Evidence-based management of concussion in youth athletes

Aaron Robert Hoekje

The University of Toledo
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Dedication

To my parents: Jeff and Wendy Hoekje.

Because of their support, advice, friendship, and continual love.

For no one do I strive to make prouder and for no one am I more proud.
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**Introduction**

The concussion syndrome is transient, can present with a variety of symptoms, has no focal defect, results in functional not obvious anatomical abnormality, and cannot be discerned with standard imaging techniques. These characteristics and various others contribute to the uncertainty surrounding the diagnosis and management of concussion. The ambiguity of concussion makes the basics of practicing evidence-based medicine even more important. Although youth concussion is a common sports injury, the management and return to play process has been debated for years. The most important aspect of concussion management is clinical decision making, which requires clinicians to undergo a continual educational process (Cantu, 2001). Recommendations based on the latest research are constantly updated and it is important that clinicians are aware that their management of concussion may need adjustment (McCrory et al., 2005). Conservative treatment that allows the youth time to recover is essential for preventing serious sequelae and reinjury (Tavazzi et al., 2007). Professional athletes suffering from the effects of concussion draw the attention of sports fans everywhere. These athletes are employed by franchises that pay them millions of dollars and place a high value on their physical health and ability to continue playing their sport. The fame and fortune involved is one of the reasons for the development of concussion guidelines in professional and collegiate sports (Moser & Schatz, 2002). Though there is a vast amount of research regarding athletic concussion, there is still much controversy concerning clinical management. In no group is this more apparent than in the youth population (Lovell, Collins, Iverson, Johnston, & Bradley, 2004), which for the purposes of this paper will include all children that are eligible to participate in organized sports through the high school years.
Epidemiology

Each year in the United States, approximately 1.6 to 3.8 million traumatic brain injuries (TBI) occur in sport-related activities (Langlois, Rutland-Brown, & Wald, 2006). It is estimated that mild TBI, or concussion, accounts for 80-90% of these injuries (Nacajauskaite, Endziniene, Jureniene, & Schrader, 2006; Patel, Shivdasani, & Baker, 2005). More specifically, for children under age 16, concussion is one of the most common injuries reported (Browne & Lam, 2006). There are more than 1.25 million US high school athletes that participate in contact sports. Football, the sport with the greatest concussion risk, accounts for an estimated 63% of high school sport-related concussions (Powell & Barber-Foss, 1999) with an estimated 15% of the players sustaining at least one each year (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). Though sports with higher rates of player contact have an increased risk of concussion, no sport is an exception for the potential of an athlete to sustain a concussion (Powell & Barber-Foss). Sliding and hitting in baseball and softball, takedowns in wrestling, diving in soccer, spiking in volleyball, or falling on the court in basketball are just some examples of plays potentially resulting in concussion.

Definition of Concussion

In 2004, the second International Conference on Concussion in Sport was held with the objective to improve current understanding of concussion management recommendations. A new definition of concussion was formed, as: “a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces” (McCrory et al., 2005). Subsets were also developed to clarify the definition and are shown in Table 1. Along with a more accurate definition of concussion, a more practical grading system was introduced. A binary system (simple vs. complex) was created to simplify and provide for better continuity of care based on
the available evidence. A simple concussion resolves in less than 10 days without complication and requires no further medical intervention other than rest (McCrory et al.). Professional athletes typically recover from concussion the fastest, in about three days, and collegiate athletes usually recover in about seven days. Therefore, the vast majority of concussions in these age groups fall into the simple category. However, youth athletes have been shown to take longer than collegiate athletes, making concussions in this age group more often complex and a medical priority (Iverson, 2007). A complex concussion may be diagnosed at the point of injury if the athlete has a concussive convulsion, is unconscious for one minute or more, or has greater than 10 days cognitive impairment following the injury (including symptoms brought on by exertion). If the athlete has had two or more previous concussions, every subsequent concussion should also be considered complex.

There are many medical terms that are synonymous with concussion such as: mild traumatic brain injury (mTBI), concussive head injury, mild head injury, minor blunt head trauma, minor closed head injury, mild traumatic head injury, minor head trauma, and commotion cerebri. This paper will use the term ‘concussion,’ as it is the most well-known and accepted term for the injury.

**Misconceptions**

In addition to the medical terms for concussion, there are a few slang terms that are used by athletes, coaches, and other lay people such as, ‘dazed,’ ‘stunned,’ ‘dinged,’ or ‘bell-ringer’ that may signify a concussion. These words make apparent a general lack of awareness about the effects of concussion in the world of sports. Players that leave the field with a “ding” may be expected to return to play (RTP) as quickly as their ‘head clears’, or even sooner. For athletes and coaches lacking concussion education, this may seem like a reasonable expectation (Lovell,
Collins, Iverson et al., 2004). When considering that the majority of the more than 3.5 million youth coaches in the US cannot pass a basic first aid assessment, it is alarming to note that there is no nationally adopted certification program (Ransone & Dunn-Bennett, 1999). Valovich et al. found that youth coaches with previous coaching education were more likely to recognize common concussion symptoms than those without formal education. Some of the findings of the survey found glaring misconceptions. Of the 250 of coaches surveyed, 42% were unaware that LOC was not required for a diagnosis of concussion, an alarming finding considering that fewer than 10% of concussions result in LOC. Also, 32% did not think that what was previously termed a grade 1 concussion required removal from play, and 26% would let a symptomatic player RTP (Valovich McLeod, Schwartz, & Bay, 2007). Youth players also have misunderstandings and often view a concussion as something that resolves quickly and will produce no noticeable lingering or long-term effects (Williamson & Goodman, 2006). In addition, an athlete at any level of sport may feel pressured to continue playing or may feel that they would rather play than sit out due to a lack of significant consequences. Because of the subjective nature of the symptoms involved in concussion, it is important that players inform their trainers and coaches about injuries. Williamson and Goodman studied the under-reporting of concussions in youth ice hockey and found greater than a thirty-fold difference in injury reports between observational strategies and official injury reporting (Williamson & Goodman). Similarly, McCrea et al. found that only 47.3% of injured high school football players reported concussion to either coach or trainer. The study also illustrated the following reasons for which concussions are not reported in this population (in descending order): athletes did not think the injury was serious enough, athletes did not want to leave the game, athletes did not know it was a
concussion, athletes fear of letting their teammates down (2004). It is reasonable to assume that under-reporting happens across all youth sports.

Problem Statement

Current sport-related concussion guidelines and management strategies were developed based on extensive research on the adult and collegiate population. Experts have noted that youth concussion research has been somewhat neglected up until the last few years (Lovell et al., 2006; Patel et al., 2005). Several studies were carried out once the lack of research in this area was recognized by researchers and clinicians alike. Some literature reviews have consolidated this information, but they were either not specific to the pediatric population, or are already outdated given the amount of recent research that is being produced.

Purpose

Estimates of high school sport participation approximate over seven million athletes each year play an organized sport, and are thus at risk of suffering a concussion. This dwarfs the 385,000 collegiate athletes by eighteen-fold (Gessel, Fields, Collins, Dick, & Comstock, 2007). In the past, there was an insufficiency of information about youth concussion; however, recent research offers many evidence-based suggestions regarding this population. Each study alone does not provide definitive evidence to make general recommendations or guidelines, but a collaborative depiction of the management of youth concussion can be made when the results are synthesized. The purpose of this literature review was to address and compile the latest research regarding youth sport-related concussion and to make evidence-based clinical recommendations based on this information.
Scope & Design

This review of the literature focused on the management and guidelines related to youth sport-related concussion. This was supplemented with information regarding the etiology, pathophysiology, genetics, grading scales, imaging, neuropsychological testing, sequelae, prevention, and education regarding concussion. The databases used to gather research were “Medline” and “Pubmed.” Search terms were: concussion, mild traumatic brain injury, youth, adolescent, pediatric, high school, sport, treatment, management, and neuropsychological testing. Articles for this literature review were selected from peer reviewed journals related to the topic of youth concussion. The target audience includes physician assistants, pediatricians, family physicians, nurse practitioners, and those providing care in the emergency setting.
Genetics

Clinicians should be aware of the important effect of certain genotypes and their synergy on concussion. Currently, apolipoprotein E (APOE) has been the gene most implicated in determining a person’s response to concussion. APOE is one component involved in the formation of the protein apoliprotein E (apoE), the most important lipid transporter in the brain, and is located on chromosome 19. The protein apoE also carries out several functions necessary for cellular repair. In a 2005 literature review, 12 TBI studies were analyzed with a range of APOE-ε4 carriers from 16% to 41% and mean of 27%, demonstrating the common nature of this genetic abnormality (Blackman, Worley, & Strittmatter). There are three alleles of APOE: ε2, ε3, and ε4. The allele APOE-ε4 appears to play the most important role for the ability of the brain to recover from concussion. The gene APOE-ε4 is related to worse outcome after TBI in adults. The protein apoE-ε4 is associated with deposition of β-amyloid, which is linked with Alzheimer’s Disease, following brain injury (Blackman et al.). Adults that are APOE-ε4 carriers score worse on nearly all neuropsychological testing parameters post concussion and are more vulnerable to subsequent brain injury (Ariza et al., 2006).

Contrary to the findings regarding adult studies, Blackman et al. found that the allele APOE-ε4 was associated with neuroprotective effects in youths. There was a link between the gene and less severe initial injury and better outcome. It was hypothesized that during the teenage years, there is a shift in the effect of APOE-ε4 which leads to a damaging effect on adults (2005). These findings have started a potential debate concerning genotyping youths prior to participation in contact sports (Patel et al., 2005). This is an ethical question that might be posed to some providers by concerned parents. The results may also be fodder for scientists researching new forms of treatment (Blackman et al.). Currently, genetic influence of
concussion is not yet substantiated and therefore should not have heavy influence on decision making. However, as more research is compiled regarding APOE and its effects, parents and clinicians of youth athletes may possibly be able to make evidence-based decisions regarding play in high risk sports.
Biomechanics

The shearing and compressive events that result in concussion can be produced by acceleration, deceleration, or rotational forces (Barth, Freeman, Broshek, & Varney, 2001). Concussions may be a product of a direct blow to the head, or to another part of the body that is transmitted to the head (McCrory et al., 2005), and are more likely to be caused by collisions than falls (Browne & Lam, 2006). This explains why sports such as football and hockey, with high rates of player collisions, have the highest rates of concussion. A recent study on head impacts in football that compared college and high school athletes revealed new information on the effect of collisions in relation to concussions. Using electronic force transmitters implanted in the players’ helmets, the study found that linemen sustained a low grade head impact on almost every play, while skill position players experienced fewer overall impacts, but each impact involved a greater force. The NCAA Concussion Study found that linebackers are most at risk [0.99 per 1,000 athlete exposures (95% CI)], followed by offensive linemen (0.95 per 1,000) (Guskiewicz et al., 2003). The violent nature of these positions is what leads to the highest rates of concussion per position. It is well supported that in order for youth athletes to show clinical signs of concussion, they must sustain a greater force of impact, up to three times the force necessary for adults (Browne & Lam; Patel et al., 2005). However, youth athletes are still more vulnerable to concussion than their older cohort. Reasons for this may be underdeveloped nerves and myelin immaturity, greater head-to-body ratio, thinner cranial bones, weaker neck muscles which absorb force, and poor autoregulation of cerebral blood flow (Buzzini & Guskiewicz, 2006).
Neurophysiology

The pathophysiological response to concussive-type impacts on the body is complex and not presently fully understood, but recent research has elucidated the subject. A concussion’s effects are due to functional changes which are a product of a cascade of molecular events inside the brain. The force of the blow to the head is thought to directly impact neurons, for a brief moment, causing an excitability state (Shaw, 2002). This results in increased release of neurotransmitters and mass ionic fluxes across the neuronal membrane. The brain activates sodium-potassium ATP-dependant pumps to restore proper membrane potential by importing potassium into the cell (Giza & Hovda, 2001). In turn, this causes an increased glucose demand and an increase in cerebral blood flow (Shaw). However, soon after injury, blood flow drops extensively; a problem especially for youths who have poorer autoregulation of cerebral blood flow than adults (Field, Collins, Lovell, & Maroon, 2003). Along with a decrease in cerebral blood flow, mitochondrial energy output is decreased as a result of the impact, thus causing a vast discrepancy between ATP demand and supply (Tavazzi et al., 2007). In turn, induction of anaerobic glycolytic pathways results in an increase in lactate production. The consequence of unregulated ionic fluxes, large production of lactate and free radicals, and depleted neurotransmitter stores provides a pathophysiological explanation for post-injury symptoms that may last for weeks (Giza & Hovda). During this symptomatic period of persisting metabolic dysfunction, the brain is at a particularly high risk for re-injury that is synergistically worse than the first (Tavazzi et al.). In the context of this review, it should also be mentioned that youths are especially vulnerable to the long-term effects of concussion because of brain immaturity and continuing development (Giza & Hovda).
Second Impact Syndrome

SIS occurs almost exclusively in youths and is the result of sustaining a subsequent concussion prior to resolution of the first (Cantu, 1998). As stated earlier, the metabolic effects of concussion cause a high energy demand that cannot be met by supply, leaving the brain vulnerable to changes in cerebral blood flow (Tavazzi et al., 2007). A second impact within a short period of time can overwhelm the brain’s ability to compensate for injury and quickly cause loss of the autoregulation of blood supply, leading to vascular engorgement, marked increase in intracranial pressure, brain herniation and coma or death (Buzzini & Guskiewicz, 2006). While it is rare in the U.S., with only 1-2 estimated cases per year, SIS carries with it a mortality rate of 50% (Cantu). The neurological effects that result from the second concussion compound the effects of the first concussion, multiplying severity of injury (Cantu). The effects of SIS follow a rapid pace; however, immediately after the second impact, the athlete may be able to walk off the field and speak. Within seconds to minutes the athlete will lose consciousness and collapse, with dilated pupils and fixed eye movements; then, within two to five minutes, experience respiratory and potentially brainstem failure (Cantu).

The risk factors for SIS include the following: age (12-18 years), type of sport (i.e. collision sports), and history of prior concussion. Following proper RTP guidelines is crucial for prevention of SIS and demonstrates the value of a well-connected multidisciplinary approach involving the medical provider, athletic trainer, coaches, parents, and the athlete (Cobb & Battin, 2004).
Post Concussion Syndrome

PCS is defined as a cluster of symptoms (headache, dizziness, malaise, fatigue, noise intolerance, irritability, depression, emotional lability, and insomnia) that occur as sequelae of concussion (Nacajauskaite et al., 2006). Though many aspects of concussion management are controversial, PCS is possibly the most intensely debated topic, especially in youths, who seem more vulnerable to its effects (Satz et al., 1997). The reason for this debate is centered on the etiology of the phenomenon; is there an organic cause or is it simply a psychological disorder? Recent research has shown that in the absence of psychological factors, an organic cause may indeed be the root of the symptomology (Chen, Johnston, Collie, McCrory, & Ptito, 2007). However, for others, a psychological disorder is the only answer (Lee, 2007). Thus, both the DSM-IV TR and the ICD-10 have diagnostic criteria for PCS, which is shown in Table 2. There are many similarities between the two subsets of diagnostic symptom criteria. This is a tribute to the difficulty of discerning whether the patient’s symptoms are a problem of physiogenesis or psychogenesis (Lee).

Pre-existing psychological disorders, postinjury and social factors, as well as subjective cognitive symptoms without neuropsychological dysfunction are the cornerstones of the psychological argument (Lee, 2007). Evidence for psychological features include: worse outcome when a pre-existing psychological disorder exists (Lishman, 1988); depression and anxiety are early predictors and occur at high rates with PCS; and PCS is exacerbated by stress (King, 2003). Interestingly, a study on PCS symptoms and related compensation seeking in adults showed that though there was an association with symptom severity and lawsuits (Binder & Rohling, 1996), few of these patients had relief from their symptoms a year after settling (King).
The physiogenic origin of symptoms is supported by continued alteration in cerebral blood flow, delayed evoked responses and impaired information processing months after injury (Lishman, 1988). A study by Chen et al. validated PCS by showing correlation between functional magnetic resonance imaging (fMRI) and neuropsychological testing results in adults. Those with PCS symptoms scored significantly worse on testing, while fMRI studies showed functional abnormalities (Chen et al., 2007).

In youths, a combination of physiological and psychological factors may contribute to PCS; preexisting vulnerability, postinjury child and family adjustments, and postinjury functional changes may all contribute (Yeates & Taylor, 2005). Although PCS has been described and shown to be a valid disorder, a 25 year review of concussion in youths concluded that scholastic activities have not been shown to suffer from it (Satz et al., 1997). Nonetheless, because PCS is a debilitating problem for youths, clinicians must recognize and treat it. So far, as with concussion, the best treatment seems to be prevention. It has been demonstrated that a single, hour-long assessment and treatment session, including education and reassurance performed within the first few weeks of injury significantly reduces symptoms and limits the onset of other persisting problems (Wade, King, Wenden, Crawford, & Caldwell, 1998). Treatment for PCS is conservative and includes emphasizing the non-malignant nature of the patient’s symptoms, giving realistic likely recovery time and optimistic prognosis, explaining coping strategies, and assisting in the return to school or work process. Persisting PCS, however, remains a problem with few answers (King, 2003).
Acute Management and On the Field Assessment

Proper knowledge of the immediate effects of concussion is vital for quality management. In order to care for the injured youth athlete properly, the clinician must first properly diagnose the condition and then recognize the severity of injury. After a sports injury, it is usually a trainer, coach, or parent that accompanies the youth athlete to the medical provider’s office (physician, PA or NP). These individuals can serve as a historian and provide important information that aids in the clinician’s determination of the next step in care.

On the field assessment of the injured athlete typically follows basic guidelines shown in Table 3. The certified athletic trainer or other first responder should observe the athlete for mental and physical change before, during, and after assessment. Before the athlete is removed from the field, airway, breathing, and circulation must be evaluated and the athlete assessed for skull or vertebral fracture, though these issues are rare with concussion (Buzzini & Guskiewicz, 2006). After the few moments it takes to determine the athlete’s probability of serious injury, he/she will be ready to ambulate to the sideline, with or without the help of others for stabilization. In an athlete that cannot ambulate or maintain any degree of balance, a more serious head injury should be considered. Once the athlete is taken off the field of play (i.e. to the sidelines) a more thorough cognitive evaluation can be completed. Multiple experts agree that orientation, memory, concentration, balance, coordination, cranial nerves, and level of consciousness should all be assessed (Buzzini & Guskiewicz; Hayden, Jandial, Duenas, Mahajan, & Levy, 2007; Kirkwood, Yeates, & Wilson, 2006; Lovell, Collins, Iverson et al., 2004). The Sideline Concussion Assessment Tool (SCAT) quickly measures these different aspects and should be administered to every athlete in whom concussion is questioned. The test takes about five minutes and may be performed by a coach trained to recognize concussion, an
athletic trainer or the team medical provider. It consists of the following: signs (LOC, seizures, balance, and coordination), memory assessment, post-concussion symptom scale, cognitive assessment (five word recall, months in reverse order, etc.) and neurological screening (speech, eye motion, pupils, pronator drift, and gait) (McCrory et al., 2005). Good observation techniques are necessary when working with youth athletes because many have a sense of invulnerability and possibly will think that a concussion carries no consequence, and therefore, may underreport their symptoms (Williamson & Goodman, 2006). Also, concussion symptoms can take several minutes to develop and may wax and wane, thus it is important that the athlete be monitored for acute changes in behavior or symptoms and not be left alone (Patel et al., 2005). The Modified Maddocks Questions were developed to quickly evaluate memory and orientation and are part of the SCAT. Here are some examples: at what venue are we, which half is it, who scored last, what team did we play last, did we win the last game? (McCrory et al.). Though simple questions can yield valuable information, they are not necessarily sensitive or specific to a concussion, which is why the SCAT is the most important assessment tool after the athlete is taken to the sidelines (Kirkwood et al.).

Signs observed by staff can give important clues regarding not only the severity of concussion, but also the progression of recovery. Examples of signs of concussion severity are as follows, the athlete: appears to be dazed and confused, is puzzled about assignment, forgets plays, is unsure of game, score, or opponent, moves clumsily, answers questions slowly, has LOC, shows behavior or personality change, shows retrograde amnesia, shows anterograde amnesia (Lovell, Collins, & Bradley, 2004).

Vital signs and level of consciousness should be measured every five minutes until the condition improves (Buzzini & Guskiewicz, 2006). The next step during the sideline assessment
is grading the concussion. As discussed earlier, the concussion should be graded as either simple or complex. In an effort to validate the new system, Iverson completed a study on high school athletes to determine if neuropsychological testing within the first 72 hours post concussion can predict whether the concussion will be simple or complex at 10 days (2007). Results of the study did not reveal statistically significant differences in recovery between those with history of one or two concussions and those without concussions. However, a history of three or more concussions was shown to be associated with long-term changes, greater susceptibility to subsequent injury, and worse on-field presentation. Further, athletes with complex concussions were 18 times more likely to have three low composite scores and were five times more likely to score a 40 or more on the post concussion symptom scale than the simple group. The results also indicate that about fifty percent of high school athletes would have been classified as complex if the new classification system had been used (Iverson). The question that arises is whether youth grading guidelines should differ from their older counterparts, if the only distinction is time of recovery with no difference in long-term effects. Though more research is needed in this area, results of the study do support the binary system as well as neuropsychological testing of concussed athletes in order to assist in determining the individual management strategy.

Although the simple vs. complex scale is now recommended over traditional grading systems, clinicians should still be familiar with them. As with many aspects of medicine, practice often lags behind research. There are over twenty different sets of grading and RTP guidelines available in the literature. However, significant discontinuity exists between them, and these grading scales may not be appropriate for managing youths as the current grading systems are based on collegiate and adult studies (Buzzini & Guskiewicz, 2006; Patel et al., 2005). The most commonly used and supported grading scales are the Cantu Grading System for
Concussion, AAN Practice Parameter, and the Colorado Medical Society Grading System for (Cantu, 2001). Traditionally, the certified athletic trainer or other healthcare provider chooses the grading scale based on personal preference, or sport specific mandates. Familiarity, ease of use, and continuity of care are some of the reasons for which these decisions are based. It is noteworthy though, that the Cantu grading system is the only one that is based on evidence and is completed after resolution of all concussion signs and symptoms (Buzzini & Guskiwicz).

However, as alluded to before, none has been exclusively studied regarding effectiveness and accuracy of grading concussion in youths.

Minor concussions can be managed appropriately by the athlete’s primary care provider or a certified athletic trainer under medical supervision (McCrory et al., 2005). However, it has been recommended that referral should be made to an emergency department (ED) if the athlete has manifestations of more severe injury (Table 4). Athletes with more severe form of concussion should be managed by an interdisciplinary approach, including concussion experts such as sports medicine physicians or neurologists, as well as the primary care provider (McCrory et al.).
Medical Management

After on the field assessment is complete and concussion has been diagnosed, or there is still question regarding whether a concussion took place, it is recommended that care of the athlete be under medical supervision per Canadian Academy of Sports Medicine concussion guidelines (Canadian Academy of Sport Medicine Concussion Committee, 2000). Thus, primary care providers will often be the clinicians responsible for the management of concussion. Some patients with concussions may have frank symptoms and can be diagnosed and treated almost upon first inspection. However, many athletes do not realize that brief cognitive impairment following an impact is a concussion, and thus, do not report their symptoms (Martineau, Kingma, Bank, & McLeod, 2007). Regardless of how or when the patient with concussion presents, it is important that a thorough evaluation take place so that the provider may accurately diagnose and treat the injury. A concise synopsis of the medical management of concussion is found in Table 5.

History and Physical

By definition, the acute effects of concussion are temporary, so upon presenting to the clinic, many symptoms of concussion may have already subsided. This makes eliciting a good history of the event essential for proper medical management. It is also helpful to have a credible witness to the injury or family member of the patient that may be able to give clinical clues about the concussion or the athlete’s behavior that the athlete may not remember or appreciate (Patel et al., 2005). The pathophysiological effects of concussion on the brain are diffuse, and therefore create a variety of generalized symptoms (Patel et al.). Thus, it is important, as with any medical interview, to start with an open-ended question. Let the patient explain his/her symptoms in their own words. This may yield better information than directing
the patient by asking about specific symptoms. Experts recommend gathering information about timing, type/severity of impact, any concurrent mental or cognitive disorders, convulsions, and signs of more severe cerebral injury (Buzzini & Guskiewicz, 2006; McCrory et al., 2005; Patel et al.). It is broadly accepted that psychosocial risk factors affect cognitive outcome of patients experiencing concussion; so developmental, educational, and social situations should be taken into account when developing management strategies (Teasdale & Engberg, 2003). Everyone suffering a concussion should be instructed to fill out a graded symptom checklist, such as the one found in the National Athletic Trainer’s Association Position Statement (Guskiewicz et al., 2006). Symptom checklists supply a baseline with incremental follow-up scores. Reported symptoms are one way to assess the recovery of the athlete, but should not be used alone. Symptoms fall under three domains: somatic, emotional/behavioral, and cognitive (Kirkwood et al., 2006). As stated before, lack of LOC does not exclude the diagnosis of concussion, but it is still an important finding and one that deserves attention. Though LOC is often associated with concussion severity, post traumatic amnesia (PTA) is thought by some to be just as important of a predictor (Cantu, 2001). PTA is defined as a “period of mental confusion immediately after head trauma during which disorientation as to person, place and time accompanied by the inability to retain (new) experiences are present” (Ruijs, Keyser, & Gabreels, 1994). When normal memory of current events resolves, the amnesia has subsided.

It should be taken into consideration that an athlete may fabricate a lack of symptoms in order to return to practice or play (Williamson & Goodman, 2006). The clinician should be prepared to explain and educate the patient and their family of the potential adverse effects of under-reporting symptoms and premature RTP for even a mild appearing simple concussion. In a study by Lovell et al., it was found that high school athletes with the mildest form of injury had
residual effects after six days post injury. Athletes that did not experience on the field mental status change or sideline cognitive symptoms that were considered to have what was previously termed a grade 1 concussion were still experiencing symptoms one week following injury. Based on the current guidelines, these athletes may have been allowed to RTP too soon and could have been at risk for more serious injury. These findings make apparent the need for youth specific concussion guidelines and the importance of a thorough investigation of even mild appearing trauma (Lovell, Collins, Iverson et al., 2004).

Clinicians must be able to gather information in order to understand how the injury took place and recognize symptoms reported by the athlete that support the diagnosis of concussion. Thus, if a youth presents with mild headache that has persisted since a wrestling match the day before, simple concussion is an appropriate diagnosis. When in doubt, the clinician should err on the side of caution.

**Physical Exam**

Following the history of the event, the clinician should then proceed with a physical exam. Assessing severity of brain injury is the most important part of the clinician’s evaluation. If clues are present that indicate the need for ER referral (see Table 4), an appropriate and reliable way to assess severity of brain injury would be to administer the Glasgow Coma Scale (GCS) (Lee, 2007). In order of importance, best motor response is scored from 1-6, best verbal response from 1-5, and eye opening from 1-4. These areas are summed for a total score of 3-15. Mild head injury is defined as 13-15, moderate 9-12, and severe is eight or less (Lee). The result of timely administration of the GCS is a quick identification of those that need immediate neurology consultation and head computed tomography (CT). If it seems practical to the clinician, or it is an ED, administration of the GCS may commence the evaluation. Once a mild
score is recognized the clinician may then proceed with the remainder of the evaluation. However, most concussions do not necessitate administration of the GCS because, as stated before, the majority of them are simple, with cognitive dysfunction quickly resolving.

The neurological exam typically commences with cranial nerve assessment. Olfactory nerve assessment is especially important because it is the most commonly damaged nerve in TBI (Kelly, 2000). Following the cranial nerve assessment, the remainder of the neurological exam should include assessment of strength, sensation, coordination, reflexes, and “soft” neurological signs as listed in Table 6 (Kirkwood et al., 2006).
Radiological Studies

Another area of concussion management that is controversial is the question of when to perform radiological studies; like a head CT scan. In a meta-analysis of radiological studies for youths with minor head trauma reporting to the ED in the US, the use of CT scan ranged from 5% - 50% (Schnadower, Vazquez, Lee, Dayan, & Roskind, 2007). The variability of use can be partly attributed to the lack of established guidelines for when to use the CT (Simon, Letourneau, Vitorino, & McCall, 2001). It is easy to understand why a provider would want to use the CT as a tool to rule out more severe injury. Brain injuries, especially in youths, can be difficult to manage and may possibly result in permanent impairment or death. Delayed surgical intervention of these disorders may lead to unnecessary brain damage and death, but bleeding may not make itself apparent until well after the injury. Thus, it is recommended that the concussed athlete be carefully observed for 24 hours for worsening symptoms and roused every 2-3 hours during sleep (Cantu, 1996). A combined listing of expert recommendations for indications for the use of CT is shown in Table 4.

The guidelines for mild head injury are less clearly defined (Simon et al., 2001). In the US, less than 4-8% of CT scans performed on youths with concussion show evidence of TBI, with an overall rate of 0.5% that warrant neurosurgical intervention (Schnadower et al., 2007). In a study on youth minor head trauma and the use of CT, it was found that transient LOC had poor sensitivity and poor negative and positive predictive value for severe brain injury. The same study found that no particular symptom or clinical finding (including vomiting, headache, confusion, or amnesia) was reliably associated with intracranial injury (Simon et al.).

Clearly, the use of CT to evaluate concussion is controversial. The benefit of neuroimaging is the possibility of finding an intracranial injury that presents without frank signs
or symptoms. The negative aspects of the CT scan are plentiful and include the high cost of the study, the use of medical staff time, the potential need for sedation, overall ED visit times, lost parental work and wages, travel expenses, parental anxiety and potential adverse effects of the procedure itself (Thiessen & Woolridge, 2006). Probably the most important reason to withhold CT is the potential of the radiation to have a carcinogenic effect. Youths have a greater relative risk than adults from the effects of radiation because their neurons are still rapidly dividing and they have longer life spans in which to develop cancer (Schnadower et al., 2007). A single adult head CT exposes 200-600 times the amount of radiation compared to one radiograph (Schnadower et al.). Out of the 600,000 youths each year exposed to abdominal or head CT, it is estimated that 500 will eventually die due to cancer caused by the radiation (Brenner, Elliston, Hall, & Berdon, 2001). One way to decrease this risk is to adjust the radiation settings of the CT for the size of a youth’s head. The higher the amount of radiation used in a scan, the better the image, but youths have smaller heads than adults so the settings should be adjusted accordingly (Thiessen & Woolridge). The American Academy of Neurology Quality Standards Subcommittee suggests that if the patient’s exam findings are normal, and there are no alarming signs or symptoms, CT should be withheld ("Practice parameter: the management of concussion in sports (summary statement). Report of the Quality Standards Subcommittee," 1997). Reasons for this suggestion are that the benefits of finding intracranial injury early on are only marginal, and the small amount of severe injury is not enough to outweigh the cost, resource allocation, and potential adverse effects of the procedure (Thiessen & Woolridge).

**Other Radiological Studies**

Though CT is the study of choice recommended by the American Academy of Neurologists (AAN) and the American Academy of Pediatricians (AAP) (Schnadower et al.,
2007; Thiessen & Woolridge, 2006), there is potential for other radiology techniques to be used for assessment of concussion and intracranial injury. Functional MRI (fMRI) and diffusion tensor imaging (DTI) are newer technology methods that can detect more subtle changes than CT (Chen et al., 2007; Lovell et al., 2007; Wozniak et al., 2007). fMRI is a study in which contrast material is introduced intravenously and is then viewed as it passes through the cerebral vasculature. The study compares the brain at rest and upon activation by observing areas of higher flow (Aminoff, Greenberg, & Simon, 2005). Chen et al. performed a study using fMRI to validate the post concussion symptom scale because fMRI is sensitive to functional changes unlike CT or normal MRI scanning techniques. For this reason, Chen et al. believe that fMRI is the method of choice for evaluating behavioral changes because of its high sensitivity and non-invasiveness (2007).

DTI is one of the newest imaging techniques and is gaining interest because of its sensitivity to normal developmental changes in the pediatric population and its potential to show mechanisms of plasticity involved in recovery from TBI (Wozniak et al., 2007). DTI measures the properties of water in tissue and is particularly sensitive to white matter changes. This is important to the study of concussion because diffuse axonal injury is a subtle finding that is representative of the shearing forces that, by definition, are a sign of concussion. Normal MRI and CT are adequate for detecting severe structural injury, but cannot show the subtle white matter changes that represent normal concussion (Wozniak et al.). Although fMRI and DTI are highly sensitive to concussive type injury, they are not yet recommended screening techniques for severe injury following concussion. However, they lend important alternatives to CT in complicated cases or for the study of the effects of concussion.
Neuropsychological Testing

Neuropsychological testing, along with the history and physical, form the cornerstones of evidence-based concussion management (Broglio, Ferrara, Piland, Anderson, & Collie, 2006; McCrory et al., 2005; Patel et al., 2005). Reasons why testing benefits the management of the athlete are plentiful and well established. The value of testing is substantial due to its sensitivity to the effects of concussion (Iverson, Brooks, Collins, & Lovell, 2006). Thus, experts recommended that both formal cognitive assessment and a symptom score be performed at baseline for organized contact sports, regardless of age (McCrory et al.). Testing can aid in management and RTP decisions or even long-term withdrawal from risky activities (Iverson, Brooks, Lovell, & Collins; Patel et al.) by assessing cognitive, psychosocial, and achievement difficulties, as well as assisting with differential diagnosis (Kirkwood et al., 2006). It is vital to understand, however, that neuropsychological testing should not be the only basis of decision making and that every athlete should be treated individually (Barr, 2003; McCrory et al.).

Testing should start with a preseason baseline examination and may be subsequently administered for follow-up assessment as needed (Patel et al., 2005). The testing is now more often administered electronically. Baseline computerized testing only takes about 30 minutes, as compared to several hours for conventional paper and pencil testing (Kirkwood et al., 2006). The test battery typically examines some or all of the following cognitive domains usually effected by concussion: verbal and visual memory, reaction time, continuous learning, executive function, visuospatial and visuomotor abilities, attention, and speed of information processing (Martineau et al., 2007; Patel et al.). The cognitive deficits that result from concussion resolve at variable rates for different athletes and clinical signs and symptoms may resolve more quickly than neurocognitive deficits, making testing important for accurate management decision making.
Iverson, 2007). Memory and speed of information processing are the most vulnerable cognitive abilities and may not return to baseline for days to months post injury (Iverson).

The last decade has produced several studies evaluating neuropsychological testing, significantly expanding the knowledge base and its utilization in youth concussion management. Literature has shown that in the beginning, testing this population seemed troublesome. In 2001, Barr et al. examined the reliability of neuropsychological testing on high school athletes. Pre-test and post-test indices were studied to determine whether the results from the tests accurately depicted the subject’s cognitive ability, while taking into account practice effects. Three general results were taken from the study. There were no pre-test score differences between those with prior concussion, or prior learning disability, and those without history of concussion (Barr & McCrea). The group found that females scored significantly better on portions of the tests than did their male counterparts suggesting that sex-specific tests would be more accurate than a global pediatric assessment. Also, several of the testing parameters were found to be less reliable than desired, meaning that the scores achieved by youths during repeat testing did not accurately represent their cognitive function (Barr & McCrea). Patel et al. supported this sentiment, also suggesting that there is more variability associated with youth testing than adult (2005). Lovell et al.’s 2004 study, along with Barr’s study in 2003 suggest that there may be practice effects associated with multiple testing in youth athletes (Barr; Lovell, Collins, Iverson et al.). However, the practice effects were deemed small and, at the time, the improved computerized testing programs lessened this effect (Lovell, Collins, Iverson et al.). Secondary to the multiple confounding factors associated with testing youths (see Table 7); simply to return to baseline should not be considered adequate for recovery to be complete (Patel et al.). Along with innate differences that can make testing youths complex, palliative pharmaceuticals can also
skew testing results (Martineau et al., 2007). All medications the patient is currently taking should be reviewed and possibly discontinued prior to neuropsychological testing. As with any medical test, errors and problems with sensitivity and specificity should be taken into account when interpreting results. Though there are downfalls to neuropsychological testing in the youth population, it is still highly promoted by experts in the field who continue to study and modify testing parameters to better fit this unique population (Van Kampen, Lovell, Pardini, Collins, & Fu, 2006).

Perhaps the most important benefit of neuropsychological testing is the ability of the test to separate those that are fully recovered from those that may only appear fully recovered. In a 2004 inspection of high school athletes with documented grade 1 concussions, Lovell et al. found that the athletes had no on-field mental status change, sideline confusion, or amnesia lasting greater than 15 minutes, and they were completely symptom free after 15 minutes (Lovell, Collins, Iverson et al., 2004). Yet, 36 hours post-concussion, they scored worse than baseline on memory, processing speed, and reaction time. Clearly, full recovery was not yet attained, but at the time of this study, based on AAN and American Orthopaedic Society for Sports Medicine (AOSSM) guidelines, these athletes were eligible for RTP during the same game, putting them at greater risk for more severe injury (Lovell, Collins, Iverson et al.). Similarly, Field et al.’s study showed that high school athletes with what was previously classified as mild concussion had normal function return in three to five days, while neurocognitive dysfunction remained for at least seven days (2003). Perhaps this study’s results spawned a 2006 study by Iverson et al., which tracked neuropsychological progress of high school and middle school age athletes following concussion. As was expected, at day one post injury, athletes had a large number of symptoms and scored worse than baseline during testing (Iverson, Brooks, Collins et al.).
Tracking during days five through ten showed less symptoms and better scores, indicating recovery; however, 37% of athletes still had two or more composite scores worse at day 10. Some athletes still had not returned to baseline after three weeks, signifying that neurocognitive deficits last longer than perceived symptoms (Iverson, Brooks, Collins et al.). Results of another 2006 study are comparable to that of Iverson et al. McClincy et al. found that while most of the sample (mean age 16.11, SD 2.22) of athletes in the study had been classified as mild type concussion, some neurocognitive symptoms persisted at least two weeks, the longest being verbal memory. Other composite scores, such as processing speed, reaction time, and symptom reporting, lasted somewhere between one and two weeks. Based on AAN guidelines, potentially 80% of the athletes in the study would have been allowed to RTP prematurely (McClincy, Lovell, Pardini, Collins, & Spore, 2006).

Iverson’s 2007 study of high school football players evaluated the ability of neuropsychological testing following injury to predict simple versus complex type concussion. The findings indicated that the complex group was 18 times more likely to have three low composite scores than athletes with simple concussion. Furthermore, approximately half of the athletes would have been classified as complex type based on time to recovery (Iverson). Perhaps this is one reason why, for the sake of management strategies and RTP decisions, neuropsychological testing post injury is only indicated if the athlete is not experiencing symptoms and there is still suspicion of ongoing recovery (Kirkwood et al., 2006). Testing while the athlete is still symptomatic adds nothing to those decisions and may taint the testing process by allowing practice effects to skew future results (McCrorry et al., 2005). Testing is most important for managing complex type concussions, and some do not recommend it with simple concussions (McCrorry et al.; Patel et al., 2005).
Though neuropsychological testing is recommended by concussion experts as a tool in the management of youth concussion, it is not yet the standard of care. This is unfortunate considering that the computerized tests may be administered by a person with minimal training. Access to the internet is only needed after testing is complete so that the raw scores may be sent to an analyst. The final test scores are then sent back to a medical practitioner for final interpretation and, in most cases, that person does not need specialized neuropsychological proficiency. An example of one electronic testing firm is CogState Sport. This testing costs an annual amount of $500 for a team of 50 players with an additional $100 for every 10 additional players. This amounts to only $10 a player, a small price to pay for a valuable tool that will help to aid in timely and safe RTP (CogState, 2008). The benefits of neuropsychological testing are well-supported. It is now a question of whether parents or schools want to pay another fee in order for their children to participate in youth sports.
Palliative Care

There are two aims of treating concussion pharmacologically: symptom management and modification of underlying pathological factors (McCrory et al., 2005). Palliative care may treat symptoms of concussion such as: insomnia, anxiety, depression, and headache (Martineau et al., 2007; McCrory et al.). To be safe, the clinician should abstain from suggesting aspirin or NSAIDs, and should warn the patient and family that these products may exacerbate possible intracranial bleeding or mask some concussion related symptoms that aid in diagnosis (Martineau et al.). Clinicians should also abstain from prescribing opioid analgesia (Meares et al., 2006). In adults, it has been recommended to use sleep aids, CNS stimulants, SSRIs, or anxiolytics depending on reported symptoms and their severity (Martineau et al.). The only analgesic that has not been shown to increase risk of bleeding or interfere with concussion resolution is acetaminophen. Acetaminophen may be given to children based upon a dosage schedule of 10-15 mg/kg every 4-6 hours for children less than 12 years old with a maximum of 2.6 grams per day, or 325-650 mg every 4-6 hours for children greater than 12 years old with a maximum of 4 grams per day (Epocrates, 2008).

Several pharmacotherapies have been implicated for treatment of concussion but few have empirical data that support such claims (Table 8) (McCrory, 2002). Antioxidants, although needing further study, may halt the progression of concussion and aid in speed of recovery by protecting the brain’s natural enzymatic and metabolic pathway to recovery (Tavazzi et al., 2007). Pharmacologic therapy may skew the results of neuropsychological testing, so they should either be discontinued prior to testing, or the results of the tests should be interpreted with this in mind (Martineau et al., 2007). Also, the continued use of any pharmacologic therapy indicates that the athlete is still symptomatic and therefore the athlete can not progress through
the RTP process until they are discontinued (McCrory et al.). However, after the acute phase of concussion some providers may find certain pharmaceuticals necessary when treating symptoms of concussion (i.e. acetaminophen for headache). Clinicians should recognize that there are no recommendations regarding the treatment of youth concussion with pharmaceuticals based on lack of evidence and the potential harmful effects that are especially significant in this population.
The Return to Play Process

The RTP decision is at the crux of concussion management. How does a clinician make sure that the young athlete has had adequate time to recover without wasting valuable practice and game time? The question of RTP is often one of the first posed to, and probably the most important to address for the provider managing athletic concussion (Field et al., 2003). It is important to remember that in the youth athlete, the potential serious sequelae of premature RTP, such as loss of cognitive function or SIS, far outweigh the benefits of returning too quickly (Kirkwood et al., 2006). Since serious injuries can happen because of premature RTP, it is vital that the clinician and athletic staff use caution and correctly identify the amount of time needed to abstain from play. Since athletes recover from concussion on an individual basis, it is nearly impossible to set forth broad ranging guidelines (Patel et al., 2005). Though there are no specific guidelines that are agreed upon, it is well supported that youth athletes be treated with more caution than adults (Buzzini & Guskiewicz, 2006; Field et al.; Iverson, 2007; Lovell, Collins, Iverson et al., 2004; McClincy et al., 2006).

Studies that span more than 20 years show that the vast majority of concussions suffered by athletes are of the simple type (Iverson, 2007). The RTP process for simple concussions follows a stepwise progression, with more vigorous activity added each day (Buzzini & Guskiewicz, 2006). During the acute management, ongoing and repeated examination is necessary to determine if the athlete is ready to begin the RTP process (Field et al., 2003). Some authors suggest an arbitrary waiting period such as one or two weeks (Buzzini & Guskiewicz; Martineau et al., 2007). However, others suggest that because recovery from concussion is individualized, each athlete should be evaluated as such and can begin the process as soon as they are deemed ready by a medical professional (Patel et al., 2005). Iverson et al.’s 2006 study
on high school football players revealed that some had completely recovered within five days, while others took up to three weeks (Iverson, Brooks, Collins et al.). In a similar high school age study by McClincy et al., results demonstrated that recovery time was not related to concussion grade, therefore predictions regarding RTP should not be made based upon initial grading of concussion (2006). Virtually all experts agree that physical, cognitive, and behavioral symptoms must be completely resolved prior to the onset of the RTP process (Buzzini & Guskiewicz; Iverson; Kirkwood et al., 2006). Cognitive symptoms may be more insidious than physical or behavioral, but they are probably most important. When dealing with the student-athlete, it is important to note that in the days following concussion the patient needs cognitive rest just as they need physical rest (Buzzini & Guskiewicz). The brain is in a state of metabolic chaos and when these young students attempt to be attentive, perform complex executive functions, and learn, exacerbation of symptoms and delayed recovery may result (McCrorry et al., 2005). This may require absence from school until the athlete can perform these tasks (Martineau et al.). Neuropsychological testing may help to diagnose and manage cognitive dysfunction so that, if necessary, educational changes may be made based upon data (Patel et al.). Along with being symptom-free, the neurologic exam must be normal, and, if performed, neuroimaging must be unremarkable (Kirkwood et al.). If there is any doubt that the athlete is reporting all symptoms, the athlete should be formally assessed using neuropsychological or balance testing (Iverson). The RTP stepwise progression, along with next step recommendations, is found in Table 9. If any concussion symptoms recur, at rest or during exertion, the athlete is directed to return to the previous level and begin again in one full day (McCrorry et al.). It is crucial that the athlete be restrained from play until completely asymptomatic due to a critical temporal window of brain vulnerability (Tavazzi et al., 2007).
By studying the pathophysiological events that result from concussion in rats, Tavazzi et al. provided evidence that supported the theory that athletes are more likely to suffer another concussion if RTP is completed too hastily. Though the study does not accurately predict the amount of time it takes to pass through the window of vulnerability, it provides evidence for its existence. During the window of vulnerability the metabolic effects of concussion are cumulative and if another concussion does occur it will lead to severe, difficult to reverse brain damage. Following proper RTP guidelines prevents the issue of repeat concussion due to inadequate time for recuperation and is the most crucial factor affecting the ability of the brain to reverse the metabolic alterations incurred from concussion (Tavazzi et al., 2007). Though the interpretation of results were not age specific, they have particular significance for the management of youth concussion due to the severity of potential sequelae such as SIS, for which this population is the most at risk (Iverson, Gaetz, Lovell, & Collins, 2004).
Long-Term and Cumulative Effects

Review of recent literature leaves no doubt that cumulative, long-term effects of concussion exist. Retrospective studies from all age groups provide a breadth of evidence for multiple types of brain impairment. The brain’s continuing development and concussion’s effects on maturation make managing the youth athlete unique. Long-term associations have been made between concussion and decreased proficiency in arithmetic, writing, increased incidence of hyperactivity and stuttering in boys, and depression in girls and all are more apparent with more severe concussion (especially with LOC) (Segalowitz & Brown, 1991). High school football players with what was previously defined as grade 3 concussion with LOC were found to be four times more likely to suffer another grade 3 concussion than those who did not lose consciousness previously (Gerberich, Priest, Boen, Straub, & Maxwell, 1983). Along with type, the number of concussions has been shown to have cumulative effects. Recent youth studies show that three or more concussions leads to cumulative deficits (Iverson, 2007) and increased risk of future concussion (Iverson, Brooks, Collins et al., 2006). Those with three or more concussions were found to be six times more likely to experience anterograde amnesia, eight times more likely to experience five minutes or more of mental status disturbance, and eight times more likely to have memory dysfunction two days following subsequent concussion (Iverson et al., 2004). Those with one or two concussions, however, did not score differently on neuropsychological testing than those with no previous history of concussion (Iverson, Brooks, Lovell et al.; Lovell, Collins, Iverson et al.). Moser and Schatz found slightly different results, indicating that two concussions in youths produce mild but significant long-term effects (2002).

Retrospective studies of the adult population coincided with youth studies. A study by the NCAA found that college athletes with previous history of three or more concussions were
more likely to sustain subsequent concussion than athletes with no concussion history (Guskiewicz et al., 2005). Concussion in professional football players is a risk factor for the development of mild cognitive impairment (MCI), memory impairment, and earlier onset of Alzheimer’s disease. Three or more concussions is also a significant risk factor for developing depression in the geriatric population, with the likelihood of depression three times that of the general population (Guskiewicz et al.). Along with cognitive decline, motor function has also been shown to be affected by concussion. In a study by De Beaumont et al., subclinical motor system dysfunction was found to be related to brain abnormalities that result from complex concussion, as well as multiple concussions. The findings were consistent regardless of the amount of time since last concussion, providing evidence that more severe concussions result in sustained brain abnormalities. Normal neuropsychological testing failed to show these effects, suggesting that these tests may have decreased sensitivity for neuromotor dysfunction (De Beaumont, Lassonde, Leclerc, & Theoret, 2007).
Throwing in the Towel

The gravity of the long-term effects of concussion should be taken into account when managing youth athletes. The decision of when to retire from a given sport in any age group has not been addressed scientifically, only with clinical judgment (Cantu, 2003). Absolute contraindications for any age group for RTP are: abnormal neurological exam, concussion symptoms at rest or exertion, below baseline neuropsychological scores, or abnormal imaging (Cantu). Relative contraindications include increasingly long recovery time between concussions (Kirkwood et al., 2006) or less force necessary to cause concussion, such as indirect blow. In adult populations, number of concussions is not the predicator of retirement, but rather the athlete’s recovery and response to injury (Cantu). However, in the youth population a more conservative approach may be warranted. Exclusion from RTP for the remainder of the season may be the first step with another attempt at play the subsequent year (McCrory, 2001). In some cases though, permanent retirement may be necessary and should be at the discretion of the provider, parents, and athlete (Kirkwood et al., 2006).
Prevention and Education

Unlike other body tissues that may be strengthened and stretched to prevent injury, the brain has no ability to be trained to become more resilient (Cantu, 1996). Thus, decreasing risk of concussion is a difficult task. There are five areas that may be manipulated to reduce risk for the youth athlete:

1. Sports rules and regulations
2. Coaching techniques
3. Strength and conditioning (especially the neck)
4. Equipment
5. Medical Supervision (Cantu).

Education is the single most important factor for decreasing risk of concussion (Buzzini & Guskiewicz, 2006). The need for coaching education is paramount because it has been shown that youth athletes have difficulty perceiving signs of concussion and making RTP decisions on their own (Sye, Sullivan, & McCrory, 2006). Because certified athletic trainers are not mandated and are an expense, coaches are often the main providers of first-aid (Ransone & Dunn-Bennett, 1999). Coaches should also be instructed on teaching better techniques in order to put their athletes in positions that minimize the risk of concussion (Cantu, 1996). Also, if videotape is available, coaches should review the injurious play with the athlete to determine if anything could be done by the player to prevent it from happening again (Cantu). Rule and regulation changes meant to protect the athlete should be further investigated in sports with high concussion rates (i.e. football, hockey, etc.). A Canadian study comparing body-checking rules and related injuries in hockey found that athletes in Ontario who were not allowed to body-check until age 14 had a history of fewer concussions than those allowed to body-check at age 10 (Macpherson, Rothman, & Howard, 2006). Aside from simply obeying rules, youth athletes should be taught good sportsmanship. An athlete that keeps this in mind is probably less likely to hit another
player unnecessarily, and out of the realm of helping his/her team. Along with mental readiness, physical preparation can help to prevent concussion. A strong neck and upper torso dissipate the acceleration-deceleration forces of a blow to the head away from the brain and reduce the chance of whiplash effect (Barth et al., 2001). Overall conditioning and strength training may better prepare the athlete for play and reduce the risk of injury.

Coaches should also be educated on the benefits of sound equipment. Though the National Federation of State High School Associations (NFSHSA) must meet standards set in place by the National Operating Committee on Standards for Athletic Equipment (NOCSAE), studies on helmet design and concussion prevention were almost nonexistent until just two years ago. In the groundbreaking high school study by Collins et al., newer Riddel Revolution® helmets were associated with a relative risk reduction of an astounding 31% compared to older style helmets, and for athletes with no prior history of concussion the relative risk reduction was 41% (Collins, Lovell, Iverson, Ide, & Maroon, 2006). Also, athletes wearing the newer helmets tended to recover faster than athletes wearing the older version (Collins et al.). Along with better helmets, proper use of mouthguards may reduce risk of concussion (Barth et al., 2001; Knapik et al., 2007). Typically newer and proper fitting equipment reduces risk of injury; however, it is important to note the concept of risk compensation in the youth population. Risk compensation is the phenomenon of more hazardous play associated with better equipment because of the athlete’s belief that he/she will be protected (McCrory et al., 2005). Cantu’s fifth area of risk reduction, medical supervision, is the final step for proper preparation. Standaert, Herring and Cantu outlined seven ways for the clinician to prepare for the athlete at risk for concussion:

1) Know your athlete
2) Have baseline health and cognitive data whenever possible
3) Establish effective communication with the coaching staff, trainers, athletes and families
4) Be prepared to manage acute injury
5) Have a system for providing appropriate sideline and postgame supervision of the injured athlete
6) Provide structured, ongoing follow-up
7) Know the literature (2007).

Though these guidelines are meant for team physicians, they can be adopted by any practitioner who treats concussions.
Conclusion and Recommendations

The purpose of medical management of any athletic injury is to allow the athlete to RTP as soon, and more importantly, as safely, as possible. Approaching youth concussion should be no different. However, let us not forget that unlike a musculoskeletal injury, there can be significant, long-term, cumulative neurological effects of concussions. The goal of concussion management is to combine conservative medical decision making with a practical RTP timeline.

It is unlikely that any one clinician will be present from injury to RTP. However, clinicians that manage youth sport-related concussions must understand the entire process so that they may direct the patient’s care with confidence, even from a distance. Injury recognition is the first step. Basic on-the-field management steps are outlined in Table 3, simplifying the sometimes complex nature of dealing with a neurological injury process. Before making any diagnosis, the injured, possibly unconscious, athlete’s ABC’s must be assessed. The clinician must then recognize any signs or symptoms that warrant immediate referral to the ED, as noted in Table 4. Once these immediate concerns are cleared, the athlete should be removed from the field of play for a more thorough evaluation. The SCAT should be administered to every youth athlete suspected of concussion. Following these steps, if the athlete is completely asymptomatic, he/she may RTP immediately, as a concussion has not occurred. However, if the athlete reports a mild headache, amnesia, or any other vague symptom, they are to be withdrawn from play for the rest of the game and further evaluated. Recognizing the sometimes occult symptoms of acute concussion is at the crux of proper management. Evidence-based decision making demonstrates that it is no longer acceptable to let an athlete, even after reporting they are asymptomatic, RTP in the same game after simple concussion. Athletes that RTP too soon are at
high risk for subsequent concussion which can result in far worse short- and long-term outcome than one simple concussion.

After making the sideline diagnosis, the clinician should grade the concussion using the simple vs. complex scale. Recent literature suggests that traditional grading systems are no longer the best way to grade concussion (Iverson, 2007; McCrory et al., 2005). Though better known than the binary system, they are actually less practical. Using the simple vs. complex system would help to make clear that every concussion warrants investigation and medically supervised management. The binary system, if adopted by the medical community will also lessen some of the controversy surrounding management of youth concussion. Youths suffering from concussion display a variety of symptoms which do not always correlate with severity of injury, thus they should always be treated individually; this fits better with a more generalized grading system. The simple vs. complex grading system also provides a protocol for when to administer neuropsychological testing (i.e. prior to participation and then only in complex-type concussion when unsure of symptom resolution).

Diagnosis of concussion always mandates medical evaluation. Table 5 provides a brief synopsis of the medical management of concussion with recommendations based on the disposition of the patient. Special mention should be made regarding history of previous concussion. This is an important part of the history that may be missed in the chaotic sideline environment or in the busy clinic setting. Previous concussion history may change the diagnosis of simple concussion to complex and therefore warrants a different management strategy. During medical management, the Graded Symptom Checklist should be administered at the first medical visit and at any follow-up appointments to track the patient’s progress. Worsening symptoms, among other signs, as noted in Table 4, raise suspicion of severe brain injury and
require CT. Once the athlete with simple concussion is completely asymptomatic at rest, the RTP process may be initiated as described in Table 9. If complex concussion is diagnosed, formal neuropsychological testing, as well as a multi-disciplined approach should be considered. Testing immediately following the complex concussion, with possible serial follow-up testing, will provide evidence that will add to difficult medical decision making regarding the RTP timeline.

Prevention remains the key when dealing with youth concussion. Newer helmet technology has been shown to both significantly decrease risk and severity of concussion (Collins et al., 2006). Newer helmets should be the standard and used exclusively, replacing older style helmets. Along with better equipment, better coaching instruction of proper hitting and body position would also help to prevent concussion. Coaches should also be instructed in basic first aid with a component of concussion recognition and management. Those that have better training in concussion recognition are more likely to withhold the youth from play and refer for proper management later (Valovich McLeod et al., 2007). Also, because of the recommendation that all youth athletes suspected of concussion be administered the SCAT; it would be prudent that all youth coaches have SCAT training.

Clinicians have the responsibility to educate both the parents and the youth regarding concussion. It has been shown that when educated and reassured, youths tend to have less post concussion symptoms (Wade et al., 1998). Parents should also be informed on how the RTP process works and that for simple concussion, it may only commence once the athlete is completely asymptomatic. This may mean the following day or up to 10 days, at which point the concussion would then be termed complex and neuropsychological testing would be recommended as well as possible referral to a concussion specialist.
Recent research has shed light on the difficult topic of youth concussion. However, there are several areas that are still in need of more specific youth related studies. Study of the gene APOE and its influence of concussion and brain recovery in youths is an important issue that requires more research. The precise pathophysiology of concussion is not yet fully understood; therefore areas of the cascade that could be targets for pharmaceutical therapy have not yet been discovered. Further pathophysiological research may someday explain the controversial topic of PCS as well as long-term effects. Also, an important question regarding the grading of concussion is whether the same standards of recovery time should be used for youths as adults. Youth concussion may never be completely understood, but the literature has already shown that research in this area guides clinical management through evidence-based medicine.


### Table 1.

**Definition of Concussion: Subsets**

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
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<tr>
<td>Concussion may be caused by a direct head insult or a transmitted force to</td>
<td>Subsets</td>
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<tr>
<td>concussive forces due to an impact elsewhere on the body.</td>
<td></td>
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<tr>
<td>Usually concussions are low in severity and involve a short period of</td>
<td>Neurological impairment which spontaneously resolves.</td>
</tr>
<tr>
<td>Neurological impairment which spontaneously resolves</td>
<td></td>
</tr>
<tr>
<td>The course of concussion can usually be graded based upon clinical</td>
<td>Neuroimaging of the brain following concussion is grossly normal (McCrory et al., 2005).</td>
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<tr>
<td>symptoms and typically resolves sequentially</td>
<td></td>
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<tr>
<td>Gross neuroanatomy is characteristically normal following concussion,</td>
<td></td>
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<tr>
<td>indicating symptoms have a functional not structural etiology</td>
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<tr>
<td>Neuroimaging of the brain following concussion is grossly normal (McCrory</td>
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<td>et al., 2005)</td>
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Table 2.

*Post Concussion Syndrome*

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<tr>
<th>Timing</th>
<th>ICD-10</th>
<th>DSM-IV</th>
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<tbody>
<tr>
<td>History of head trauma with LOC precedes symptom onset within 4 weeks</td>
<td>Symptoms last at least 3 months, beginning shortly after head trauma</td>
<td></td>
</tr>
<tr>
<td>Includes 3 or more of the following symptoms</td>
<td>Easily fatigued</td>
<td>Disordered sleep</td>
</tr>
<tr>
<td><strong>Somatic</strong>: headache, dizziness, malaise, fatigue, noise intolerance</td>
<td>Headache</td>
<td>Dizziness/vertigo</td>
</tr>
<tr>
<td><strong>Emotional</strong>: irritability, depression, anxiety, emotional lability</td>
<td>Irritability, aggression with little provocation</td>
<td>Anxiety, depression, affect lability</td>
</tr>
<tr>
<td><strong>Cognitive</strong>: subjective concentration, decreased memory, intellectual difficulties without neuropsychological evidence of impairment</td>
<td>Changes in personality (e.g., social/sexual inappropriateness)</td>
<td>Apathy or lack of spontaneity</td>
</tr>
<tr>
<td>Insomnia, reduced alcohol intolerance</td>
<td>Psychological: preoccupation with above symptoms, fear of brain damage with hypochondriacal concern, and adoption of sick role</td>
<td></td>
</tr>
<tr>
<td><strong>Other factors</strong></td>
<td></td>
<td>Symptoms cause significant impairment in social, occupational, and/or educational functioning and represent a significant decline from prior level of functioning. Symptoms are not better accounted for by other mental disorders</td>
</tr>
<tr>
<td>(Lee, 2007)</td>
<td>(Lee, 2007)</td>
<td></td>
</tr>
</tbody>
</table>
Table 3.

**Acute Concussion Assessment**

<table>
<thead>
<tr>
<th>On/Off Field Assessment</th>
<th>Next Step Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Recognize injurious play with potential for concussion</td>
<td>• If concussion is not suspected allow to RTP</td>
</tr>
<tr>
<td>2) Assess ABC’s, check for skull/vertebral fracture</td>
<td>• Refer to ED</td>
</tr>
<tr>
<td>3) Check for S/S cause for referral to ED (prolonged LOC, amnesia &gt; 15 minutes, focal neurological changes, vomiting, worsening of symptoms)</td>
<td>• Remove from play and follow-up with PCP</td>
</tr>
<tr>
<td>4) Administer SCAT</td>
<td></td>
</tr>
<tr>
<td>5) Administer Maddock’s Questions (optional)</td>
<td></td>
</tr>
<tr>
<td>6) Grade Concussion (Simple vs. Complex)</td>
<td></td>
</tr>
<tr>
<td>(Buzzini &amp; Guskiewicz, 2006; Kirkwood et al., 2006; McCrory et al., 2005; Patel et al., 2005)</td>
<td>(Buzzini &amp; Guskiewicz, 2006; Kirkwood et al., 2006; McCrory et al., 2005; Patel et al., 2005; Standaert et al., 2007)</td>
</tr>
</tbody>
</table>
Table 4.

**Signs of More Severe Injury**

<table>
<thead>
<tr>
<th>Reasons for prompt referral to ED</th>
<th>Indications for CT scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prolonged LOC</td>
<td>Symptoms worsen over time</td>
</tr>
<tr>
<td>Amnesia greater than 15 minutes</td>
<td>Cranial nerve deficits</td>
</tr>
<tr>
<td>Deterioration of neurological function</td>
<td>Deterioration of mental status</td>
</tr>
<tr>
<td>Decreasing level of consciousness</td>
<td>Severe or unrelenting headache lasting for greater than three hours</td>
</tr>
<tr>
<td>Respiration or pulse irregularity</td>
<td>Retrograde amnesia</td>
</tr>
<tr>
<td>Increasing blood pressure</td>
<td>LOC for greater than five minutes</td>
</tr>
<tr>
<td>Pupil irregularity</td>
<td>Persistent vomiting</td>
</tr>
<tr>
<td>Cranial nerve deficits</td>
<td>Seizures</td>
</tr>
<tr>
<td>Spine or skull fracture or bleeding</td>
<td>Multiple concussions in the same game (or practice)</td>
</tr>
<tr>
<td>Mental status change</td>
<td>Underlying bleeding disorder</td>
</tr>
<tr>
<td>Seizure activity</td>
<td>GCS &lt;13</td>
</tr>
<tr>
<td>Vomiting</td>
<td>(Committee on Quality Improvement, 1999; Patel et al., 2005; Simon et al., 2001)</td>
</tr>
<tr>
<td>Worsening of postconcussion symptoms</td>
<td>(Buzzini &amp; Guskiewicz, 2006)</td>
</tr>
</tbody>
</table>
Medical Evaluation and Management

<table>
<thead>
<tr>
<th>Medically Guided Assessment &amp; Management</th>
<th>Next Step Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) History of concussive event and subsequent symptomology</td>
<td>• Withhold from practice until RTP protocol completed</td>
</tr>
<tr>
<td>2) Previous concussion history</td>
<td>• Formal neuropsychological testing if complex concussion</td>
</tr>
<tr>
<td>3) Concurrent neurological, psychological, and/or learning disorders</td>
<td>• Depending on previous concussion history remove from play for season (possibly permanent retirement)</td>
</tr>
<tr>
<td>4) Graded symptom checklist</td>
<td>(Buzzini &amp; Guszkiewicz, 2006; Cantu, 2003; Kirkwood et al., 2006; Lee, 2007; Martineau et al., 2007; Patel et al., 2005)</td>
</tr>
<tr>
<td>5) Physical Exam: thorough neurological exam</td>
<td></td>
</tr>
</tbody>
</table>

(Buzzini & Guszkiewicz, 2006; Kirkwood et al., 2006; Lee, 2007; Martineau et al., 2007; Patel et al., 2005)
Table 6.

*Soft Neurologic Signs*

<table>
<thead>
<tr>
<th>Soft Sign</th>
<th>Method</th>
<th>Normal Response</th>
<th>Abnormal Reflex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glabeller Sign (Damasceno et al., 2005)</td>
<td>Repetitive tapping between the patient’s eyebrows</td>
<td>Blinking a few times, then stopping</td>
<td>Continuation of blinking as long as the tapping persists</td>
</tr>
<tr>
<td>Snout Sign (Damasceno et al., 2005)</td>
<td>Position a finger vertically over the lips of the patient and tap with a reflex hammer or opposite finger</td>
<td>Slight protrusion of the lips</td>
<td>Exaggerated protrusion of the lips</td>
</tr>
<tr>
<td>Palmomental Reflex (Damasceno et al., 2005)</td>
<td>Scratching the length of the palmar surface of the hand</td>
<td>None</td>
<td>Contraction of the ipsilateral mentalis and orbicularis oris muscles</td>
</tr>
<tr>
<td>Jaw Jerk (Aminoff et al., 2005)</td>
<td>Hold a finger on the patient’s relaxed chin, then strike with a reflex hammer</td>
<td>Slight contraction of the masseters</td>
<td>Exaggerated contraction of the masseters</td>
</tr>
<tr>
<td>Hoffmann Reflex (Stedman's medical dictionary online, 2006)</td>
<td>Tap the volar surface of the fingers</td>
<td>None</td>
<td>Flexion of the distal phalanx of the thumb</td>
</tr>
<tr>
<td>Trömner Reflex (Stedman's medical dictionary online, 2006)</td>
<td>Tap the second or third distal phalanx</td>
<td>None</td>
<td>Flexion of all four fingers</td>
</tr>
</tbody>
</table>
Table 7.

*Confounding Factors of Neuropsychological Testing*

- Age
- Education
- Cultural Background
- Medications
- Learning Disabilities
- Sleep Deprivation
- Test Anxiety
- Normal continual childhood development

(Patel et al., 2005)
Table 8.

*Potential Pharmaceuticals for the Treatment of Concussion*

<table>
<thead>
<tr>
<th>High potential but lack data</th>
<th>Likely ineffective</th>
<th>Likely to cause harm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arachidonic acid metabolism inhibitors</td>
<td>TRH/TRH analogues</td>
<td>MAOIs</td>
</tr>
<tr>
<td>Calcium channel antagonists</td>
<td>Neurotrophic factors</td>
<td>Hyperbaric oxygen</td>
</tr>
<tr>
<td>Corticosteroids</td>
<td>(McCrory, 2002)</td>
<td>Free radical scavengers</td>
</tr>
<tr>
<td>Antioxidants</td>
<td></td>
<td>(McCrory, 2002)</td>
</tr>
<tr>
<td>Glycolytic stimulators</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other metabolic mediators</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(McCrory, 2002; Tavazzi et al., 2007)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 9.

The RTP Process

<table>
<thead>
<tr>
<th>RTP Process</th>
<th>Next Step Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once athlete is asymptomatic at rest the RTP process may begin. If the athlete becomes symptomatic during any step or following any step activity is to be ceased for 24 hours and begin again at the previously asymptomatic step: 1) No activity, complete rest until completely asymptomatic 2) Light aerobic exercise 3) Sport specific training 4) Non-contact training drills 5) Full contact training after medical clearance</td>
<td>• If athlete successfully completes all steps then they may return to game play • For refractory complex concussion possibly refer to neurologist, or concussion expert</td>
</tr>
<tr>
<td>(McCrory et al., 2005)</td>
<td>(Kirkwood et al., 2006; McCrory et al., 2005)</td>
</tr>
</tbody>
</table>
Figure Caption

*Figure 1.* Youth Concussion Flow Diagram
Youth Concussion Flow Diagram

Potentially injurious play

LOC

Check ABCs, C-Spine, Rapid Neuro check

Pass

Fail

Immediate ED Referral & CT if:
- Prolonged LOC
- Amnesia greater than 15 minutes
- Deterioration of neurological function
  Decreasing level of consciousness
- Respiration or pulse irregularity
- Increasing blood pressure
- Pupil irregularity
- Cranial nerve deficits
- Spine or skull fracture or bleeding
- Mental status change
- Seizure activity
- Vomiting
- Worsening of postconcussion symptoms
- GCS <13
- Multiple concussions in same game

CT & Consider Neurology/Neurosurgery consult pending results & clinical signs

Complications or prolonged recovery – refer to concussion specialist & withholding from rest of season

No LOC

Remove from play – administer SCAT

Grade Concussion

Pass

RTP

Simple
(Progresively resolves after injury without intervention)

Consider ED Referral

Complex
(prolonged LOC or cognitive impairment, convulsion, or ≥ 3 concussion)

Vitals & Neuro assessment every 5 minutes

Medical evaluation & Management

Complex Only

Neuropsychological Testing

Studies negative

Fail

Pass

Once completely asymptomatic: begin RTP process
*Reminder to educate parents/youth about normal post concussive symptoms and to reassure their resolution with time

Fail

Pass
Abstract

**Objective:** Each year, seven million high school students participate in athletics, yet there is no standard youth concussion guideline. The purpose of this literature review was to address and compile the latest research regarding youth sport-related concussion and to make evidence-based recommendations for medical management and the return to play (RTP) process.

**Method:** The databases used to gather research were Medline and PubMed.

**Results:** Recent research has shown that youth concussion is categorically different than adult concussion. New findings regarding assessment, medical management, radiographical studies, neuropsychological testing, the RTP process, as well as sequelae highlight this information.

**Conclusion:** A universal, systematic approach from sideline assessment to medical evaluation and then on to the RTP process should be the foundation of management. Grading should be binary: simple versus complex. Safety and prevention of possible sequelae should be the main goal of every practitioner.