Concussion in the Pediatric and Adolescent Population: "Different Population, Different Concerns"

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Abstracts: Sports-related concussions are common among pediatric and adolescent athletes, yet a scarcity of age-specific research often has meant that practitioners use guidelines developed for collegiate or adult populations. This situation is changing, as more studies are being published about this population that bears special attention because of the immaturity of the developing brain. This article describes existing knowledge about the epidemiology and etiology of concussions in youth athletes; discusses issues related to assessment, clinical management, and return to activity; examines special concerns related to the effects of concussion on the developing brain; and discusses prevention and education initiatives related to concussion in youth athletes.

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INTRODUCTION

Concussions in the pediatric population are common and have been recognized as having a potential for significant acute and long-term consequences for the child's ongoing neurodevelopment [1]. Although research studies and clinical review articles that pertain to the diagnosis and management of sports-related concussion have increased markedly during the past decade, few articles have focused on the pediatric or "youth" athlete—those aged 18 years and younger—who comprise both the "adolescent" (aged 12-18 years) and "preadolescent" (aged <12 years) athlete populations. Removing the medical literature on high school–age athletes from this clinical grouping considerably reduces the amount of information available to guide the management of the younger adolescent and pediatric populations. Clinicians may find themselves using practice principles, guidelines, and recommendations based on collegiate or adult populations.

As recently as 10 years ago, after being "dinged" and sustaining what would have been defined as a low-grade concussion, a youth athlete would be able to return to play (RTP) after concussion-related symptoms resolved, as early as 15 minutes after the event [2]. Current management of youth concussion has evolved, supported by increased recognition that the effects of concussion on the developing pediatric brain are different from the effects on older brains. Much of this research suggests that a youth athlete with a concussion should be managed more conservatively than older athletes because of longer recovery times and possible long-term effects on the developing brain and the rare but potentially catastrophic effects of premature RTP. This article aims to summarize the current literature on the facets of concussive injury and its management that are unique to the pediatric population.

DEFINITION

Earlier definitions required a loss of consciousness (LOC) associated with a head injury for diagnosis of a concussion [3]. Multiple studies have questioned the significance of LOC as a prerequisite, citing LOC rates as low as 10%. It has become widely accepted that a diagnosis of concussion does not require LOC. In its most recent consensus statement, the Concussion in Sport (CIS) group provided a proposed definition of concussion as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" [4]. Furthermore, the CIS group addressed the frequently observed interchangeability of the terms "concussion" and "mild traumatic brain injury" (mTBI), which suggests

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that the two "refer to different injury constructs and should not be used interchangeably"[4]. The delineation between the two terms focuses mainly on the idea that concussion is first and foremost a functional injury, whereas mTBI may be both a structural and a functional injury. Use of the correct terminology has clinical importance. Results of one study found that, of children admitted to a large children's hospital for TBI, those diagnosed with concussion were discharged from the hospital earlier and returned to school significantly sooner, independent of their Glasgow Coma Scale score on initial presentation [5]. For the purposes of this article, the term "concussion" will be used solely when referring to this injury.

EPIDEMIOLOGY

An estimated 30-45 million children and adolescents participate in nonscholastic organized sports in the United States each year, and some children start participating in athletics as early as 3 and 4 years of age [6]. During the 2009-2010 school year, more than 7.6 million U.S. adolescents participated in high school athletics. American football alone included an estimated 1.1 million high school participants [7,8].

The Centers for Disease Control and Prevention (CDC) has estimated that concussion occurs in 1.7 million children and adults a year; 20% of these incidents are sports related [8,9]. Because children and adolescents overwhelmingly participate in sports more frequently than adults do, they sustain the majority of sports-related concussions [2]. In high school athletics, an estimated 300,000 head injuries occur annually, and 90% of these injuries are concussions [1]. More than 100,000 of these concussions are sustained while playing high school football [10]. In U.S. high schools, the sports with the highest incidence of concussion are football and ice hockey, followed by soccer, wrestling, basketball, field hockey, baseball, softball, and volleyball [11]. By the start of high school, 53% of student athletes have reported a history of concussion. Furthermore, 36% of collegiate athletes have reported a history of multiple concussions [12]. It is estimated that concussion represents 8.9% of all high school and 5.8% of collegiate athletic injuries [13].

In the years 2001-2005, an estimated 502,000 patients aged 8-19 years were diagnosed with a concussion in U.S. emergency departments (EDs), with half being sports related [14]. Although the number of ED visits for concussion from 2001-2005 was highest in the population aged 14-19 years, approximately 35% were in children 8-13 years of age, with the latter group representing approximately 40% of the total number of sports-related concussions.

Results of studies have shown that concussion in children and adolescents, specifically those aged 6 to 16 years, is more likely to occur during organized sports than other activities [15]. Before age 10 years, children tend to sustain concussions primarily from non–sports-related falls and then transition to sports-related injuries after age 10 years. The injuries of these younger children often occur at home, at school, or the playground [16].

The actual incidence of concussion in the pediatric population is likely to be underestimated and under-reported because of factors such as a lack of initial recognition by the athlete, coaches, trainers, or other medical personnel; a lack of follow-up in a medical setting; and the failure to report symptoms because of a fear of loss of playing time or the youth athlete's desire to try to "push through" concussion symptoms [17]. One study found that nearly 70% of athletes reported symptoms suggestive of a concussion but that only 20% realized that they had sustained a concussion [18]. McCrea et al [19] found that fewer than 50% of student athletes with symptoms of concussion reported their symptoms.

POTENTIAL FOR INCREASED SUSCEPTIBILITY IN PEDIATRICS

The plasticity of the developing brain often has been considered to be protective in pediatric patients with respect to brain injury, but that belief has come into question in youth concussion. A number of studies have shown that the rate of concussion in high school athletes is higher than that of older athletes [20-22]. Furthermore, average times to normalization to preconcussion baselines on neurocognitive testing in high school students are reported as 10-14 days compared with 5-7 days and 3-5 days in collegiate and professional athletes, respectively [12,23,24]. In addition, multiple studies support the concept that neurocognitive deficits in high school athletes may persist well after self-reported symptoms of concussion have resolved [25,26]. For example, one study found normalization of symptoms but ongoing verbal memory deficits at 14 days after the injury [27]. In another study, 26% of athletes with a concussion who reported being asymptomatic and ready to RTP had persisting neurocognitive deficits [28].

Few studies of sports-related concussions have specifically referenced the preadolescent athlete (aged $<$12 years); the majority of youth concussion medical literature concerns adolescents (aged 14-18 years) [29]. One prospective study found that children who were younger than 7 years at the time of a head injury fared worse in age-adjusted performance on neurocognitive testing afterward than did those older than 7 years at the time of injury [30], which underscores the concern that more research in the preadolescent age group is warranted.

The causes for the reported differences in vulnerability to and recovery between the pediatric and adult populations are not entirely clear. Immaturity of the developing central nervous system has been cited as a potential risk factor, as have a larger head-to-body ratio, thinner cranial bones, a larger subarachnoid space in which the brain can move freely, and differences in cerebral blood volume. It has been suggested that the reduced development of neck and shoulder musculature in youth compared with adults contributes to the inability to efficiently dissipate the energy from the head impact to the rest of the body. Contributing further, gains in weight and mass that occur during the adolescent growth spurt increase the force and momentum during collision without concomitant gains in neck strength [31]. Incomplete myelination and the elasticity of the skull vault also may put the developing brain at higher risk for shear injury [32-34].

From a pathophysiological standpoint, studies in moderate to severe TBI have shown that, after injury, more prolonged and widespread cerebral swelling may occur in children than in adults [35]. In keeping with the "metabolic cascade" theory of concussion, sensitivity to glutamate and N-methyl-d-aspartate has been estimated as being up to 60 times higher in the developing brain [36]. Together, they may contribute to a longer recovery time from concussion for youth athletes [37]. After concussion, the injured brain's natural timeline of neuronal maturation may be altered because of disturbances caused by brain trauma [38].

INITIAL ASSESSMENT ON THE FIELD

The National Athletic Trainers Association estimates that only 42% of high schools have access to a certified athletic trainer [39]. Many youth athletic leagues are staffed by volunteer coaches and officials. The presence of trained medical personnel at these events is even rarer, which means that important medical decision making is left up to persons with little or no training or experience [40]. As a result, reduced or delayed identification of concussion may be more likely in youth athletics than in athletics with older participants [31].

It is beyond the scope of this article to describe the complete sideline assessment of the athlete with a concussion. It is important that cognitive assessment be included as part of the sideline assessment. Common examples include the Standardized Assessment of Concussion and the Sports Concussion Assessment Tool (SCAT). The Standardized Assessment of Concussion includes normative values for children as young as 6 years [41]. The SCAT2 may be used in athletes as young as 10 years [2]. After a suspected concussion, the youth athlete should not be left alone, and serial neurologic examinations should be performed during the first few hours after the injury [4,31]. The need for medical follow-up with a medical provider after a suspected concussion, whether at a local ED, in a primary care provider's office, or with a concussion specialist, should be communicated while still on the playing field.

IN THE ED

In the ED, the use of neuroimaging studies to evaluate concussion is a source of much discussion. Because concussion is more a metabolic and functional disturbance than a structural injury to the brain, standard neuroimaging (ie, computed tomography [CT] or magnetic resonance imaging [MRI]) findings generally are normal [20]. In one study, 69% of pediatric patients eventually diagnosed with a concussion received some type of imaging, which was CT in nearly all cases [42]. The risk of clinically significant intracranial pathology in the child with a concussion who has normal mental status, no focal neurologic abnormalities, and no evidence of skull fracture on examination has been estimated to be as low as 0.02% [42].

Exposure to radiation and subsequent malignancy risk are common concerns. For the same CT settings, younger children receive higher radiation doses than do adolescents or adults [43]. The malignancy risk from radiation exposure is cumulative; because children have a longer potential lifetime of exposure than do adults, this concern is merited [19,44]. The lifetime risk of malignancy after one head CT is approximately 1:2000 for a child younger than 2 years and approximately 1:10,000 for a 15-year-old girl [44]. Adjusting CT scanner settings so they account for a child's smaller head size is one way to address this concern. CT scans are indicated with symptoms such as focal neurologic findings, a progressive neurologic decline, or a high-risk mechanism of injury (eg, a motor vehicle collision) that cause concern for skull fracture or intracranial hemorrhage [4]. It has been suggested that pediatric patients with LOC >30 seconds also may warrant neuroimaging because of the increased risk of intracranial injury [45].

Follow-up with a medical provider after ED evaluation is a concern. One study that looked at ED admission found that 28% of discharged pediatric patients with a concussion did not receive instructions to be seen by an outside physician for follow-up for their injury [20]. Another study demonstrated a lack of discharge instructions, including activity restrictions that emphasize both physical and cognitive rest [46]. It is important that youth athletes and their family be informed in detail of the expected symptoms of concussion, the varying time course for resolution, and recommended management strategies. Doing so has been shown to result in significantly reduced reports of postconcussion symptoms and behavioral changes at 3 months after injury [47]. Additional guidelines regarding which signs and symptoms warrant more urgent follow-up in a specialist's office or local ED must be reviewed to help identify signs of slowly developing subdural hematomas. Depending on the severity of symptoms, removal from school until further outpatient evaluation may be prudent. The physical and cognitive stresses of school attendance alone may serve to exacerbate the youth athlete's symptoms, such as headache, photophobia and/or phonophobia, and nausea. Furthermore, other concussion-related symptoms,

Table 1. *Elements of the outpatient concussion visit**

Current concussion history
1. Sport and position
2. Mechanism of injury
3. Loss of consciousness?
4. Amnesia
5. Events after the concussion
Previous concussion history
Premorbid personal or family history of modifying factors
1. Migraines or other headache history
2. Psychiatric illness
3. Learning disabilities or dyslexia
4. Attention-deficit/hyperactivity disorder
5. Sleep disruption
6. Seizure disorder
Postconcussion symptom inventory
1. Include progression of symptoms after the injury
2. Response to mental and physical exertion
Physical examination
1. Neurologic examination
2. Cranial nerve examination
Balance testing
Review of neuroimaging
Review of neuropsychological testing if available

*Adapted from [91].

such as reduced memory functioning, difficulty focusing and/or concentrating on tasks, slowed processing speeds, and excessive daytime somnolence and/or fatigue may adversely affect retention of learned material and academic performance.

CLINICAL MANAGEMENT CONCERNS

Beyond the typical clinical history taking, the basic components of the evaluation of a pediatric sports-related concussion are summarized in Table 1. All concussions involve patient-specific symptoms and courses of symptom resolution, and thus an individualized approach is most appropriate. The symptoms and their severity and duration depend on a wide array of factors related to the injury (eg, severity and location), the athlete (eg, history of concussion, premorbid factors, and possibly genetics), and the environment (eg, school, family, and social relationships) [11].

A number of premorbid diagnoses have been shown to increase the risk for prolonged recovery in the pediatric population. These premorbid diagnoses include a history of chronic headaches or migraines; attention-deficit/hyperactivity disorder; learning disabilities; and psychiatric illness, such as anxiety disorder or depression [48]. Premorbid behavioral characteristics in children and adolescents with a history of learning disabilities, attention deficit disorder or attention deficit/hyperactivity disorder, and psychiatric illness may affect the report of concussion-related symptoms after the injury [49].

A history of concussion should always be ascertained. Results of multiple studies have shown that the risk of subsequent concussion is increased in athletes with a history of concussion [50-52]. In addition, athletes with a history of >2 concussions have been shown to have more significant symptoms and a higher rate of remaining symptomatic for ≥ 1 week than do those with a history of ≤ 1 concussion [53].

The CIS emphasizes activity restrictions that support physical and cognitive rest until concussion-related symptoms resolve to preconcussion baselines [4]. Supplying the patient and family with a symptom inventory checklist (such as that included with the SCAT2) at the time of the first office visit may be helpful to the clinician in tracking the patient's progress with respect to symptom resolution between subsequent evaluations [4,28,54].

Some symptoms may predict greater deficits and prolonged recovery after sports-related concussion and may help the clinician set reasonable expectations for the youth athlete and his or her family. In one study, self-reported cognitive decline and slower reaction time scores on computerized neurocognitive testing were associated with prolonged time to clinical recovery [55]. In addition, high school and collegiate athletes who have a concussion and exhibit post-traumatic migraines (ie, headache plus nausea, photophobia, and/or phonophobia) exhibit a statistically significant increase in the number of overall concussion-related symptoms reported after injury and a significantly greater decline in neurocognitive performance compared with athletes with a concussion and either headache alone or no headache at all [56]. Therefore youth athletes with migraine symptoms may warrant additional concern.

Physical rest and cognitive rest each pose challenges unique to the pediatric and adolescent populations. Physical rest includes removal of the child not only from athletic practices and games but also from all other activities that may put the child at risk for a reinjury. A return to physical education class and recess should be postponed until the child has been cleared for full RTP [57]. While the pediatric athlete remains symptomatic, office visits should emphasize the importance of refraining from activities that may cause a subsequent head injury (eg, horseplay with a sibling and bicycling) [58].

Cognitive rest includes reduction or a discontinuation of activities such as watching television, reading, using the computer, video gaming, texting, doing homework, listening to music on headphones, and using the telephone. It is not uncommon for young athletes to report an exacerbation of concussion-related symptoms with any of these activities. Driving may need to be restricted in athletes who show a marked reduction in their reaction times [2].

Schoolwork frequently suffers as a result of a student's concussion-related symptoms, including adverse effects on reading comprehension, recall of new or previously learned material, and decreased ability to complete tests or homework assignments on time. Students commonly report an exacerbation of symptoms when they attend school and attempt to do schoolwork, which requires the clinician to make a difficult decision about restricting the student from school attendance to provide more complete cognitive rest.

Any decision to remove a child from school may have serious repercussions. Much of the psychosocial development of child and adolescent athletes occurs in the school setting. Prolonged absence from school may result in changes in relationships with peers, perceptions of reduced social acceptance, feelings of isolation at home, and development of symptoms of anxiety or depression that are difficult to discern from those related to the concussion. From an administrative standpoint, any absence from school may go toward allowable absences deemed acceptable by the school district. Depending on the duration of the absence, the young athlete may be at risk of having to repeat entire courses or full school years.

In addition, makeup work and postponed testing accumulate, which adds to the stress on the student athlete. This "double work" frequently starts once the student returns to the classroom because, without outward signs of physical impairment, his or her cognitive well-being is then assumed, which often is not the case, and the increased cognitive exertion may exacerbate symptoms and prolong recovery. Because symptoms may worsen when the youth athlete is challenged with the cognitive and social stressors of returning to school, it may be advisable to hold off on returning to school until symptoms at rest are resolved or at least minimal at home.

Alternative plans of action may include half-day or limited school attendance that focuses on classes in which attendance is most necessary. In this way, a graduated approach to the return to school may be used. Informal, academic accommodations (eg, untimed or open-book testing, preprinted class notes, tutoring, decreased time on computers, and reduction in workload) can be recommended. An effort should be made to postpone any standardized school testing during the recovery period from concussion because optimal performance is not to be expected [4,59].

The importance of communication between the clinician and school administration in formulating a plan for a successful return to school cannot be overstated, yet it is often overlooked. In a study that focused on the return to school of pediatric and adolescent patients who had sustained a head injury, teachers were aware of their students' diagnosis only 39.8% of the time. Furthermore, special education resources were provided to only 65% of returning students who needed such interventions [60]. Often, the school nurse or guidance counselor is a valuable liaison with the physician, family, school administration, and teachers. A certified athletic trainer can help in the management of the athlete with a concussion and can serve as a resource for the physician, student athlete, and coach. If possible, all parties involved in the academic life of the athlete with a concussion can be educated regarding expectations during recovery from the concussion. It is important to keep in mind that strategies commonly incorporated into a plan of care for a child without a concussion and with a learning disability or behavioral problem may not be effective or appropriate for the child with a concussion who exhibits similar symptomatology. Material provided in the CDC's "Heads Up" initiative includes easy-to-follow educational fact sheets for teachers and school personnel that incorporate valuable information and detail many of the potential concerns when young athletes who are recovering from a concussion return to school [61]. Depending on the clinical scenario, components for a successful transition back to school may include the following: multidisciplinary decision making, frequent plan of care reviews, strong parental involvement, and identification of an appropriate person at the school to serve as case manager [62].

Two formal policies for educational accommodations are common in current practice: the 504 Plan and an individualized education plan (IEP). The 504 Plan is born from Section 504 of the Rehabilitation Act of 1973 [63]. This section of law states that a public school district must provide free and appropriate public education to any individual with a disability, regardless of the severity of the disability [63]. An IEP is derived from the Individuals with Disabilities Act and focuses on individuals receiving special education in public schools. An IEP sets up the opportunity for a multidisciplinary team (eg, the student athlete's physician, school nurse, teachers, and parents) to meet and put together an appropriate educational plan of care [64]. The decision to go forward with the development of either an IEP or a 504 Plan is not to be done without careful consideration. It is important for the physician to weigh its potential benefits (potentially easing the student athlete's transition back to a school that is now more understanding of his or her concussion and its symptoms) against the potential negative effects (possibly isolating the student athlete and leading him or her to be stigmatized as a "special case" in a way that may adversely affect recovery).

The stages of cognitive and psychosocial development in the youth athlete with a concussion always should be taken into account when defining the plan of care (see Table 2). These stages are generalizations and may overlap, but they offer insight for the clinician managing different pediatric age groups.

ROLE OF NEUROPSYCHOLOGICAL TESTING

Neuropsychological (NP) testing is frequently incorporated into the serial evaluation and management of the athlete with a concussion. Many guidelines advocate the use of NP testing before making the decision about when the athlete with a concussion can RTP. The CIS 2008 Zurich statement [4] notes clinical value and contribution of NP testing to the

Table 2. *Age range and developmental stages in management of concussion**

Age Range	Developmental Stage	Challenge to Concussion Management	Potential Clinical Approach
Pre-adolescence (6-11 y)	Short attention span, high distractability, limited ability to plan in accordance with potential consequences to actions	Difficult to relate the importance of adherence to treatment	Involve parent, siblings, and other adults to reinforce recommendations; frequent follow-up
Early adolescence (12-14 y)	Concrete thinking, narcissistic-type concern for one's appearance and social status	Under-reporting of symptoms, poor compliance with plans	Involve parents and coaches
Middle adolescence (15-16 y)	Working toward independence and separation from parents, typically understand potential consequences for noncompliance	May be highly motivated to return to play for the sake of peer acceptance; may lead to underreporting	Establish rapport with patient and accurately relate potential outcomes of noncompliance
Late adolescence (17-19 y)	Abstract thinking and comprehension for potential long-term consequences have developed	Improved compliance with treatment recommendations; maybe less parental involvement with older teens	Accurately relate the potential consequences and importance of compliance

*Adapted from [1,91].

evaluation of concussion. In child and adolescent athletes, the CIS group adds the caveat that testing may be beneficial not only when the youth athlete is asymptomatic, as is the recommendation for adults, but also while he or she is still symptomatic, because the NP testing may provide guidance for school-based interventions. It recommends that NP testing, interpreted by an experienced neuropsychologist, be considered in this younger population when premorbid diagnoses of learning disabilities or behavioral disorders are known [4]. Neurocognitive impairment in the child with a concussion may occur within the same functional domains as adults, but the negative effect on the child's educational and social development may be more marked [46].

It is important to keep in mind that the brain is still maturing in the pediatric and adolescent population. This period of cognitive development may affect not only the rate of recovery from concussion but also the assessment tools used for neurocognitive evaluation [65]. Improvement of performance on NP testing is expected throughout childhood and adolescence. In studies of healthy children aged 9-18 years without a concussion, significant improvements in NP testing performance were noted; the greatest improvement occurred between the ages of 9 and 15 years, with minimal changes thereafter [33]. Therefore repeated NP testing performed over a prolonged clinical course may show a return to baseline without true full recovery [1]. The NP testing that is used should be developmentally sensitive and take into account the expected performance improvements over time.

NEUROIMAGING

As previously mentioned, because concussion is primarily a functional disturbance rather than a structural injury to the brain, more common neuroimaging, such as CT and MRI scans, generally show no abnormalities. It may be appropriate to consider MRI in patients with persistent symptoms, although a well-accepted guideline as to the exact duration of symptoms that warrant such imaging has not yet been defined for the pediatric population. Other nontraditional imaging studies, such as functional MRI and single-photon emission CT, may prove to have a role in the prediction of concussion severity and time to clinical recovery [28,66].

RETURN TO ATHLETICS

The pediatric athlete should never be allowed to RTP the same day as the concussion. In addition, an individualized approach to that child's return to athletics is necessary, including consideration of the sport and the level of participation. Currently, no evidence-based RTP guidelines for pediatric athletes with a concussion have been evaluated or validated by a double-blinded prospective study [67]. Most RTP guidelines for children with concussion are modeled after those for adults, with the assumption that clinical recovery is similar, regardless of age [30]. However, such a similarity of clinical recovery is unlikely given the differences that are evident even within the preadolescent and adolescent populations themselves. As a result, a more cautious, conservative approach to the youth athlete's RTP is prudent [4,5,11,67].

A graduated RTP protocol is the recommended practice and should be initiated after the young athlete is asymptomatic at rest [4]. The recommended duration of prerequisite resolution of symptoms before initiation of a graduated RTP varies in the literature from 24 hours to more than 7-10 days, and no consensus has been formed at this time [4,30,68,69].

Table 3. *Graduated return to play protocol**

Rehabilitation Stage
1. No activity until asymptomatic at rest
2. Light aerobic exercise; no resistance training
3. Sport-specific exercise; increased aerobic training
4. Noncontact training drills; add progressive resistance training
5. Full-contact practice
6. Return to play

*From McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on concussion in sport: The 3rd International Conference on Concussion in Sport, Zurich, Switzerland, November 2008. Br J Sports Med 2009; 43(Suppl): 76-90 [4].

This process involves a 6-step pathway; each step should take a minimum of 24 hours, and the youth athlete should remain asymptomatic throughout before progression to the next step (Table 3). As young athletes advance through a graduated RTP protocol, increasing their physical exertion as they progress, their return-to-school plan should operate in a parallel fashion, with increasing cognitive exertion. Recurrence of concussion-related symptoms during the graduated RTP protocol that are associated with either physical or cognitive stressors should prompt discontinuation of activity and resumption of prior physical and cognitive rest until the patient is asymptomatic for at least 24 hours. The youth athlete then should resume the graduated RTP at the level last tolerated without a return of symptoms. When the youth athlete has completed all of these steps without exacerbation of symptoms, he or she can be cleared for a full return to athletics. It also has been suggested that the child demonstrate intact neurocognitive function before being granted a full release [37].

Premature RTP remains a frequent occurrence despite increasing awareness of the dangers. A study of high school athletes diagnosed with a concussion during the years 2005-2008 reported that at least 40% of athletes with a concussion failed to follow American Academy of Neurology RTP guidelines and that more than 16% failed to follow established RTP guidelines [70].

SECOND IMPACT SYNDROME

Compared with collegiate and professional athletes, younger athletes may be at increased risk not only for premature clearance to RTP based on their self-reported symptoms but also for the catastrophic effects of repeated concussion [71,72]. Researchers have hypothesized that second impact syndrome (SIS) occurs when youth athletes sustain a second head injury before the initial concussion has completely healed [73]. However, there is debate as to whether SIS occurs as the result of 2 separate hits indirectly related or a single hit alone. Disruption to autoregulation of cerebral blood flow then leads to severe vascular congestion, diffuse brain swelling, and increased intracranial pressure. Over minutes, brain herniation, coma, and death may occur [12,74]. SIS has estimated rates of 50% mortality and 100% morbidity. All reported cases of SIS have occurred in athletes younger than 20 years of age [75].

LONG-TERM CONSEQUENCES OF YOUTH CONCUSSION

Cumulative Effects of Concussion

Although youth athletes who have had a single concussion may have resultant, long-term effects such as the development of postconcussion syndrome (PCS), it is generally thought that a single concussion has limited long-term consequences, if any [76]. The effects of multiple concussions on the developing pediatric brain appear to be cumulative; however, the degree to which this may affect the youth athlete later in life is not known [2]. Asymptomatic athletes with a history of ≥2 concussions more than 6 months before NP testing performed similarly to athletes who had sustained a concussion the prior week. Athletes with 2 or more concussions exhibited significantly lower grade point averages than did matched students with no concussion history [77].

PCS

A review of both concussion and mTBI literature reveals the varying presentations of PCS symptoms in the pediatric population and, possibly more importantly, their potential for prolonged duration. One study reported that nearly 14% of children aged 6-18 years with mTBI remained symptomatic 3 months after the date of injury, and 2.3% of children aged 0-18 years were symptomatic at 1 year [78]. Another study reported persistent deficits in processing complex visual stimuli more than 3 months after a concussion in children aged 8-16 years, which suggests prolonged cortical dysfunction [79]. Any persistent, long-term impairment to brain function that affects attention or information processing can have significant effects on the ability of the child with a concussion to optimally deal with the demands of reintegration into school [40].

One study that looked at potential long-term behavioral effects showed that children aged 0-10 years who had sustained an mTBI that resulted in hospital admission were statistically more likely to exhibit adverse behavioral outcomes, such as inattention and hyperactivity and conduct-disordered behavior, at 10-13 years of age. This outcome was even more likely if the injury occurred before 5 years of age, which reinforced the concern that the younger the child, the higher the potential vulnerability to the effects of concussion [80].

With respect to long-term cognitive sequelae from concussion, one study that evaluated the effects of mTBI in young children aged 3-7 years found significantly reduced performance in story recall and verbal fluency compared with age-matched control subjects without concussion at 6 and 30 months after injury [81]. The mTBI group eventually improved over time, although the researchers did suggest that the transient impairments associated with mTBI in this age population may interrupt normal brain functions, causing delay in the acquisition of neurodevelopmental skills rather than permanent deficits [81].

The potential for disruption of normal sleep patterns should be closely monitored in the youth athlete with a concussion, when considering the important role that adequate sleep may play in brain healing. A study of pediatric patients aged 11-17 years who had blunt head trauma and who had been admitted for treatment of mTBI found that, although reported symptoms had improved 2-3 weeks after injury, nearly half still had abnormal symptoms, with disordered sleep being most notable. The most common symptom was sleeping more than usual, whereas the most-severe symptom was trouble falling asleep [82]. Clinicians should consider counseling patients and parents regarding good sleep hygiene with consistent bedtime routines and reduction in daytime sleeping hours after the initial acute period after injury.

Long-term Rehabilitation

The potential benefits of the incorporation of active rehabilitation into the plan of care for youth athletes with concussion and with persistent symptoms that extend beyond the acute period (>1 month after injury) is an area of interest. Active rehabilitation allows the youth with a concussion to perform a metered amount of light exercise despite ongoing symptoms. For the small percentage of children with more chronic symptoms, the continuation of significant lifestyle and physical activity restrictions can contribute to their remaining symptomatic [80]. The positive effects of exercise on mental health and the potential negative psychological effects of being classified as injured and restricted from activity have been cited as underlying principles [83]. Although limited by self-report and the use of a not-yet validated activity intensity scale, one study reported that moderate levels of exertion (equating to school activity and slow jogging) may be beneficial during concussion recovery in high school students, with fewer reported symptoms and higher neurocognitive functioning [84,85]. These approaches are still experimental and differ from the CIS consensus statement recommendations.

The psychosocial and emotional symptoms associated with PCS are important to consider. These symptoms often include significant feelings of anxiety and depression, a sense of isolation because of absence from social interactions at school with peers, loss of control over one's own body and activity level, and even fear of reinjury and long-term consequences [83]. The youth athlete's restriction from sports participation and absence from the team, which is an important part of the youth's social network, may be challenging for the youth athlete. The persistence of any health problem in the pediatric population has been recognized as increasing the risk for psychological difficulties [86]. In particular, cognitive behavioral psychotherapy has been cited as a potential intervention for addressing mood and behavioral difficulties, as well as headache and sleep disruption [60].

Retirement From Youth Athletics

At this time, no consensus exists regarding the exact number of concussions in the pediatric population that is considered to be too many. The decision to leave contact and/or collision athletics or other high-risk activities for a season or a lifetime must be assessed on an individual basis [12]. Many researchers have suggested removal when the time intervals between repeated concussions are decreasing, when postconcussion symptoms are increasingly severe or are prolonged in duration with each subsequent injury, or when concussions require less and less force to occur [87].

EDUCATION

The CDC has built an extensive concussion awareness program aimed at educating not only coaches, trainers, and youth athletes but also their parents, teachers, and physicians. The CDC's "Heads Up" initiatives include a variety of free multimedia educational tool kits [61]. Each is specifically directed toward coaches, athletic directors, athletic trainers, athletes, teachers, parents, and clinicians for both the high school and youth athlete populations. A study on the effectiveness of the initiative showed that 82% of coaches who use the "Heads Up" materials found them useful, and half reported that the material changed their views on how serious a concussion can be, which makes them more cautious when evaluating their athletes [88]. Schools in general, through their coaches or teachers, are ideal environments for concussion prevention and awareness because of the emphasis on education in the classroom and on the field.

The youth athlete's preparticipation physical examination appointment gives the clinician the opportunity to instruct the patient and parent on the signs and symptoms of a concussion and the first steps in acute management, which emphasizes the need for immediate removal from sport and initiation of cognitive and physical rest. This preinjury counseling is important when considering the number of studies that demonstrate that many athletes lack knowledge about what a concussion is or the potential seriousness of their injury and therefore may not report symptoms or seek care [19,89,90].

The preparticipation physical examination can provide an opportunity to obtain a thorough neurologic history to ascertain the youth athlete's history of concussions. For example, a child who has had multiple concussions in the past may require counseling for himself or herself and the family about the risks of repeated concussion and potential long-term sequelae, and the importance of prompt recognition and subsequent management of future concussive injuries.

STATE LEGISLATION

The potential dangers of concussion have become a basis for legislation at the state level. In May 2009, the state of Washington passed the Zackery Lystedt Law, which requires the removal of any athlete suspected of a concussion from the game or practice and requires evaluation and written clearance by a licensed health care provider before being cleared to RTP. Parents and athletes must sign a preseason consent form that acknowledges the potential dangers of concussion. The law also requires that school boards set up educational programs for coaches, athletes, and parents. This law is named after a 13-year-old football player who sustained a severe TBI after returning to play after having sustained a concussion earlier in the game [92]. To date, more than 20 other states have passed comparable youth concussion legislation, with more proposed bills pending in several other states. Although they vary in scope and breadth of concussion education requirements, their aims remain similar: to increase concussion awareness and protect the youth athlete from premature RTP and potential catastrophic injury.

CONCLUSION

Many clinicians who treat youth athletes find themselves using practice principles, guidelines, and recommendations developed for adults. Treatment of the pediatric population involves a number of unique concerns with respect to the developing brain. The youth athlete appears to be more susceptible to concussion and requires more time to recover, thus putting him or her at higher risk for both acute catastrophic events and long-term sequelae. To ensure optimal outcomes it is important to tailor an individualized, multifaceted approach to the athletic, school, family, and social environments to which each child is returning.

Proper recognition of the youth athlete with a concussion and immediate removal from play on the day of injury is the first step in proper management. In this population, prompt initiation of both physical and cognitive rest, followed by a closely monitored graduated RTP protocol, are integral facets of concussion management. The clinician who cares for youth athletes with a concussion must consider that return to activity includes not only the return to athletics but also to the academic rigors of school, with each environment having its own specific concerns that must be taken into account.

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