

Sport-related concussion in the young athlete

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Purpose of review

The purpose of this review is to present an overview of sport-related concussion in the young athlete and review recent publications of clinical and scientific importance.

Recent findings

Recent findings show that young athletes are more susceptible to concussions than older athletes and more likely to develop second impact syndrome, as well as long-term negative cumulative consequences. Further, ongoing research suggests a more prolonged disturbance of brain function following a concussion than previously believed.

Summary

Given the increased vulnerability of the young athlete, current research suggests conservative management of concussion and return-to-play decisions. A decision tree diagram to assist the practitioner in making return-to-play recommendations for the young athlete is included in this review.

Keywords

concussion, mild traumatic brain injury, return-to-play, sports, young athlete

Introduction

The diagnosis and management of concussion in athletes have become an intensely debated topic in sports medicine. As the vast majority of people playing contact or collision sports are under the age of 19 years, it is important to understand age-related differences in risk and recommended concussion management for these athletes. The purpose of this review is to present an overview of sport-related concussion in the young athlete and to review recent publications of clinical and scientific importance. Failure to properly diagnose and manage concussion in the young athlete may lead to long-term cumulative consequences [1–3], second impact syndrome (SIS) [4–6] or risk of coma or death [4].

Definition of ‘concussion’

No universally accepted definition of ‘concussion’ exists. The word ‘concussion’ is derived from the Latin word *concutere*, which means to shake violently. Historically, concussions were defined based on loss of consciousness (LOC); LOC, however, is only one of a wide range of signs or symptoms that may be associated with concussion [7,8]. One of the most popular working definitions is ‘a trauma-induced alteration in mental status that may or may not be accompanied by a LOC’ [9]. Other terms commonly used to describe concussion include mild traumatic brain injury, mild closed head injury and mild traumatic head injury. The most common term – ‘concussion’ – will be used in this review.

Epidemiology

The Centers for Disease Control and Prevention estimate that approximately 300 000 sport-related concussions occur annually in the United States [10]. The highest number of sport-related concussions has been reported in American football. An estimated 5.6% of high-school football players sustain a concussion in a given season [11]. Taking into consideration unreported concussions, however, closer to 15% of high-school football players sustain a concussion each season [12]. Evidence also shows that concussions are under-reported in youth ice hockey [13^{*}]. Soccer, wrestling, basketball, field hockey and lacrosse are similarly associated with a high number of concussions [14,15].

Biomechanics and pathophysiology

Concussion may be caused by a direct blow to the head, face, neck or elsewhere on the body with a secondary force transmitted to the head [16]. The primary mechanism of concussion involves biomechanical forces of

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Abbreviations

LOC	loss of consciousness
MRI	magnetic resonance imaging
RTP	return-to-play
SIS	second impact syndrome

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acceleration, deceleration or rotation of the head, leading to compressive, tensile and shearing forces on the brain [17].

The pathophysiology of concussion has been described in experimental models and includes abrupt neuronal depolarization, release of excitatory neurotransmitters, ionic shifts, changes in glucose metabolism, altered cerebral blood flow and impaired axonal function. These neurochemical and neurometabolic events may last weeks to months following a concussion [18]. Consequently, concussion should be viewed as ‘a process, not an event’ [19].

Another pathophysiological process has been described predominantly in young athletes: the SIS. The syndrome occurs following an initial head injury, usually a concussion, when an individual sustains a second head injury before symptoms associated with the first have fully cleared. The pathophysiology of SIS is thought to involve loss of autoregulation of the brain’s blood supply, leading to vascular engorgement, marked increase in intracranial pressure, brain herniation and ultimately coma or death [4]. While limited cases of SIS are reported in the literature, it is associated with athletes 19 years old and younger and therefore must be considered when making a return-to-play (RTP) decision.

Evidence that genetic factors may influence brain injury severity and outcome is increasing. Apolipoprotein E – an important mediator of cholesterol and lipid transport in the brain – is coded by a polymorphic gene (APOE). The epsilon 4 allele of APOE is believed to increase vulnerability to poor outcome following traumatic brain injury [20^{••},21[•]].

Aspects of concussion specific to younger compared with older athletes

High-school athletes are more vulnerable to concussions than older athletes [22–24] and various theories attempt to explain why. These include decreased myelination, a greater head-to-body ratio and thinner cranial bones, all of which provide less protection to the developing nervous system. In addition, differences in fitness level and equipment have been raised as possible explanations for this increased rate of occurrence [24]. As the adolescent undergoes a growth spurt, there is increased weight and mass, which increase the force and momentum during collision. This, coupled with the fact that these adolescents have weaker neck muscles than adults, may impair the dissipation of forces applied to the head, increasing their risk of concussion [25]. Further, it has been suggested that the immature or developing brain cannot autoregulate the brain’s blood supply in cases of SIS, providing sound rationale for managing concussions in young athletes more cautiously than those involving older

athletes. In addition, evidence exists for a more protracted recovery from concussion in younger athletes [26,27,28^{••}].

Recognition and management of concussion

Lack of recognition of concussion is a common problem among high-school athletes. Coaches and the popular press use phrases such as ‘he had his bell rung’ or ‘suffered a ding’ to describe a blow to the head. Such descriptions can lead athletes and their families to assume that a concussion is part of the game, warranting no concern. An athlete who experiences a concussion is more likely to sustain future concussions [3,11]. Moreover, symptoms following repeat concussions may be more serious and resolve at a slower rate [3,29].

While many young athletes will not recognize all the concussions that they may have suffered, a detailed concussion history is invaluable [30,31^{••},32,33[•]]. The history should include specific questions regarding number and injury characteristics of previous concussions (e.g. recovery time, RTP timeline and medical treatment). In addition, health professionals should ask questions to assess whether symptom severity correlates with severity of impact. If symptom severity is greater than impact severity, the athlete may be experiencing progressive vulnerability to injury, increasing the risk of SIS. Athletes should also be questioned about concussion and head injuries outside sports. Athletes should additionally be queried regarding their recent and remote use of protective equipment, allowing for modification and optimization of protective behavior and education. Evidence shows that use of protective equipment may alter playing behavior deleteriously, and athletes may actually adopt risk-taking behavior when wearing protective equipment, increasing their risk of brain injury [34,35]. Documenting a history of attention disorders, learning disabilities or other cognitive development disorders is also critical for interpreting an individual player’s baseline and postinjury performance on neuropsychological testing.

Appropriate care of the acutely concussed athlete begins with accurate assessment of the gravity of the situation. The first priority is to evaluate the athlete’s level of consciousness and ABCs (airway, breathing and circulation) [36]. Concussive blows can be associated with cervical spinal injury, skull fracture and intracranial hemorrhage, and exclusion of these medical emergencies is paramount during the on-field assessment [5,37]. The attending medical staff must be prepared with an emergency action plan in the event that the evacuation of an athlete with a critical head or neck injury is necessary. Given that concussion is a metabolic rather than structural injury, traditional neurodiagnostic techniques like computerized tomography or magnetic resonance imaging

(MRI) are almost invariably normal following concussive insult [38], but should be used whenever suspicion of an intracerebral structural lesion exists. Newer structural MRI modalities, including gradient echo, perfusion and diffusion-weighted imaging, are more sensitive for structural abnormalities [5]. Imaging studies such as positron emission tomography (PET), single photon emission computerized tomography (SPECT) and functional MRI provide important metabolic and regional cerebral blood flow information; data on their application in the assessment of concussion, however, are limited [38].

Upon ruling out more severe injury, acute evaluation continues with assessment of the concussion. The health provider should record the time of the initial injury and document serial assessments, noting the presence or absence of signs and symptoms of concussion. The health provider should monitor vital signs and level of consciousness every 5 min after a concussion until the athlete's condition improves. The athlete should also be monitored for several days after the concussion for the presence of delayed signs and symptoms and to assess recovery. It is recommended that the health provider use a sign and symptom checklist similar to the one provided in Table 1. Sideline evaluation of cognitive function is an essential component in the assessment of concussion. This assessment should include evaluation of orientation, memory (anterograde and retrograde

amnesia), concentration, balance/coordination and cranial nerves [36]. An athlete with a concussion should be referred to the emergency room if he/she has experienced prolonged LOC; amnesia lasting longer than 15 min; deterioration in neurological function; decreasing level of consciousness; decrease or irregularity in respirations/pulse; increasing blood pressure; unequal, dilated or unreactive pupils; cranial nerve deficits; any signs or associated injuries, spine or skull fracture or bleeding; mental status changes (lethargy, difficulty maintaining arousal, agitation); seizure activity; vomiting; and post-concussion symptoms that worsen. Oral and written instructions for home care should be given to the young athlete and to a responsible adult who will observe and supervise the athlete during the acute phase of the concussion [32,33^{*}].

Currently, there are more than 20 concussion grading systems and RTP guidelines; none of these, however, is specific to children and adolescents. The Cantu Evidence-Based Grading system and RTP guideline is one of the most widely cited in the literature [6]. Most grading systems emphasize the presence of LOC and amnesia as indicators of injury severity. Recent research, however, suggests that these two factors, either alone or in combination, are not good predictors of injury severity [3,39,40]. In the Cantu grading system, the grading of concussion is completed after resolution of all concussion

Table 1 Graded Symptom Checklist (GSC) [32]

Symptom	Time of injury	2–3 h after injury	24 h after injury	48 h after injury	72 h after injury
Blurred vision					
Dizziness					
Drowsiness					
Excess sleep					
Easily distracted					
Fatigue					
Feel 'in a fog'					
Feel 'slowed down'					
Headache					
Inappropriate emotions					
Irritability					
Loss of consciousness					
Loss of orientation					
Memory problems					
Nausea					
Nervousness					
Personality change					
Poor balance/coordination					
Poor concentration					
Ringing in ears					
Sadness					
Seeing stars					
Sensitive to light					
Sensitivity to noise					
Sleep disturbance					
Vacant stare/glassy-eyed					
Vomiting					

Note: The GSC should be used not only for the initial evaluation but also for each subsequent follow-up assessment until all signs and symptoms have cleared at rest and during physical exertion. In lieu of simply checking each symptom present, the sports medicine health provider can ask the athlete to grade or score the severity of the symptom on a scale of 0–6, in which 0 = not present, 1 = mild, 3 = moderate and 6 = most severe.

Table 2 Cantu Evidence-Based Grading System for Concussion [6]

Grade 1 (mild)	No loss of consciousness; posttraumatic amnesia* or postconcussion signs or symptoms lasting less than 30 min
Grade 2 (moderate)	Loss of consciousness lasting less than 1 min or posttraumatic amnesia* or postconcussion signs or symptoms lasting longer than 30 min but less than 24 h
Grade 3 (severe)	Loss of consciousness lasting more than 1 min or posttraumatic amnesia* lasting longer than 24 h or postconcussion signs or symptoms lasting longer than 7 days

*Retrograde and anterograde.

signs and symptoms (Table 2) [6]. This system places less emphasis on LOC and amnesia as predictors of subsequent impairment and additional weight on overall symptom duration [6,41]. The Cantu RTP guideline is more conservative than other guidelines for mild concussions (grade 1), in that the athlete is not allowed to return to play in the same game and may only return to play after a symptom-free week (Table 3) [6]. It has been reported, however, that 30% of all high-school and collegiate football players sustaining concussions return to competition on the same day of injury; the remaining 70% average only 4 days of rest before returning to participation [11]. Although many clinicians deviate from this recommendation, there is evidence to suggest that a 7-day waiting period can minimize the risk of recurrent injury [3,39]. In addition, same-season repeat injuries typically take place within a short window of time, 7–10 days after the first concussion [3]. This may be due to increased neuronal vulnerability or blood-flow changes during that time, as shown in animal models [18].

Another approach to the evaluation and RTP decision is not to use a grading system or guideline but rather focus attention on the athlete's recovery by symptoms, formal neuropsychological tests and formal postural-stability tests [16,32,33*]. This approach is based on the evidence that complete cognitive and balance/coordination recovery may precede or follow clinical symptom resolution. Therefore, these tests could help the health provider to more accurately identify deficits caused by concussion and protect players from the potential risks associated with prematurely returning to competition and sustaining a repeat concussion. One model calls for preinjury or baseline formal neuropsychological and postural-stability testing followed by postinjury comparison testing for athletes who sustain concussion during the season. This

has led various experts and groups to endorse the use of formal baseline testing when making RTP recommendations in certain situations [31**,32,33*]. Although this model has been regarded as the most sensitive means of documenting the effects of concussion and is now used by a number of professional, collegiate and high-school programs [42], routine baseline testing has not been broadly implemented to date [43**]. It is important to note that a return of function to baseline following a concussion in the young athlete does not necessarily indicate full recovery. In interpreting the results of these measures, one needs to take into account the effects of continued neurological maturation that normally occurs during childhood and adolescence [44,45*]. Younger athletes may require more frequent updates of baseline measures compared with older athletes. Examples of formal tests for sideline use include the Standardized Assessment of Concussion (SAC, a neuropsychological test) [46] and the Balance Error Scoring System (BESS, a postural-stability test) [47]. More extensive neuropsychological [48,49] and balance-testing [50,51] measures are available to more precisely track postconcussion recovery.

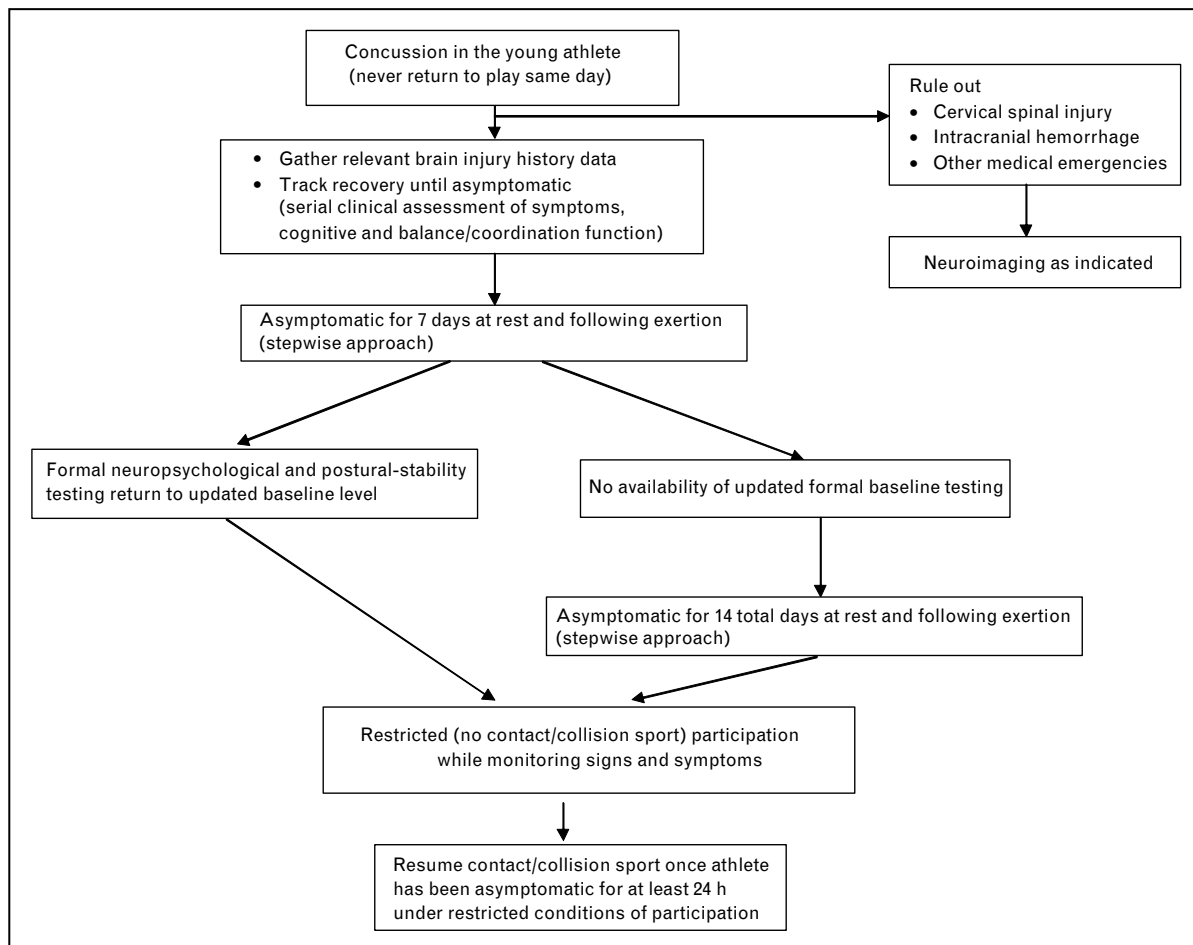
During the initial period of recovery following the concussion, it is important to emphasize to the athlete that physical and cognitive rest is required. The presence of self-reported symptoms serves as a major counter-indication for return to play. Activities that require concentration and attention may exacerbate the symptoms and delay recovery [31**]. Once sign and symptom free, the RTP decision should be made after an incremental increase in activities that do not place the athlete at risk for a subsequent concussion. Return to play after a concussion follows a stepwise process [52]. Level 1 involves no activity – complete rest. Once asymptomatic,

Table 3 Cantu Guidelines for Return to Play After Concussion [6]

	First concussion	Second concussion	Third concussion
Grade 1 (mild)	May return to play if asymptomatic for 1 week	Return to play in 2 weeks if asymptomatic for 1 week	Terminate season; may return to play next season if asymptomatic
Grade 2 (moderate)	Return to play after asymptomatic for 1 week	Minimum of 1 month; may return to play then if asymptomatic for 1 week; consider terminating season	Terminate season; may return to play next season if asymptomatic
Grade 3 (severe)	Minimum of 1 month; may then return to play if asymptomatic for 1 week	Terminate season; may return to play next season if asymptomatic	

Asymptomatic in all cases means no postconcussion symptoms, including retrograde or anterograde amnesia, at rest or with exertion.

Figure 1 Return-to-play decision making for the young athlete



proceed to level 2, which is light aerobic exercise, such as walking or stationary cycling – no resistance training. Level 3 comprises sport-specific exercise, such as skating in hockey or running in soccer, with progressive addition of resistance training at step 3 or 4. Step 4 involves noncontact training drills, step 5 full contact training after medical clearance, and step 6 game play. With this stepwise progression, the athlete should continue to proceed to the next level if asymptomatic at the current level. If any postconcussion symptoms occur, the patient should be scaled back to the previous asymptomatic level and try to progress again after 24 h.

As damage to the maturing brain of a young athlete can be catastrophic, young athletes should be managed more conservatively, using stricter RTP guidelines. We propose a decision tree for the young athlete (Fig. 1) to assist the health provider in RTP decisions after concussion. For those young athletes who demonstrate normalization of formal neuropsychological and postural-stability measures (when compared with up-to-date preinjury

baseline measures), a 7-day symptom-free (rest and exertion) waiting period is recommended before full return to contact or collision sport participation. Recent studies [28••] suggest that persistent neuropsychological deficits may last for 14 days after a concussion. In the absence of updated baseline testing, a 14-day symptom-free (rest and exertion) waiting period should be recommended. It is important to note that for athletes whose recovery is not progressing in a typical fashion (i.e. symptom clearance within 1–2 weeks), referral options to specialists such as neurologists, neuropsychologists, neurosurgeons and neuro-otologists should be considered.

Education and prevention

Education is critical in the prevention and management of sport-related concussion. Most players, coaches and parents do not understand the magnitude of the problem of concussion. Health providers should play an active role in educating young athletes, parents and coaches about signs and symptoms associated with concussion, potential risks of playing while still symptomatic, risks associated

with multiple concussions and principles of safe return to play [31^{••},32,33[•]]. The athlete must be specifically informed that loss of consciousness and memory loss are important qualifiers, but are often not present following concussive injury. They also must be informed that concussions may not be immediately obvious, and headaches, sensitivity to light and concentration difficulties can develop hours after the injury. These young athletes must also understand that once they have sustained a first concussion, they are much more likely to sustain a second and third concussive injury with potential serious consequences.

The Center for Disease Control and Prevention has produced a free tool kit on concussion for high-school coaches, entitled 'Heads Up: Concussion in High School Sports', which can be ordered through the CDC's website at http://www.cdc.gov/ncipc/tbi/coaches_tool_kit. No clinical evidence shows that currently available protective equipment will prevent concussion [31^{••}]. In certain sports, a properly fitted helmet may prevent severe forms of head injury such as skull fractures and intracranial bleeding [32,33[•]]. Rule enforcement, promotion of fair play and respect for opponents should be encouraged [31^{••}].

Conclusion

Several recent research studies and consensus statements indicate the necessity of using a systematic approach to evaluate the severity and duration of all possible signs and symptoms after a concussion, and to be cautious in RTP decisions. Given the increased incidence of concussion among young athletes, the increased vulnerability of the developing brain and the paucity of concussion research focusing on this age group, a more conservative approach should be emphasized. Continued research is essential to gain a better understanding of how to best manage or rehabilitate the young athlete suffering from concussion. Prospective investigation is warranted to further determine the acute and long-term effects of concussions in young athletes.

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References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

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Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 460).

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