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Sport-Related Concussion in Children and Adolescents

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abstract

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.

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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.

FROM THE AMERICAN ACADEMY OF PEDIATRICS

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% 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]

TABLE 2 Signs and Symptoms of a Concussion

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

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	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue and/or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or anxious	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6

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 be 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 Act[193]:

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 S100β, 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 ε4, apolipoprotein E ε4 promoter G-219T-TT genotype, and $\tau^{Ser}53^{Pro}$ 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 lack of symptom resolution and may benefit from referral to an appropriate health care provider who can evaluate and treat these problems.
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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