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CRITICAL REVIEW—INTRODUCTION

Sports-related concussion: What do we know in 2009—A Neurosurgeon's Perspective

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There has been a growth in sports-related mild traumatic brain injury (MTBI) or concussion awareness and incidence during the past two decades. The Centers for Disease Control and Prevention (2006) has increased estimates of annual incidence from 300,000 during the 1990s to the contemporary number ranging from 1.6 to 2.3 million, reflecting better understanding on the part of caretakers and athletes and more accurate reporting of injuries. Despite many advances in our understanding of concussion, many athletic injuries go undiagnosed. Although reports have varied, up to one half of sports concussions are not recognized, not deemed as serious injuries, or are not consistently identified to the athletic training staff.

Using the American Academy of Neurology definition of concussion as "any trauma induced alteration in mental status that may or may not include a loss of consciousness," we now know that the vast majority, approximately 90%, of athletes with MTBI are not rendered unconscious. From the outset, this frames an often difficult population not only to treat but also to study. Nonetheless, during the past decade, significant strides have been made in our ability to identify and properly manage athletes with MTBI (Meehan & Bachur, 2009).

Our knowledge of athletic concussion has grown in several important aspects. First, we now know that the physiological changes have a metabolic basis, reflecting both extracellular and intracellular dysfunction in neurotransmitter release, ionic shifts, Na/K ATPase activation, and other perturbations, which lead to a period of hyperglycolysis. The resultant ionic shifts may lead to neuronal depolarization and suppression and energy expenditure in an attempt to restore homeostasis (Hovda et al., 1999). Although usually transient, the effects on the cerebral blood flow may be hazardous, particularly if a recurrent injury occurs. In addition to the metabolic effects, we know that alterations to the neuronal cytoskeleton are a possible consequence, leading to alterations in axoplasmic flow, and if of sufficient severity, the inability of the dendritic connections to be maintained, with permanent injury in neuronal connections. In many cases, there appears to be an immediate disruption of neuronal membranes (Buki & Povlishock, 2006).

The pathological accumulation of tau protein, the major structural protein of the neuron and its interconnecting fibers, has been shown in autopsy studies of former professional athletes. Current evidence suggests that secondary concussions, likely leading to more lasting or cumulative effects, occur in the minority but may happen soon after the original injury (De Beaumont et al., 2009; Guskiewicz et al., 2005). The possibility of the second impact syndrome and cumulative brain injury leading to chronic traumatic encephalopathy, the latter originally described in retired boxers but more recently identified in professional football players and wrestlers, are two entities that are compelling reasons for mandating proper management of the brain-injured athlete (Omalu et al., 2006). The role of genetic predisposition, particularly the well-known relationship of the apolipoprotein ApoE E4 genotype in increasing vulnerability to brain trauma, remains incompletely understood insofar as application or screening potential to mitigate the potential for chronic effects (Rabadi & Jordan, 2001).

In our laboratory, using a weight-drop method in a rodent model, we have observed that a single nonlethal MTBI, which leaves the animal with no long-term behavioral or clinical deficits and no hemorrhage on brain examination, may nonetheless cause axonal damage in fibers projecting from the frontal lobe to the brain stem within the corticospinal tract. Using amyloid precursor protein immunoflurorescence staining, a single impact to the cranium will universally result in the presence of axonal damage in the medulla and pons (Mills et al., 2009). Further investigation using tau protein and apoptotic and other markers should lead us to greater understanding of the relationship between cranial impact with linear and rotational forces and their impartation of kinetic energy to the cortex, mesencephalon, and brain stem.

The proper management of the athlete with MTBI requires identification during the contest, accurate sideline or locker room testing, and correct decision making regarding return to play during that same contest (Mayers, 2008). Several guidelines have been proposed to assist the caregiver during this

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initial decision-making process and for determining the *initial* grade of the concussion. It is now clear that concussion is best graded twice, and since many of the symptoms are not readily apparent, a *delayed* concussion grading leads to improved accuracy in both diagnosis and management. Headache, difficulty in concentration, dizziness, visual disturbance, diminished school performance, and other symptoms are often only apparent in the days following concussion.

The use of neuroimaging studies such as computed tomography or magnetic resonance imaging scans has limited benefit due to the fact that they are almost always normal following athletic MTBI. Although newer diagnostic techniques such as functional magnetic resonance imaging and diffusion tensor imaging offer us the potential to visualize or document specific areas of brain injury, they currently are not used or practical in most instances. Clinical decision making has greatly benefited from the introduction of neuropsychological testing for athletes in an attempt to determine the brain-behavior localization and extent of injury (Lovell, 2008).

Although there are many nuances of correctly applying neuropsychological testing and interpreting their results, both traditional and computer-based instruments have proven valuable in athletic concussion and its management. Neuropsychological testing, whether in consultation with a neuropsychologist or computer based, is objective data, which greatly aid the sports medicine clinician when deciding when to return an athlete to a contact sport. Many guidelines have been proposed for return-to-play management, but in addition to the clinical symptom assessment, the neuropsychological performance of the brain-injured athlete is paramount in current decision making. The advent of computerized test platforms, with access to the Internet and qualified neuropsychological opinion, makes neuropsychological testing all the more practical and available for a larger population.

In this edition of the journal, Randolph and Kirkwood have presented a detailed and scholarly review of many issues related to concussion. They advance several arguments regarding the potential for improvements in measuring sports MTBI and for management. The belief that concussion in athletes with catastrophic injury ensues from the immediate consequence of a single traumatic brain injury ignores the fact that particularly in football and boxing, there are likely prior subconcussive or concussive forces within the same contest that go unrecognized. The final serious impact may lead to a clinically recognized event; however, there is no doubt that often other blows may have led to cerebral edema and/or intracranial hemorrhage. In addition, there are documented cases in which the time interval between the catastrophic and the prior brain injuries was several weeks. Their criticism, bolstered by a single reference, of currently available computerized neuropsychological testing, ignores the multitude of clinical studies that have confirmed its utility, particularly with increased availability and interest. While there is potential for practice effects, diminished reproducibility, and insufficient stability coefficients in the world of everyday practice, neuropsychological testing has become an important component of player evaluations. Combined with the neurological examination and clinical symptom checklist, the neuropsychological evaluation, irrespective of any potential shortcomings, is integrated and used to assist in determining player management. Moreover, in instances where the validity of the particular test is questioned or where ambiguity exists for safe return to play, a neuropsychological consultation often may lead to valued and definitive input for the clinician.

It is difficult to place a monetary value on implementation of baseline programs; but more than just preventing delayed brain swelling, one must also consider the potential for poor school performance, diminished athletic prowess, personality change, chronic physical symptoms such as dizziness or headache, future cognitive impairment, chronic traumatic encephalopathy, and other detrimental effects. Thus, I also disagree that a sport-related concussion may only cause long-term effects if it is associated with brain hemorrhage or swelling. In summary, with 20 years' football experience as a sideline physician and 10 as a player, I believe that our current management is served by a concussion grading as initial and delayed, monitoring of clinical symptoms, and incorporation of neuropsychological testing to best advise the contact sport athlete on activity recommendations. While not perfect, in practice, there is a general consensus regarding the overall conservative approach with multifactorial input in an attempt to not return a symptomatic athlete to participation.

Establishing the diagnosis of sports concussion is paramount to successful player management. Most athletes thus injured will follow a progressive sequence of recovery within the first week. The danger of an acute cerebral edema event, such as the second impact syndrome, and the potential for development of CTE are remote but most likely always involve multiple concussions or subconcussive impacts. How many concussions are too many? We are not certain, and most likely, factors such as age, sex, concussion severity and proximity, genetic predisposition, underlying learning disabilities, and others play a role. In the management of sports-related MTBI, an individualized and measured approach, along with the use of adjuvant testing such as neuropsychological evaluation, is recommended. Ironically and importantly, this is the only group of patients who are asking, "doctor, since my prior brain injury has healed is it now alright for me to go back and play and sustain more brain impacts?"

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