce rule changes that reduce the risk of contact, modifying practices to eliminate unnecessary or extra contact, and determining if equipment modifications may

help mitigate the SRC risk are all important SRC reduction goals.

CONCLUSIONS

Our conclusions are as follows:

1. SRCs remain common in youth and high school sports. Further research continues to be needed, especially in middle school and younger athletes.
2. Each concussion is unique and has a spectrum of severity and types of symptoms. These symptoms may overlap with other medical conditions.
3. Conventional neuroimaging is generally normal after an SRC. Following evidence-based guidelines may significantly reduce unnecessary imaging.
4. Various tools exist to evaluate the athlete after an SRC. Familiarity with these tools and their limitations can aid clinicians in appropriate evaluation after a suspected SRC.
5. The majority of pediatric athletes with SRCs will have a resolution of the symptoms within 4 weeks of the time of injury.
6. After a concussion, initial reductions in physical and cognitive activity can be beneficial to recovery, but prolonged restrictions on physical exertion or removal from school can have negative effects on recovery and symptoms.
7. The long-term effects of a single concussion or multiple concussions has still not been conclusively determined. Prolonged exposure over many years to repetitive brain trauma has been associated with pathologic changes in the brain in collegiate and professional athletes but is notably less in younger athletes. The exact correlation of clinical symptoms

with pathologic findings has not yet been established.

8. Currently, no medications have been developed to specifically prevent or treat the symptoms of SRCs. There are no quality studies at this time that demonstrate benefit in concussion recovery.
9. Retirement from sports after an SRC is an individualized decision that may benefit from consultation with a physician who has experience in recommendations for retirement after SRC.

RECOMMENDATIONS

Our recommendations are as follows:

1. Neurocognitive testing after an SRC is only 1 tool that may be used in assessing an athlete for recovery and should not be used as a sole determining factor to determine when return to play is appropriate. Testing should be performed and conducted by providers who have been trained in the proper administration and interpretation of the tests.
2. Athletes who remain unconscious after a head injury should be assumed to have a cervical spine injury. Appropriate stabilization of the cervical spine should occur, and the patient should be transported to an emergency facility for further evaluation.
3. Athletes with prolonged symptoms after an SRC should be evaluated for coexisting problems that may be contributing to the
4. All athletes with a suspected SRC should be immediately removed from play and not returned to full sports participation until they have returned to their baseline level of symptoms and functioning and completed a full stepwise return-to-sport progression without a return of concussion symptoms. If injury recovery occurs during the academic year, a return to the full academic workload is expected before a return to full sports participation.
5. Although all concussions cannot be prevented, reducing the risk through rule changes, educational programs, equipment design, and cervical strengthening programs may be of benefit. Prevention efforts should be focused on reducing the risk of long-term injury after a concussion.
6. Health care providers should have an understanding of their individual state's laws regarding return to play after a concussion.

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ABBREVIATIONS

AAP: American Academy of Pediatrics
ADHD: attention-deficit/hyperactivity disorder
AE: athletic exposure
BESS: Balance Error Scoring System
CNT: computerized neurocognitive test
CT: computed tomography
CTE: chronic traumatic encephalopathy
GCS: Glasgow Coma Scale
mTBI: mild traumatic brain injury
PCS: postconcussion syndrome
SCAT: Sport Concussion Assessment Tool
SRC: sport-related concussion

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REFERENCES

1. Stein CJ, MacDougall R, Quatman-Yates CC, et al. Young athletes' concerns about sport-related concussion: the patient's perspective. *Clin J Sport Med*. 2016;26(5):386–390
2. Fishman M, Taranto E, Perlman M, Quinlan K, Benjamin HJ, Ross LF. Attitudes and counseling practices of pediatricians regarding youth sports participation and concussion risks. *J Pediatr*. 2017;184:19–25
3. 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

4. Broglio SP, Cantu RC, Gioia GA, et al; National Athletic Trainer's Association. National Athletic Trainers' Association position statement: management of sport concussion. *J Athl Train*. 2014;49(2):245–265
5. Harmon KG, Drezner JA, Gammons M, et al. American Medical Society for Sports Medicine position statement: concussion in sport. *Br J Sports Med*. 2013;47(1):15–26
6. Herring SA, Cantu RC, Guskiewicz KM, et al; American College of Sports Medicine. Concussion (mild traumatic brain injury) and the team physician: a consensus statement–2011 update. *Med Sci Sports Exerc*. 2011;43(12):2412–2422
7. Giza CC, Kutcher JS, Ashwal S, et al. Summary of evidence-based guideline update: evaluation and management of concussion in sports: report of the guideline development Subcommittee of the American Academy of Neurology. *Neurology*. 2013;80(24):2250–2257
8. Graham R, Rivara FP, Ford MA, Spicer CM, eds. *Sports-Related Concussions in Youth: Improving the Science, Changing the Culture*. Washington, DC: The National Academies Press; 2014
9. Mannings C, Kalynych C, Joseph MM, Smotherman C, Kraemer DF. Knowledge assessment of sports-related concussion among parents of children aged 5 years to 15 years enrolled in recreational tackle football. *J Trauma Acute Care Surg*. 2014;77(3, suppl 1):S18–S22
10. Mrazik M, Perra A, Brooks BL, Naidu D. Exploring minor hockey players' knowledge and attitudes toward concussion: implications for prevention. *J Head Trauma Rehabil*. 2015;30(3):219–227
11. Stoller J, Carson JD, Garel A, et al. Do family physicians, emergency department physicians, and pediatricians give consistent sport-related concussion management advice? *Can Fam Physician*. 2014;60(6):548, 550–552
12. Carl RL, Kinsella SB. Pediatricians' knowledge of current sports concussion legislation and guidelines and comfort with sports concussion management: a cross-sectional study. *Clin Pediatr (Phila)*. 2014;53(7):689–697
13. Lebrun CM, Mrazik M, Prasad AS, et al. Sport concussion knowledge base, clinical practises and needs for continuing medical education: a survey of family physicians and cross-border comparison. *Br J Sports Med*. 2013;47(1):54–59
14. Lin AC, Salzman GA, Bachman SL, et al. Assessment of parental knowledge and attitudes toward pediatric sports-related concussions. *Sports Health*. 2015;7(2):124–129
15. Zemek R, Eady K, Moreau K, et al. Knowledge of paediatric concussion among front-line primary care providers. *Paediatr Child Health*. 2014;19(9):475–480
16. Register-Mihalik JK, Guskiewicz KM, McLeod TC, Linnan LA, Mueller FO, Marshall SW. Knowledge, attitude, and concussion-reporting behaviors among high school athletes: a preliminary study. *J Athl Train*. 2013;48(5):645–653
17. Zonfrillo MR, Master CL, Grady ME, Winston FK, Callahan JM, Arbogast KB. Pediatric providers' self-reported knowledge, practices, and attitudes about concussion. *Pediatrics*. 2012;130(6):1120–1125
18. Aubry M, Cantu R, Dvorak J, et al; Concussion in Sport (CIS) Group. Summary and agreement statement of the 1st international symposium on concussion in sport, Vienna 2001. *Clin J Sport Med*. 2002;12(1):6–11
19. McCrory P, Meeuwisse W, Dvořák J, et al. Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. *Br J Sports Med*. 2017;51(11):838–847
20. Carney N, Ghajar J, Jagoda A, et al. Concussion guidelines step 1: systematic review of prevalent indicators. *Neurosurgery*. 2014;75(suppl 1):S3–S15
21. Johnston KM, McCrory P, Mohtadi NG, Meeuwisse W. Evidence-based review of sport-related concussion: clinical science. *Clin J Sport Med*. 2001;11(3):150–159
22. Barth JT, Freeman JR, Broshek DK, Varney RN. Acceleration-deceleration sport-related concussion: the gravity of it all. *J Athl Train*. 2001;36(3):253–256
23. Denny-Brown DE, Russell WR. Experimental concussion: (section of neurology). *Proc R Soc Med*. 1941;34(11):691–692
24. Ommaya AK, Gennarelli TA. Cerebral concussion and traumatic unconsciousness. Correlation of experimental and clinical observations of blunt head injuries. *Brain*. 1974;97(4):633–654
25. Collins CL, Fletcher EN, Fields SK, et al. Neck strength: a protective factor reducing risk for concussion in high school sports. *J Prim Prev*. 2014;35(5):309–319
26. Buzzini SR, Guskiewicz KM. Sport-related concussion in the young athlete. *Curr Opin Pediatr*. 2006;18(4):376–382
27. Giza CC, Hovda DA. The new neurometabolic cascade of concussion. *Neurosurgery*. 2014;75(suppl 4):S24–S33
28. Barkhoudarian G, Hovda DA, Giza CC. The molecular pathophysiology of concussive brain injury. *Clin Sports Med*. 2011;30(1):33–48, vii–iii
29. Giza CC, Hovda DA. The neurometabolic cascade of concussion. *J Athl Train*. 2001;36(3):228–235
30. Choe MC, Babikian T, DiFiori J, Hovda DA, Giza CC. A pediatric perspective on concussion pathophysiology. *Curr Opin Pediatr*. 2012;24(6):689–695
31. Katayama Y, Becker DP, Tamura T, Hovda DA. Massive increases in extracellular potassium and the indiscriminate release of glutamate following concussive brain injury. *J Neurosurg*. 1990;73(6):889–900
32. Maugans TA, Farley C, Altaye M, Leach J, Cecil KM. Pediatric sports-related concussion produces cerebral blood flow alterations. *Pediatrics*. 2012;129(1):28–37
33. Yoshino A, Hovda DA, Kawamata T, Katayama Y, Becker DP. Dynamic changes in local cerebral glucose utilization following cerebral conclusion in rats: evidence of a hyper- and subsequent hypometabolic state. *Brain Res*. 1991;561(1):106–119
34. Sunami K, Nakamura T, Ozawa Y, Kubota M, Namba H, Yamaura A. Hypermetabolic state following

- experimental head injury. *Neurosurg Rev.* 1989;12(suppl 1):400–411
35. Creed JA, DiLeonardi AM, Fox DP, Tessler AR, Raghupathi R. Concussive brain trauma in the mouse results in acute cognitive deficits and sustained impairment of axonal function. *J Neurotrauma.* 2011;28(4):547–563
 36. Ajao DO, Pop V, Kamper JE, et al. Traumatic brain injury in young rats leads to progressive behavioral deficits coincident with altered tissue properties in adulthood. *J Neurotrauma.* 2012;29(11):2060–2074
 37. Prins ML, Hales A, Reger M, Giza CC, Hovda DA. Repeat traumatic brain injury in the juvenile rat is associated with increased axonal injury and cognitive impairments. *Dev Neurosci.* 2010;32(5–6):510–518
 38. Comstock D, Logan K. *Epidemiology and Prevention in Mild Traumatic Brain Injury in Children and Adolescents: From Basic Science to Clinical Management.* New York, NY: Guilford Press; 2012
 39. Gessel LM, Fields SK, Collins CL, Dick RW, Comstock RD. Concussions among United States high school and collegiate athletes. *J Athl Train.* 2007;42(4):495–503
 40. 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
 41. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. *J Head Trauma Rehabil.* 2006;21(5):375–378
 42. Thurman DJ, Branche CM, Sniezek JE. The epidemiology of sports-related traumatic brain injuries in the United States: recent developments. *J Head Trauma Rehabil.* 1998;13(2):1–8
 43. Bryan MA, Rowhani-Rahbar A, Comstock RD, Rivara F; Seattle Sports Concussion Research Collaborative. Sports- and recreation-related concussions in US youth. *Pediatrics.* 2016;138(1):e20154635
 44. McCrea M, Hammeke T, Olsen G, Leo P, Guskiewicz K. Unreported concussion in high school football players: implications for prevention. *Clin J Sport Med.* 2004;14(1):13–17
 45. LaRoche AA, Nelson LD, Connelly PK, Walter KD, McCrea MA. Sport-related concussion reporting and state legislative effects. *Clin J Sport Med.* 2016;26(1):33–39
 46. Daneshvar DH, Nowinski CJ, McKee AC, Cantu RC. The epidemiology of sport-related concussion. *Clin Sports Med.* 2011;30(1):1–17, vii
 47. Arbogast KB, Curry AE, Pfeiffer MR, et al. Point of health care entry for youth with concussion within a large pediatric care network. *JAMA Pediatr.* 2016;170(7):e160294
 48. Setnik L, Bazarian JJ. The characteristics of patients who do not seek medical treatment for traumatic brain injury. *Brain Inj.* 2007;21(1):1–9
 49. Rosenthal JA, Foraker RE, Collins CL, Comstock RD. National high school athlete concussion rates from 2005–2006 to 2011–2012. *Am J Sports Med.* 2014;42(7):1710–1715
 50. Gilchrist J, Thomas KE, Xu L, et al; Centers for Disease Control and Prevention. Nonfatal traumatic brain injuries related to sports and recreation activities among persons aged ≤19 years—United States, 2001–2009. *MMWR Morb Mortal Wkly Rep.* 2011;60(39):1337–1342
 51. Bakhos LL, Lockhart GR, Myers R, Linakis JG. Emergency department visits for concussion in young child athletes. *Pediatrics.* 2010;126(3). Available at: www.pediatrics.org/cgi/content/full/126/3/e550
 52. Guerriero RM, Proctor MR, Mannix R, Meehan WP III. Epidemiology, trends, assessment and management of sport-related concussion in United States high schools. *Curr Opin Pediatr.* 2012;24(6):696–701
 53. Wallace J, Covassin T, Nogle S, Gould D, Kovan J. Knowledge of concussion and reporting behaviors in high school athletes with or without access to an athletic trainer. *J Athl Train.* 2017;52(3):228–235
 54. Sye G, Sullivan SJ, McCrory P. High school rugby players' understanding of concussion and return to play guidelines. *Br J Sports Med.* 2006;40(12):1003–1005
 55. Chrisman SP, Quitiquit C, Rivara FP. Qualitative study of barriers to concussive symptom reporting in high school athletics. *J Adolesc Health.* 2013;52(3):330–335.e3
 56. Pfister T, Pfister K, Hagel B, Ghali WA, Ronksley PE. The incidence of concussion in youth sports: a systematic review and meta-analysis. *Br J Sports Med.* 2016;50(5):292–297
 57. Wallace J, Covassin T, Beidler E. Sex differences in high school athletes' knowledge of sport-related concussion symptoms and reporting behaviors. *J Athl Train.* 2017;52(7):682–688
 58. 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
 59. Meehan WP III, 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
 60. O'Connor KL, Baker MM, Dalton SL, Dompier TP, Broglio SP, Kerr ZY. Epidemiology of sport-related concussions in high school athletes: national athletic treatment, injury and outcomes network (NATION), 2011–2012 through 2013–2014. *J Athl Train.* 2017;52(3):175–185
 61. Currie DW, Fields SK, Patterson MJ, Comstock RD. Cheerleading injuries in United States high schools. *Pediatrics.* 2016;137(1):e20152447
 62. Castile L, Collins CL, McIlvain NM, Comstock RD. The epidemiology of new versus recurrent sports concussions among high school athletes, 2005–2010. *Br J Sports Med.* 2012;46(8):603–610
 63. Agel J, Harvey EJ. A 7-year review of men's and women's ice hockey injuries in the NCAA. *Can J Surg.* 2010;53(5):319–323
 64. Covassin T, Elbin RJ. The female athlete: the role of gender in the assessment and management of sport-related concussion. *Clin Sports Med.* 2011;30(1):125–131, x

65. Kerr ZY, Cortes N, Caswell AM, et al. Concussion rates in U.S. middle school athletes, 2015-2016 school year. *Am J Prev Med.* 2017;53(6):914–918
66. Caswell S, Prebble M, Romm K, Ambegaonkar J, Caswell A, Cortes N. Epidemiology of sports injuries among middle school students. *Br J Sports Med.* 2017;51(4):305
67. O’Kane JW, Spieker A, Levy MR, Neradilek M, Polissar NL, Schiff MA. Concussion among female middle-school soccer players. *JAMA Pediatr.* 2014;168(3):258–264
68. Kontos AP, Elbin RJ, Fazio-Sumrock VC, et al. Incidence of sports-related concussion among youth football players aged 8-12 years. *J Pediatr.* 2013;163(3):717–720
69. Kontos AP, Elbin RJ, Sufrinko A, et al. Incidence of concussion in youth ice hockey players. *Pediatrics.* 2016;137(2):e20151633
70. Buzas D, Jacobson NA, Morawa LG. Concussions from 9 youth organized sports: results from NEISS hospitals over an 11-year time frame, 2002-2012. *Orthop J Sports Med.* 2014;2(4):2325967114528460
71. Xiang J, Collins CL, Liu D, McKenzie LB, Comstock RD. Lacrosse injuries among high school boys and girls in the United States: academic years 2008-2009 through 2011-2012. *Am J Sports Med.* 2014;42(9):2082–2088
72. Meehan WP III, d’Hemecourt P, Comstock RD. High school concussions in the 2008-2009 academic year: mechanism, symptoms, and management. *Am J Sports Med.* 2010;38(12):2405–2409
73. Master CL, Scheiman M, Gallaway M, et al. Vision diagnoses are common after concussion in adolescents. *Clin Pediatr (Phila).* 2016;55(3):260–267
74. Ellis MJ, Cordingley DM, Vis S, Reimer KM, Leiter J, Russell K. Clinical predictors of vestibulo-ocular dysfunction in pediatric sports-related concussion. *J Neurosurg Pediatr.* 2017;19(1):38–45
75. Rowhani-Rahbar A, Chrisman SP, Drescher S, Schiff MA, Rivara FP. Agreement between high school athletes and their parents on reporting athletic events and concussion symptoms. *J Neurotrauma.* 2016;33(8):784–791
76. Davis GA, Purcell L, Schneider KJ, et al. The child sport concussion assessment tool 5th edition (Child SCAT5): background and rationale. *Br J Sports Med.* 2017;51(11):859–861
77. Ono KE, Burns TG, Bearden DJ, McManus SM, King H, Reisner A. Sex-based differences as a predictor of recovery trajectories in young athletes after a sports-related concussion. *Am J Sports Med.* 2016;44(3):748–752
78. Zuckerman SL, Apple RP, Odom MJ, Lee YM, Solomon GS, Sills AK. Effect of sex on symptoms and return to baseline in sport-related concussion. *J Neurosurg Pediatr.* 2014;13(1):72–81
79. Brown DA, Elsass JA, Miller AJ, Reed LE, Reneker JC. Differences in symptom reporting between males and females at baseline and after a sports-related concussion: a systematic review and meta-analysis. *Sports Med.* 2015;45(7):1027–1040
80. Gibson S, Nigrovic LE, O’Brien M, Meehan WP III. The effect of recommending cognitive rest on recovery from sport-related concussion. *Brain Inj.* 2013;27(7–8):839–842
81. Heyer GL, Schaffer CE, Rose SC, Young JA, McNally KA, Fischer AN. Specific factors influence postconcussion symptom duration among youth referred to a sports concussion clinic. *J Pediatr.* 2016;174:33–38.e2
82. Meehan WP III, 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
83. Meehan WP III, Mannix R, Monuteaux MC, Stein CJ, Bachur RG. Early symptom burden predicts recovery after sport-related concussion. *Neurology.* 2014;83(24):2204–2210
84. Biederman J, Feinberg L, Chan J, et al. Mild traumatic brain injury and attention-deficit hyperactivity disorder in young student athletes. *J Nerv Ment Dis.* 2015;203(11):813–819
85. 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
86. Kriz PK, Stein C, Kent J, et al. Physical maturity and concussion symptom duration among adolescent ice hockey players. *J Pediatr.* 2016;171:234–239.e1–e2
87. Grubenhoff JA, Currie D, Comstock RD, Juarez-Colunga E, Bajaj L, Kirkwood MW. Psychological factors associated with delayed symptom resolution in children with concussion. *J Pediatr.* 2016;174:27–32.e1
88. Echemendia RJ, Meeuwisse W, McCrory P, et al. The sport concussion assessment tool 5th edition (SCAT5): background and rationale. *Br J Sports Med.* 2017;51(11):848–850
89. Giola G, Collins M; Centers for Disease Control and Prevention. Acute Concussion Evaluation (ACE): physician/clinician office evaluation. 2006. Available at: <https://www.cdc.gov/headsup/pdfs/providers/ace-a.pdf>. Accessed May 14, 2018
90. Glaviano NR, Benson S, Goodkin HP, Broshek DK, Saliba S. Baseline SCAT2 assessment of healthy youth student-athletes: preliminary evidence for the use of the Child-SCAT3 in children younger than 13 years. *Clin J Sport Med.* 2015;25(4):373–379
91. Jinguiji TM, Bompadre V, Harmon KG, et al. Sport concussion assessment tool-2: baseline values for high school athletes. *Br J Sports Med.* 2012;46(5):365–370
92. Brooks MA, Snedden TR, Mixis B, Hetzel S, McGuine TA. Establishing baseline normative values for the child sport concussion assessment tool. *JAMA Pediatr.* 2017;171(7):670–677
93. Hansen C, Cushman D, Anderson N, et al. A normative dataset of the balance error scoring system in children aged between 5 and 14. *Clin J Sport Med.* 2016;26(6):497–501
94. Schneider KJ, Emery CA, Kang J, Schneider GM, Meeuwisse WH. Examining sport concussion assessment tool ratings for male and female youth hockey players with and without a history of concussion. *Br J Sports Med.* 2010;44(15):1112–1117

95. Snedden TR, Brooks MA, Hetzel S, McGuine T. Normative values of the sport concussion assessment tool 3 (SCAT3) in high school athletes. *Clin J Sport Med*. 2017;27(5):462–467
96. Khanna NK, Baumgartner K, LaBella CR. Balance error scoring system performance in children and adolescents with no history of concussion. *Sports Health*. 2015;7(4):341–345
97. Alsalaheen B, McClafferty A, Haines J, Smith L, Yorke A. Reference values for the balance error scoring system in adolescents. *Brain Inj*. 2016;30(7):914–918
98. Murray N, Salvatore A, Powell D, Reed-Jones R. Reliability and validity evidence of multiple balance assessments in athletes with a concussion. *J Athl Train*. 2014;49(4):540–549
99. Hansen C, Cushman D, Chen W, Bounsanga J, Hung M. Reliability testing of the balance error scoring system in children between the ages of 5 and 14. *Clin J Sport Med*. 2017;27(1):64–68
100. Tjarks BJ, Dorman JC, Valentine VD, et al. Comparison and utility of King-Devick and ImPACT® composite scores in adolescent concussion patients. *J Neurol Sci*. 2013;334(1–2):148–153
101. Mucha A, Collins MW, Elbin RJ, et al. A brief Vestibular/Ocular Motor Screening (VOMS) assessment to evaluate concussions: preliminary findings. *Am J Sports Med*. 2014;42(10):2479–2486
102. Pearce KL, Sufrinko A, Lau BC, Henry L, Collins MW, Kontos AP. Near point of convergence after a sport-related concussion: measurement reliability and relationship to neurocognitive impairment and symptoms. *Am J Sports Med*. 2015;43(12):3055–3061
103. Vernau BT, Grady MF, Goodman A, et al. Oculomotor and neurocognitive assessment of youth ice hockey players: baseline associations and observations after concussion. *Dev Neuropsychol*. 2015;40(1):7–11
104. McCrory PR, Berkovic SF. Video analysis of acute motor and convulsive manifestations in sport-related concussion. *Neurology*. 2000;54(7):1488–1491
105. Pulsipher DT, Campbell RA, Thoma R, King JH. A critical review of neuroimaging applications in sports concussion. *Curr Sports Med Rep*. 2011;10(1):14–20
106. Davis GA, Iverson GL, Guskiewicz KM, Ptito A, Johnston KM. Contributions of neuroimaging, balance testing, electrophysiology and blood markers to the assessment of sport-related concussion. *Br J Sports Med*. 2009;43(suppl 1):i36–i45
107. Zonfrillo MR, Kim KH, Arbogast KB. Emergency department visits and head computed tomography utilization for concussion patients from 2006 to 2011. *Acad Emerg Med*. 2015;22(7):872–877
108. Fung M, Willer B, Moreland D, Leddy JJ. A proposal for an evidenced-based emergency department discharge form for mild traumatic brain injury. *Brain Inj*. 2006;20(9):889–894
109. Kirkwood MW, Yeates KO, Wilson PE. Pediatric sport-related concussion: a review of the clinical management of an oft-neglected population. *Pediatrics*. 2006;117(4):1359–1371
110. Hamilton M, Mrazik M, Johnson DW. Incidence of delayed intracranial hemorrhage in children after uncomplicated minor head injuries. *Pediatrics*. 2010;126(1). Available at: www.pediatrics.org/cgi/content/full/126/1/e33
111. Johnston KM, Ptito A, Chankowsky J, Chen JK. New frontiers in diagnostic imaging in concussive head injury. *Clin J Sport Med*. 2001;11(3):166–175
112. Huang WY, Muo CH, Lin CY, et al. Paediatric head CT scan and subsequent risk of malignancy and benign brain tumour: a nation-wide population-based cohort study. *Br J Cancer*. 2014;110(9):2354–2360
113. Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. *Lancet*. 2012;380(9840):499–505
114. Brenner DJ. Estimating cancer risks from pediatric CT: going from the qualitative to the quantitative. *Pediatr Radiol*. 2002;32(4):228–231; discussion 242–244
115. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. *N Engl J Med*. 2007;357(22):2277–2284
116. Haydel MJ, Preston CA, Mills TJ, Lubner S, Blaudeau E, DeBlieux PM. Indications for computed tomography in patients with minor head injury. *N Engl J Med*. 2000;343(2):100–105
117. Stiell IG, Lesiuk H, Wells GA, et al; Canadian CT Head and C-Spine Study Group. The Canadian CT Head Rule Study for patients with minor head injury: rationale, objectives, and methodology for phase I (derivation). *Ann Emerg Med*. 2001;38(2):160–169
118. Kuppermann N, Holmes JF, Dayan PS, et al; Pediatric Emergency Care Applied Research Network (PECARN). Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. *Lancet*. 2009;374(9696):1160–1170
119. Osmond MH, Klassen TP, Wells GA, et al; Pediatric Emergency Research Canada (PERC) Head Injury Study Group. CATCH: a clinical decision rule for the use of computed tomography in children with minor head injury. *CMAJ*. 2010;182(4):341–348
120. Lee B, Newberg A. Neuroimaging in traumatic brain imaging. *NeuroRx*. 2005;2(2):372–383
121. Bonow RH, Friedman SD, Perez FA, et al. Prevalence of abnormal magnetic resonance imaging findings in children with persistent symptoms after pediatric sports-related concussion. *J Neurotrauma*. 2017;34(19):2706–2712
122. Toledo E, Lebel A, Becerra L, et al. The young brain and concussion: imaging as a biomarker for diagnosis and prognosis. *Neurosci Biobehav Rev*. 2012;36(6):1510–1531
123. Eierud C, Craddock RC, Fletcher S, et al. Neuroimaging after mild traumatic brain injury: review and meta-analysis. *Neuroimage Clin*. 2014;4:283–294
124. Shenton ME, Hamoda HM, Schneiderman JS, et al. A review of

- magnetic resonance imaging and diffusion tensor imaging findings in mild traumatic brain injury. *Brain Imaging Behav.* 2012;6(2):137–192
125. Cernich A, Reeves D, Sun W, Bleiberg J. Automated neuropsychological assessment metrics sports medicine battery. *Arch Clin Neuropsychol.* 2007;22(suppl 1):S101–S114
 126. Collie A, Maruff P, Makdissi M, McCrory P, McStephen M, Darby D. CogSport: reliability and correlation with conventional cognitive tests used in postconcussion medical evaluations. *Clin J Sport Med.* 2003;13(1):28–32
 127. Erlanger D, Feldman D, Kutner K, et al. Development and validation of a web-based neuropsychological test protocol for sports-related return-to-play decision-making. *Arch Clin Neuropsychol.* 2003;18(3):293–316
 128. Schatz P, Pardini JE, Lovell MR, Collins MW, Podell K. Sensitivity and specificity of the ImPACT test battery for concussion in athletes. *Arch Clin Neuropsychol.* 2006;21(1):91–99
 129. Segalowitz SJ, Mahaney P, Santesso DL, MacGregor L, Dywan J, Willer B. Retest reliability in adolescents of a computerized neuropsychological battery used to assess recovery from concussion. *NeuroRehabilitation.* 2007;22(3):243–251
 130. Van Kampen DA, Lovell MR, Pardini JE, Collins MW, Fu FH. The “value added” of neurocognitive testing after sports-related concussion. *Am J Sports Med.* 2006;34(10):1630–1635
 131. Fazio VC, Lovell MR, Pardini JE, Collins MW. The relation between post concussion symptoms and neurocognitive performance in concussed athletes. *NeuroRehabilitation.* 2007;22(3):207–216
 132. Collins MW, Field M, Lovell MR, et al. Relationship between postconcussion headache and neuropsychological test performance in high school athletes. *Am J Sports Med.* 2003;31(2):168–173
 133. Erlanger D, Saliba E, Barth J, Almquist J, Webright W, Freeman J. Monitoring resolution of postconcussion symptoms in athletes: preliminary results of a web-based neuropsychological test protocol. *J Athl Train.* 2001;36(3):280–287
 134. Broglio SP, Ferrara MS, Macciocchi SN, Baumgartner TA, Elliott R. Test-retest reliability of computerized concussion assessment programs. *J Athl Train.* 2007;42(4):509–514
 135. Randolph C, McCrea M, Barr WB. Is neuropsychological testing useful in the management of sport-related concussion? *J Athl Train.* 2005;40(3):139–152
 136. MacDonald J, Duerson D. Reliability of a computerized neurocognitive test in baseline concussion testing of high school athletes. *Clin J Sport Med.* 2015;25(4):367–372
 137. Elbin RJ, Schatz P, Covassin T. One-year test-retest reliability of the online version of ImPACT in high school athletes. *Am J Sports Med.* 2011;39(11):2319–2324
 138. Brett BL, Smyk N, Solomon G, Baughman BC, Schatz P. Long-term stability and reliability of baseline cognitive assessments in high school athletes using ImPACT at 1-, 2-, and 3-year test-retest intervals [published online ahead of print August 18, 2016]. *Arch Clin Neuropsychol.* doi:10.1093/arclin/acw055
 139. Barr WB. Neuropsychological testing of high school athletes. Preliminary norms and test-retest indices. *Arch Clin Neuropsychol.* 2003;18(1):91–101
 140. McClure DJ, Zuckerman SL, Kutscher SJ, Gregory AJ, Solomon GS. Baseline neurocognitive testing in sports-related concussions: the importance of a prior night’s sleep. *Am J Sports Med.* 2014;42(2):472–478
 141. Kostyun RO, Milewski MD, Hafeez I. Sleep disturbance and neurocognitive function during the recovery from a sport-related concussion in adolescents. *Am J Sports Med.* 2015;43(3):633–640
 142. Sufrinko A, Johnson EW, Henry LC. The influence of sleep duration and sleep-related symptoms on baseline neurocognitive performance among male and female high school athletes. *Neuropsychology.* 2016;30(4):484–491
 143. Stocker RPJ, Khan H, Henry L, Germain A. Effects of sleep loss on subjective complaints and objective neurocognitive performance as measured by the immediate post-concussion assessment and cognitive testing. *Arch Clin Neuropsychol.* 2017;32(3):349–368
 144. Brooks BL, Mrazik M, Barlow KM, McKay CD, Meeuwisse WH, Emery CA. Absence of differences between male and female adolescents with prior sport concussion. *J Head Trauma Rehabil.* 2014;29(3):257–264
 145. Mannix R, Iverson GL, Maxwell B, Atkins JE, Zafonte R, Berkner PD. Multiple prior concussions are associated with symptoms in high school athletes. *Ann Clin Transl Neurol.* 2014;1(6):433–438
 146. Zuckerman SL, Lee YM, Odom MJ, Solomon GS, Sills AK. Baseline neurocognitive scores in athletes with attention deficit-spectrum disorders and/or learning disability. *J Neurosurg Pediatr.* 2013;12(2):103–109
 147. Littleton AC, Schmidt JD, Register-Mihalik JK, et al. Effects of attention deficit hyperactivity disorder and stimulant medication on concussion symptom reporting and computerized neurocognitive test performance. *Arch Clin Neuropsychol.* 2015;30(7):683–693
 148. Hutchison M, Comper P, Mainwaring L, Richards D. The influence of musculoskeletal injury on cognition: implications for concussion research. *Am J Sports Med.* 2011;39(11):2331–2337
 149. Broglio SP, Eckner JT, Surma T, Kutcher JS. Post-concussion cognitive declines and symptomatology are not related to concussion biomechanics in high school football players. *J Neurotrauma.* 2011;28(10):2061–2068
 150. Covassin T, Elbin RJ III, Larson E, Kontos AP. Sex and age differences in depression and baseline sport-related concussion neurocognitive performance and symptoms. *Clin J Sport Med.* 2012;22(2):98–104
 151. Moser RS, Schatz P, Neidzwski K, Ott SD. Group versus individual administration affects baseline neurocognitive test performance. *Am J Sports Med.* 2011;39(11):2325–2330
 152. Lichtenstein JD, Moser RS, Schatz P. Age and test setting affect the prevalence of invalid baseline scores

- on neurocognitive tests. *Am J Sports Med.* 2014;42(2):479–484
153. Vaughan CG, Gerst EH, Sady MD, Newman JB, Gioia GA. The relation between testing environment and baseline performance in child and adolescent concussion assessment. *Am J Sports Med.* 2014;42(7):1716–1723
 154. Schatz P, Kelley T, Ott SD, et al. Utility of repeated assessment after invalid baseline neurocognitive test performance. *J Athl Train.* 2014;49(5):659–664
 155. Erdal K. Neuropsychological testing for sports-related concussion: how athletes can sandbag their baseline testing without detection. *Arch Clin Neuropsychol.* 2012;27(5):473–479
 156. Schatz P, Glatts C. “Sandbagging” baseline test performance on ImPACT, without detection, is more difficult than it appears. *Arch Clin Neuropsychol.* 2013;28(3):236–244
 157. Higgins KL, Denney RL, Maerlender A. Sandbagging on the immediate post-concussion assessment and cognitive testing (ImPACT) in a high school athlete population. *Arch Clin Neuropsychol.* 2017;32(3):259–266
 158. Schmidt JD, Register-Mihalik JK, Mihalik JP, Kerr ZY, Guskiewicz KM. Identifying impairments after concussion: normative data versus individualized baselines. *Med Sci Sports Exerc.* 2012;44(9):1621–1628
 159. Schatz P, Robertshaw S. Comparing post-concussive neurocognitive test data to normative data presents risks for under-classifying “above average” athletes. *Arch Clin Neuropsychol.* 2014;29(7):625–632
 160. Pleacher MD, Dexter WW. Concussion management by primary care providers. *Br J Sports Med.* 2006;40(1):e2, discussion e2
 161. Echemendia RJ, Herring S, Bailes J. Who should conduct and interpret the neuropsychological assessment in sports-related concussion? *Br J Sports Med.* 2009;43(suppl 1):i32–i35
 162. Elbin RJ, Sufrinko A, Schatz P, et al. Removal from play after concussion and recovery time. *Pediatrics.* 2016;138(3):e202160910
 163. Terwilliger VK, Pratson L, Vaughan CG, Gioia GA. Additional post-concussion impact exposure may affect recovery in adolescent athletes. *J Neurotrauma.* 2016;33(8):761–765
 164. 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
 165. Moor HM, Eisenhauer RC, Killian KD, et al. The relationship between adherence behaviors and recovery time in adolescents after a sports-related concussion: an observational study. *Int J Sports Phys Ther.* 2015;10(2):225–233
 166. Buckley TA, Munkasy BA, Clouse BP. Acute cognitive and physical rest may not improve concussion recovery time. *J Head Trauma Rehabil.* 2016;31(4):233–241
 167. Sufrinko AM, Kontos AP, Apps JN, et al. The effectiveness of prescribed rest depends on initial presentation after concussion. *J Pediatr.* 2017;185:167–172
 168. Grool AM, Aglipay M, Momoli F, et al; Pediatric Emergency Research Canada (PERC) Concussion Team. Association between early participation in physical activity following acute concussion and persistent postconcussive symptoms in children and adolescents. *JAMA.* 2016;316(23):2504–2514
 169. Howell DR, Mannix RC, Quinn B, Taylor JA, Tan CO, Meehan WP III. Physical activity level and symptom duration are not associated after concussion. *Am J Sports Med.* 2016;44(4):1040–1046
 170. Brown NJ, Mannix RC, O’Brien MJ, Gostine D, Collins MW, Meehan WP III. Effect of cognitive activity level on duration of post-concussion symptoms. *Pediatrics.* 2014;133(2). Available at: www.pediatrics.org/cgi/content/full/133/2/e299
 171. Leddy J, Hinds A, Sirica D, Willer B. The role of controlled exercise in concussion management. *PM R.* 2016;8(suppl 3):S91–S100
 172. Halstead ME, McAvoy K, Devore CD, Carl R, Lee M, Logan K; Council on Sports Medicine and Fitness; Council on School Health. Returning to learning following a concussion. *Pediatrics.* 2013;132(5):948–957
 173. Baker A, Unsworth CA, Lannin NA. Fitness-to-drive after mild traumatic brain injury: mapping the time trajectory of recovery in the acute stages post injury. *Accid Anal Prev.* 2015;79:50–55
 174. Preece MH, Horswill MS, Geffen GM. Driving after concussion: the acute effect of mild traumatic brain injury on drivers’ hazard perception. *Neuropsychology.* 2010;24(4):493–503
 175. Kinnaman KA, Mannix RC, Comstock RD, Meehan WP III. Management strategies and medication use for treating paediatric patients with concussions. *Acta Paediatr.* 2013;102(9):e424–e428
 176. Kinnaman KA, Mannix RC, Comstock RD, Meehan WP III. Management of pediatric patients with concussion by emergency medicine physicians. *Pediatr Emerg Care.* 2014;30(7):458–461
 177. Stache S, Howell D, Meehan WP III. Concussion management practice patterns among sports medicine physicians. *Clin J Sport Med.* 2016;26(5):381–385
 178. Heyer GL, Idris SA. Does analgesic overuse contribute to chronic post-traumatic headaches in adolescent concussion patients? *Pediatr Neurol.* 2014;50(5):464–468
 179. Schneider KJ, Meeuwisse WH, Nettel-Aguirre A, et al. Cervicovestibular rehabilitation in sport-related concussion: a randomised controlled trial. *Br J Sports Med.* 2014;48(17):1294–1298
 180. Taubman B, McHugh J, Rosen F, Elci OU. Repeat concussion and recovery time in a primary care pediatric office. *J Child Neurol.* 2016;31(14):1607–1610
 181. Nelson LD, Guskiewicz KM, Barr WB, et al. Age differences in recovery after sport-related concussion: a comparison of high school and collegiate athletes. *J Athl Train.* 2016;51(2):142–152
 182. Williams RM, Puetz TW, Giza CC, Broglio SP. Concussion recovery time among high school and collegiate athletes: a systematic review and meta-analysis. *Sports Med.* 2015;45(6):893–903

183. Erlanger D, Kaushik T, Cantu R, et al. Symptom-based assessment of the severity of a concussion. *J Neurosurg.* 2003;98(3):477–484
184. Lee YM, Odom MJ, Zuckerman SL, Solomon GS, Sills AK. Does age affect symptom recovery after sports-related concussion? A study of high school and college athletes. *J Neurosurg Pediatr.* 2013;12(6):537–544
185. Purcell L, Harvey J, Seabrook JA. Patterns of recovery following sport-related concussion in children and adolescents. *Clin Pediatr (Phila).* 2016;55(5):452–458
186. McClincy MP, Lovell MR, Pardini J, Collins MW, Spore MK. Recovery from sports concussion in high school and collegiate athletes. *Brain Inj.* 2006;20(1):33–39
187. Sabatino M, Zynda A, Miller S. Same-day return to play after pediatric athletes sustain concussions. In: *American Academy of Pediatrics National Conference and Exhibition*; October 22–25, 2016; San Francisco, CA. Abstract
188. Kerr ZY, Zuckerman SL, Wasserman EB, Covassin T, Djoko A, Dompier TP. Concussion symptoms and return to play time in youth, high school, and college American football athletes. *JAMA Pediatr.* 2016;170(7):647–653
189. Boden BP, Tacchetti RL, Cantu RC, Knowles SB, Mueller FO. Catastrophic head injuries in high school and college football players. *Am J Sports Med.* 2007;35(7):1075–1081
190. Bey T, Ostick B. Second impact syndrome. *West J Emerg Med.* 2009;10(1):6–10
191. DiFazio M, Silverberg ND, Kirkwood MW, Bernier R, Iverson GL. Prolonged activity restriction after concussion: are we worsening outcomes? *Clin Pediatr (Phila).* 2016;55(5):443–451
192. Canadian Academy of Sport Medicine Concussion Committee. Guidelines for assessment and management of sport-related concussion. *Clin J Sport Med.* 2000;10(3):209–211
193. Green L; National Federation of State High School Associations. Legal perspectives, recommendations on state concussion laws. 2014. Available at: <https://www.nfhs.org/articles/legal-perspectives-recommendations-on-state-concussion-laws/>. Accessed March 28, 2017
194. Simon LM, Mitchell CN. Youth concussion laws across the nation: implications for the traveling team physician. *Curr Sports Med Rep.* 2016;15(3):161–167
195. Concannon LG. Effects of legislation on sports-related concussion. *Phys Med Rehabil Clin N Am.* 2016;27(2):513–527
196. Pfaller AY, Nelson LD, Apps JN, Walter KD, McCrema MA. Frequency and outcomes of a symptom-free waiting period after sport-related concussion. *Am J Sports Med.* 2016;44(11):2941–2946
197. Shenouda C, Hendrickson P, Davenport K, Barber J, Bell KR. The effects of concussion legislation one year later—what have we learned: a descriptive pilot survey of youth soccer player associates. *PM R.* 2012;4(6):427–435
198. 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
199. Chrisman SP, Schiff MA, Chung SK, Herring SA, Rivara FP. Implementation of concussion legislation and extent of concussion education for athletes, parents, and coaches in Washington State. *Am J Sports Med.* 2014;42(5):1190–1196
200. Root JM, Zuckerbraun NS, Wang L, et al. History of somatization is associated with prolonged recovery from concussion. *J Pediatr.* 2016;174:39–44. e1
201. World Health Organization. *The ICD-10 Classification of Mental and Behavioural Disorders: Clinical Descriptions and Diagnostic Guidelines*. Geneva, Switzerland: World Health Organization; 1992
202. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders*. 4th ed. Washington, DC: American Psychiatric Association; 2000
203. Mez J, Daneshvar DH, Kiernan PT, et al. Clinicopathological evaluation of chronic traumatic encephalopathy in players of American football. *JAMA.* 2017;318(4):360–370
204. Savica R, Parisi JE, Wold LE, Josephs KA, Ahlskog JE. High school football and risk of neurodegeneration: a community-based study. *Mayo Clin Proc.* 2012;87(4):335–340
205. Deshpande SK, Hasegawa RB, Rabinowitz AR, et al. Association of playing high school football with cognition and mental health later in life. *JAMA Neurol.* 2017;74(8):909–918
206. McLendon LA, Kralik SF, Grayson PA, Golomb MR. The controversial second impact syndrome: a review of the literature. *Pediatr Neurol.* 2016;62:9–17
207. Cantu RC, Voy R. Second impact syndrome. *Phys Sportsmed.* 1995;23(6):27–34
208. Mueller FO. Catastrophic head injuries in high school and collegiate sports. *J Athl Train.* 2001;36(3):312–315
209. Cantu RC, Register-Mihalik JK. Considerations for return-to-play and retirement decisions after concussion. *PM R.* 2011;3(10, suppl 2):S440–S444
210. Concannon LG, Kaufman MS, Herring SA. The million dollar question: when should an athlete retire after concussion? *Curr Sports Med Rep.* 2014;13(6):365–369
211. Mayer C. Tooth protectors for boxers. *Oral Hyg.* 1930;20:298–299
212. Watts G, Woolard A, Singer CE. Functional mouth protectors for contact sports. *J Am Dent Assoc.* 1954;49(1):7–11
213. Stenger JM, Lawson EA, Wright JM, Ricketts J. Mouthguards: protection against shock to head, neck and teeth. *J Am Dent Assoc.* 1964;69:273–281
214. Labella CR, Smith BW, Sigurdsson A. Effect of mouthguards on dental injuries and concussions in college basketball. *Med Sci Sports Exerc.* 2002;34(1):41–44
215. Wisniewski JF, Guskiewicz K, Trope M, Sigurdsson A. Incidence of cerebral concussions associated with type of mouthguard used in college football. *Dent Traumatol.* 2004;20(3):143–149
216. Finch C, Braham R, McIntosh A, McCrory P, Wolfe R. Should football players wear custom fitted mouthguards? Results from a group randomised controlled trial. *Inj Prev.* 2005;11(4):242–246

217. Mihalik JP, McCaffrey MA, Rivera EM, et al. Effectiveness of mouthguards in reducing neurocognitive deficits following sports-related cerebral concussion. *Dent Traumatol.* 2007;23(1):14–20
218. Viano DC, Withnall C, Wonnacott M. Effect of mouthguards on head responses and mandible forces in football helmet impacts. *Ann Biomed Eng.* 2012;40(1):47–69
219. Singh GD, Maher GJ, Padilla RR. Customized mandibular orthotics in the prevention of concussion/mild traumatic brain injury in football players: a preliminary study. *Dent Traumatol.* 2009;25(5):515–521
220. McGuine TA, Hetzel S, McCrear M, Brooks MA. Protective equipment and player characteristics associated with the incidence of sport-related concussion in high school football players: a multifactorial prospective study. *Am J Sports Med.* 2014;42(10):2470–2478
221. Winters J, DeMont R. Role of mouthguards in reducing mild traumatic brain injury/concussion incidence in high school football athletes. *Gen Dent.* 2014;62(3):34–38
222. Section on Oral Health. Maintaining and improving the oral health of young children. *Pediatrics.* 2014;134(6):1224–1229
223. Viano DC, Withnall C, Halstead D. Impact performance of modern football helmets. *Ann Biomed Eng.* 2012;40(1):160–174
224. Levy ML, Ozgür BM, Berry C, Aryan HE, Apuzzo ML. Birth and evolution of the football helmet. *Neurosurgery.* 2004;55(3):656–661; discussion 661–662
225. Collins CL, McKenzie LB, Ferketich AK, Andridge R, Xiang H, Comstock RD. Concussion characteristics in high school football by helmet age/recondition status, manufacturer, and model: 2008–2009 through 2012–2013 academic years in the United States. *Am J Sports Med.* 2016;44(6):1382–1390
226. Schneider DK, Grandhi RK, Bansal P, et al. Current state of concussion prevention strategies: a systematic review and meta-analysis of prospective, controlled studies. *Br J Sports Med.* 2017;51(20):1473–1482
227. McGuine T, Nass S. Football helmet fitting errors in Wisconsin high school players. In: Hoerner EF, ed. *Safety in American Football. ASTM STP 1305.* West Conshohocken, PA: American Society for Testing and Materials; 1996:83–88
228. Greenhill DA, Navo P, Zhao H, Torg J, Comstock RD, Boden BP. Inadequate helmet fit increases concussion severity in American high school football players. *Sports Health.* 2016;8(3):238–243
229. Mihalik JP, Bell DR, Marshall SW, Guskiewicz KM. Measurement of head impacts in collegiate football players: an investigation of positional and event-type differences. *Neurosurgery.* 2007;61(6):1229–1235; discussion 1235
230. Mihalik JP, Lynall RC, Wasserman EB, Guskiewicz KM, Marshall SW. Evaluating the “Threshold theory”: can head impact indicators help? *Med Sci Sports Exerc.* 2017;49(2):247–253
231. Siegmund GP, Guskiewicz KM, Marshall SW, DeMarco AL, Bonin SJ. Laboratory validation of two wearable sensor systems for measuring head impact severity in football players. *Ann Biomed Eng.* 2016;44(4):1257–1274
232. McCrory P. The role of helmets in skiing and snowboarding. *Br J Sports Med.* 2002;36(5):314
233. Sulheim S, Holme I, Ekland A, Bahr R. Helmet use and risk of head injuries in alpine skiers and snowboarders. *JAMA.* 2006;295(8):919–924
234. Fukuda O, Hirashima Y, Origasa H, Endo S. Characteristics of helmet or knit cap use in head injury of snowboarders. *Neurol Med Chir (Tokyo).* 2007;47(11):491–494; discussion 494
235. Mueller BA, Cummings P, Rivara FP, Brooks MA, Terasaki RD. Injuries of the head, face, and neck in relation to ski helmet use. *Epidemiology.* 2008;19(2):270–276
236. Cusimano MD, Kwok J. The effectiveness of helmet wear in skiers and snowboarders: a systematic review. *Br J Sports Med.* 2010;44(11):781–786
237. Caswell SV, Deivert RG. Lacrosse helmet designs and the effects of impact forces. *J Athl Train.* 2002;37(2):164–171
238. Bond GR, Christoph RA, Rodgers BM. Pediatric equestrian injuries: assessing the impact of helmet use. *Pediatrics.* 1995;95(4):487–489
239. Brandenburg MA, Archer P. Survey analysis to assess the effectiveness of the bull tough helmet in preventing head injuries in bull riders: a pilot study. *Clin J Sport Med.* 2002;12(6):360–366
240. Downey DJ. Rodeo injuries and prevention. *Curr Sports Med Rep.* 2007;6(5):328–332
241. Wasserman RC, Buccini RV. Helmet protection from head injuries among recreational bicyclists. *Am J Sports Med.* 1990;18(1):96–97
242. Clark JM, Post A, Hoshizaki TB, Gilchrist MD. Protective capacity of ice hockey helmets against different impact events. *Ann Biomed Eng.* 2016;44(12):3693–3704
243. Withnall C, Shewchenko N, Gittens R, Dvorak J. Biomechanical investigation of head impacts in football. *Br J Sports Med.* 2005;39(suppl 1):i49–i57
244. Elbin RJ, Beatty A, Covassin T, Schatz P, Hydeman A, Kontos AP. A preliminary examination of neurocognitive performance and symptoms following a bout of soccer heading in athletes wearing protective soccer headbands. *Res Sports Med.* 2015;23(2):203–214
245. McIntosh AS, McCrory P. Impact energy attenuation performance of football headgear. *Br J Sports Med.* 2000;34(5):337–341
246. Guskiewicz KM, Marshall SW, Broglio SP, Cantu RC, Kirkendall DT. No evidence of impaired neurocognitive performance in collegiate soccer players. *Am J Sports Med.* 2002;30(2):157–162
247. Withnall C, Shewchenko N, Wonnacott M, Dvorak J. Effectiveness of headgear in football. *Br J Sports Med.* 2005;39(suppl 1):i40–i48; discussion i48
248. Tierney RT, Higgins M, Caswell SV, et al. Sex differences in head acceleration during heading while

- wearing soccer headgear. *J Athl Train*. 2008;43(6):578–584
249. McIntosh AS, McCrory P. Effectiveness of headgear in a pilot study of under 15 rugby union football. *Br J Sports Med*. 2001;35(3):167–169
 250. McIntosh AS, McCrory P, Finch CF, Best JP, Chalmers DJ, Wolfe R. Does padded headgear prevent head injury in rugby union football? *Med Sci Sports Exerc*. 2009;41(2):306–313
 251. Marshall SW, Loomis DP, Waller AE, et al. Evaluation of protective equipment for prevention of injuries in rugby union. *Int J Epidemiol*. 2005;34(1):113–118
 252. Glang AE, Koester MC, Chesnutt JC, et al. The effectiveness of a web-based resource in improving postconcussion management in high schools. *J Adolesc Health*. 2015;56(1):91–97
 253. Reisner A, Burns TG, Hall LB, et al. Quality improvement in concussion care: influence of guideline-based education. *J Pediatr*. 2017;184:26–31
 254. Parker EM, Gilchrist J, Schuster D, Lee R, Sarmiento K. Reach and knowledge change among coaches and other participants of the online course: “concussion in sports: what you need to know”. *J Head Trauma Rehabil*. 2015;30(3):198–206
 255. Bramley H, Patrick K, Lehman E, Silvis M. High school soccer players with concussion education are more likely to notify their coach of a suspected concussion. *Clin Pediatr (Phila)*. 2012;51(4):332–336
 256. Papa L, Ramia MM, Edwards D, Johnson BD, Slobounov SM. Systematic review of clinical studies examining biomarkers of brain injury in athletes after sports-related concussion. *J Neurotrauma*. 2015;32(10):661–673
 257. Moran LM, Taylor HG, Ganesalingam K, et al. Apolipoprotein E4 as a predictor of outcomes in pediatric mild traumatic brain injury. *J Neurotrauma*. 2009;26(9):1489–1495
 258. Kutner KC, Erlanger DM, Tsai J, Jordan B, Relkin NR. Lower cognitive performance of older football players possessing apolipoprotein E epsilon4. *Neurosurgery*. 2000;47(3):651–657; discussion 657–658
 259. Kawata K, Liu CY, Merkel SF, Ramirez SH, Tierney RT, Langford D. Blood biomarkers for brain injury: what are we measuring? *Neurosci Biobehav Rev*. 2016;68:460–473
 260. Petraglia AL, Winkler EA, Bailes JE. Stuck at the bench: potential natural neuroprotective compounds for concussion. *Surg Neurol Int*. 2011;2:146
 261. Ashbaugh A, McGrew C. The role of nutritional supplements in sports concussion treatment. *Curr Sports Med Rep*. 2016;15(1):16–19
 262. Trojian TH, Jackson E. Ω -3 polyunsaturated fatty acids and concussions: treatment or not? *Curr Sports Med Rep*. 2011;10(4):180–185
 263. Barrett EC, McBurney MI, Ciappio ED. ω -3 fatty acid supplementation as a potential therapeutic aid for the recovery from mild traumatic brain injury/concussion. *Adv Nutr*. 2014;5(3):268–277
 264. Eckner JT, Oh YK, Joshi MS, Richardson JK, Ashton-Miller JA. Effect of neck muscle strength and anticipatory cervical muscle activation on the kinematic response of the head to impulsive loads. *Am J Sports Med*. 2014;42(3):566–576
 265. Brooks A, Loud KJ, Brenner JS, et al; Council on Sports Medicine and Fitness. Reducing injury risk from body checking in boys’ youth ice hockey. *Pediatrics*. 2014;133(6):1151–1157
 266. Council on Sports Medicine and Fitness. Tackling in youth football. *Pediatrics*. 2015;136(5). Available at: www.pediatrics.org/cgi/content/full/136/5/e1419
 267. Comstock RD, Currie DW, Pierpoint LA, Grubenhoff JA, Fields SK. An evidence-based discussion of heading the ball and concussions in high school soccer. *JAMA Pediatr*. 2015;169(9):830–837

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