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Topical Review

The Diagnosis and Management of Concussion in Children and Adolescents

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ABSTRACT

BACKGROUND: Concussion is a complex brain injury that results in more than 100,000 emergency department visits for school-aged children each year in the United States. All 50 US states have passed concussion legislation designed to promote safety in youth sports. Most of these laws require medical clearance by a licensed health care provider before returning to sport, which may have contributed to an increase in pediatric subspecialty referrals, particularly referrals to the child neurologist. **METHODS:** We reviewed the literature on pediatric concussion. **RESULTS:** This review summarizes the current knowledge and recommendations for concussion diagnosis and management in children and adolescents, athletes and nonathletes. It highlights concussion epidemiology, pathophysiology, advances in neuroimaging, and potential health risks including second impact syndrome and chronic traumatic encephalopathy. It also underscores clinical areas where evidence is lacking. **CONCLUSIONS:** The diagnosis and management of concussion requires specific considerations in children. Further concussion research must be done to minimize injury risk and to optimize medical care for this common problem.

Keywords: concussion, mTBI, pediatric, adolescent, second impact syndrome, postconcussion syndrome, chronic traumatic encephalopathy

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Introduction

While playing a junior high school football game in 2006, 13-year-old Zackery Lystedt tackled an opposing player late in the second quarter. The collision caused his head to strike the ground. He was removed from the game with a severe headache. Zackery returned to play in the third quarter, and near the end of the game he collapsed on the field. Airlifted to a level 1 trauma center, doctors performed an emergent neurosurgical procedure to alleviate cerebral edema. It would be nearly 3 years before Zackery would stand again, with assistance.[1]

Discouraged that their son was not properly evaluated following his initial on-field head injury, Zackery's family worked with many individuals including members of the Washington State Congress and the Centers for Disease Control and Prevention to enact a bill that could help prevent similar injuries in youth athletes. On May 14, 2009, the Zackery Lystedt Law was passed in Washington State.[2] The law requires that student athletes be removed from competition when a head injury is suspected. The athlete may return to play only after receiving written clearance from a licensed healthcare provider.[2]

Following passage of the Zackery Lystedt Law, other states began enacting similar youth concussion legislation. As of February 2014, all 50 states and the District of Columbia had passed concussion laws designed to help protect youth athletes.[3] Most of these laws require that a

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licensed health care provider evaluates the athlete following injury and medically clear him or her before returning to sport. The new legislation promotes safety in youth sports. It also may promote greater health care utilization. From 2006 to 2012, states with concussion laws in effect had a 10% increase in health care utilization for concussions compared with states without active legislation, and the rates of pediatric concussion referrals to neurologists have increased steadily compared with the 2008-2009 rates, up 36% in 2009-2010, 84% in 2010-2011, and 150% in 2011-2012.[4] The following review summarizes the current knowledge and consensus guidelines in youth concussion. It is written to aid health professionals in the diagnosis and clinical management of the pediatric patient with concussion.

Concussion definition and epidemiology

The American Academy of Neurology defines concussion as a biomechanically induced clinical syndrome related to alterations in brain function that can affect memory and orientation.[5] The injury can be caused by a direct blow to the head, face, or neck or by a blow elsewhere to the body with force transmitted to the head.[6] Loss of consciousness occurs in only 8%-19% of concussions and is not a defining feature.[7,8] Concussion symptoms typically resolve within 7-10 days, but a minority of patients report symptoms that persist for months, even years.[6] Children may take longer to recover than adults. Most clinicians consider concussion to represent a subset of mild traumatic brain injury (TBI), defined as a Glasgow Coma Scale score of 13-15, loss of consciousness of less than 30 minutes (if present), and posttraumatic amnesia of 24 hours (if present).[9] Symptom grading scales for concussion severity are no longer recommended because they are poorly predictive of outcome.[5] "Subconcussive" impacts, defined as biomechanically induced injuries to the brain that do not result in clinical symptoms, may have a cumulative effect leading to chronic traumatic brain injury in some adult patients.[10] Little is known about subconcussive injuries in youth.

It is estimated that 1.6-3.8 million sport-related TBIs occur in the United States each year; the majority of these injuries represent mild TBI and concussion.[11] Concussions result in more than 100,000 emergency department visits each year for school-aged children in the United States.[12] Approximately 1 in every 220 pediatric patients seen in the emergency department is diagnosed with concussion, and 30%-50% of the concussions are sports-related.[12,13] Additionally, concussion represents approximately 9% of all high school sports injuries.[14] The overall incidence of youth concussion is not known because some injuries go unrecognized and some patients do not seek medical care.[11] Although boys may have more sports-related concussions overall, girls appear to have a higher concussion risk when comparing similar sports.[15-17] Sports differ in terms of concussion risks between genders: football, ice hockey, lacrosse, and wrestling have the highest risks for boys; soccer, lacrosse, ice hockey, field hockey, and basketball have the highest risks for girls.[16,18] It is unclear whether age or level of competition affects concussion risk, but concussion rates tend to be higher in games than in practices.[14,16,19]

Pathophysiology

Concussion represents a functional, rather than a structural, brain injury.[6] Seminal studies have demonstrated that acceleration-deceleration and rotational forces related to head impact can induce concussion.[20,21] The pathophysiology of brain dysfunction results from an abnormal neurometabolic cascade. This begins with the disruption of neuronal cell membranes, potassium efflux, and glutamate release.[22] Ion pumps use adenosine triphosphate to restore the normal cellular membrane potentials. The increase in cellular adenosine triphosphate metabolism following injury can produce a relative energy deficit, with a consequent depression of neuronal activity.[23] Additionally, intracellular calcium accumulation, mitochondrial dysfunction, free radical production, impaired glucose metabolism, cytoskeletal injury, abnormal axonal transport, and alterations in neurotransmission all can contribute to the altered neurometabolic state.[23-29] Regional changes in cerebral blood flow may exacerbate the energy crisis.[30] These physiologic perturbations correlate with clinical features of concussion including the increase in concussion vulnerability early after injury and the gradually resolving neurocognitive symptoms.[31] Injury to the young, developing brain may be associated with greater risk of long-term functional impairments because of altered neuronal plasticity and immature myelination.[32,33]

Following a concussive injury, there is a brief temporal window of increased concussion vulnerability in the animal model that appears to resolve gradually during 7-10 days. Longhi and colleagues demonstrated that adult mice with concussive injuries had significantly greater functional impairments with repeat injuries at 3 or 5 days compared with 7 days, suggesting that the vulnerability to repeat concussion in the animal model diminishes within 7 days from the initial TBI.[34] Vestibular dysfunction and axonal injury were worse when the impacts were spaced only 3 days apart. In juvenile rats, repeat concussions spaced 1 day apart caused greater cumulative memory impairments, whereas concussions spaced 5 days apart led to memory impairments that were similar to the initial injury.[35] Fewer data about the duration of increased concussion vulnerability are available in humans. Maugans and colleagues found diminished cerebral blood flow in concussed children aged 11-15 years compared with controls.[36] Cerebral blood flow values in their study improved over time; 27% matched the control values by 14 days postinjury, 64% after 30 days.

Loss of cell membrane integrity with concussion may cause leakage of some neuronal and glial cell components. The cellular components that are detectable in serum could serve as biomarkers for the concussive injury and injury recovery. Biomarker studies have yielded inconsistent results evaluating S100 calcium-binding protein B, neuron-specific enolase, tau protein, neurofilament light protein, amyloid beta protein, myelin basic protein, and glial fibrillary acidic protein.[37-41] S100 calcium-binding protein B and neuron-specific enolase levels drawn within 6 hours of mild TBI did not differ between symptomatic and asymptomatic children aged 6 months to 15 years.[39] S100 calcium-binding protein B levels drawn within 6 hours of concussion did not predict postconcussion symptoms 3 months later.[37] In