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Masterclass

Interprofessional management of concussion in sport

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ABSTRACT

Due to the high incidence of sports concussion, various health and medical providers are likely to encounter athletes who have sustained such an injury. Management of concussion necessitates coordinated care by the members of the sports medicine team due to its pathophysiology and complexity of management during recovery. All members of the sports medicine team must possess contemporary knowledge of concussion management as well as strong interprofessional communication skills to ensure effective care and safe return to sports participation. Therefore, the aim of this manuscript is to review the current best practices in interdisciplinary management of sports concussion with a special emphasis on the required interprofessional communication among the sports medicine team.

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1. Introduction & background

Concussion and mild traumatic brain injury in sport has been gaining such significant attention in both the media and literature that the issue of concussion is being classified as an epidemic that needs immediate action (Carroll & Rosner, 2012; Murray, Murray, & Robson, 2015). Estimates of concussion in sports and recreational activities have ranged from 1.6 to 3.8 million per year in the United States (Langlois, Rutland-Brown, & Wald, 2006). Recent epidemiological studies have reported concussion diagnosis increases due to both increased athletic participation in all levels of sports (Daneshvar, Nowinski, McKee, & Cantu, 2011; Marar, McIlvain, Fields, & Comstock, 2012) as well as enhanced awareness and knowledge on the topic resulting in fewer missed diagnoses (Macpherson, Fridman, Scolnik, Corallo, & Guttmann, 2014). This growth has been corroborated by the United States Centers for Disease Control and Prevention (CDC), who has reported a 62% increase in emergency room visits per year are due to concussion in adolescents (CDC, 2011).

Concussions occur in athletes of various levels of competition and sport. Epidemiological studies often find a distribution among numerous sports, with contact sports typically being most

involved, followed by women's sports at the collegiate level (Hootman, Dick, & Agel, 2007; Meehan, d'Hemecourt, & Comstock, 2010). Many athletes who suffer sports-related concussions do not go to the emergency room or visit their physician for care (Gerberich, Priest, Boen, Straub, & Maxwell, 1983; McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004; Tommasone & McLeod, 2006). In fact, these athletes often never report their injuries. McCrea and colleagues found that only 47.3% of high school football players will report their injuries (McCrea et al., 2004). An additional study found that only 22% of high school American football players who suffered concussions were examined by medical personnel and 29% received no examination (Gerberich et al., 1983).

Concussion management guidelines have been adopted and openly distributed by international experts from the International Conference on Concussion in Sport (McCroory et al., 2013). These guidelines propose a multifaceted approach to comprehensive concussion management. Interestingly, recent studies suggest that these guidelines are not being followed to their full intent (Carson et al., 2014; Haran et al., 2015; Stoller et al., 2014). This is likely due to the notion that meeting the established international guidelines is resource dependent. All athletic organizations and teams are unlikely to possess a comprehensive array of sports medicine providers who are trained in the contemporary management of concussion. A comprehensive team of interdisciplinary professionals working collaboratively may be best suited to substantiate the aim of these comprehensive procedures. Therefore the purpose of this manuscript is to review concussion management in

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sport with special consideration to the interdisciplinary teamwork necessary for best practice and safe return of all athletes to sport participation.

1.1. Definition of concussion

Concussion is defined as a brain injury involving “a complex physiological process ... induced by traumatic biomechanical forces” (McCroly et al., 2013, p. 250). In addition, there are a number of common features incorporated into defining the nature of concussive head injury. These include the following (McCroly et al., 2013):

1. Caused by a blow to the head, neck, face or somewhere else on the body.
2. Results in rapid onset of short lived neurological impairment that resolves spontaneously.
3. May result in neuropathological changes but the acute clinical symptoms largely reflect functional disturbances rather than structural injury.
4. Results in a graded set of symptoms that may or may not include loss of consciousness.
5. Resolution of clinical and cognitive symptoms generally follows a sequential course.
6. Post concussive symptoms may be prolonged in a small percentage of people.
7. No abnormality is seen on standard structural neuroimaging.

1.2. Signs & symptoms

When an athlete sustains a concussion, he or she can present with numerous signs and symptoms across a broad spectrum (Table 1). The CDC breaks down the signs and symptoms of concussion into four categories: cognitive, physical, emotional, and sleep (CDC, 2015a,b); additionally, typical signs and symptoms of concussion were developed and distributed after the last International Conference for Concussion in Sport (McCroly et al., 2013).

1.3. Pathophysiology

The most common cause of concussion is direct blow, impulse, or sudden movement of the head that causes an impact with resultant neurologic injury. The linear and/or rotational acceleration in the brain results in a biomechanic trauma, with translational forces producing focal lesions and rotational forces produce more diffuse lesions (Almasi & Wilson, 2012). Shortly after this neuronal disruption, these translational or rotational forces initiate a complex neurometabolic cascade (Barkhoudarian, Hovda, & Giza, 2011; Giza & Hovda, 2014; Meaney & Smith, 2011; Post et al., 2014). Shearing forces damage neuronal cellular membranes releasing potassium to the extracellular space causing depolarization.

Table 1
Signs & symptoms of concussion.

Category	Signs & symptoms	
Cognitive	Slow reaction time	Lack of concentration
	Disorientation	Amnesia
Physical	Headache	Visual disturbances
	Loss of consciousness	Nausea/vomiting
	Dizziness	Loss of balance
Emotional	Irritability	Depressed mood
	Lability	Anxiety
Sleep	Drowsiness	Sleep disturbances

Depolarization causes the release of glutamate which in turn binds ionic channels causing the influx of sodium and calcium. To restore ionic imbalance, the sodium-potassium pump is activated which utilizes increased amount of ATP and requires high glucose metabolism that depletes intracellular energy stores. This ionic flux has been associated with migraine headache and photophobia. Extracellular accumulation of lactate increases membrane permeability, acidosis and cerebral edema (Barkhoudarian et al., 2011; Seifert & Shipman, 2015).

The increase in cellular metabolism happens at the same time as a decrease in cerebral blood flow resulting in an energy crisis of discrepancy in glucose supply and demand (McKee, Daneshvar, Alvarez, & Stein, 2014). The energy imbalance increases the susceptibility of the brain cells to a second insult or injury (Giza & Hovda, 2014; Herring et al., 2011). Calcium is sequestered into the mitochondria which causes disruption in oxidative metabolism. In healthy people, an increase in cerebral blood flow matches an increase in neural activity and metabolism. The opposite happens in patients with traumatic brain injury. There is a decrease in cerebral blood flow instead of hyper perfusion resulting in a secondary injury (Adelson et al., 1997; Ellis, Leddy, & Willer, 2015).

The biomechanical forces in a concussion damage dendrites and axons. Axonal stretch causes microtubule disruption which diminishes neural transmission and increase the potential for disconnection resulting in impaired cognitive function and slower reaction time (Giza & Hovda, 2014). This is sometimes referred to as traumatic axonal injury as opposed to the term diffuse axonal injury (Büki & Povlishock, 2006). In a single concussion, the neurometabolic changes are usually temporary and self-limiting (Barkhoudarian et al., 2011). The most common injuries in concussion are caused by lateral or side-to-side forces. Injuries resulting from front-to-back or sagittal forces have better outcomes than injuries from lateral forces (McKee et al., 2009).

2. Principles of interprofessional management

Due to its complex pathophysiology, concussion management is multifaceted, involving an array of assessment and continuous monitoring. After a concussive event, symptoms continue as the brain attempts to restore a normal physiological state and return to a pre-morbid state of homeostasis. During this time, activities that are stressful to the system can exacerbate symptoms and interfere with recovery. Thus, symptom tracking on a continuous basis throughout the recovery cycle is necessary and involves optimal communication among all members of the sports medicine team to allow for informed decision-making.

2.1. Interdisciplinary team building

Effective concussion management requires an array of professionals working collaboratively throughout the spectrum of the disease process. The management spans prevention, early identification and acute management, continuous assessment and reassessment, and return to play (RTP). Thus, there is an interdependency of all health and medical professionals to appropriately guide an athlete through recovery. This management requires a variety of sports medicine professionals performing as a high-functioning team.

Clinicians trained in interprofessional care more effectively optimize the skillsets of all team members, which ultimately improves patient care and clinical outcomes (Institute of Medicine [IOM], 2015; World Health Organization [WHO], 2010). Thus, the focus on collaborative practice of the sports medicine team is necessary in order to achieve optimal health outcomes. Continuous development of team-based care should include values and ethics

for professional practice, identification of roles and responsibilities, interprofessional communication, and teamwork (Interprofessional Education Collaborative [IPEC] Expert Panel, 2011). The Institute of Medicine (IOM), the Interprofessional Education Collaborative (IPEC), and the World Health Organization (WHO) have all recently taken the stance that best practices in health and medical care are reached through interdisciplinary patient care (IOM, 2015; IPEC, 2011; WHO, 2010). This position has been substantiated through empirical research which suggests that team training can significantly influence performance. A recent meta-analysis examining ninety-three effect sizes over forty-five published studies and involving over 200 teams sought to determine if training of interdisciplinary teams improves overall performance. It found a moderately positive effect for all outcomes (cognitive outcomes, affective outcomes, performance outcomes, and team functioning) with 12%–19% of the variance being explained by the presence of interdisciplinary team training (Salas et al., 2008).

The results of this meta-analysis has been further supported in studies involving several healthcare disciplines. In a primary care trauma setting, formal interprofessional team training was able to significantly reduce medical errors in a primary care trauma setting by 65% during a six-month period post training (Deering et al., 2011). In addition, another recent study found team training to significantly improve communication and patient safety with reported effect sizes demonstrating a large impact ($d = 1.01$ communication; $d = 0.71$ safety in clinical practice) (Brock et al., 2013). Team training in healthcare and medical settings has been found to be effective in collaborative practice involving communication, patient safety, knowledge of roles, and team behaviors in patient care in numerous healthcare disciplines and settings. These include both the emergency and hospital settings (Harvey, Echols, Clark, & Lee, 2014; Liaw, Zhou, Lau, Siau, & Chan, 2014; Lisbon et al., 2016; Sawyer, Laubach, Hudak, Yamamura, & Pocrnich, 2013) with effect sizes reporting a large influence ($d = 1.49$) (Sawyer et al., 2013).

Due to the consistency of these findings it may be postulated that many other areas of health and medical care may benefit from interdisciplinary team training. The intricate demands involved with the management of concussion in sports results in the need for input from various professionals working within their respective disciplines. Thus interdisciplinary team training is necessary to optimize care and ensure a safe recovery of athletes.

2.2. Policy changes & establishment

Concussion management has caught the attention of public policy makers, professional associations, and various other organizations involved in sport and recreational activities. Patient cases involving fatal second impact syndrome have led to legislative changes throughout multiple jurisdictions in the United States (McCrorry & Berkovic, 1998; McCrorry, Davis, & Makdissi, 2012). According to the CDC, currently all 50 states in the United States have concussion laws which address actions which should occur when a concussion is suspected. These policies often include requirements for education of athletes, parents and coaches, the requirement for removal from play when a concussion is suspected, and procedures for return to activities (CDC, 2015a,b).

Although concussion management policies typically contain some similarities, there may be subtle differences based on jurisdiction that can impact healthcare providers' management process. Therefore it is imperative that any practicing medical and healthcare providers become familiar with their jurisdiction's policies for management of concussion. In such manner, the National Collegiate Athletic Association (NCAA) outlines its concussion management policies in its annual Sports Medicine Handbook, where it not only

identifies the hallmarks of concussion from recent literature (Table 2), but also mandates that each institution possess a comprehensive concussion management plan to guide all aspects of administration, prevention, and care (NCAA, 2014).

3. The concussion management team

A team approach to concussion management will cross a wide spectrum from prevention to acute management to return to activity and involve various members of the sports medicine team. This involves physicians, physical therapists, athletic trainers, nurses, exercise scientists, neuropsychologists, and others. Providers from these disciplines often possess multiple skillsets and educational backgrounds that are unique in some ways but also often duplicative of each other in other ways. In addition, subtle variations in jurisdiction guidelines and practice acts can also add potential confusion with roles and responsibilities. Therefore, all members of the sports medicine team must be aware of their local professional practice guidelines as well as the strengths and limitations of each other's training. Further, clear communication policies must be established and strictly followed. The team must appoint lead provider(s) for the overall care as well as those providers guiding an athlete at any given stage of recovery. In consideration of these aspects of care, the authors pose a sample format for functions of typical providers involved in the concussion management team (Table 3).

3.1. Primary role of the physician

The sports medicine physician often leads the healthcare team and collaborates with the other health care professionals throughout the continuum of care in the athlete's best interest. A crucial part of this process is ensuring that the organization (high school, college, professional team) performs adequate pre-participation evaluations at enrollment, prior to the start of the season. Preparticipation physicals are important to detect history of injuries in the musculoskeletal and neurological systems, presence of chronic diseases, and assess cardiovascular risk. For the majority of athletes, this is the only contact with a health care provider (Conley et al., 2014; Roberts et al., 2014). It is vital for the sports medicine physician to be aware of concussion history, time to recovery from previous injury, and presence of premorbidities or comorbidities (history of migraines, attention deficit disorder, learning disabilities, sleep disorders) and communicate these conditions to all members of the sports medicine team when appropriate in order to provide optimal care (Broglio et al., 2014; Reynolds, Collins, Mucha, & Troutman-Ensecki, 2014).

The entry point is also a valuable time for education on concussion education, as well as establishment of baseline neurocognitive and balance testing. It is important for the athletes to know the symptoms, comprehend the dangers of repeated injury, and understand the appropriate steps in return to play. In addition, baseline neurocognitive and balance assessment can provide invaluable information for comparative data points when assessing for deficits post concussion. The baseline test for each athlete will be an integral portion of managing an athlete with a concussion on the sidelines. (Broglio et al., 2014; Guskiewicz, Weaver, & Padua, 2000). While this data is often collected by the other members of the sports medicine team, the physician is the member who most commonly interprets the data and patient presentation to ultimately make return to play decisions or progression decisions during recovery with collective input from the other members of the sports medicine team (Herring, Kibler, & Putukian, 2013).

The sports medicine physician also assumes a leadership role in the development and review of the emergency management plan

Table 2
NCAA concussion policy and legislation.

NCAA CONCUSSION policy and legislation	
The NCAA executive Committee adopted (April 2010) the following policy for institutions in all three divisions	
"Institutions shall have a concussion management plan on file such that a student-athlete who exhibits signs, symptoms or behaviors consistent with a concussion shall be removed from practice or competition and evaluated by an athletics health care provider with experience in the evaluation and management of concussions. Student-athletes diagnosed with a concussion shall not return to activity for the remainder of that day. Medical clearance shall be determined by the team physician or his or her designee according to the concussion management plan.	
"In addition, student-athletes must sign a statement in which they accept the responsibility for reporting their injuries and illnesses to the institutional medical staff, including signs and symptoms of concussions. During the review and signing process, student-athletes should be presented with educational material on concussions."	
NCAA adopted concussion management plan legislation	
An active member institution shall have a concussion management plan for its student-athletes. The plan shall include, but is not limited to, the following:	
a)	An annual process that ensures student-athletes are educated about the signs and symptoms of concussions. Student-athletes must acknowledge that they have received information about the signs and symptoms of concussions and that they have a responsibility to report concussion-related injuries and illnesses to a medical staff member;
b)	A process that ensures a student-athlete who exhibits signs, symptoms or behaviors consistent with a concussion shall be removed from athletics activities (e.g., competition, practice, conditioning sessions) and evaluated by a medical staff member (e.g., sports medicine staff, team physician) with experience in the evaluation and management of concussions;
c)	A policy that precludes a student-athlete diagnosed with a concussion from returning to athletic activity (e.g., competition, practice, conditioning sessions) for at least the remainder of that calendar day;
d)	A policy that requires medical clearance for a student-athlete diagnosed with a concussion to return to athletics activity (for example, competition, practice, conditioning sessions) as determined by a physician (e.g., team physician) or the physician's designee.
Effect of violation. A violation of Constitution 3.2.4.17 shall be considered an institutional violation per Constitution 2.8.1; however, the violation shall not affect the student-athlete's eligibility.	

Adopted from 2014 to 2015 NCAA Sports Medicine Handbook, p. 63.

Table 3
Health care provider and function on concussion management.

Health care provider	Primary function	Phase
Athletic Trainer	E,SM, RH	P,DM,RTL, PCM
Coach	SM	P, DM, PCM
Exercise Physiologist	EP	RTL, PCM
Neuropsychologist	E,RH	DM
Nurse	T	RTL,PCM
Physical Therapist	E,RH	P,DM,RTL, PCM
Physician	E,SM,RH	P,DM,RTL
Teacher	T	RTL,PCM

Function – Evaluation (E), Exercise Prescription (EP), Sideline Management(SM), Rehabilitation (RH), Treatment (T).

Phases – Prevention (P), Diagnosis and Management (DM), Return to Learn and Play Protocol (RTL), Post Concussion Monitoring (PCM).

and comprehensive concussion management plan (Herring et al., 2013; Herring et al., 2011). When addressing athlete safety, having an emergency action plan will lead to quicker and more efficient response in emergent situations (Drezner et al., 2007).

3.2. Primary role of the athletic trainer

Although the risk of a concussion will vary between sports, athletes, experience level, age, and gender (Hootman et al., 2007), it is vital to have qualified medical personnel that can identify, assess, and manage an athlete with a concussion as soon as possible. Due to their proximity to the athlete during athletic events, athletic trainers are typically the first licensed medical professionals to evaluate an athlete for potential concussion and provide acute management (Broglia et al., 2014). Due to the serious nature of concussive injuries, the member of the sports medicine team providing the initial care should not only possess adequate training in the acute management of concussion, but should also accomplish additional criteria in order to enhance assessment and initial management. First, they must evaluate the emergency action plans and policies and procedures guiding the initial care. Next, they should clarify interprofessional communication among personnel, location of necessary equipment, transportation procedures of the athlete, and emergency care facilities locations. Finally, the procedures involved in the acute management of concussion should be

reviewed and practiced with all involved sports medicine team members on an annual basis, at minimum (Andersen, Courson, Kleiner, & McLoda, 2002).

As stated, when an athlete experiences a concussion mechanism, the athletic trainer often represents the first line of defense from further injury (Guskiewicz & Broglia, 2011). The first step is to conduct a primary survey of the athlete. This includes assessing for loss of consciousness, airway, breathing, circulation, and vital signs. Most of the time athletes will show no outward visible sign of a concussion. The cervical spine should be stabilized in a neutral position during the primary survey until an injury has been ruled out. If the athlete is conscious and severe injuries are ruled out, the athlete can be taken to the sidelines for the secondary survey (Guskiewicz et al., 2000). The secondary survey should be standardized for each athlete and should include history, observation, palpation, special tests, range of motion assessment, and functional testing (Guskiewicz & Broglia, 2011). During continuous monitoring, if there are signs of rapid neurological deterioration, EMS should be activated (Broglia et al., 2014).

During the history portion of the clinical evaluation the AVPU scale (alert, voice, pain, and unresponsive) can be utilized to assess the athlete's level of consciousness. Next, the patient should be assessed for signs of retrograde or anterograde amnesia. Memory loss prior to trauma is indicative of retrograde amnesia. Conversely, memory loss post trauma indicates the presence of anterograde amnesia. Therefore, questions that incorporate details before and after the patient experienced the head trauma should be included (Guskiewicz & Broglia, 2011). To complete the patient's history, a symptom checklist can be administered to quantify the number of symptoms and their intensity. The National Athletic Training Association recommends a 27 item symptom checklist (Broglia et al., 2014). Observation and palpation can be done throughout the evaluation process. Observation should include speech patterns, pupil size, reactivity to light and posture. The cervical spine and facial bones should all be palpated to assess for a potential fracture to those structures (Guskiewicz & Broglia, 2011). The range of motion portion should include active, passive and resistive range of motion of cervical spine flexion, extension and rotation to each side (Guskiewicz & Broglia, 2011). This screening may assist in detecting associated injuries that will need to be communicated to and addressed by the evaluating physician and physical therapist.

The last step is the functional testing. This part of the evaluation should only be completed if the patient has no other neurological dysfunction up to this point. The goal is to elicit symptoms that may not have revealed themselves otherwise. The athletic trainer should start by asking the patient to perform the Valsalva maneuver, pushup and or sit-ups. If no symptoms arise then the athlete can perform light cardiovascular exercise like jogging or short sprints. Lastly, the athlete can perform some sport specific drills. If no symptoms arise up to this point, then a concussion is most likely not present and the athlete can be considered for return to play (Guskiewicz & Broglio, 2011).

If presenting symptoms indicative of a concussion are present, then the athletic trainer should be completely remove the athlete from participation, limit all physical and cognitive activity, monitor for any neurological decline and referred to the sports medicine physician for initial management. Suspicion of concussion should automatically trigger the concussion management process, and include initial documentation to the athlete and/or caretakers outlining education on initial management with instructions on when to seek emergency care (see Table 4). All initial findings during the primary survey, secondary survey, history, and functional testing should be discussed with the primary care physician and clearly documented for reference by all other members of the sports medicine team who will be interacting with the athlete during the subsequent recovery.

3.3. Primary role of the physical therapist

A sports physical therapist can potentially participate in various components of a concussion management program. Participation will likely span from preparticipation examination, return to play progression, and management of associated disorders. Depending on the qualifications in the acute management of concussion and jurisdictional policy, a physical therapist may be involved in the acute management of concussion in similar nature as the athletic trainer. Although the primary duties of the physical therapist in management of athletes post-concussion are most directly aligned during the rehabilitation phase, it is also likely that a physical therapist can be involved in other areas of concussion management, spanning acute management to return to play progression due to the diverse training and qualifications of a physical therapist.

Due to the nature of insult, physical therapy assessment of patients with concussion often transpires after the acute symptoms are managed and includes screening for vestibular dysfunction and cervical spine instability (Ellis & McDonald, 2015; Ellis et al., 2015). The presence or likelihood of presence of these types of injuries can be ascertained through discussion with the athletic trainer or other provider who managed the initial injury, with special consideration to the mechanism of injury, acute symptoms, and premorbidities or comorbidities.

Vestibular dysfunction can be assessed by examining gross extraocular movements, visual acuity, visual fields, saccades, smooth pursuit and the vestibulo-ocular reflex (VOR). The physical therapist should also perform a screening for Benign Paroxysmal

Positional Vertigo (BPPV) using the Dix-Hallpike and Roll tests. Cervical spine assessment include assessment of cervical alignment, posture, range of motion, palpation of cervical muscles for tenderness and spasm of the anterior scalenes, paraspinal and suboccipital muscles (Ellis et al., 2015). Patients who complain of dizziness and disequilibrium may show impairments on balance, oculomotor, vestibular and gait examinations. The sense of being in motion even when the individual is not moving is common in patients who suffer from Post-Concussion Syndrome (PCS) with vestibular involvement. PCS is characterized by signs and symptoms of concussions that continue for weeks to months after the incident (Harmon et al., 2013). Approximately 40% of athletes report balance impairments and 30% report visual problems within the first week following a concussion (Mucha et al., 2014). While 80% of concussed athletes will spontaneously recover from balance and vestibular impairments, management of these symptoms should begin from initial impact and should not finish until resolution of symptoms. Vestibular rehabilitation has been shown to improve impairments in balance, gait and dizziness after a concussion (Aligene & Lin, 2013; Alsalaheen et al., 2010). The most common exercises prescribed by physical therapist for patients with concussion who have undergone vestibular rehabilitation included eye-hand coordination, standing static balance and ambulation (Alsalaheen et al., 2013).

Patients with cervical spine involvement may have limitation of motion, radiculopathy, postural misalignment and neck pain (Ellis & McDonald, 2015). Due to the incidence of neuropraxia of the cervical nerve roots or brachial plexus in football, this may also be an associated condition encountered when treating concussive disorders (Rihn et al., 2009). Further, while the use of Head Impact Telemetry have shown that linear impact accelerations between 60 and 160 g (gravity) causes concussion (Broglio, Surma, & Ashton-Miller, 2012; Marshall, Vernon, Leddy, & Baldwin, 2015), a much smaller force can cause strain on the neck musculature (Marshall et al., 2015; Spitzer et al., 1995).

Physical therapy treatment of patients post concussion has gained recent attention in the literature. In a recent randomized controlled trial, it was found that cervical and vestibular physiotherapy decreased the time to obtain medical clearance to return to sport in concussed patients complaining of dizziness, cervical pain and/or headache. The cervical physiotherapy included manual therapy, sensorimotor and craniovertebral flexor and extensor training while the vestibular component included habituation, gaze stabilization, adaptation, balance exercises and canalith repositioning maneuver (Schneider et al., 2014). In addition, a recent study utilizing functional MRI to monitor cerebral blood flow during aerobic exercise, concluded that structured aerobic exercises may help restore regulation of normal cerebral blood flow (Leddy et al., 2010, Leddy, Sandhu, Sodhi, Baker, & Willer, 2012, 2013). These researchers have further proposed a return-to-activity algorithm for concussion and PCS that factors the time of symptom resolution and results of graded exercise-treadmill testing that can be incorporated into physical therapy management (Leddy et al., 2012). The implementation of this type of protocol into physical therapy management is a hallmark example of how physical therapists will likely interact with exercise physiologists in the management of concussion.

3.4. Primary role of the exercise scientist

Exercise physiologists and strength and conditioning professionals are also likely to be a part of the sports medicine team during the management of athletes returning from concussion (Pabian, Greeno, Vander Heiden, & Hanney, 2013). This is most likely to occur during either the pre-participation examinations or

Table 4

Indications to seek emergency medical care.

Worsening headache
Repeated Vomiting
Unusual behavior
Seizures
Weak or numbness in arms and legs
Slurred speech
Unsteady when attempting to stand

Adapted from (SCAT3, 2013).

the return to play timeframe. Once the athlete has returned to baseline in neurological, balance, and neurocognitive tests, and has no symptoms after a full day, then he or she is allowed to start the graded return to play protocol. The predominant involvement of an exercise physiologist during collaborative management of athletes post concussion will be during the graduated return to play protocol. This protocol involves completion of specific types of exercises at different heart rate or exertional intensities (McCrorry et al., 2013). These exercises may be delivered by an exercise physiologist with input and supervision by a physical therapist or athletic trainer trained in concussion management, or with oversight by the sports medicine physician, who directs all patient care (Herring et al., 2013).

It is crucial that the athlete is monitored for any concussion symptoms before, during, immediately after, and the day after each step of the exercise progression. This monitoring is important due to the fact that although studies have found cerebral blood flow is increased even with low level intensity exercise, patients experiencing post-concussive complications can perform most low level exercises without exacerbation of symptoms (Kozlowski, Graham, Leddy, Devinney-Boymel, & Willer, 2013). In addition, aggressive exercise intervention prior to symptom resolution may result in delayed recovery (Griesbach, Hovda, Molteni, Wu, & Gomez-Pinilla, 2004). Therefore, it is important to recognize that each step in the return to play protocol may take 1–2 days, as it necessitates that the athlete is asymptomatic 24 h after each step (McCrorry et al., 2013). Due to the fact that the graduated RTP protocol lacks great detail, this is a time period in which coordination of care, communication, and monitoring is essential. Also, specific athletic demands based on sport and position played in the sport will need strong consideration in the intensity, dosing, and monitoring of athlete response. All changes in status or resumption of symptoms must be communicated to the sports medicine physician for medical evaluation.

3.5. Collaborative care

Although some disciplines may have greater involvement in different stages of concussion management, all healthcare professionals work collaboratively throughout nearly all stages. The sports medicine physician should work in conjunction with the lead providers in all related areas (athletic training, physical therapy, nursing, psychology, exercise science, etc.) to develop a concussion management plan that identifies the appropriate channels of communication. In most cases, ultimate authority lies with the sports medicine physician in the coordination of care between acute management, the rehabilitation process, and return to play.

While the sports medicine physician generally will make the ultimate decisions on care, recognition of each provider's scope of legal and professional practice to make decisions is necessary. Furthermore, care should be individualized with strong consideration of baseline comparisons of performance, history, concussive modifiers (Table 5), and symptom monitoring throughout the return to play process. The stepwise return to play program as presented by the International Conference on Concussion in Sport is presented in Table 6 (McCrorry et al., 2013).

4. Complications & repeat injury

As noted previously, healthcare team building with emphasis on communication and understanding of roles and responsibilities enhances patient outcomes (Brock et al., 2013; Liaw et al., 2014; Lisbon et al., 2016; Salas et al., 2008; Sawyer et al., 2013). These skills are essential to prevent re-injury or mis-management.

During the recovery from concussion, significant risks exist as the patient is vulnerable to re-injury that can have a much more significant impact on his or her future health. Due to the neuro-metabolic cascade after a concussive event, there is a decreased ability on a cellular level to appropriately respond to another acute insult, resulting in the potential for apoptotic cell death. Thus, there is a heightened danger of experiencing chronic atrophy and persistent cognitive impairments with repeated injuries such as second impact syndrome, chronic traumatic encephalopathy, or post-concussion syndrome (Giza & Hovda, 2014). It is paramount for providers managing athletes post concussion to understand the etiology and recognition of these conditions as they will certainly alter the care plan for the sports medicine team.

4.1. Post-concussion syndrome

Post-concussion syndrome (PCS) is a complication of concussion that is defined as a set of signs and symptoms of concussion or mild traumatic brain injury (mTBI) lasting longer than the regular recovery period or more than 3 months. Approximately 10–20% of individuals who suffered a mTBI will have PCS (Broshek, DeMarco, & Freeman, 2015). Signs and symptoms of PCS include anxiety, cognitive difficulty, dizziness, decrease in concentration, fatigue, headache, emotional lability, insomnia, irritability, loss of memory, sensitivity to light, sleep disturbance, vertigo (Harmon et al., 2013; King & Kirwilliam, 2011). Symptoms of PCS may last months or even years, with some patients experiencing permanent symptoms (King & Kirwilliam, 2011).

In 1992, the WHO defined PCS as a syndrome that occurs following head trauma with three or more of the following eight symptoms: headache, dizziness, fatigue, irritability, mental task and concentration difficulty, memory impairment, insomnia, and reduced tolerance to stress, emotional excitement, or alcohol (WHO, 1992). ICD 10 definitions remove the three symptom requirement and redefined PCS as any number of these different symptoms. The new diagnostic criteria is a revision of old guidelines that has been used for almost two decades. The transition from concussion to post-concussion syndrome is unclear and not specific (Broshek et al., 2015; Harmon et al., 2013), although repeat concussions seems to increase the risk of PCS (Guskiewicz et al., 2003; King & Kirwilliam, 2011). Thus, knowledge of concussion history is imperative to the sports medicine team.

Pre-injury anxiety or depressive disorder and post-traumatic stress disorder five days post-injury have been shown to be predictive of symptoms of PCS (Meares et al., 2011). Additionally, studies have found other predictors to be depression and anxiety (Dischinger, Ryb, Kufera, & Auman, 2009), female gender (Meares et al., 2011; Ponsford et al., 2012), and post injury headache (Faux, Sheedy, Delaney, & Riopelle, 2011; Ganti et al., 2014; Hou et al., 2012). While it is intuitive that the post-injury symptoms can be identified, the pre-injury factors are also issues that members of the sports medicine team can identify. The anxiety and depressive disorders may be brought to light by the pre-participation screenings by the physician. However, these are also issues that may be identified by the exercise physiologists or athletic trainers, who have most of the direct, daily contact and interaction with the athletes.

4.2. Chronic Traumatic Encephalopathy

Chronic Traumatic Encephalopathy (CTE) is the most severe complication of patients post head-injury. It is a progressive neurodegenerative disease of the brain resulting from total or repetitive brain trauma that cause symptomatic or asymptomatic concussions (Saulle & Greenwald, 2012; Yi, Padalino, Chin,

Table 5
Concussion modifiers.

Factors	Modifier
Symptoms	Number Symptoms Duration >10 days Severity
Signs	Prolonged loss of consciousness (>1min) Amnesia
Sequae	Convulsive convulsions
Temporal	Frequency—repeated concussions over time Timing—injuries close together in time "Recency"—recent concussion or traumatic brain injury
Threshold	Repeated concussions occurring with progressively less impact force or slower recovery after each successive concussion
Age	Child and adolescent (<18 years old)
Co- and pre-morbidities	Migraine, depression or other mental health disorders, attention deficit hyperactivity disorder, learning disabilities, sleep disorders
Medication	Psychoactive drugs, anticoagulants
Behavior	Dangerous style of play
Sport	High risk activity, contact and collision sport, high sporting level

Table 6
Graduated return to play.

Rehabilitation stage	Functional exercise at each stage of rehabilitation	Objective of each stage
1. No activity	Symptom limited physical & cognitive rest	Recovery
2. Light aerobic exercise	Walking, swimming, or stationary cycling, keeping intensity <70% maximum permitted heart rate. No resistance training.	Increase heart rate
3. Sport-specific exercise	Running drills, skating drills per sport specific criteria. No impact activities.	Add movement
4. Non-contact training drills	Progression to more complex training drills, e.g. Passing drills in football and ice hockey. May start progressive resistance training.	Exercise, coordination, and cognitive load
5. Full contact practice	Following medical clearance participate in normal training activities	Restore confidence and assess functional skills by coaching staff
6. Return to play	Normal game play	

Montenegro, & Cantu, 2013). Signs and symptoms of CTE normally do not manifest until several decades after the last incident of brain trauma. This include deterioration of executive functions, short term memory loss, behavioral disturbances such as anger, aggressiveness, depression, irritability, impulsivity, heightened suicidality, lack of insight and poor judgement. CTE is most common in boxers but has also been found in other athletes including football (Omalu et al., 2005, 2006), soccer (Matser, Kessels, Jordan, Lezak, & Troost, 1998; Tysvaer, Storli, & Bachen, 1989) and hockey players (McCrary, Turner, & Murray, 2004). CTE is only diagnosed after death with confirmatory histopathology analysis for tau protein by distinctive immunoreactive stain, making the etiology difficult to examine (Iverson, Gardner, McCrary, Zafonte, & Castellani, 2015; McKee et al., 2010; Saulle & Greenwald, 2012). It is histologically identified by the presence of tau-immunoreactive neurofibrillary tangles (NFTs) and neutrophil threads (NT). There is absence of beta-amyloid deposits throughout the brain. CTE is sometimes clinically mistaken for Alzheimer's disease and frontotemporal dementia (FTD) (Gavett, Stern, Cantu, Nowinski, & McKee, 2010; Saulle & Greenwald, 2012).

CTE may eventually progress to dementia or Parkinsonism with speech and walking difficulties and sometimes develop into a progressive motor neuron disease called Chronic Traumatic Encephalomyopathy (CTEM) (Gavett et al., 2010; McKee et al., 2010). Signs and symptoms of CTEM include atrophy, fasciculations, spasticity and weakness. Cognitive and behavioral symptoms manifest several years after the appearance of motor neuron symptoms in majority of individuals with CTEM. Individuals with

motor neuron symptoms tend to die earlier because of respiratory insufficiency compared to individuals without motor neuron symptoms (McKee et al., 2013).

Prevention of repeat head injury is the ideal management of CTE (Saulle & Greenwald, 2012; Yi et al., 2013). The risk of CTE can be decrease by decreasing the risk of concussions. Reducing the number of concussions can be accomplished by reducing risk of head trauma, especially during the recovery stage from previous injury, and strictly following return to play criteria emphasizing symptom monitoring (McKee et al., 2009; Yi et al., 2013). Decreasing an athlete's exposure to trauma is recommended by creating policies that penalize dangerous play, improving protective equipment, and setting equipment standards is also an important part of concussion prevention (McKee et al., 2009; Saulle & Greenwald, 2012).

The suspicion of CTE may be ascertained through assessment of comprehensive concussion history in association with current signs and symptoms. The sports medicine team would have to take into account the length of sports participation, type of sports played, and factors associated with all head injuries. Many of these factors would be identified during pre-participation screening conducted

by the sports medicine physician or other providers assisting in the preparticipation evaluations. Any report or concern of repeated concussive episodes in an athlete's history should be communicated to all providers so that they can exercise vigilance with the athlete during sports participation and in the event of a concussive episode.

4.3. Considerations for the adolescent athlete

Concussions result in more than 100,000 emergency department visits each year for school aged children in the United States (Rose, Weber, Collen, & Heyer, 2015). While this number is alarming it may not be entirely accurate as many injuries remain unrecognized and therefore not assessed by a health care professional. Children are particularly vulnerable to injury for a variety of reasons including: 1) biomechanical forces of a larger head to body proportions 2) weaker neck strength 3) metabolic, biochemical and molecular mechanisms of a developing brain (McCarthy & Kosofsky, 2015). The pediatric population requires special consideration throughout the continuum of care from diagnosis to management and ultimately returns to play.

Despite the recommendations for removal of play when concussion is suspected, a study by Haran et al. found that 19% of children were not removed from play at the time and injury and 27% were not evaluated by qualified personnel (Haran et al., 2015). The qualifications of coaches and availability of appropriately trained health care professionals vary depending on the age of the child and resources of the organization conducting the athletic

event.

Signs and symptoms seen most frequently in children are headache, fatigue, dizziness, and difficulty concentrating (McCarthy & Kosofsky, 2015; Rose et al., 2015). A complete medical history is critical as a prior concussion, premorbid migraines, learning disabilities, mood disorders, or attentional deficits may predict a prolonged recovery (McCarthy & Kosofsky, 2015). CT scans are the most common neuroimaging studies utilized in adults with concussion; however, these studies are ordered less frequently in children based on concerns of exposure to radiation (McCarthy & Kosofsky, 2015).

Neuropsychological testing can be a valuable tool in concussion management by objectively documenting the impact of a concussion on children and adolescent athletes. Pre-season baseline computerized neuropsychological testing may be utilized in school-aged athletes to assist in determining return to learn. It has been noted, however, that school-aged athletes not yet recovered from concussion report adverse academic effects (Ransom et al., 2015). Thus, information from post-concussion testing may also assist physicians, parents, therapists, and others identify any needed school accommodations. Short term school based accommodations may minimize the negative academic effects and lower the risk of prolonged recovery (Ransom et al., 2015). Therefore, a period of cognitive rest may be equally important as the physical rest due to the fact that these athletes have school expectations and demands. Academic accommodations, such as longer time for testing or an alternative location for testing, may be needed as a child is recovering from concussion (Harmon et al., 2013; Ransom et al., 2015; Rose et al., 2015). The Centers for Disease Control has developed resources for school administrators and teachers to address the potential impact on academics after concussion (Harmon et al., 2013). These accommodations will require ongoing communication between health care professionals, parents/caregivers, teachers, and the child to assess progress and identify when the child no longer has provocation of symptoms with academic activities has returned to academic baseline (Harmon et al., 2013; McCrory et al., 2013; Rose et al., 2015). Participation in some form of activity in a controlled time frame which can vary from 15 up to 45 min following a symptom threshold with progressive increase over time has been shown to hasten recovery (Baker et al., 2014; Thomas, Apps, Hoffmann, McCrea, & Hammeke, 2015). With the current gaps in the practices or return to learn, communication between physician, school nurses, and teachers continues to be emphasized in order to successfully re-integrate student-athletes into learning (Wing, Amanullah, Jacobs, Clark, & Merritt, 2016).

A recent study has highlighted some of the challenges with management of concussion in children and adolescents. In a study with 93 children who had sustained a concussion, even when guidelines are in place, 93% of parents and 96% of patients were unaware of concussion or return to play guidelines from their organization (Haran et al., 2015). Additional education resources are needed for coaches, parents, caregivers, and children/adolescents on guidelines for recovery following concussion and return to play (Harmon et al., 2013; McCrory et al., 2013; Haran et al., 2015). However, continued education of both the public and healthcare and medical professionals is necessary. Two recent retrospective studies have shown that adolescents are returning to school and sport while still exhibiting symptoms (Carson et al., 2014; Stoller et al., 2014).

The limited research available suggests that the majority of children and adolescents diagnosed with concussion (80–90%) experience full recoveries. (McCarthy & Kosofsky, 2015). However, some children and adolescents experience post-concussive symptoms (Rose et al., 2015) or subtle cognitive and behavioral changes (Moore et al., 2015). Headaches are the most common post-

concussion symptom experience by children. Additional post-concussion symptoms may include cognitive difficulties, mood swings, depression, or anxiety. The post-concussion symptoms are best managed by a health care team incorporating pharmacological and therapeutic modalities. (Rose et al., 2015). One study documented subtle deficits on behavioral and neural levels in children two years after a single concussive event. (Moore et al., 2015). Persistent post-concussion symptoms, a slow and prolonged recovery, frequent or severe concussions should prompt the team managing the care of that child or adolescent to begin a discussion of retirement or disqualification of a youth athlete with the patient and parent/caregiver (Rose et al., 2015). There are no clear guidelines or criteria for these difficult decisions regarding continued participation vs. retirement or disqualification of a child or adolescent athlete. Decisions should incorporate all parties including physician, physical therapists, athletic trainer, neuropsychologist, parent/caregiver, coaches, and the child. Current best practice in caring for children and adolescents recovering from concussions draws upon current research and incorporates a multi-disciplinary team of professionals with concussion management experience.

5. Conclusion

Concussion management is multifaceted and involves an interdependence of several health and medical providers. These providers must operate as a collaborative unit to allow for informed decision-making and optimal care. Physicians, athletic trainers, physical therapists, exercise scientists, and others will interact with athletes recovering from concussion at various stages. An intimate understanding of each other's roles and responsibilities with optimal communication between members, and contemporary knowledge of best practices in concussion management will ensure safe and efficient return to activity by athletes.

Conflict of interest statement

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