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ABSTRACT

An estimated 300,000 sports concussions are suffered in the USA every year, frequently as the result of full contact sports such a football and boxing. As these concussions can have serious and long-term consequences, a complete understanding of their causes and effects is critical for both clinical care as well as public health awareness and prevention. In this chapter, we discuss the etiology and sequelae of sports concussions, offer a summary of the guidelines on triage and treatment of these injuries.

INTRODUCTION

Concussions, or mild traumatic brain injuries, are a persistent problem in athletic competition. Full contact sports, such as football and boxing, report the highest incidence of sports concussions, but the injuries are also frequently reported in other sports, including soccer, hockey, lacrosse, and basketball. With an estimated 300,000 sports-related concussions occurring in the USA every year (Sosin et al. 1996), defining, assessing, and treating these injuries have become critical questions for physicians, coaches, and players alike. Recent evidence that repeated concussions can have long-term or even fatal effects has raised policy questions for diagnosis and return-to-play guidelines. Increased participation in athletics at both the high school and collegiate levels has resulted in more and more youths being exposed to concussion risks (National Federation of State High School Associations 2006). The increase in participation and competition also means that elite athletes are sometimes subject to the effects of multiple concussions over many years of athletic competition prior to their professional or even college careers. Some neurocognitive testing has been developed to attempt to assess the damage caused by these injuries and to categorize injury severity and necessary treatment. However, recent discoveries in some deceased National Football League (NFL) players of chronic traumatic encephalopathy (CTE, tau protein deposition in brain tissue) highlight that there is much to learn. In this chapter, we review the literature of sports concussions etiology and sequelae and present a culmination of the literature's guidelines on triage and treatment for both youths and adults.

ETIOLOGY AND SYMPTOMS OF SPORTS CONCUSSIONS

The etiology of sports concussions varies from sport to sport, but common mechanisms of injury include rotational acceleration (shearing), linear acceleration (compressive and tensile stresses on axons), carotid artery injuries, and deceleration on impact (Cantu 1996 ; Lampert and Hardman 1984). Sports with the greatest chance of causing catastrophic head injury are football, gymnastics, ice hockey, and wrestling (Cantu and Mueller 1990) . Boxing carries especially high risks of concussions since injury is a goal of the sport; in contrast to football, concussion is an objective of boxing rather than a competitive risk (Ryan 1987). Additionally, as boxers are subject to numerous (and sometimes rapidly consecutive) blows to the head, whether concussive or sub-concussive, these athletes often demonstrate a range of neurological defects (Corsellis 1973). A longitudinal study of 484 amateur boxers revealed statistically significant correlations between the number of bouts completed before the baseline examination and changes in memory, visual-spatial ability, and perceptual/motor ability 2 years later (Stewart et al. 1994). Another study of 41 boxers and 27 control subjects revealed that boxers performed worse on psychometric tests than controls; furthermore, boxers with more bouts performed worse than less experienced boxers (Kemp et al. 1995). Additionally, controls had fewer aberrations in cerebral perfusion than boxers, as detected by PET scanning. Finally, an estimated 9–25% of boxers develop "punch drunk syndrome," or CTE, discussed later in this chapter (Ryan 1987). Another sport of particular interest is football, in which the nature of the sport and the frequency of impact with other players are of considerable concern. The popularity of the sport across ages and regions of the country also contributes to the public health concern; one insurance company reported that rates of injury in organized high school football were double those of the general population (DeLee and Farney 1992). It has been estimated that as many as 1.5 million young men participate in American football at the high school and collegiate levels alone. An estimated 1.2 million football-related injuries are sustained annually; concussions account for as many as 5% of all these injuries (Saal 1991 ; Zemper 1989 ; Canale et al. 1981 ; DeLee and Farney 1992). These injuries were largely the result of direct competition; a 2-year study of over 6,000 football players found that the rate of injury was 8.6 times higher in games than in practice, consistent with previous reports in other sports (Zemper 1989).

Recognition of head injury is obvious when there is a loss of consciousness. However, over 90% of head injuries in sports fall into the category of mild concussions, those in which there is no loss of consciousness (LOC) (Cantu 1986, 1991). The resulting difficulty in sideline diagnoses, in addition to internal and external pressures on a player to return to play, has been a difficult challenge for the medical community. In addition to LOC (which may or may not occur with a mild concussion), immediate effects of concussions include vacant stare, delayed verbal and motor responses, confusion and inability to focus attention, disorientation, slurred or incoherent speech, gross observable incoordination, disproportionate emotions, and memory deficits (Kelly and Rosenberg 1998). As the brain is possibly the most variable of human organs in its response to external stimuli or insult (McKeag 2003), it should come as no surprise that the presentation of concussed athletes varies significantly from individual to individual. In addition to individual differences, contributing factors to varying presentations include biomechanical forces involved and the athlete's prior history of injury, among others (Lovell 2009).

Concussed individuals commonly describe headaches, disorientation, confusion, or amnesia. Nausea and emesis are also common (Heegaard 2007). In children, symptoms typically include restlessness, lethargy, confusion, or irritability. The adult symptoms are classically thought to suggest intracranial lesions. However, the data supporting this conclusion are sparse; the need for additional diagnostic tests after a thorough neurological examination, including detailed mental status examination, depends upon the individual's risk factors (Heegaard 2007). In fact, it has been reported that less than 1% of patients with minor head trauma have surgically significant lesions (Narayan 1994). The consequences of a concussive event can last for several days. McCrea et al. (2003) found that concussed football players continue to show acute symptoms for at least 5 days, cognitive impairments for up to 7 days, and balance effects for up to 5 days after injury.

LASTING EFFECTS OF SPORTS CONCUSSION

The lasting effects of sports concussions were first highlighted in the public eye in the early 1990s when NFL players Al Toon and Merrill Hoge retired from the league because of prolonged post-concussion syndrome. Some reviews report an incidence of post-concussive syndrome of approximately 10–20% of concussed athletes (Lovell 2009). Symptoms of the syndrome include headache, dizziness, anxiety, and impaired cognition and memory (Rutland-Brown et al. 2006). These symptoms affect more than 58% of patients 1 month following their injury (Bazarian and Atabaki 2001) and 15% of patients 1 year following injury (Rutherford et al. 1979). The presence of headache, nausea, and dizziness during the acute head injury assessment can be predictive of post-concussive syndrome as the presence of all three is associated with a 50% likelihood of PCS at 6 months post-injury; an absence of all three symptoms is associated with only a 28% likelihood. Additionally, research has long suggested that the effects of sports concussions can extend far out from the time of injury. Gronwall and Wrightson (1975) originally reported over 30 years ago that the rate at which young adults processed information was reduced more in those subjects who had suffered two concussions compared to those who had been concussed only once. It has also been long suspected that sustaining one concussion increases the risk of additional concussions (Salcido and Costich 1992 ; Annegers et al. 1980). One study of over 15,304 player-seasons examined high school and collegiate football players prospectively over a 2-year period and reported that the relative risk for repeat concussions in individuals with a history of concussion is 5.8 times greater than for individuals with no history (Zemper 2003). Recent studies in high school and collegiate athletes have also shown that cumulative effects may result from three or more concussive episodes. Collins et al. (2002) found that athletes with three or more concussions were more likely to experience on-field LOC (6.7 times more likely), anterograde amnesia (3.8 times), and confusion (4.1 times) after a subsequent concussion. Guskiewicz et al. (2003) found an association between the reported number of previous concussions and the likelihood of incident concussion during follow-up of 4,251 player-seasons. The study additionally found that players who reported a history of three or more previous concussions were three times more likely to have an incident concussion than players with no concussive history. Similarly, players with two previous concussions were 2.8 times more likely to have an incident concussion, and those with one previous concussion, 1.5 times more likely. These findings are supported by animal studies that show a neurochemical and metabolic cascade that detrimentally affects cognitive functions for up to 2 weeks after a concussive injury (Hovda et al. 1995, Giza and Hovda 2001). Studies of high school and collegiate athletes showed with ImPACT testing (an automated neurocognitive test battery) that there were no detectable cumulative effects of only one or two previous concussions (Iverson et al. 2006), but marked effects in athletes with three or more concussions (Iverson et al. 2004). These discoveries highlight the need for adequate treatment and prevention strategies in the sports world. A discovery of considerable concern to athletes at all levels has been the reports of "second impact syndrome." Initially reported in 1984 (Saunders and Harbaugh 1984), there have since been several other reports of this syndrome in the literature (Kelly et al. 1991 ; Cantu and Voy 1995). In these cases, athletes suffer a concussion, usually mild, and sometimes, but not always, with LOC. After returning to play within a few days, they experience a second head injury, which may be very minor, that results in subsequent collapse, a semicomatose state, and respiratory failure. The malignant brain swelling that causes these symptoms is often fatal and has only been reported in teenage athletes. The confinement of this syndrome to such a youthful population may indicate an increased risk for SIS in the developing brain. Alternatively, another hypothesis is if the syndrome is due to a genetic mutation with low prevalence, the reporting of SIS exclusively in teenagers may be due to a combination of this low prevalence and the age structure of populations in contact sports. These cases show that repeated mild brain injuries occurring within a short period of time can be catastrophic or fatal, and highlight a need for proper initial diagnosis, increased education, and vigilance surrounding athletes with head injuries. One of the more severe consequences of the multiple concussions that can be suffered by an athlete over the course of a career is CTE. This condition, first described by Harrison Martland (1928) as dementia pugilistica, is characterized by early symptoms of slight mental confusion, a slowing of muscular movements, hesitancy in speech, and hand tremors. In time, these symptoms become more severe and progressive; they include speech and gait disturbance, pyramidal tract dysfunction, memory impairment, extrapyramidal features, behavior or personality changes, and psychiatric disease (Jordan 1993, 1998 ; Jordan et al. 1997 ; Unterharnscheidt 1970) . Corsellis first identified the neuropathology of this syndrome in the brains of 15 deceased boxers, 8 of whom were world or national champions (Corsellis 1973). Through autopsy, he found that the neuropathology of CTE was characterized by septum pellucidum, degeneration of substantianigra, septal fenestration, cerebellar scarring, diffuse neuronal loss, and prominent neuro fibrillary tangles, now known to be composed of tau protein. The syndrome has recently become an issue of increased public interest when the first documented case of long-term neurodegenerative changes in a retired professional NFL player consistent with CTE was published (Omalu et al. 2005). Since that study, the group has reported neuropathological changes associated with CTE in six former professional football players. As this issue gains more attention, an ongoing prospective research study, the C.O.N.T.A.C.T. research program (Consent to Offer Neural Tissue of Athletes with Concussive Trauma) has been developed. This study involves more than 150 former athletes, including 40 retired NFL players and 3 active NFL players. All participant athletes have agreed to be interviewed annually by phone throughout their lives and, upon their death, will donate their brains to be examined by the Center for the Study of Traumatic Encephalopathy (CSTE), an independent academic research center located at the Boston University School of Medicine (BU CSTE 2010).

DIFFERENCES DUE TO AGE AND DEVELOPMENTAL LEVEL

Age differences in concussion diagnosis and management were not often considered until recent studies appeared to reveal marked differences in the way youths and adults respond to and recover from concussions. Multiple studies have now shown that high school athletes require more time to recover cognitive performance than college athletes (Sim et al. 2008 ; Pellman et al. 2006), in spite of the fact that college athletes had a greater prior incidence of concussion which typically slows recovery (Field et al. 2003). Lovell and colleagues (2003, 2004) also revealed a heightened vulnerability to concussion in younger athletes (ages 13–17), proposing that the currently accepted return-to-play guidelines for adults may be too liberal for adolescents. It has been proposed that the immature brain's sensitivity to glutamate (Pickles 1950), a neurotransmitter involved in the metabolic cascade following concussion, may partly explain these differences in recovery time (Lovell 2009). It is also possible that youths may undergo more prolonged and diffuse cerebral swelling after traumatic injury, so are thus more at risk for secondary injury, partly explaining why SIS has only been reported in youths (McCrory et al. 2005). Whatever the reason, these new findings suggest that clinicians exercise caution in returning young athletes to play following a concussion or concussive symptoms.

TRIAGE AND TREATMENT

It should be noted that most people recover successfully from a concussion with no noticeable long-term effects. McCrea et al. (2003) found that 91% of concussed football players had returned to their pre-injury baselines within a week following injury. The severe conditions that can result from sports head injuries in a small but noteworthy number of cases, however, highlight the necessity of taking concussions seriously and being conservative in return-to-play guidelines. Concussive sports injuries have encouraged the development of easy-to-administer neurocognitive tests that can be given on the sidelines of a playing field immediately after a suspected concussion to guide return-to-play decisions. Of those reported in the literature, the SAC, the Standardized Assessment of Concussion, is possibly the most popular and well-studied. This assessment takes approximately 5 min to administer (and requires no prior experience in neuropsychological testing) and consists of four components: orientation, immediate memory, concentration, and delayed recall (McCrea et al. 1997). An assessment of strength, sensation, and coordination is included as is the documentation of LOC, retrograde amnesia, and post-traumatic amnesia. The total composite score on the exam was sufficient to differentiate between non-concussed controls and those players who had suffered even mild concussions. A study of this test in 141 high school football players demonstrated that more demanding cognitive measures utilized could be sensitive enough for the detection of mild concussions (McCrea et al. 1997). These findings were later supported by a larger study of 568 high school and college football players (McCrea et al. 1998). Normative data from more than 2,500 male and female junior high, high school, college, and professional athletes has shown that the SAC is reliable over repeated administrations and is free of significant gender effects. It is also acceptable for use at all competitive and educational levels (McCrea et al. 2000). In addition to the SAC, the Second International Symposium on Concussion Prague 2004 developed another sideline assessment, the Sport Concussion Assessment Tool (SCAT) (McCrory et al. 2005). This tool was created by combining several common tools into one standardized test; it includes a neurologic screening, cognitive and memory assessments, and queries symptoms, LOC, convulsive activity, and balance problems. However, this tool has not been tested for reliability and validity. This tool was recently updated to include the calculation of the SAC score as well as the Maddocks questions for sideline concussion assessment (McCrory et al. 2009 ; Maddocks et al. 1995). These tools have been used by the military to develop the Military Acute Concussion Evaluation (MACE) which is used by combat medics on the battle field to evaluate service members in whom a concussion is suspected (Coldren et al. 2010). The MACE uses many of the same examination tasks as the SAC and also includes collection of demographic and injury incident details.

Neuropsychological testing is also becoming common among sports health professionals. The wide range of tests available show sensitivity to concussion impairments and include both paper and pencil tests as well as computerized assessments. Conventional tests include the Trail Making Tests A and B (Reitan and Wolfson 1985), Digit Symbol Substitution Test (Weschler 1944), Controlled Oral Word Association (COWA) test (Benton and Hamsher 1976), Hopkins Verbal Learning Test (Shapiro et al. 1999), and the Stroop Word Color Test (Golden and Freshwater 2002). Computerized tests developed included the Automated Neuropyschological Assessment Metrics (ANAM) (Jones et al. 2008), CogState Sport (2008), Headminder Cognitive Stability Index (CSI) (Erlanger et al. 2002), Braincheckers (Elsmore et al. 2007), CNS Vital Signs (Gualtieri and Johnson 2006), Immediate Post-Assessment of Concussion Test (ImPACT) (Iverson et al. 2003), and the Defense Automated Neurobehavioral Assessment (Lathan et al.). The popularity of these tests has increased in light of research that shows a need to test higher cognitive functioning, rather than relying on reports of LOC and amnesia. One study reported that the presence of amnesia, not brief LOC, was most predictive of post-injury difficulties measured at 3 days after injury (Collins et al. 2003). Another study similarly found that impairment of immediate recall was much more frequent than disorientation and suggested that evaluating cognitive function and disability by asking the concussed athlete to state the day, time, month, and year may not be the most clinically useful evaluation task (Pellman et al. 2004 —part III). A third study again found that athletes reporting memory problems following injury had significantly more symptoms, longer duration of symptoms, and significantly decreased performance on neurocognitive testing (Erlanger 2003). These results indicate that the conventional focus on LOC and disorientation as predictors for severity of a concussion may be misplaced. This type of evaluation of memory and immediate recall is of critical importance in sports concussions, where prolonged LOC is even less frequent than in other concussive events (where it is rare to begin with and occurs in less than 10% of concussive injuries) (Collins et al. 2003). McCrea and colleagues (2003) published an important report on their NCAA concussion study which prospectively examined 1,631 football players from 15 US colleges. Their findings showed that injured athletes experienced the most severe symptoms immediately after a concussion, followed by a curve of recovery over 5–7 days, often needing full 7 days to return to baseline and control levels for clinical symptoms, longer than the 5 days needed to return to normal cognitive functioning. This large cohort study supported the clinical experience of many professionals and contributed scientific evidence to return to play guidelines that suggest a gradual reintroduction to sport over the course of several days to weeks, depending on the severity of injury.

In spite of growing research and interest in addressing sports concussions, there is little consensus in the field on when and how to return athletes with head injuries to play. Hunt and Asplund (2010) suggest that whatever assessment tools are used, they include a cognitive assessment, some measure of balance testing, and a self-reported symptom assessment. Many guidelines promote allowing athletes to recover from all symptoms before testing so as to prevent learning effects. In the US military, exercise to a target heart rate is recommended prior to repeat neurocognitive testing to assess whether clinical symptoms, such as headache, have fully resolved (DVBIC 2007). Many institutions have started mandating baseline neurocognitive testing for athletes at risk for head injury so as to obtain an individualized standard in the event of a concussion. These pre-season baselines, therefore, account for any co-morbidities that may affect testing, such as learning disabilities, previous concussion history, medication usage, and mental conditions. The decision about when to return an athlete to play without limitations is an issue of considerable importance in the sports medicine field, given the potential for external or internal pressures on an athlete to return prematurely. There are many published guidelines in the literature, which are based largely on clinical experience and expertise in the field rather than on rigorous studies. Most guidelines currently recommend a gradual, stepwise return to full activity once the athlete has become asymptomatic. Injured athletes are returned to rest or must return to a previous step if they exhibit any symptoms with increased activity. The guidelines proposed by the Third International Conference on Concussion in Sport, in Zurich, Switzerland, in November 2008 (McCrory et al. 2009) improved upon the guidelines previously presented by the same conference in Vienna (Aubry et al. 2002) and Prague (McCrory et al. 2005). Additionally, the research on the effect of multiple concussions has prompted clinicians to differentiate return-to-play guidelines based on the severity of the concussion and the athlete's concussion history. The approach to suspected concussion occurring during a game is now summed up best with the moto – "When in Doubt, Sit them Out." Regarding treatment, the only class I or Level A evidence is rest and education regarding clinical sequelae to be expected. Without education, clinical sequelae are more likely.

NEUROIMAGING AND CONCUSSIONS

CT and MRI remain the imaging technique of choice for initial assessment of acute head injury for skull fractures and intracranial hemorrhage while MRI is standard of care for evaluation of subacute or chronic traumatic brain injury (Tuong and Gean 2009). However, the study of the neuroimaging of concussions has not been thoroughly explored as most mTBIs that result in concussion do not result in abnormalities that can be detected by computed tomography (CT) and standard MRI imaging studies (DiFiori and Giza 2010). Research has suggested that less than 10% of patients with minor head injuries have positive CT findings and less than 1% require neurosurgical intervention (Jeret et al. 1993). The reliance on neurocognitive testing and symptom checklists for concussion diagnosis has motivated clinicians and researchers in the field to use advanced imaging techniques to better quantify and de fi ne structural injuries in the brain following concussion. Possible techniques with increased sensitivity over traditional neuroimaging studies include diffusion tensor MRI (DTI), functional MRI (fMRI), magnetic resonance spectroscopy (MRS), and positron emission tomography (PET). DTI provides a measurement modality for white matter integrity and connectivity. Functional MRI offers the opportunity to receive real-time feedback on cerebral metabolism and brain activation patterns during specific cognitive or motor tasks. MRS and PET alike provide images that indicate functional cerebral metabolism. All of these modalities, however, require relatively long collection times and, with the exception of PET, require post-imaging data processing. These technologies are not currently used in clinical assessments of sports concussion, but following investigation of their sensitivity and specificity, may soon serve to estimate injury severity.

CONCLUSION

The complex and wide-ranging presentations of concussions make the careful study and care of concussed athletes an important issue for the medical community. With recent studies showing the potential long-term effects and increased future risk for concussed athletes, it is our hope that the increase in awareness among the public and medical professionals will lead to evidence-based practices in diagnosing and treating concussed athletes. Since concussion is perhaps the single most common form of brain injury, it is imperative that both health providers and sports professionals receive education and develop an understanding of the risks, prevention, diagnosis, and treatment of sports concussions.

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