Current Concepts Review

Sports-Related Concussion: Assessment and Management

Richard Ma, MD, Chealon D. Miller, MD, MaCalus V. Hogan, MD, B. Kent Diduch, MD, Eric W. Carson, MD, and Mark D. Miller, MD

Investigation performed at the University of Virginia, Charlottesville, Virginia

- Most major U.S. professional sports and the National Collegiate Athletic Association (NCAA) have adopted concussion policies. Current National Football League and NCAA guidelines do not permit an athlete with a concussion to return to play on the same day as the injury. No adolescent or high-school athletes with a concussion should be allowed to return to play on the same day regardless of severity.
- Loss of consciousness is uncommon with concussion.
- Acute concussion symptoms are generally self-limited, and most symptoms typically resolve within two weeks. Concussion risk and severity may be affected by age, sex, and genetic predisposition.
- Athletes with a concussion should rest physically and cognitively until symptoms have resolved at rest and with exertion. Rehabilitation following concussion progresses through a stepwise graded fashion.
- Neuropsychological testing can provide objective data on an athlete after a concussion. However, it alone cannot be used to diagnose a concussion or determine when an athlete is allowed to return to play.
- Retirement from contact or collision sports may be necessary for an athlete who has sustained multiple concussions or has a history of prolonged symptoms after concussions.
- Long-term effects of concussions are still relatively unknown, and further research is required to offer guidance for athletes of all levels.

Approximately forty-four million adolescents and 170 million adults in the United States participate in organized and recreational sports annually[1]. Many sporting activities place participants at risk for brain injury including concussions. The U.S. Centers for Disease Control and Prevention (CDC) estimated the annual sports-related concussion incidence to be between 1.6 and 3.8 million[2]. As a result of the increasing incidence, many national initiatives, including the CDC's "Heads Up" program (Table I), have been developed to raise concussion awareness among coaches, players, and parents.

The management of sports-related concussion continues to evolve. Most professional U.S. sports organizations, including the National Football League (NFL), National Hockey League (NHL), and Major League Baseball (MLB), have a league-wide policy on concussion management[3]. Individual states have also passed legislation aimed at protecting their young athletes. In May 2009, Washington became the first state to ratify a law regarding concussion management[4]. In addition to raising concussion awareness, the legislation prohibited any young athletes suspected of sustaining a concussion from returning to sport on the same

Disclosure: None of the authors received payments or services, either directly or indirectly (i.e., via his or her institution), from a third party in support of any aspect of this work. One or more of the authors, or his or her institution, has had a financial relationship, in the thirty-six months prior to submission of this work, with an entity in the biomedical arena that could be perceived to influence or have the potential to influence what is written in this work. No author has had any other relationships, or has engaged in any other activities, that could be perceived to influence or have the potential to influence what is written in this work. The complete **Disclosures of Potential Conflicts of Interest** submitted by authors are always provided with the online version of the article.

TABLE I Internet Concussion Resources

Title*	Web-Site Address
Educational material on sports-related concussion	
NCAA Concussion in Sports	www.ncaa.org/wps/portal/ncaahome?WCM_GLOBAL_CONTEXT = /ncaa/NCAA/Academics+and+Athletes/Personal+Welfare/Health+and+Safety/Concussion
Centers for Disease Control and Prevention Heads Up Toolkit for High School Sports	www.cdc.gov/concussion/HeadsUp/high_school.html
Centers for Disease Control and Prevention Heads Up Toolkit for Schools	www.cdc.gov/concussion/HeadsUp/schools.html
Centers for Disease Control and Prevention Heads Up Toolkit for Physicians	www.cdc.gov/concussion/HeadsUp/physicians_tool_kit.html
Computerized neuropsychological tests	
ImPACT	www.impacttest.com
CogState	www.cogstate.com/go/sport
HeadMinder	www.headminder.com
U.S. Army Medical Department, Automated Neurocognitive Assessment Metrics (ANAM)	www.armymedicine.army.mil/prr/anam.html

*NCAA = National Collegiate Athletic Association, and ImPACT = Immediate Post-Concussion Assessment and Cognitive Testing.

day as the injury. Many other states have subsequently either passed or are considering similar legislation.

While media coverage has raised public awareness and has called attention to the issues surrounding sports-related concussion, the goal is to have the treatment of athletes driven by available scientific evidence and not media anecdotes. The management of athletes who have sustained concussions can be complex. While the athlete should remain the central figure, the ability to deliver optimal care will involve coaches, athletic trainers, and even parents and teachers in the cases of student athletes. This article highlights the current state of understanding regarding sports-related concussions.

Definition of Concussion

Unlike fractures, concussion can be hard to recognize and diagnose, given the lack of a specific test or finding. Furthermore, use of terms such as "dings" or having one's "bell rung" are still commonplace, and may diminish the perception of injury severity and perpetuate the notion that concussion is something an athlete can play through. These factors may ultimately result in erroneous premature return to play. In an attempt to arrive at a consensus position, three international symposia on Concussion in Sports (CIS) have been held since 2000[5-7]. The latest CIS symposium, held in 2008, defined concussion as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces."[6] Concussion is defined as having five major clinical features (Table II)[6].

Epidemiology of Concussion and High-Risk Populations

The incidence of athletic activity-related head injuries is rising[8,9]. Sports-related concussion is within a spectrum of traumatic brain injuries and has an estimated annual incidence in the U.S. of up to 3.8 million[1]. These rates are higher than in prior reports. This is partly attributed to earlier diagnostic criteria

TABLE II Major Features of Concussion*

1. Concussion may be caused by a direct blow to the head, face, neck, or elsewhere on the body with an ''impulsive'' force transmitted to the head.
2. Concussion typically results in rapid onset of short-lived impairment of neurologic function that resolves spontaneously.
3. Concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury.
4. Concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course; however, it is important to note that, in a small percentage of cases, postconcussive symptoms may be prolonged.
5. No abnormality on standard structural neuroimaging studies is seen in concussion.

*Information from: McCrory P, Meeuwisse W, Johnston K, Dvorak J, Aubry M, Molloy M, Cantu R. Consensus statement on Concussion in Sport 3rd International Conference on Concussion in Sport held in Zurich, November 2008. Clin J Sport Med. 2009;19:185-200.

TABLE III Frequency and Rate of Concussion in NCAA Sports from 1988 to 2004*

	Percentage of All Injuries	Injury Rate Per 1000 Athletic Exposure
Men's football	6.0	0.37
Men's baseball	2.5	0.07
Men's basketball	3.2	0.16
Men's lacrosse	5.6	0.25
Men's hockey	7.9	0.41
Men's soccer	3.9	0.28
Men's wrestling	3.3	0.25
Women's basketball	4.7	0.22
Women's field hockey	3.9	0.18
Women's soccer	5.3	0.41
Women's softball	4.3	0.14
Women's ice hockey	18.3	0.91
Women's volleyball	2.0	0.09

*Table reproduced, with modification, from: Daneshvar DH, Nowinski CJ, McKee AC, Cantu RC. The epidemiology of sport-related concussion. Clin Sports Med. 2011;30:1-17, vii. Reproduced with permission. NCAA = National Collegiate Athletic Association.

mandating the presence of loss of consciousness for a concussion diagnosis. Studies, however, have shown that loss of consciousness only occurs in a minority of athletes who have sustained concussions[10-12]. Guskiewicz et al. reported an incidence of loss of consciousness of only 8.9% (eighty-nine episodes after 1003 concussive injuries) among collegiate and high-school football players who had sustained concussions[11].

Adolescents, between the ages of ten and nineteen years, are most vulnerable to sustaining athletic activity-related head injuries[8]. In terms of organized sports, American football has the highest number of sports-related concussions although hockey has the highest incidence (Table III)[13,14]. For female athletes, hockey, soccer, and basketball are high-risk organized sports.

In addition, activity-related risk, concussion risk, and severity may also be affected by age, sex, and genetic predisposition. Young athletes, such as high-school students, take longer to recover cognitively on the basis of neuropsychological testing compared with college and professional athletes[15-17], usually by a period of seven to ten days[18]. Female athletes also have an increased risk of concussion as well as an increased duration and severity of symptoms once diagnosed[16,19]. The reason for the age and sex difference is unclear. Furthermore, genetic predisposition has also been implicated, particularly individuals carrying the apolipoprotein E epsilon4 allele. This allele has been associated with a greater risk for sustaining a concussion and higher severity once one occurs[20-22]. Other genes that have been implicated include catechol *O*-methyltransferase (COMT), dopamine D2 receptor (DRD2), angiotensin-converting enzyme (ACE), calcium channel alpha 1 (CACNA1A), and p53, although the exact cause-relationship of these genes is unclear[23].

Pathophysiology of Concussion

The pathophysiology of concussion remains a topic of research and debate. Most agree that concussion is caused by a sentinel event consisting of acceleration-deceleration and rotational forces on the brain[24]. Animal models demonstrate that a series of neurophysiologic events are put in motion beginning with destabilization of the neural cell membrane[25-27]. The cell membrane disruption leads to ion channel alterations and efflux of potassium and glutamate, an excitatory amino acid. The neural cell then works to restore normal ion balance, which leads to excess adenosine triphosphate and glucose consumption and lactate accumulation. At this point, oxidative metabolism is impaired[28], and a hypometabolic state subsequently ensues from continued depletion in energy stores, which may last up to four weeks[24]. Calcium also accumulates in the cell, which further impairs oxidative metabolism and sets the stage for neuronal cell apoptosis[28]. New theories surrounding repetitive traumatic brain injury suggest that this process may not be self-limited or transient as previously believed. The duration of the altered metabolic state of the brain following repetitive injury or second impact syndrome, as well as the long-term effects, is a major component of ongoing research[29,30].

Signs and Symptoms of Concussion

The complexity of concussions extends beyond the pathophysiology. The signs and symptoms of concussions cross a broad spectrum (Table IV). The CDC breaks these down into four categories: physical, cognitive, emotional, and sleep[31]. Many of the early symptoms are not specific to sports-related concussion. This, combined with the athlete's lack of recognition or unwillingness to report symptoms, reinforces the importance of a careful and thorough evaluation whenever a concussion is suspected[32].

Headache is the most often reported symptom of concussions, but it is a symptom with multiple etiologies[11,33,34]. While loss of consciousness is uncommon with concussions, when present, it can represent a more severe injury pattern. Loss of consciousness of greater than one minute has been shown to be associated with more serious injury and longer time to recovery[34]. Amnesia, prolonged confusion, and subjective fogginess are also potential signs of more severe injury and prolonged recovery[10,35,36].

Initial Assessment

In-Game Assessment and Management

The initial assessment of an athlete who has sustained a head blow, particularly when he or she has lost consciousness, should begin with assessing the airway, breathing, and circulation. The cervical spine should be stabilized and precautions maintained until neurologic function can be thoroughly assessed and it has been determined that the patient does not have any neck pain or tenderness. Transportation to a medical facility should occur in any situation when the cervical spine cannot be cleared. If cervical spine clearance is possible, then further assessment can occur on the sideline.

TABLE IV Stages of Concussive Injury

	Acute Concussion	Postconcussion Syndrome	Prolonged Concussion Syndrome	Chronic Traumatic Encephalopathy
Duration	Usually lasting 2 weeks	Persistent concussion with symptoms lasting 1-6 weeks after injury	Symptoms lasting >6 months	Latency period
			Lowered concussion threshold	
Physical symptoms	Headache	Self-limited		
	Dizziness			
	Hearing loss			
	Balance difficulty			
	Insomnia, nausea, and/or vomiting			
	Diminished athletic performance		Diminished athletic performance	
Cognitive deficits	Loss of short-term memory			
	Difficulty with concentration			
	Decreased attention			
	Diminished work or school performance		Diminished work or school performance	
Emotional lability	Irritability, anger, fear, and/or mood swings			Irritability, anger, fear, and/or mood swings
				Personality disturbances
				Depression
				Alcohol and/or substance abuse
				Suicide attempt or completion
Sleep disturbance	Difficult falling asleep			
	Sleeping more than usual			
	Drowsiness			

Sideline concussion assessment should consist of evaluating the athlete's symptoms and neurological examination. There are a number of sideline assessment tools available for sports-related concussions, including Maddocks' questions[37], the Standardized Assessment of Concussion[6], and the Sport Concussion Assessment Tool (SCAT 2)[6]. Assessment of postural stability with use of the Balance Error Scoring System (BESS) is effective as well[38]. It is important to recognize that these sideline assessment tools are an abbreviated evaluation for the in-game setting and that each should be followed by comprehensive clinical evaluations. Furthermore, the reliability of these tools, such as BESS, can be biased by different factors such as practice effect (i.e., athletes performing better on a test they have taken before)[39,40]. After the initial assessment, an athlete who has sustained a concussion should be monitored serially on the sideline. Any athlete who demonstrates progression of symptoms should trigger immediate referral to a medical center for urgent evaluation.

The policy on return to play on the same day following concussion varies with each sporting organization and is controversial. Both the NFL and NCAA concussion policies prohibit athletes suspected of having a concussion from returning on the same day[41]. Common policies across the major professional U.S. sports include a requirement that a decision for return to play be based on the assessment by the team physician and staff familiar with concussion management[3]. In terms of adolescent or high-school athletes, the general consensus based on the recent CIS statement is to be conservative and withhold any young athlete who is suspected of having sustained a concussion from returning to sports the same day, regardless of severity[6,42]. Initial management of the athlete includes rest (cognitive and physical), and the athlete is not allowed to participate in any practices, training, or competition until symptoms have resolved.

Outpatient Assessment and Neuropsychological Testing

After the event, an athlete who has sustained a concussion should be seen in the clinical setting. A complete neurological examination and assessment, including eliciting any history of concussions or head trauma, should be performed. On the basis of the CIS statement, imaging, such as computed tomography (CT) and magnetic resonance imaging (MRI) scans, is not recommended as a routine part of sports-related concussion management[6]. If there is a concern for a structural intracranial or cervical

spine injury, then neuroimaging would be appropriate. Symptoms of potentially severe head injury that could indicate a need for further imaging include severe headaches, seizures, focal neurological findings, repeat emesis, and prolonged loss of consciousness[43].

In addition to clinical examinations, neuropsychological testing has become commonplace in concussion management. Most major U.S. sports mandate preseason neuropsychological testing in their concussion policy[3]. Computerized examinations, such as ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing), CogState, and HeadMinder, are commonly used, are reliable, and have been validated (Table I)[44,45]. The addition of neuropsychological testing provides an objective assessment tool that assists clinicians in concussion diagnosis and return-to-play decisions. In a case-control study, Van Kampen et al. reported a net 19% increase in concussion diagnosis sensitivity, from 64% to 83% of 122 athletes with concussions, after the addition of ImPACT testing compared with diagnosis on basis of symptoms alone[46]. Likewise, the prognostic value of neuropsychological testing has been evaluated as well. Iverson administered computerized neurocognitive testing within seventy-two hours of injury to high-school athletes who had sustained a concussion[47]. Athletes who required more than ten days to recover were more likely to achieve multiple scores below the 10th percentile relative to normative data.

While neuropsychological tests have proven to be a valuable tool in concussion management, to our knowledge, no evidence-based data exist to establish when to administer the test as well as the frequency of testing following a concussion. Lovell provided a framework from which to base decisions[48]. Ideally, an athlete should undergo a neuropsychological evaluation seventy-two hours after sustaining a sports-related concussion. If deficits are present, follow-up cognitive testing is recommended five to seven days later. Subsequent weekly or biweekly intervals are then used to monitor and track an athlete's recovery. While the clinical outlines, such as the one provided by Lovell, are useful, further research is needed to establish validated protocols and determine the optimal time for administering and repeating neuropsychological tests following a sports-related concussion.

Management

Rest

Current consensus regarding treatment of sports-related concussions is physical and cognitive rest[6]. Physical rest is achieved by removing the athlete from activities that may place him or her at risk for further injury and from strenuous exercises, such as aerobic conditioning and strength training. While exercise is discouraged for the athlete who has sustained an acute concussion, there may be a beneficial role for early light exercises for a protracted concussion. In a small, prospective case series of thirteen patients, Leddy et al. evaluated the role of a subsymptom threshold exercise program in athletes and nonathletes with postconcussion syndrome[49]. Subjects were placed on a supervised treadmill regimen for three weeks, and supervised patients reported subjective improvement with regard to postconcussion syndrome symptoms as well as having returned to their respective work and/or sport.

Unlike physical rest, cognitive rest may be harder to grasp conceptually and achieve during the recovery period. The academic workload and school attendance for student athletes who have sustained a concussion may need to be adjusted[6]. Studies have demonstrated that athletes who have sustained a concussion have cognitive deficits compared with their baseline preseason function[45,46,50,51]. As a result, both memory and mental processing speed can be negatively impacted, which may affect academic performance and grades. Hence, athletes who have sustained a concussion may require adjustments to minimize endeavors that require prolonged concentration and attention after a concussion. This restriction extends to nonacademic activities that require concentration and attention as well, such as leisure reading and video games. Recognition of these facts may help the athletes to preserve their grades and facilitate their rehabilitation during the recovery process.

Role of Medications

The available evidence documenting the efficacy of medications for the treatment of postconcussion symptoms is mixed[52,53]. No effective pharmacological treatment regimen can expedite a concussed athlete's recovery. Guidance on when to use medications is similarly lacking in the literature. Most athletes who sustain a sports-related concussion should have resolution of their symptoms and return to baseline function within two weeks. However, some athletes have lingering symptoms that negatively affect their daily lives. Therefore, in considering the use of medications, the physician must consider the athlete's duration of symptoms, the benefit of medication versus side effects, and whether the input of a clinician experienced in concussion management would be helpful prior to initiating medication treatment[54].

Commonly reported symptoms following sports-related concussion include headaches, sleep disturbances, and cognitive deficits[11,33,35]. Use of analgesics for treatment of headaches, such as ibuprofen, may have short-term benefits. However, side effects, such as rebound headaches, have been reported; hence, frequent use should be discouraged[55]. Antidepressants, particularly amitriptyline, have also been used to treat headaches following concussions; however, their efficacy is unclear[53]. Other agents reported in the literature include β-blockers, antiepileptics, triptans, and gabapentin[53,56].

Emotional sequelae following sports-related concussions, particularly depression, are common[54,57,58]. While most episodes are self-limited and managed conservatively, recalcitrant cases may require pharmacologic intervention. Both tricyclic antidepressants and selective serotonin reuptake inhibitors have been used with success for the treatment of brain injury-related depression[54]. The administration of these medications is best left to clinicians who are experienced in managing depression. Finally, the use of methylphenidate and amantadine for the management of cognitive deficits, such as a lag in concentration and mental processing speed, has been reported. While there are randomized placebo-controlled trials documenting their

efficacy in improving performance on attention tasks, other similar quality studies have demonstrated equivocal results as well[59-62].

In addition to prescription medication, dietary supplements have also recently gained public media coverage for so-called brain protection following concussion[63]. Fish oil, or omega-3 fatty acid, has been reported to possibly have a protective effect on a concussed brain[64,65]. Mills et al. evaluated the effect of high-dose fish oil supplements in an experimental rodent brain injury model[65]. The investigators demonstrated evidence of decreased axonal injury in animals treated with fish oil for thirty days compared with control animals following brain injury. These results are promising, given that fish oil supplements have a relatively benign side-effect profile. However, further supportive work is needed prior to widespread use of this medication in human athletes.

Return to Play and Rehabilitation After Concussive Injuries

Most athletes who have sustained a concussion will have resolution of symptoms after two weeks and a return of neuropsychological testing to baseline in seven to ten days[66]. McCrory et al. outlined three main components for return to play: evaluation of subjective symptoms, neuropsychological assessment, and balance testing[6]. These factors are consistent with the internationally accepted return-to-play criteria[6]:

1. The athlete must be asymptomatic at rest.
2. The athlete must be asymptomatic with full cognitive and physical exertion.
3. Balance testing must return to baseline.
4. Neurocognitive testing must return to baseline.

Once symptom-free at rest, an athlete who has sustained a concussion is permitted to begin rehabilitation toward return to play in a stepwise fashion (Table V). The graded protocol was first proposed by the Canadian Academy of Sport Medicine and has been endorsed by the CIS group[7,67]. Each step should take at least twenty-four hours. Hence, a concussed athlete requires at least five days to progress through the protocol prior to resumption of full game participation, provided concussive symptoms do not recur. Recurrence of symptoms may indicate incomplete recovery, and a twenty-four-hour asymptomatic rest period is required prior to attempting the previous step again. Certain factors, such as younger age and athletes with high postconcussion symptom burden or premorbid cognitive and learning disability, may require more time between each step[15,50,68].

TABLE V Guidelines for Treatment of Patients with a Sports-Related Concussion*

Rehabilitation Stage	Functional Exercise
1. No activity	Complete physical and cognitive rest
2. Light aerobic activity	Walking, swimming, stationary cycling at 70% maximum heart rate; no resistive exercises
3. Sports-specific exercises	Specific sports-related drills but no head impact
4. Noncontact training drills	More complex drills, may start light resistance training
5. Full contact practice	After medical clearance, participate in normal training
6. Return to play	Normal game play

*Information from: Guidelines for assessment and management of sport-related concussion. Canadian Academy of Sport Medicine Concussion Committee. Clin J Sport Med 2000;10:209-11.

Prevention Measures for Sports-Related Concussions

Education

Preventive measures for sports-related concussion are paramount in high-risk sports. Education and recognition of sports-related concussion remain central in the preventive process. Modern day athletes are bigger, stronger, and faster, resulting in more violent collisions[69]. Therefore, the players' understanding of the types of impact that may be at high risk for injury is important for concussion preventive purposes. Proper tackling techniques also reduce risks for injuries in the case of American football. Rule changes include regulations against leading with the head or "spear tackling" in football[70]. These changes in behavior continue to be a work in progress, as many football players believe that their particular sport requires aggressive behavior[71]. The NFL has distributed informational brochures and posters for locker rooms of professional football players on how to recognize and properly manage concussion. The CDC modified this for youth sports in its Heads Up initiative with verbiage that is more appropriate for younger individuals, families, and coaches[31] (Table I).

Education has a role not only in prevention but also in treatment following a sports-related concussion. Ponsford et al. demonstrated that concussed individuals who were supplied with educational material and informed on the expected course of recovery along with coping strategies fared better in terms of residual symptoms at three months compared with the non-intervention group[72].

Helmets and Mouth Guards

Helmets have been shown to decrease head injuries and concussion risk by reducing the acceleration of the head on impact[73,74]. Football, hockey, and skiing organizations either advocate or require helmet use at all levels[73,74]. The evidence for helmet use and concussion prevention in some sports, such as soccer, is inconclusive[75,76]. Helmet designs, particularly football helmets, have evolved to reduce concussion injuries. Features include specialized interior laminar shock absorbers that allow differential response to impact levels and exterior shell modifications aimed at improving energy attenuation from blows (Fig. 1)[77]. Studies evaluating the new helmet technology have been promising[77,78]. One study that evaluated newer football helmet technology in high-school athletes demonstrated a 31% decrease in relative risk and 2.3% decrease in absolute risk for concussion[77]. Laboratory studies of a newer helmet technology have suggested a potential 10% decrease in the risk of reproduced concussion hits[78]. Football helmets equipped with an accelerometer to provide real-time in-game helmet collision

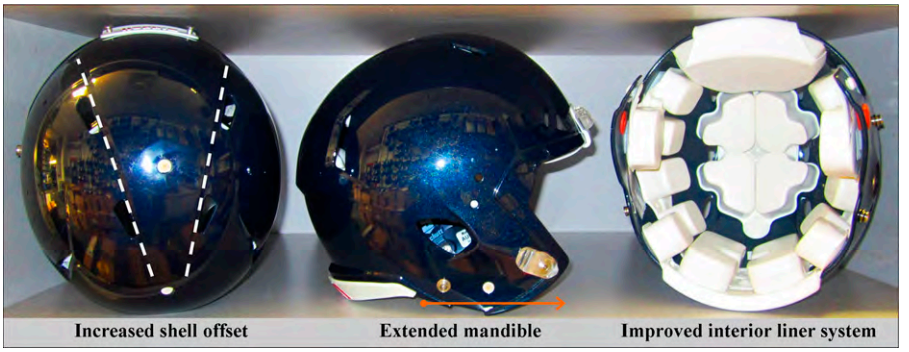

Fig. 1

Distinct football helmet design features aimed at reducing head injuries and concussions include an exterior shell with an increased crown offset, an extension anterior to and distal to traditional shell shapes along the wearer's mandible, and an improved interior liner construction. The new liner configuration over the zygoma and mandible improves energy attenuation when blows are delivered to the side of the head or face.

data, which may be beneficial for alerting the sideline medical staff of a dangerous collision, have also been developed[79].

Unlike helmets, the role of mouth guards in the prevention of concussion is controversial. There is lack of conclusive evidence that the use of a mouth guard reduces sports-related concussion[80-82]. The use of mouth guards, however, does reduce the risk of dental trauma, and the importance of mouth guards in collision sports in that regard cannot be diminished.

Complications

Postconcussion Syndrome

As defined by the World Health Organization, postconcussion syndrome is the persistence of any of the following symptoms after a concussion: headaches, dizziness, fatigue, irritability, difficulty with concentration and mental tasks, memory impairment, insomnia, and reduced tolerance to stress[83]. Postconcussion syndrome after concussion should be suspected if the above symptoms persist more than one to six weeks after the initial injury[84]. Makdissi et al. demonstrated that the initial concussion symptom burden is somewhat predictive of the duration of cognitive defects[85]. Athletes who presented with four or more concussive symptoms, headache that lasted more than sixty hours, and fogginess or fatigue took longer to recover[85]. Once symptoms have persisted for more than a few weeks, they often persist for and may be resistant to treatment. Anxiety and depression are reported by more than a third of patients with persistent postconcussion syndrome[57,58,86]. Current data to guide treatment of postconcussion syndrome are lacking. Most therapies, as detailed earlier in the section on the role of medications, are focused on medical treatment of symptoms of postconcussion syndrome[52,53]. Nonmedication therapies, including vestibular rehabilitation, have also shown promise in treating specific postconcussion syndrome symptoms such as persistent dizziness and balance dysfunction following concussion[87,88]. A recent investigation has also suggested a beneficial effect of subsymptom threshold exercises in decreasing postconcussion symptoms and returning both athletic and nonathletic individuals back to activity[49]. The advantages of treatments such as vestibular rehabilitation and subsymptom threshold exercises over medications include the avoidance of potential adverse reactions and side effects, which may be seen with drug therapy.

Second Impact Syndrome

Second impact syndrome is believed to occur when an athlete sustains two successive head injuries before symptoms from the first insult have resolved. The statistics regarding the occurrence of this entity following sports-related concussions remain largely unknown[30,89]. The pathomechanics may be related to failure of cerebral autoregulation, which result in cerebral vascular congestion, diffuse brain swelling, and possibly death[30,89]. The morbidity and mortality following second impact syndrome are frequent and severe[90]. Whether the phenomenon is truly the product of two separate successive head insults or a single severe injury remains a topic of debate.

While the nature of the insult leading to second impact syndrome is unclear, young athletes are preferentially vulnerable to this rare condition. With the exception of the boxing athlete, nearly all published cases of second impact syndrome are in the adolescent population[90]. The disparity may highlight the increased susceptibility of a child's brain to damage and swelling as well as a different cerebral autoregulatory response to injury in children relative to that in adults[90]. The preventive strategy for second impact syndrome highlights the concept that a concussed athlete should be completely asymptomatic prior to returning to sports and activities.

Chronic Traumatic Encephalopathy

Unlike concussion and postconcussion syndrome, which are temporary states, chronic traumatic encephalopathy is a neurodegenerative disease that occurs years after recovery from head trauma[91,92]. Symptoms typically emerge later in life after an athlete has already retired from his or her sport. Early symptoms may include behavioral changes such as irritability, apathy, and depression. Cognitive dysfunction can include poor episodic memory and executive dysfunction. Late onset motor abnormalities including speech and movement may also emerge[91].

Clinical and neuropathic evidence of chronic traumatic encephalopathy have been shown with various sports including

TABLE VI Factors for Consideration in the Decision to Retire from Competition*

Season-ending factors†
Prolonged postconcussion syndrome
≥3 concussions in one season
≥2 major concussions in one season
Diminished academic or athletic performance
Structural abnormality on CT or MRI brain scan
Career-ending factors†
Brain malformations (i.e., Chiari malformations)
Associated intracranial hemorrhage
Persistent postconcussion syndrome
Decreased threshold for repeat concussions
CT or MRI-documented structural brain abnormality
Nonresolving functional MRI deficits
Chronic traumatic encephalopathy

*Table reproduced, with modification, from: Sedney CL, Orphanos J, Bailes JE. When to consider retiring an athlete after sports-related concussion. Clin Sports Med. 2011;30:189-200, xi. Reproduced with permission. †CT = computed tomography, and MRI = magnetic resonance imaging.

boxing, football, professional wrestling, hockey, and soccer. The prevalence of chronic traumatic encephalopathy is unclear because of a lack of diagnostic tests. It could vary depending on the sport, duration of exposure, age at the time of the initial trauma and subsequent reinjury, as well as genetic disposition[91,92]. While the exact predisposition factors for chronic traumatic encephalopathy are not elucidated, younger age at exposure, larger magnitude of head trauma, and multiple repetitive concussions are all believed to be risk factors for chronic traumatic encephalopathy[91]. Characteristic postmortem neuropathologic findings of chronic traumatic encephalopathy include tau-immunoreactive inclusions, beta-amyloid deposits, and TDP-43 proteinopathy[92,93].

Retirement from Sports

Determining when an athlete should retire from sports because of concussion is often difficult for all individuals involved. The basis for an athlete's decision to retire from competition can be attributed to the severity of acute symptoms following a concussion, the duration and disability related to postconcussion syndrome, and the cumulative deleterious effects of repetitive concussive episodes that lead to decline in performance on and off the field[29,94-96]. Further complicating the situation are the societal and financial implications for an athlete who is considering retirement. Currently, there are no evidence-based guidelines for consideration of retiring an athlete from a sport because of concussion[96]. Use of imaging modalities to evaluate for structural abnormalities that may predispose an athlete to further injury as well as neuropsychological testing may be valuable in evaluating and counseling an athlete contemplating retirement. Involvement of a neuropsychologist may be beneficial in difficult cases. Ultimately, the decision to retire is highly individualized. Table VI represents factors for consideration in season-ending and career-ending scenarios in the setting of sports-related concussion[96].

Overview

The management of the athlete who has sustained a concussion is complex and requires a multidisciplinary team approach for optimal care. Guidelines for sideline and outpatient management continue to be refined as our knowledge regarding relationships between risk factors and disease severity expands. While improvement in protective equipment is important, the education of our players, families, and coaching staff along with changes in game rules may be more important as prevention strategies. The role of the sideline team physician in this process cannot be understated. While the media has a role in raising awareness among the mainstream community, concussion care should be driven and tested by scientific peer review and not media anecdotes. ■

NOTE: The authors thank Dr. Michael Collins, PhD, Director of the University of Pittsburgh Concussion Program, for his input on the content of this manuscript.

Richard Ma, MD
Sports Medicine and Shoulder Service,
Hospital for Special Surgery, 535 East 70th Street,
New York, NY 10021

Chealon D. Miller, MD
Department of Orthopaedic Surgery,
University of Pittsburgh Medical Center,
3471 Fifth Avenue, Pittsburgh, PA 15213

MaCalus V. Hogan, MD
Eric W. Carson, MD
Mark D. Miller, MD
Department of Orthopaedic Surgery,
University of Virginia School of Medicine,
P.O. Box 800159, Charlottesville, VA 22903.
E-mail address for M.D. Miller: MDM3P@virginia.edu

B. Kent Diduch, MD
Department of Health Sciences,
James Madison University,
MSC 4301, Harrisonburg, VA 22807

References

1. Centers for Disease Control and Prevention (CDC). Behavioral Risk Factor Surveillance System survey data: exercise. Atlanta: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention; 2006.

2. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. J Head Trauma Rehabil. 2006 Sep-Oct;21(5):375-8.

3. Brady E, Falgoust JM. Concussions now a hot issue as leagues toughen policies. Updated 2011 Oct 25. www.usatoday.com/sports/2011-04-12-nba-concussions_N.htm. Accessed 2011 Jul 27.

4. Washington State Department of Health. Concussion management for school sports. Updated 2012 Jan 5. http://www.doh.wa.gov/ehp/ts/school/concussion.htm. Accessed 2011 Jul 28.

5. McCrory P, Johnston K, Meeuwisse W, Aubry M, Cantu R, Dvorak J, Graf-Baumann T, Kelly J, Lovell M, Schamasch P; International Symposium on Concussion in Sport. Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. Clin J Sport Med. 2005 Mar;15(2):48-55.

6. McCrory P, Meeuwisse W, Johnston K, Dvorak J, Aubry M, Molloy M, Cantu R. Consensus statement on Concussion in Sport 3rd International Conference on Concussion in Sport held in Zurich, November 2008. Clin J Sport Med. 2009 May;19(3):185-200.

7. Aubry M, Cantu R, Dvorak J, Graf-Baumann T, Johnston KM, Kelly J, Lovell M, McCrory P, Meeuwisse WH, Schamasch P; Concussion in Sport (CIS) Group. Summary and agreement statement of the 1st International Symposium on Concussion in Sport, Vienna 2001. Clin J Sport Med. 2002 Jan;12(1):6-11.

8. Zafonte R. Diagnosis and management of sports-related concussion: a 15-year-old athlete with a concussion. JAMA. 2011 Jul 6;306(1):79-86. Epub 2011 May 31.

9. Centers for Disease Control and Prevention (CDC). Nonfatal traumatic brain injuries from sports and recreation activities—United States, 2001-2005. MMWR Morb Mortal Wkly Rep. 2007 Jul 27;56(29):733-7.

10. Collins MW, Iverson GL, Lovell MR, McKeag DB, Norwig J, Maroon J. On-field predictors of neuropsychological and symptom deficit following sports-related concussion. Clin J Sport Med. 2003 Jul;13(4):222-9.

11. Guskiewicz KM, Weaver NL, Padua DA, Garrett WE Jr. Epidemiology of concussion in collegiate and high school football players. Am J Sports Med. 2000 Sep-Oct;28(5):643-50.

12. Kelly JP. Loss of consciousness: pathophysiology and implications in grading and safe return to play. J Athl Train. 2001 Sep;36(3):249-52.

13. Daneshvar DH, Nowinski CJ, McKee AC, Cantu RC. The epidemiology of sport-related concussion. Clin Sports Med. 2011 Jan;30(1):1-17, vii.

14. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. J Athl Train. 2007 Apr-Jun;42(2):311-9.

15. Field M, Collins MW, Lovell MR, Maroon J. Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. J Pediatr. 2003 May;142(5):546-53.

16. Dick RW. Is there a gender difference in concussion incidence and outcomes? Br J Sports Med. 2009 May;43 Suppl 1:i46-50.

17. Catroppa C, Anderson V, Godfrey C, Rosenfeld JV. Attentional skills 10 years post-paediatric traumatic brain injury (TBI). Brain Inj. 2011;25(9):858-69. Epub 2011 Jun 29.

18. Sim A, Terryberry-Spohr L, Wilson KR. Prolonged recovery of memory functioning after mild traumatic brain injury in adolescent athletes. J Neurosurg. 2008 Mar; 108(3):511-6.

19. Colvin AC, Mullen J, Lovell MR, West RV, Collins MW, Groh M. The role of concussion history and gender in recovery from soccer-related concussion. Am J Sports Med. 2009 Sep;37(9):1699-704. Epub 2009 May 21.

20. Jordan BD, Relkin NR, Ravdin LD, Jacobs AR, Bennett A, Gandy S. Apolipoprotein E epsilon4 associated with chronic traumatic brain injury in boxing. JAMA. 1997 Jul 9;278(2):136-40.

21. Jordan BD. Genetic influences on outcome following traumatic brain injury. Neurochem Res. 2007 Apr-May;32(4-5):905-15. Epub 2007 Mar 7.

22. Alexander S, Kerr ME, Kim Y, Kamboh MI, Beers SR, Conley YP. Apolipoprotein E4 allele presence and functional outcome after severe traumatic brain injury. J Neurotrauma. 2007 May;24(5):790-7.

23. McAllister TW, Rhodes CH, Flashman LA, McDonald BC, Belloni D, Saykin AJ. Effect of the dopamine D2 receptor T allele on response latency after mild traumatic brain injury. Am J Psychiatry. 2005 Sep;162(9):1749-51.

24. Barkhoudarian G, Hovda DA, Giza CC. The molecular pathophysiology of concussive brain injury. Clin Sports Med. 2011 Jan;30(1):33-48, vii-iii.

25. Yoshino A, Hovda DA, Kawamata T, Katayama Y, Becker DP. Dynamic changes in local cerebral glucose utilization following cerebral conclusion in rats: evidence of a hyper- and subsequent hypometabolic state. Brain Res. 1991 Oct 4;561(1): 106-19.

26. Kawamata T, Katayama Y, Hovda DA, Yoshino A, Becker DP. Lactate accumulation following concussive brain injury: the role of ionic fluxes induced by excitatory amino acids. Brain Res. 1995 Mar 20;674(2):196-204.

27. Katayama Y, Becker DP, Tamura T, Hovda DA. Massive increases in extracellular potassium and the indiscriminate release of glutamate following concussive brain injury. J Neurosurg. 1990 Dec;73(6):889-900.

28. Giza CC, Hovda DA. The neurometabolic cascade of concussion. J Athl Train. 2001 Sep;36(3):228-235.

29. Cantu RC. Recurrent athletic head injury: risks and when to retire. Clin Sports Med. 2003 Jul;22(3):593-603, x.

30. Cantu RC. Second-impact syndrome. Clin Sports Med. 1998 Jan;17(1):37-44.

31. Centers for Disease Control and Prevention, U.S. Department of Health and Human Services. Heads up: facts for physicians about mild traumatic brain injury (MTBI). www.cdc.gov/NCIPC/pub-res/tbi_toolkit/physicians/mtbi/mtbi.pdf. Accessed 2011 May 26.

32. McCrea M, Hammeke T, Olsen G, Leo P, Guskiewicz K. Unreported concussion in high school football players: implications for prevention. Clin J Sport Med. 2004 Jan;14(1):13-7.

33. Guskiewicz KM, McCrea M, Marshall SW, Cantu RC, Randolph C, Barr W, Onate JA, Kelly JP. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. JAMA. 2003 Nov 19; 290(19):2549-55.

34. Putukian M. The acute symptoms of sport-related concussion: diagnosis and on-field management. Clin Sports Med. 2011 Jan;30(1):49-61, viii.

35. McCrea M, Guskiewicz KM, Marshall SW, Barr W, Randolph C, Cantu RC, Onate JA, Yang J, Kelly JP. Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study. JAMA. 2003 Nov 19;290(19): 2556-63.

36. Iverson GL, Gaetz M, Lovell MR, Collins MW. Relation between subjective fogginess and neuropsychological testing following concussion. J Int Neuropsychol Soc. 2004 Oct;10(6):904-6.

37. Maddocks DL, Dicker GD, Saling MM. The assessment of orientation following concussion in athletes. Clin J Sport Med. 1995;5(1):32-5.

38. Guskiewicz KM. Balance assessment in the management of sport-related concussion. Clin Sports Med. 2011 Jan;30(1):89-102, ix.

39. Valovich McLeod TC, Perrin DH, Guskiewicz KM, Shultz SJ, Diamond R, Gansneder BM. Serial administration of clinical concussion assessments and learning effects in healthy young athletes. Clin J Sport Med. 2004 Sep;14(5):287-95.

40. Valovich TC, Perrin DH, Gansneder BM. Repeat administration elicits a practice effect with the Balance Error Scoring System but not with the Standardized Assessment of Concussion in high school athletes. J Athl Train. 2003 Mar;38(1):51-56.

41. Solomon GS, Ott SD, Lovell MR. Long-term neurocognitive dysfunction in sports: what is the evidence? Clin Sports Med. 2011 Jan;30(1):165-77, x-xi.

42. Halstead ME, Walter KD; Council on Sports Medicine and Fitness. American Academy of Pediatrics. Clinical report—sport-related concussion in children and adolescents. Pediatrics. 2010 Sep;126(3):597-615. Epub 2010 Aug 30.

43. Fung M, Willer B, Moreland D, Leddy JJ. A proposal for an evidenced-based emergency department discharge form for mild traumatic brain injury. Brain Inj. 2006 Aug;20(9):889-94.

44. Schatz P. Long-term test-retest reliability of baseline cognitive assessments using ImPACT. Am J Sports Med. 2010 Jan;38(1):47-53. Epub 2009 Sep 29.

45. Schatz P, Pardini JE, Lovell MR, Collins MW, Podell K. Sensitivity and specificity of the ImPACT Test Battery for concussion in athletes. Arch Clin Neuropsychol. 2006 Jan;21(1):91-9. Epub 2005 Sep 6.

46. Van Kampen DA, Lovell MR, Pardini JE, Collins MW, Fu FH. The ''value added'' of neurocognitive testing after sports-related concussion. Am J Sports Med. 2006 Oct;34(10):1630-5. Epub 2006 Jun 30.

47. Iverson G. Predicting slow recovery from sport-related concussion: the new simple-complex distinction. Clin J Sport Med. 2007 Jan;17(1):31-7.

48. Lovell MR. Neuropsychological assessment of the professional athlete. In: Echemendia RJ, editor. Sports neuropsychology: assessment and management of traumatic brain injury. New York: The Guilford Press; 2006. p 176-189.

49. Leddy JJ, Kozlowski K, Donnelly JP, Pendergast DR, Epstein LH, Willer B. A preliminary study of subsymptom threshold exercise training for refractory post-concussion syndrome. Clin J Sport Med. 2010 Jan;20(1):21-7.

50. Lovell MR, Collins MW, Iverson GL, Field M, Maroon JC, Cantu R, Podell K, Powell JW, Belza M, Fu FH. Recovery from mild concussion in high school athletes. J Neurosurg. 2003 Feb;98(2):296-301.

51. Majerske CW, Mihalik JP, Ren D, Collins MW, Reddy CC, Lovell MR, Wagner AK. Concussion in sports: postconcussive activity levels, symptoms, and neurocognitive performance. J Athl Train. 2008 May-Jun;43(3):265-74.

52. Chew E, Zafonte RD. Pharmacological management of neurobehavioral disorders following traumatic brain injury—a state-of-the-art review. J Rehabil Res Dev. 2009;46(6):851-79.

53. Comper P, Bisschop SM, Carnide N, Tricco A. A systematic review of treatments for mild traumatic brain injury. Brain Inj. 2005 Oct;19(11):863-80.

54. Neurobehavioral Guidelines Working Group, Warden DL, Gordon B, McAllister TW, Silver JM, Barth JT, Bruns J, Drake A, Gentry T, Jagoda A, Katz DI, Kraus J, Labbate LA, Ryan LM, Sparling MB, Walters B, Whyte J, Zapata A, Zitnay G. Guidelines for the pharmacologic treatment of neurobehavioral sequelae of traumatic brain injury. J Neurotrauma. 2006 Oct;23(10):1468-501.

55. Lenaerts ME, Couch JR, Couch JR. Posttraumatic headache. Curr Treat Options Neurol. 2004 Nov;6(6):507-517.

56. Lew HL, Lin PH, Fuh JL, Wang SJ, Clark DJ, Walker WC. Characteristics and treatment of headache after traumatic brain injury: a focused review. Am J Phys Med Rehabil. 2006 Jul;85(7):619-27.

57. Dinan TG, Mobayed M. Treatment resistance of depression after head injury: a preliminary study of amitriptyline response. Acta Psychiatr Scand. 1992 Apr;85(4):292-4.

58. Paniak C, Reynolds S, Phillips K, Toller-Lobe G, Melnyk A, Nagy J. Patient complaints within 1 month of mild traumatic brain injury: a controlled study. Arch Clin Neuropsychol. 2002 May;17(4):319-34.

59. Whyte J, Hart T, Vaccaro M, Grieb-Neff P, Risser A, Polansky M, Coslett HB. Effects of methylphenidate on attention deficits after traumatic brain injury: a multidimensional, randomized, controlled trial. Am J Phys Med Rehabil. 2004 Jun; 83(6):401-20.

60. Lee H, Kim SW, Kim JM, Shin IS, Yang SJ, Yoon JS. Comparing effects of methylphenidate, sertraline and placebo on neuropsychiatric sequelae in patients with traumatic brain injury. Hum Psychopharmacol. 2005 Mar;20(2):97-104.

61. Meythaler JM, Brunner RC, Johnson A, Novack TA. Amantadine to improve neurorecovery in traumatic brain injury-associated diffuse axonal injury: a pilot double-blind randomized trial. J Head Trauma Rehabil. 2002 Aug;17(4):300-13.

62. Schneider WN, Drew-Cates J, Wong TM, Dombovy ML. Cognitive and behavioural efficacy of amantadine in acute traumatic brain injury: an initial double-blind placebo-controlled study. Brain Inj. 1999 Nov;13(11):863-72.

63. Rosenthal G. Concussion prevention proposal emerges. 2009 Dec 16. profootballtalk.nbcsports.com/2009/12/16/concussion-prevention-proposal-emerges/. Accessed 2011 May 27.

64. Mills JD, Hadley K, Bailes JE. Dietary supplementation with the omega-3 fatty acid docosahexaenoic acid in traumatic brain injury. Neurosurgery. 2011 Feb;68(2): 474-81; discussion 481.

65. Mills JD, Bailes JE, Sedney CL, Hutchins H, Sears B. Omega-3 fatty acid supplementation and reduction of traumatic axonal injury in a rodent head injury model. J Neurosurg. 2011 Jan;114(1):77-84. Epub 2010 Jul 16.

66. Belanger HG, Vanderploeg RD. The neuropsychological impact of sports-related concussion: a meta-analysis. J Int Neuropsychol Soc. 2005 Jul;11(4):345-57.

67. Guidelines for assessment and management of sport-related concussion. Canadian Academy of Sport Medicine Concussion Committee. Clin J Sport Med. 2000 Jul;10(3):209-11.

68. Lovell M, Collins M, Bradley J. Return to play following sports-related concussion. Clin Sports Med. 2004 Jul;23(3):421-41, ix.

69. Barth JT, Freeman JR, Broshek DK, Varney RN. Acceleration-deceleration sport-related concussion: the gravity of it all. J Athl Train. 2001 Sep;36(3):253-6.

70. Barth JT, Camiolo-Reddy C, Zafonte R. Sports concussion in an adolescent. PM R. 2009 Aug;1(8):769-73.

71. Emery CA, Kang J, Shrier I, Goulet C, Hagel BE, Benson BW, Nettel-Aguirre A, McAllister JR, Hamilton GM, Meeuwisse WH. Risk of injury associated with body checking among youth ice hockey players. JAMA. 2010 Jun 9;303(22):2265-72.

72. Ponsford J, Willmott C, Rothwell A, Cameron P, Kelly AM, Nelms R, Curran C. Impact of early intervention on outcome following mild head injury in adults. J Neurol Neurosurg Psychiatry. 2002 Sep;73(3):330-2.

73. Hagel BE, Russell K, Goulet C, Nettel-Aguirre A, Pless IB. Helmet use and risk of neck injury in skiers and snowboarders. Am J Epidemiol. 2010 May 15;171(10): 1134-43. Epub 2010 Apr 20.

74. Pellman EJ, Viano DC, Withnall C, Shewchenko N, Bir CA, Halstead PD. Concussion in professional football: helmet testing to assess impact performance—part 11. Neurosurgery. 2006 Jan;58(1):78-96; discussion 78-96.

75. Benson BW, Hamilton GM, Meeuwisse WH, McCrory P, Dvorak J. Is protective equipment useful in preventing concussion? A systematic review of the literature. Br J Sports Med. 2009 May;43 Suppl 1:i56-67.

76. Koutures CG, Gregory AJ; American Academy of Pediatrics. Council on Sports Medicine and Fitness. Injuries in youth soccer. Pediatrics. 2010 Feb;125(2):410-4. Epub 2010 Jan 25.

77. Collins M, Lovell MR, Iverson GL, Ide T, Maroon J. Examining concussion rates and return to play in high school football players wearing newer helmet technology: a three-year prospective cohort study. Neurosurgery. 2006 Feb;58(2):275-86; discussion 275-86.

78. Viano DC, Pellman EJ, Withnall C, Shewchenko N. Concussion in professional football: performance of newer helmets in reconstructed game impacts—Part 13. Neurosurgery. 2006 Sep;59(3):591-606; discussion 591-606.

79. Riddell. Head Impact Telemetry System (HITS). www.riddell.com/innovation/hits-technology/. Accessed 2011 Jul 27.

80. Barbic D, Pater J, Brison RJ. Comparison of mouth guard designs and concussion prevention in contact sports: a multicenter randomized controlled trial. Clin J Sport Med. 2005 Sep;15(5):294-8.

81. Mihalik JP, McCaffrey MA, Rivera EM, Pardini JE, Guskiewicz KM, Collins MW, Lovell MR. Effectiveness of mouthguards in reducing neurocognitive deficits following sports-related cerebral concussion. Dent Traumatol. 2007 Feb;23(1):14-20.

82. McCrory P. Do mouthguards prevent concussion? Br J Sports Med. 2001 Apr;35(2):81-2.

83. World Health Organization. The ICD-10 classification of mental and behavioural disorders: clinical descriptions and diagnostic guidelines. Geneva: World Health Organization; 1992.

84. Cantu RC. Posttraumatic retrograde and anterograde amnesia: pathophysiology and implications in grading and safe return to play. J Athl Train. 2001 Sep;36(3):244-8.

85. Makdissi M, Darby D, Maruff P, Ugoni A, Brukner P, McCrory PR. Natural history of concussion in sport: markers of severity and implications for management. Am J Sports Med. 2010 Mar;38(3):464-71. Epub 2010 Jan 9.

86. McAllister TW, Arciniegas D. Evaluation and treatment of postconcussive symptoms. NeuroRehabilitation. 2002;17(4):265-83.

87. Alsalaheen BA, Mucha A, Morris LO, Whitney SL, Furman JM, Camiolo-Reddy CE, Collins MW, Lovell MR, Sparto PJ. Vestibular rehabilitation for dizziness and balance disorders after concussion. J Neurol Phys Ther. 2010 Jun;34(2):87-93.

88. Gurr B, Moffat N. Psychological consequences of vertigo and the effectiveness of vestibular rehabilitation for brain injury patients. Brain Inj. 2001 May; 15(5):387-400.

89. Wetjen NM, Pichelmann MA, Atkinson JL. Second impact syndrome: concussion and second injury brain complications. J Am Coll Surg. 2010 Oct;211(4):553-7. Epub 2010 Jul 14.

90. McCrory P. Does second impact syndrome exist? Clin J Sport Med. 2001 Jul;11(3):144-9.

91. Gavett BE, Stern RA, McKee AC. Chronic traumatic encephalopathy: a potential late effect of sport-related concussive and subconcussive head trauma. Clin Sports Med. 2011 Jan;30(1):179-88, xi.

92. McKee AC, Cantu RC, Nowinski CJ, Hedley-Whyte ET, Gavett BE, Budson AE, Santini VE, Lee HS, Kubilus CA, Stern RA. Chronic traumatic encephalopathy in athletes: progressive tauopathy after repetitive head injury. J Neuropathol Exp Neurol. 2009 Jul;68(7):709-35.

93. McKee AC, Gavett BE, Stern RA, Nowinski CJ, Cantu RC, Kowall NW, Perl DP, Hedley-Whyte ET, Price B, Sullivan C, Morin P, Lee HS, Kubilus CA, Daneshvar DH, Wulff M, Budson AE. TDP-43 proteinopathy and motor neuron disease in chronic traumatic encephalopathy. J Neuropathol Exp Neurol. 2010 Sep;69(9):918-29.

94. Cantu RC. When to disqualify an athlete after a concussion. Curr Sports Med Rep. 2009 Jan-Feb;8(1):6-7.

95. McCrory P. When to retire after concussion? Br J Sports Med. 2001 Dec;35(6):380-2.

96. Sedney CL, Orphanos J, Bailes JE. When to consider retiring an athlete after sports-related concussion. Clin Sports Med. 2011 Jan;30(1):189-200, xi.