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Sports-Related Concussion

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Abstract Sports-related concussions (SRC) are common in all ages and occur in all sports. The diagnosis based on clinical suspicion after more serious injury is ruled out. Symptoms of concussion are due to a temporary and reversible neurometabolic cascade resulting in blood flow changes, neuronal excitotoxicity, ionic shifts, and mitochondrial changes. Symptoms are nonspecific, and commonly include headache, cognitive complaints, photophobia, and phonophobia. Loss of consciousness is rare in SRC and has limited influence on recovery and prognosis. Imaging has a limited role in the management of concussion and should be used to evaluate for more serious intracranial pathology. Treatment is based on symptoms and an understanding of the typical, rapid (7–10 days) recovery. No athlete should return to play until their symptoms have resolved and they have completed a supervised, step-wise return to play protocol. The article covers the most recent literature on the diagnosis and management of SRC, including evidence-based recommendations and expert-based consensus opinion. The article will also discuss issues regarding medical retirement, legislation, and future concepts in concussion diagnosis and management.

MESH Keywords Traumatic brain injury · Brain concussion · Postconcussion syndrome · Sports medicine · Sports-related concussions

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Introduction

Sports-related concussion (SRC) is a common injury affecting 1.6–3.8 million Americans each year [1, 2]. Concussions result from mild traumatic brain injury (mTBI), and all brain injuries are serious. While the majority of concussions resolve rapidly, a small percentage of patients may suffer from lingering symptoms. Many of these patients will be students and young adults, and it is important to include scholastic and social factors when determining a comprehensive treatment plan. The increase in recognition and awareness of concussion has corresponded to a 4-fold increase in the diagnosis over an 11-year period [3]. Importantly, one study reports an increase in ED discharge instructions recommending follow-up with a concussion specialist or sports medicine provider from 8 to 43%. This will likely increase the volume of concussion patients presenting to outpatient practices [4]. Because all providers are likely to see concussion patients, a reasonable understanding of this condition is necessary. This article seeks to discuss current understanding of SRC, recent evidence-based recommendations, and review of expert consensus.

Pathophysiology

The pathophysiology of acute SRC is thought to be similar to that of mTBI from any other blunt trauma or whiplash mechanism. Blast injuries have additional pressure-related phenomena that differ from SRC. It is felt to be due to a trauma-induced metabolic cascade leading to neurotoxicity, altered blood flow, intracellular metabolism disturbance, and mitochondrial dysfunction [5–7]. Importantly, this window of metabolic dysfunction is thought to lead to the potential for second-impact syndrome (SIS) [5, 8–11]. In a rat model of mTBI, it has been found that multiple brain injuries that occur

in close temporal proximity can result in what amounts to a severe TBI [11, 12]. The mechanism proposed includes significant abnormalities in markers of oxidative stress, nitrosative stress, and mitochondrial dysregulation that change depending on the interval between the lab-induced brain injuries in rats, peaking using a 3-day interval [11]. The pathophysiology of athletes that display prolonged recoveries is not well understood and may be due to a variety of organic (genetic, prior concussion history, modifying factors) and inorganic causes (psychosocial, socioeconomic status, belief systems regarding recovery [13•].

Epidemiology

Concussions occur in all sports, though rates are highest in contact and collision sports like football, soccer, and hockey [14, 15]. There are conflicting data regarding gender differences in SRC. Several epidemiologic studies report higher rates of concussion among females when comparing similar sports. For example, multiple epidemiologic studies found that girls' soccer has higher rates of concussion than boys' soccer [3, 16, 17]. Possible explanations for these differences include biomechanical, reporting, provider bias in diagnoses, and style of play [18]. For example, the head-neck ratio differences between adolescent males and females may partially explain these differences. Other studies report no significant gender-based differences [18]. Neurocognitive evaluations of males and females show conflicting data regarding performance [19, 20]. The Consensus Statement of Concussion in Sport did not find conclusive evidence for gender differences, instead stating "…gender may be a risk factor for injury and/or influence injury severity" [21••]. Patients should be made aware of these differences and the lack of current expert consensus on the role of gender in SRC.

The rate of concussion appears to increase in athletes with history of prior concussion. Retrospective data reveals a higher symptom burden in athletes with a history of 2 or more concussions [22]. There are data to suggest a dose-response decrement in neurocognitive performance in subjects with multiple concussions [20]. Recent work also suggests that athletes with multiple concussions have longer recovery times [23]. While not commenting directly on the risks of multiple concussions, the Consensus Statement of Concussion in Sport does use decreasing threshold (amount of force that causes the concussion) and temporality of repeat concussion as modifying factors in concussion [21••]. The potential outcome of prolonged symptoms, increased symptom burden, and temporary neurocognitive changes in athletes with multiple concussions should be part of the return-to-play (RTP) decision-making process. There is no defined number of concussions that precludes participation; each athlete's situation should be evaluated individually.

Presentation

Athletes can present with a wide and varied spectrum of complaints (see Table 1). Most athletes are injured during direct contact with the head, either via head to head, head to opposing player body (i.e., elbow to the head), or head to equipment (i.e., heading in soccer, collision with a goal post), or head to playing surface. Importantly, concussions can occur within a wide spectrum of force. Put simply, concussions can occur with seemingly small impacts, and concussions may not occur even with obviously large collisions and impacts. Sideline physicians and staff are trained to watch the event for situations in which contact is likely. That being said, many concussions occur during plays that are not directly witnessed by the provider. In those instances, the sideline medical staff attempts to piece together the mechanism of injury along with the athlete and witnesses. It is now clearly understood that loss of consciousness (LOC) only occurs in the minority of cases. However, any athlete that suffers LOC has suffered a concussion and should be treated as such, regardless of the brevity of the LOC.

In the acute setting, athletes commonly complain of headache, photophobia, or feeling like they are "in a fog." They may be observed to have difficulty keeping up with the pace of play, remembering their on-field assignments, or simply playing differently than usual. Sideline physicians, trainers, and coaches have a high index of suspicion when an athlete begins behaving abnormally and may remove an athlete several plays later for evaluation.

Importantly, the sideline evaluation tools offer insight into the athlete at that one moment in time and cannot "rule out" concussion. Given our understanding of the pathophysiology of concussion, the athlete's scores may very well worsen over the first 15–30 min after the injury. Serial examinations and monitoring of the athlete on the sideline should be considered standard of care. There is an adage in sports medicine that states "When in doubt, sit them out," which is clearly a reasonable approach for athletes with suspected concussion.

The unintended consequence of our high index of suspicion is the risk of an inaccurate diagnosis of concussion to explain an athlete's nonspecific symptoms. Other potential diagnoses should be considered in any case in which the onset of symptoms is not clearly associated with a concussive event. These include common medical causes (e.g., diabetes, anemia, asthma, vision changes unrelated to concussion), primary and secondary headache disorders, ADD/ADHD, dyslexia, anxiety, depression, substance abuse, eating disorders, pregnancy, and orthopedic causes (e.g., cervicogenic headache, Chiari malformation, cervical disk disease). The specialist caring for athletes with prolonged or complex symptoms is wise to keep an open mind and a large differential diagnosis, rather than exclusively focus on concussion as the sole source of symptoms.

Table 1 Symptoms of concussion: Many of these symptoms may take several minutes to hours to present

Somatic	Cognitive	Emotional	Sleep
• Headache	• Confusion	• Emotional lability	• Increased sleep
• Nausea	• Mental fogginess	• Anxiety	• Decreased sleep
• Vomiting	• Difficulty remembering	• Sadness	• Insomnia
• Light sensitivity	• Difficulty concentrating	• Frustration	• Frequent naps
• Sound sensitivity	• Slowed reaction time		
• Fatigue			
• Balance disturbance			
• Dizziness			
• Fatigue			
• Visual disturbance			

Prognosis

The symptoms of SRC will resolve in the majority of athletes within 7–10 days [24, 25]. There are some data suggesting that neurocognitive performance is still affected at day 14 [26]. Most of the data on recovery use common team sports (football, basketball, and soccer) as their reference point. The recovery duration is less clear for high velocity sports like motocross, snow sports, and martial arts. However, using the 10-day recovery point as a guideline is a useful starting point for the clinician in guiding expectations and follow-up. Recovery from concussion is clinically defined as improvement from at-rest symptoms and exertional symptoms. Importantly, there is no readily accessible way to ensure that the brain has fully recovered and is no longer vulnerable to another injury [5]..

Treatment

Acute

Concussions resolve spontaneously and require no direct treatment from the provider. The initial visit should include education for the athlete and family regarding factors that may prolong recovery, including premature return to play, overexertion, alcohol, and drug use. There has been a tendency to prescribe significant restrictions to all athletes that suffer concussion. It is not uncommon for an athlete to be entirely removed from school, sports, and extracurricular activities while being told that they should not watch TV, read, or use their mobile phones. In the first few days, when symptoms are at their most severe, these restrictions may provide some symptomatic relief. Unfortunately, while well intentioned, these severe restrictions create unnecessary stress in the athlete's life without offering any significant increase in speed of recovery. Additionally, this level of monastic restriction is not reasonable for the families of these athletes and may lead to unintended consequences of frustration or reactive depression [27].

Recommendations include relative rest and avoidance of aggravating factors such as physical activity. It is commonly recommended that patients avoid TV, computer screens, mobile phones, and video gaming, but many athletes do not require such significant limitations. Our practice recommends that electronics can be used, provided they cause no increase in symptoms. The strongest recommendation is for the athlete to refrain from contact activities in order to prevent the possibility of repeat concussion or SIS [21••, 28].

Prolonged

In cases of athletes with prolonged recovery, treatment should be guided by individual symptoms and function rather than by a "one size fits all" approach. Multidisciplinary medical teams can be useful in addressing complicated, overlapping symptom clusters [13•]. These teams often include a primary care physician, neurologist, physiatrist, psychiatrist, neuropsychologist, physical therapist, and athletic trainer.

Athletes most commonly complain of headaches, which are often a challenge to fully address. The headache type that the athlete describes can often guide treatment. Most commonly, athletes describe a mild to moderate tension-type or chronic daily headache. The headaches stemming from concussion may frequently be refractory to pharmacologic treatment. The author typically recommends treatment if the headache and associated symptoms are significant enough to cause problems at school, at home, or cause a significant decrease in quality of life. Also recommended is a prescription medication for athletes that require daily over the counter medications, to prevent the unlikely but unfortunate rebound headache phenomenon known as medication overuse headache. Physical modalities may be of use in these athletes as well as medication, including massage, manipulation, and acupuncture, though no formal data exist for their efficacy in postconcussive headache. Physical therapy can be quite

effective in cases of tension-type headache, especially in athletes that note issues that have an ergonomic component to them (i.e., neck pain from studying leading to headache). A chapter discussing posttraumatic headache is found elsewhere in this journal.

A minority of athletes complain of dizziness, visual changes, and disequilibrium. Vestibular therapies have some data to support their use in refractory cases of dizziness and balance problems [29]. A simple eye test should be performed or recommended for athletes that complain of blurry vision or double vision. Objective, reproducible cranial nerve deficits causing diplopia on exam should be evaluated with appropriate imaging. If the imaging is unrevealing, referral to neurology, ophthalmology, or vision therapy should be considered. Undiagnosed visual issues are common in this age group and may contribute to headaches.

Significant and/or prolonged cognitive complaints are common and should trigger a consultation to a neuropsychologist with experience in sports-related concussion. These consultations are often invaluable in determining specific school accommodations and individual compensation recommendations. Additionally, these consultations help identify and address any overlay (premorbid or postmorbid) of anxiety, depression, or other contributing factors to delayed recovery [13•]. It is common for athletes with prolonged recovery to require some degree of counseling to help cope with the change in societal roles (i.e., from athlete to patient). Teenage athletes may derive an enormous sense of self from their sport, and their social interaction may be tied closely with their team and teammates. It is vital for the provider to recognize that a prolonged recovery from concussion can be traumatic to these athletes and to proactively address the potential concerns.

Initial activity restrictions are well founded and supported by consensus opinion [21••]. There is increasing data to support the safety and efficacy of graduated aerobic exercise in the rehabilitation of athletes with prolonged symptoms [30•, 31]. The author's institution typically recommends a gradual resumption of noncontact aerobic activity (e.g., walking, cycling, and swimming) as part of the treatment plan for prolonged postconcussive symptoms.

Return to Play/Return to School

The concept of graduated return to play has been in reviews and consensus statements [21••, 32••]. A systematic return to contact and collision sports allows the athlete to progress to increasingly difficult activities associated with increasing heart rate and complexity of athletic tasks. This should be done under supervision to ensure no return of symptoms as effort increases. It is impossible to fully assess an athlete's full return to "normalcy" without having them complete their usual athletic and academic activities; so, no athlete should be returned to play without completion of these protocols. It is not uncommon to have an athlete notice that while they feel normal at baseline, they note a return of symptoms when increasing physical or mental effort. Additionally, athletes that have been sidelined with a concussion for many weeks may need some time to return to their typical level of play, cardiovascular conditioning, and "shake off the rust."

Similar concepts apply to returning to school. The majority of sports concussions occur in the youth and adolescent population, and it is vital that their providers work to ensure a successful return to school. Most consensus opinion suggests a reasonably speedy return to school with accommodations to allow for participation and educational growth without overwhelming the student or increasing the symptoms. Typical accommodations may include modifying physical education class, decreasing homework assignment volume or more time to complete the task, frequent breaks during class, or a doctor's note to allow for medication administration [33]. It is the author's experience that schools are able to accommodate students better when their attendance is consistent and expected rather than a scenario when the student may or may not attend based on that day's symptoms. In other words, consistent half-day attendance may be more successful than inconsistent and unpredictable full day attendance. An early discussion with the athlete and their parents on the importance of maintaining this regular schedule may prevent problems with make-up work, missed tests, and anxiety surrounding eventual return to school.

It is recommended that the school be notified as soon as possible that an athlete has suffered a concussion to prevent any issues with academic course load. If an athlete is symptomatic enough to warrant more than a few days off from school, organize prompt school accommodations, and consider specialist referral.

Postconcussion Syndrome

Postconcussion syndrome (PCS) has been variously described in the literature as typical concussion symptoms lasting >3–6 months [34]. In clinical care, the term PCS is sometimes used inaccurately to describe any postconcussion symptom, even during the acute and subacute phases. Headache is the most common complaint in patients suffering from PCS. The pathophysiology of these prolonged symptoms is poorly understood, and controversy exists as to the source of the symptoms. Many authors feel that there is a pathologic organic source of the complaints, similar to those in posttraumatic headaches (PTH). Some authors suggest attribution error, psychogenesis, motivational, or financial issues as potential nonphysiologic sources [34]. Attribution error can occur by the provider or the patient. For example, the athlete may

attribute complaints of fatigue, change in mood, and decreased concentration to the concussion, when in fact it is premorbid or reactive depression. The provider may also attribute blurry vision and headache to the concussion, when a new eyeglass prescription is needed. Routinely, athletes diagnosed with concussions are found to have alternative diagnoses including diabetes, hypothyroidism, or anemia. Given the lack of complete understanding of the complex causes of these symptoms, a thorough medical workup for nonconcussive sources for symptoms and neuropsychological evaluation of the athlete can give a more detailed understanding of the individual suffering from PCS and give insight into potential treatments. The list of differential diagnoses (see Table 2) is broad and likely beyond the scope of any individual provider, highlighting the need for a multidisciplinary team. The provider should strongly consider alternative and concomitant diagnoses when treating an athlete with the relatively rare diagnosis of PCS.

Second Impact Syndrome

Second impact syndrome, initially described in 1984, is the most significant potential complication from premature RTP [35]. It occurs in an athlete that is still having symptoms from a recent concussion suffers a repeat head injury. On CT or MRI imaging, these athletes may display significant cerebral swelling, with or without small subdural hematoma [9]. The condition is distinct from other causes of SDH in that the small size of the SDH would not explain the degree of cerebral edema. Second impact syndrome is thought to be due to a massive cerebral "dysautoregulation" causing the brain edema with subsequent tonsillar herniation and brainstem compression. The syndrome nearly always results in death or significant disability. For greater depth, the reader is directed to Cantu's 2010 publication on the SIS for a review of 10 cases [9].

Prevention

There is no way to fully prevent concussion in sport, though rule changes in an individual sport can decrease its likelihood. Changes in the number of full-contact practices, alterations in the length of kickoffs in football, and changes to hits on "defenseless" players have all been instituted in the National Football League (NFL) and the National Collegiate and Athletic Association (NCAA). Leagues that restrict body checking in youth ice hockey have lower concussion rates and severity than leagues that allow checking [36, 37]. These efforts have largely decreased the exposure to the "riskiest" plays within an individual sport.

Helmets in football, snow sports, and cycling prevent more serious TBI and skull fracture. Proper helmet fit, maintenance, and consistent usage are critical in the prevention of serious head and neck injury. These principles are advocated by professional sports medicine societies and governing bodies of various sports leagues. While helmet technology continues to advance rapidly, there is no data to reliably conclude that there is a helmet design that can diminish the risk of concussion [38, 39]. Mouthpieces provide superb protection for maxillofacial and dental injuries, but do not proscribe a decreased risk or severity of concussion [40]. Headgear for soccer has shown no definitive decrease in risk and may even cause increased risk when the athlete may become more aggressive in style of play [41]. Multiple marketed helmets and headgear types do report a significant decrease or dispersion of linear forces, though this may not have any significant effect on rotational forces or subsequent concussion risk [41, 42]. Neck strength has been considered a factor, though no definitive conclusions regarding increased neck strength being a protective factor against injury are possible at this time [37].

A reduction in lifetime number of exposures to potential injury an athlete has during a sporting career is being evaluated. The lineman who plays offense, defense, and special teams may consider choosing one position that would reduce their

Table 2 Differential diagnosis of prolonged concussion recovery and postconcussion syndrome

Medical	Neuro/Musculoskeletal	Psychiatric	Other
• Primary headache	• Subdural hemorrhage	• Depression	• Uncorrected vision
• Upper respiratory infection	• Subarachnoid hematoma	• Anxiety	• Learning disability
• Sinusitis	• Skull fracture	• PTSD	• Dyslexia
• Seasonal allergy	• Cervicogenic headache	• Somatoform	• ADD/ADHD
• Diabetes	• Chiari malformation	• Acute stress	Substance abuse
• Anemia	• Neoplasm	• Performance anxiety	• Malingering
• Vitamin deficiency		• Conversion disorder	
• Hypothyroidism			
• Leukemia			
• Lymphoma			

This is also useful as a list of potential confounding conditions in concussion recovery

overall exposure to contact. A soccer player that plays for her high school team, club team, and on invitational tournaments may consider limiting her play to the team that is most important to her. An athlete that plays several collision sports may consider limiting participation to their favorite sport and picking up noncontact sports instead. Of course, these will not bring eliminate injury risk, but can certainly mitigate the exposure to potential concussions.

Retirement from Play

There are no evidence-based guidelines on medical retirement from play. These decisions are highly individualized, involving nature of the symptoms, neuropsychological testing, brain imaging, and factors specific to the athlete, their position and style of play, career time horizon (number of years prior to discontinuation of play), and likelihood of repeat concussion. For example, a 26-year-old professional athlete with several concussions will have a different decision process than a 14-year-old high school athlete. Medical retirement is recommended for athletes with a history of permanent neurologic sequelae, pain producing conditions around the foramen magnum (e.g., Large chiari malformation, critical spinal stenosis, atlanto-odontoid abnormalities), second impact syndrome, persistent postconcussion syndrome, or decreasing threshold for injury [43•]. Specialist consultation is recommended in these rare but challenging scenarios. Second and third opinions are common, especially in the cases of professional sports and high-level prospects for talented players. The sports medicine literature has several published reports on athletes that have pursued play despite more objective and life-threatening conditions including subarachnoid hemorrhage, cardiomyopathy, etc. [44]. Professional athletic teams have mechanisms in place to ensure that an athlete's medical condition is reported to the head team physician. In most cases, athletes will choose to retire from sports, especially in youth and adolescent sports, based on educated familial choice guided by medical input. It is rare that an athlete is medically retired and is not permitted to return despite a desire to do so.

Legislation

No other sports medicine topic has led to such widespread legislation as sports-related concussion. Washington State passed the first comprehensive sports concussion law in 2009 named after Zackary Lystedt, a young man that suffered a severe TBI during a youth football game. The Lystedt Law has become the model for the rest of the country. Its principles include (1) education of athletes, parents/guardians, and coaches regarding concussion; (2) immediate removal from play in the event of a *suspected* concussion; and (3) written clearance from a licensed health care provider prior to return to play. Through the efforts of many advocacy groups, families, and patients, all 50 states have passed similar legislation regarding sports concussion [45, 46]. The subsequent effectiveness of these laws is evidenced by an increasing awareness of SRC and its potential consequences [47]. The requirement of written clearance is important in "closing the loop" on an athlete's safe return to play. Providers that are not comfortable providing that clearance should offer quick consultation to a sports medicine provider to prevent any undue delay in RTP. Good documentation regarding conversations with the athlete and confirmation that they have completed the steps in their RTP is critical.

Conclusion

Sports-related concussions are a common sports injury and have an excellent prognosis for quick recovery. A high index of suspicion is necessary for the sideline physician to make a diagnosis of concussion. Extra care should be given to athletes that display prolonged recovery or severe symptomatology. Additionally, athletes that have a history of multiple concussions should be considered for consultation with a sports medicine provider with significant concussion experience and access to a multidisciplinary team. Ongoing research in long-term consequences of concussion will help shed light onto difficult treatment challenges for youth athletes, multiply concussed athletes, and clarify the risks of neurodegenerative diseases like chronic traumatic encephalopathy (CTE). At the time of this writing, there are no definitive methods to prevent concussion in sport, though this will continue to be an important focus of research with significant importance to brain protection in our children and adult populations. There is obvious need for inexpensive, readily available, objective markers for the diagnosis of concussion. Additionally, reliable predictors of prolonged recovery and long-term consequences will prove invaluable for the concussion specialist, athlete, and family. The passage of concussion legislation has been an enormous aid in educating the population on concussion and brain injury in sports. It is the author's belief that it will lead to measurable declines in preventable catastrophic brain injury due to premature RTP.

Compliance with Ethics Guidelines

Conflict of Interest Scott Laker declares no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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