Chapter

Sports-Related Traumatic Brain Injury: Screening and Management

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Abstract

Mild traumatic brain injury (mTBI) sustained during sports participation, also known as sport-related concussion, has received increasing attention due in large part to the growing public awareness of the risks of head injury exposure in sports and the long-term consequences of repetitive head trauma. This chapter will review the latest understanding of concussion pathophysiology and provide an up to date overview of the scientific evidence-based acute screening and detection methods available for laypersons and medical professionals providing frontline assessment for athletes. Lastly, a comprehensive summary of clinical management for recovery management and approaches for active rehabilitation will be covered.

Keywords: balance, clinical management, concussion detection, eye movements, head trauma, K-D test, King-Devick test, pathophysiology, saccades, screening, recovery, recovery acceleration program, rehabilitation, mTBI, traumatic brain injury

1. Introduction

An estimated 41 million American children participate in competitive sports each year [1]. Participation in competitive sports is not without risk, however, as the Center for Disease Control reports that 2.7 million children aged 19 and under visited the emergency room annually for sports related injuries from 2001 to 2009 [2]. Specifically sports concussion is becoming an increasing public health issue as prevalence is estimated at 1.6–3.8 million annually [3]. Youth sports also contribute significantly to high rates of mild traumatic brain injury with 29% of sports related concussions happening in athletes between 16 and 19 years of age, and 40% of sports sports-related concussions occurring between 2001 and 2005 being sustained by children ages 8–13 [4, 5]. Although, cycling is the leading cause of head injury in children under the age of 14 [6], the three highest concussion rates in high school sports can be attributed to football, boys' ice hockey, and girls' soccer, with estimated rates of 76.8, 54, and 33 concussions per 100,000 athletic exposures, respectively [7]. These reports are likely underestimated as not all injured individuals seek medical care and therefore an estimated 50% of concussive injuries go unreported [8].

There is lack of a concrete and consistent definition of concussion which also creates challenges in the accuracy of sports related concussion epidemiology estimations. However, we share here the most widely accepted definition of concussion most recently published by an international consensus group [9], which is defined as:

Concussion is a brain injury and is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces. Several common features that incorporate clinical, pathologic and biomechanical injury constructs that may be utilized in defining the nature of a concussive head injury include:

1. Concussion may be caused either 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 the rapid onset of short-lived impairment of neurological function that resolves spontaneously. However, in some cases, symptoms and signs may evolve over a number of minutes to hours.

3. Concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging studies.

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 some cases symptoms may be prolonged [9].

Concussions result in a myriad of symptomatology which are generally categorized into four main domains: (1) physical (i.e. headache, dizziness, visual dysfunction), (2) cognitive (i.e. difficult with concentration and memory), (3) emotional (i.e. depression, anxiety and mood lability), (4) sleep disturbance (hypersomnia and insomnia). The most commonly reported symptoms include headache, dizziness and difficulties with concentration and memory. Symptoms are likely caused by functional, metabolic and microstructural abnormalities as routine neuroimaging is typically unhelpful at demonstrating anatomical evidence of neuropathic changes [10].

Exposure to repetitive concussion or sub-concussive impacts, in which a significant traumatic brain injury may have occurred even in the absence of visible signs or symptoms, is now recognized as having possible long-term neurological consequences, including neurodegenerative disease [11–15]. Given the growing incidence and concern around sports concussion as well as the potential long-term sequelae associated with the injury, awareness of the current understanding of the pathophysiology is vital within the general field of sports medicine. Additionally, as targeted screening and management options are becoming increasingly available, knowledge of the current evidence-based tools for effective screening and subsequent management of the injury are important.

2. Concussion pathophysiology

2.1 Biomechanics of the injury

Biomechanical forces from sports impact that result in traumatic brain injury or concussion leads to functional impairment at the level of individual cells or neurons. This abnormal cellular function results in overall neurological function impairment and may lead to microstructural and subsequent macrostructural damage.

Inertial, or acceleration loading, transmitted to the brain is a primary cause of concussive injury. Both linear and rotational accelerations cause transient increases in pressure within the brain and causes shear forces [16]. The forces and pressure experienced within the brain leads to changes at a cellular level. Neuronal axons can become quickly stretched resulting in a complex cascade of ionic, metabolic and pathophysiological events.

2.2 Metabolic cascade

Changes in intracellular ion concentrations occur due to disruption of cell membranes causing an abnormal outflux of potassium causes irregular neuronal depolarization which in turn leads to increased extracellular potassium and neurotransmitter release. Glutamate, an excitatory neurotransmitter, further promotes potassium efflux and binds to N-methyl-D-aspartate receptors which additionally allows for hyperexcitability and continued unhindered depolarization of the neuron. Simultaneously, accumulation of excitatory neurotransmitters also leads to influx of calcium which promotes proteases, reactive oxygen species and mitochondrial impairment all of which contribute to cellular dysfunction, damage and death when the neuron is unable to recover cellular stability [17, 18].

Dysfunction in the regulation of neurotransmitters as well as the inciting excitotoxicity of the neuron causes significant stress on the cellular mitochondria to maintain to energy demands through ATP production. The sodium/potassium (Na^+/K^+) pumps which require ATP struggle to maintain the cellular ion homeostasis. The glycolysis process is activated in an attempt to provide this increased energy demand which leads to accumulation of lactic acid. This lactic acid breaks down the blood-brain barrier and leads to cerebral edema [17].

2.3 Neuroinflammatory response and cerebral blood flow alterations

There is also a neuroinflammatory response that occurs after brain trauma which increases microglial cells, cytokine mediators, proteases and reactive oxygen species which promotes widespread inflammation and breakdown of the blood-brain barrier. This leads to cerebral blood flow changes [17, 18]. Other cerebral blood flow changes also occur as a result of carbon dioxide that accumulates from the metabolic changes occurring. Carbon dioxide causes decreases in vasoreactivity acutely and chronically. These changes can lead to many of the acute and chronic symptoms experienced by individuals suffering from sports-related concussion and also puts them at increased risk for subsequent head injury during this recovery period [17, 18].

2.4 Chronic pathophysiology

Repetitive traumatic brain injury exposure and sub-concussive injuries, in which a substantial injury is sustain however no outward signs or symptoms are apparent, can lead to persistent neurodegenerative changes. The acute neuroinflammatory response discussed above as well as the sustained neuroinflammation that may occur can result in the development of more permanent neurocognitive deficit symptoms and neurodegenerative changes. Additionally, diffuse axonal injury that occurs from concussive impacts can result in further neurodegenerative processes and permanent changes [17, 19].

Concussion has been linked to sequelae such as post-concussion syndrome and long-term neurodegenerative disease [14]. Studies have shown a 1.5 fold increased risk of depression and a 4.5 fold increased risk of Alzheimer's-like symptoms in patients with concussion history [11]. Pathological neurodegeneration markers typically found in Alzheimer's disease has also been seen in individuals with a history of repetitive traumatic brain injury. Although no causal relationship has yet been established, recent research also suggests that repeated head trauma may be associated with the development of chronic traumatic encephalopathy (CTE), a neuropathological neurodegenerative disease defined by abnormal phosphorylated tau accumulation in a pattern distinct from other tauopathies and believed to be caused by the series of metabolic, ionic, membrane, and cytoskeletal disturbances [12, 15, 20]. Tau, a normal structural axonal protein, can become disrupted during brain trauma and accumulate in a phosphorylated form. This further destabilizes microtubules and results in impaired axonal function [12, 15, 20].

3. Acute screening and detection methods

Since detecting early signs of sports-related concussion and timely removal from play may reduce the occurrence of second concussions and continued repetitive injury, there is an essential need for understanding and implementing practical sideline tests to aid in diagnosis. Next, we discuss current acute screening and detection methods for sports-related concussion.

3.1 Standardized assessment of concussion

The Standardized Assessment of Concussion (SAC) is used as a brief cognitive assessment by measuring orientation, immediate memory, concentration and delayed recall. An orientation score out of 5 points possible is determined from five questions: (1) What month is it?, (2) What is the date?, (3) What day of the week is it?, (4) What year is it?, and (5) What time of day is it? (within 1 hour). The number of orientation questions answered correctly determines the orientation score. The immediate memory score captures the athlete's ability to recall five words that are read to them on three separate trials. For example, the athlete is asked to repeat the words: elbow, apple, carpet, saddle, and bubble. The number of words recalled correctly for each trial is then added with a maximum score of 15. Concentration is tested in two parts. Initially, the concussed athlete is read a string of numbers, and then the individual must repeat them in reverse order. For example, the administrator will say: 7-1-9, and the athlete should respond with: 9-1-7. Four trials are completed with number strings of three to six digits long. The second part of concentration testing requires the athlete to recall the months of the year in reverse order. The sum of the correct digits backwards trials and one point for an entirely correct recall of the months in reverse order constitutes the concentration score out of 5.

The SAC can be administered in 5–7 minutes making it a practical sideline assessment tool and athletes suffering from concussion have been shown to have worse scores than baseline and control athletes. However, the SAC presents some shortcomings. First, it only tests a narrow range of neurocognitive functions. It also has a low correlation with other neuropsychological tests, indicating that it is not a comprehensive test [21]. The SAC does not assess brainstem or cerebellar function [9, 22, 23]. Furthermore, athletes are able to memorize sections of the tool via baseline testing or through the experiences of other teammates.

3.2 Balance error scoring system (BESS)

Balance is a complex task that requires intact information from the somatosensory, visual, and vestibular systems as well as an intact central nervous system to maintain a balanced, upright stance [24]. Concussions have been shown to inhibit an individual's ability to appropriately use feedback from the vestibular system when visual and somatosensory inputs are disrupted as a result of traumatic brain injury [25–28]. Therefore, postural stability assessments have also been recognized as an important component of evaluation after concussion [25–28].

The balance error scoring system (BESS) was initially developed as a 3–5 minutes assessment tool used by clinicians for the evaluation of postural stability after a concussion [29]. The BESS consists of 3 three stances: double-leg stance (hands on the hips and feet together), single-leg stance (standing on the non-dominant leg with hands on hips), and a tandem stance (the non-dominant foot is placed behind the dominant foot in a heel-to-toe fashion). The stances are performed on both a firm and foam surface with the eyes closed for 20-second trials. Testers observe the patient or athlete for errors in performance during the balance assessment trials with a maximum of 10 errors for each stance. Types of errors are defined as (1) lifting hands off the iliac crest, (2) opening eyes, (3) stepping, stumbling or falling out of position, (4) abducting the hip by more than 30°, (5) lifting the forefoot or heel, (6) remaining out of the test position in more than 5 seconds [29]. A modified version of the BESS (modified BESS, mBESS) that consists of testing the 3 stances on only a firm surface has even been incorporated into the Sport Concussion Assessment Tool 5 (SCAT 5).

Studies have explored the repeatability and reliability of the BESS. The reliability of this test ranges from poor to good while some studies report reliability coefficients that are below clinically acceptable levels [25, 26, 30]. This wide range of reliability may be due to variability and subjectivity resulting from multiple administrators, therefore, it has been recommended that the same individual administer the BESS for serial testing [25, 26, 30]. Furthermore, studies have recommended that an average of three BESS test administrations be used to improve reliability [25, 26, 30]. Although originally developed as an objective tool, the reliability of BESS can be significantly influenced by the subjective nature of the administrator scoring that athlete. Additionally, further variation is seen among different administrators of the BESS. Likewise, the reliability of the modified BESS is not optimal due to the subjective nature of the scoring system in which the test administrator is required to count errors that include subjective components such as trying to estimate an abduction of the hip by more than 30° or timing a subject out of the testing position by more than 5 seconds. Additionally, low levels of reliability have been reported to be due to subtle changes in balance not detectable by the administrator [25, 26, 30]. Furthermore, stances included in the BESS have been criticized for being either too difficult or too easy for normal healthy controls making it difficult to detect change in performance. In an evaluation of the BESS in a healthy collegiate football cohort at pre-season baseline, the single leg stance accounted for nearly three-quarters of the total errors committed by the study sample. Additionally, over one-fifth of the study participants also demonstrated the maximum error score of 10 errors on the single leg stance. This high variability and large number of errors in the single leg stance leads to concerns over the practical utility of the single leg stance in identifying performance change as a result of suspected concussion [31].

Several other factors are known to influence balance. These include dehydration, ankle bracing, and a prior leg injury [25, 26]. Balance differences have been demonstrated between various training backgrounds and sports played as a result of neuromuscular training. Fatigue following physical exertion has also been shown to adversely affect balance for up to an estimated 20 minutes following physical activity [25, 26]. Therefore, BESS may require a waiting period and should not be successfully administered in 3–5 minutes immediately after the concussive injury.

3.3 Sport concussion assessment tool 5

The SCAT 5 [32] and the Child SCAT 5 [33] are the evaluation tools recommended by the Concussion in Sport Group (CISG) for assessing a suspected concussion. These tests offer a standardized approach to sideline evaluation which incorporates multiple domains of function.

The SCAT 5 for immediate, on-field assessment is comprised of a brief neurological examination which includes an assessment for red flags, observable signs, a brief memory assessment, the Glasgow Coma Scale (GCS) and a cervical spine assessment. Red flags include the following: neck pain or tenderness, double vision, weakness or tingling/burning in arms or legs, severe or increasing headache, seizure or convulsion, loss of consciousness, deteriorating conscious state, vomiting, increasingly restless, agitated or combative. Observable signs are documented as either witnessed or observed on video and include: (1) lying motionless on the playing surface, (2) balance, gait difficulties or motor incoordination: stumbling, slow or labored movements, (3) disorientation or confusion, or an inability to respond appropriately to questions, (4) blank or vacant look, (5) facial injury after head trauma. The brief assessment of memory uses Maddocks questions which include: (1) What venue are we at today? (2) Which half is it now? (3) Who scored last in this match? (4) What team did you play last week or last game? (5) Did your team win the last game? The GCS is scored out of 15 in which an eye, verbal and motor response is evaluated. The best eye response is scored as 1 for no eye opening, 2 for eye opening in response to pain, 3 for eye opening to speech, and 4 eyes opening spontaneously. The best verbal response is scored out of 5 as 1 for no verbal response, 2 for incomprehensible sounds, 3 for inappropriate words, 4 for confused and 5 for oriented. Lastly the best motor response is scored out of 6 as 1 for no motor response, 2 for extension to pain, 3 for abnormal flexion to pain, 4 for flexion or withdrawal to pain, 5 for the ability to localize the pain and 6 for obeying commands. Finally, the cervical spine assessment asks if the athlete reports that their neck is pain free at rest and if so, if there is a full range of active pain free movement. Also, normal limb strength and sensation is evaluated for.

The SCAT 5 in-office or off-field assessment follows the immediate assessment and is comprised of a comprehensive symptom evaluation of 22 symptoms with a 0–5 athlete grading of severity, a brief cognitive assessment using the components of the Standardized Assessment of Concussion (SAC), a neurological screen and a balance assessment using the modified-balance error scoring system.

Changes to the original SAC were made when included in the updated SCAT 5. The SAC immediate memory and delayed recall words lists include an option to use 10 words instead of just 5 in an effort to minimize ceiling effects [32]. Additionally six word lists are presented with alternate stimulus sets for the words list for randomized administration at both baseline and serially during post-injury testing [32]. Similarly, the SAC concentration task of digits backwards in which athletes are asked to repeat back digits in reverse order, contains six versions of the concentration number lists also for randomized use at both baseline and serially during post-injury testing [32]. Additionally, a notation of when the last trial of the word list was administered is required and the delayed recall component of the SAC is recommended to be administered no sooner than 5 minutes following the immediate memory subset.

Although the SCAT 5 tests many cognitive functions related to a concussion, it should be noted that there are some shortcomings. First, it takes 15–20 minutes to complete and must be administered by a medical professional, rendering it inefficient and impractical for sideline evaluation particularly for youth and high school level sports and organizations that do not have access to medical personnel on the sidelines [9]. Additionally as discussed previously, balance performance can be affected by a number of variables and therefore reliability is difficult when attempting to differentiate balance dysfunction as a result of physical fatigue from balance impairment associated with concussion [25, 26]. Therefore, it is recommended that assessment of symptom endorsement and symptom severity, neurocognitive function and balance function take place following a 15-minute rest period to avoid the influence of fatigue or exertion, adding to the time it takes to complete the test following concussive injury [34]. The SCAT symptoms checklist may also be unreliable due to the subjective nature of the evaluation as well as athletes underreporting symptoms to avoid removal from play. Research has indicated that over a quarter of athletes who reported zero symptoms on the checklist still showed cognitive changes following a concussion [35]. In anonymous survey studies of collegiate athletes, nearly half admitted to knowingly hiding symptoms of a concussion to stay in a game and 1 one out of 5 five indicated they would be unlikely or very unlikely to report concussion symptoms to a coach or athletic trainer in the future [23].

3.4 Child sports concussion assessment tool 5

Research has shown that the SCAT testing components are more variable in younger athletes and therefore the Child SCAT 5 is recommended for use by physicians and licensed healthcare professionals in evaluating children aged 5–12 years. In this version, the immediate on-field assessment also includes a check for red flags, observable signs, GCS evaluation and cervical spine assessment.

The Child SCAT 5 in-office or off-field assessment follows the immediate assessment and is comprised of a comprehensive symptom and severity evaluation of 21 symptoms. In this version, symptoms are ranked on a 0–3 scale rather than 0–6, and both children and parents are given a report section in an effort to clear up miscommunication of symptoms. For the concentration component, children are asked to give the days of the week in reverse order, rather than the months in reverse order as asked on the SCAT 5. Additionally, the balance portion of the test is modified to only include the single leg stance in older, 10 through 12-year-old athletes only.

3.5 Concussion recognition tool 5

Although SCAT batteries are to be administered by medical professionals, the Concussion Recognition Tool 5 (CRT 5) was developed for lay person use. The CRT 5 is composed of an assessment for red flags, observable signs, symptoms checklist, and a brief memory assessment [9].

Red flags include the following: neck pain or tenderness, double vision, weakness or tingling/burning in arms or legs, severe or increasing headache, seizure or convulsion, loss of consciousness, deteriorating conscious state, vomiting, increasingly restless, agitated or combative. Observable signs are documented as either witnessed or observed on video and include: (1) lying motionless on the playing surface, (2) disorientation or confusion, or an inability to respond appropriately to questions, (3) balance, gait difficulties or motor incoordination: stumbling, slow or labored movements, (4) slow to get up after a direct or indirect hit to the head, (5) blank or vacant look, (6) facial injury after head trauma. The brief assessment of memory is used only for athletes older than 12 years and includes the following: (1) What venue are we at today? (2) Which half is it now? (3) Who scored last in this match? (4) What team did you play last week or last game? (5) Did your team win the last game? Users are instructed to remove athletes from play if one or more of these indicators are present or if a memory question is answered incorrectly.

3.6 King-Devick test in association with Mayo Clinic

The *King-Devick Test in association with Mayo Clinic* (K-D Test) is a rapid-number naming test used to evaluate for impairments in saccadic eye movements, attention, concentration, and language, which involve integration of functions of the brainstem, cerebellum, and cerebral cortex [36]. The K-D test assesses over half of brain pathways and several cortical areas are involved in saccadic eye movement [36, 37].

The K-D test requires subjects to read a series of 120 single single-digit numbers aloud from left to right across three test screens that progress in difficult as quickly but as accurately as possible. There are several versions of the test to prevent memorization. The total time to complete the test and the errors are recorded. An individualized pre-injury baseline is determined ideal at pre-season and used for comparison during an acute sideline post-injury evaluation. Extensive research has demonstrated worsening in performance in concussed athletes with high sensitivity and specificity [36, 38–41]. A study by the University of Florida found that the K-D test complements components of the SCAT 5, increasing the concussion detection rate in collegiate athletes when using a combination of testing components that include the K-D test, symptoms checklist and balance assessment [38]. Additionally, the K-D test is resistant to the effects of fatigue, showing no worsening of time when athletes were tested in game-like physical fatigue situations [36, 42, 43].

Although athletic trainers or medical professionals are present on the sidelines of professional and collegiate sporting events, most youth and high school sports lack these resources. However, parents, coaches, and laypersons can administer the King-Devick test in less than 2 minutes, making it realistic for sideline concussion evaluation [40, 44, 45].

Multiple studies have also demonstrated the utility of the K-D test in screening for “unwitnessed” concussive events [41, 47–49]. In a large prospective observational cohort study of New Zealand rugby, routine post-match screening was completed with the K-D test and in doing so aiding in identifying 44 unwitnessed, unreported concussions over the duration of the study. This totaled 6 times more than the 8 witnessed concussions, which were identified pitch-side [46]. Researchers reported that by using a composite of rapid brief tests such as the K-D test, the SAC and BESS are likely to provide a series of effective clinical tools to assess players on the sideline with suspected concussive injury [41, 47–49].

4. Clinical management

The majority of sports-related concussion symptoms typically resolve spontaneously within 2 weeks [50]. Younger athletes typically require longer recovery within 4 weeks [51]. The International Concussion in Sport Group currently promotes and supports physical and cognitive rest following concussive injury until acute symptoms resolve [9]. Once symptoms are abated, individuals should then undergo a stepwise, graded program of exertion. Athletes should be symptom free at rest as well as during and after exertion prior to complete medical clearance and full return to play. Recent research supporting the inclusion of active concussion rehabilitation has been reported and may improve outcomes.

4.1 Graduated return to play protocol

The graduated return to play protocol is a stepwise process in which the athlete may continue to proceed to the next level if asymptomatic at the previous level. It is outlined that each step should be 24 hours and therefore the athletes would generally take approximately 1 week to complete all levels of the protocol. If any symptoms arise during any of the levels, the athlete should return to the previous level until asymptomatic and 24 hours of rest has occurred [9, 44].

Rehabilitation stage 1: no activity.
Symptom limited physical and cognitive rest.
Objective: recovery.
Rehabilitation stage 2: light aerobic exercise.
Walking, swimming or stationary cycling keeping intensity <70% maximum permitted heart rate. No resistance training.
Objective: increase heart rate.
Rehabilitation stage 3: sport-specific exercise.
Skating drills in ice hockey, running drills in soccer. No head impact activities
Objective: add movement.
Rehabilitation stage 4: non-contact training drills.
Progression to more complex training drills (i.e. passing drills in football and ice hockey). May start progressive resistance training.
Objective: exercise, coordination and cognitive load.
Rehabilitation stage 5: full-contact practice.
Following medical clearance participate in normal training activities.
Objective: restore confidence and assess functional skills by coaching staff
Rehabilitation stage 6: return to Play.
Normal game play

4.2 Active concussion recovery & rehabilitation

Recent research suggests that rest until all symptoms resolve may not be best and that taking a more active approach to recovery for patients with persistent, chronic symptoms may improve recovery outcomes.

Given our understanding of concussion pathophysiology and changes in cerebral blood flow autoregulation as a result of the injury, it is believed that exercise intolerance may be a physiological biomarker of ongoing impairment [52]. Therefore the return of normal exercise tolerance can be then used to establish a sign for physiological recovery from concussion. Using any symptom-exacerbation as an individual's stopping criteria, individualized sub-symptom threshold aerobic exercise treatment programs has been shown to improve recovery time and aerobic ability in athletes with persistent concussion symptoms. This symptom improvement was also associated with improved fitness and autonomic function such as heart rate and blood pressure control and resulted in speeded recovery compared to non-active recovery study participants [53].

Active treatment targeted at system specific deficits that the patient is experiences has been shown to improve recovery. Specifically, ocular motor dysfunction is very common following sports-related concussion with a reported 90% of traumatic brain injury patients reporting vision or visual related symptoms [54]. Symptoms typically include: double vision, blurred vision, headache, dizziness, difficulty with reading or other vision-based tasks. The physical and cognitive control of eye movements requires a majority of the brain's pathways including fronto-parietal, temporal and occipital circuits as well as numerous subcortical nuclei all of which are particularly susceptible to head injury [37]. Several studies have demonstrated the effectivity of ocular based rehabilitation for vision-based deficiencies in the general population and a growing number of investigations are showing similar results in the mTBI population with improvement in vision-related symptoms, reading ability and visual attention [55–58].

5. Conclusion

Given the increasing public awareness and attention revolving sports concussion and the long-term consequences of contact sport and traumatic brain injury exposure, there is growing interest in understanding the complex and concerning issues surrounding sport-related concussion. From what we understand about the pathophysiology of concussion, it is complex and involves a multifactorial process. Many mechanisms that are currently understood from the available literature were described however there is still much more to explore and understand. For example, it is unclear what the role of various factors is in the pathophysiological process. These include the role of genetics, age, gender, premorbid conditions and environmental factors and how they may affect and alter both the underlying pathophysiology, the outward clinical symptomatology experienced by the athlete and the recovery and rehabilitation course of a particular injury. Improved global understanding of these factors will be vital to understanding how best to use an individualized approach to the treatment and management of these patients.

Similarly, the ideal methodology for optimal detection and diagnosis of concussion is multifaceted requiring the use of a suite of tools to evaluate multiple systems. In the acute setting it is highly important that these assessments be quick, efficient and accurate in detecting deficits in performance that are associated with concussion. Likewise, these evaluations need to be able to be practically implemented on the sidelines therefore cost and efficient are heavily weighted. Simultaneously, concussion awareness by all stakeholders will aid in improving outcomes from this injury. Athletes, coaches, officials and other stakeholders need to be educated on the signs and symptoms of concussion, the long-term risks of continuing to participate in sports activity with a brain injury and therefore the importance of timely removal from play as well as the equally imperativeness of appropriate clearance for return to play.

Rehabilitation of sports-related concussion is ever changing given continued ongoing research which gives insights into the latest and best recommended approaches to caring and managing patients during their recovery to improve overall outcomes. The current method is a targeted and individualized approach. Additionally, active rehabilitation has been shown to be beneficial, particularly in patients with extended recovery durations and prolonged symptomatology. Continued investigations will help answer the questions of how treatments should vary among individuals based on their makeup, for example, their concussion history, outset signs and symptoms, as well as children vs. adults. These likely all play a role and can assist in developing more targeted rehabilitation programs for individuals to advance therapies.

Conflict of interest

Dr. Leong is employed by King-Devick technologies, Inc. as Chief Scientific Officer.

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