When is a concussion no longer a concussion?

Concussion has been in the medical lexicon since Hippocrates, and widespread viewing of sports concussion is now commonplace. This mildest form of traumatic brain injury (TBI) has obvious acute effects, but motor symptoms seem to abate quickly as the concussed player leaves the contest. The prompt return to baseline in most sports concussions could be considered as evidence for the transient nature of the injury, with the brain’s homeostatic equilibrium temporarily disrupted and then restored, but this view may be changing. With 1.6–3.8 million sports-related concussions annually in the United States (http://www.cdc.gov/ncipc/tbi/Physician_Tool_Kit), the possible long-term consequences of concussion clearly merit attention.

In 2008, a consensus panel from the 3rd International Conference on Concussion in Sport (The 4th International Conference on Concussion in Sport was held in Zurich in November 2012, but the proceedings have not yet been published) stated that sports concussion results from “...impulsive force transmitted to the head” that “...typically results in the rapid onset of short-lived impairment of neurologic function that resolves spontaneously.” While this statement provides an operational definition for concussion, it is based entirely on clinical judgment and observation, with no independent biomarker of brain injury. The panelists proposed a distinction between concussion and mild TBI (mTBI), noting that mTBI refers to “different constructs and should not be used interchangeably.” This distinction suggests that the concussion may be followed by complete recovery, whereas mTBI may manifest persistent symptoms. The operational definition of sports concussion was supported by the statement that “no abnormality on standard structural neuroimaging studies is seen in concussion (p. 756),” so the presence of a traumatic lesion becomes a definitive biomarker of brain injury with implications for permanency.

In an attempt to better understand the biomechanics of head impacts and when a sports concussion occurs, helmet-mounted accelerometers or other impact telemetry devices have been studied in contact sports. These showed that helmeted football players may sustain concussive blows with forces ranging from 60 to 169 g. These are not trivial impact forces, and they may occur repetitively. Using biomechanical data from actual sports-related head impacts, finite models of brain deformation have been developed that incorporate MRI to show that the greatest strains on brain parenchyma occur in the corpus callosum and long-coursing white matter (WM) tracts. What are the implications of repeated deformation of brain parenchyma, especially involving WM tracts? Comparing preseason to postseason cognitive performance, McAllister et al. demonstrated that repetitive head impacts over a single season in college varsity football players were associated with poorer performance on measures of processing speed. Processing speed is a neuropsychological metric that reflects WM integrity. In varsity hockey players who underwent MRI during the preseason and at postseason, Koerte et al. showed differences in WM diffusivity based on diffusion tensor imaging (DTI). Human and animal studies have shown the outward appearance of recovery but continued metabolic derangement, and long-term effects on WM integrity are implicated. Damage may be more severe with higher numbers of concussions, or with concussion that occurs before recovery from a previous concussion is complete.3

An important issue for neurologists is the neuroimaging of TBI. Experimental neuroimaging of TBI has advanced greatly in recent years, most notably with DTI. This technique characterizes WM microstructure, offering a number of empirically derived physiologic and anatomic metrics sensitive to WM integrity, and permitting the analysis of specific neural connections. What is becoming clear is that TBI disrupts the WM network that comprises brain connectivity, which presumably contributes to the deleterious effects of TBI. DTI differences are consistently demonstrated in mTBI, with abnormalities found in WM connectivity in otherwise normal-appearing WM based on conventional MRI.

In this issue of Neurology®, Strain et al. report on the relationship between depressive symptoms and WM integrity in retired National Football League players. From unbiased DTI techniques assessing global WM
integrity and methods examining a priori regions of interest, associations were demonstrated between depression and the forceps minor, the uncinate fasciculus, the superior longitudinal fasciculus, and the frontal aslant tract. These tracts consistently are affected in mTBI and sports concussion when DTI is used, presumably through stretch deformation due to brain movement induced by the force of a blow to the head. These fibers participate in emotional control as well as executive function, attention, working memory, and language, and the authors propose that DTI may offer a biomarker to identify individuals with concussion who may be most vulnerable to a mood disorder. Neurologically, interruption of these tracts would not produce outwardly visible motor abnormalities, but rather a variety of cognitive and behavioral disturbances.

This study examines a unique sample, but it is relatively small, and prospective, long-term studies will be needed to further explore its implications. While the range of documented concussions in the asymptomatic group was from 0 to 10, the group symptomatic for depression had a minimum of 3, with a group average of almost 6 during their playing days. Secondary variables with potential effects on mood and behavior will also require consideration, and abnormalities of WM connectivity may predispose to depression in the absence of TBI.

The importance of this work, however, lies in its demonstration of the possibility that some concussions may have long-term neurobehavioral effects. Improved recognition of potential chronic sequelae of concussion may be achieved by examining WM with DTI because these measures provide independent quantitative metrics of neural integrity. Biomarkers that may emerge in this process will bring more objectivity to the understanding and treatment of inherently subjective but sometimes disabling symptoms.

AUTHOR CONTRIBUTIONS
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