Pediatric Mild Traumatic Brain Injury in the Acute Setting

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Abstract: Pediatric mild traumatic brain injuries, most of which are concussions, are an increasingly common reason for presentation to emergency departments. The diagnosis of concussion has increased dramatically over the past decade, necessitating the acute care provider to have up-to-date knowledge of the definition, pathophysiology, signs and symptoms, physical examination findings, and acute management of pediatric concussion. This article also addresses populations most vulnerable to prolonged recovery from pediatric concussion and referral recommendations.

Key Words: concussion, mild traumatic brain injury, vestibulo-ocular examination, vestibulo-ocular deficit, cognitive rest

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TARGET AUDIENCE

This continuing medical education activity is intended for physicians, physician assistants, nurse practitioners, and emergency medical service providers who care for pediatric patients.

LEARNING OBJECTIVES

After completion of this article, the reader should be able to do the following:

1. Discuss the pathophysiologic basis for mild traumatic brain injury and the metabolic mismatch that occurs after injury.
2. Perform a concussion-specific history and physical examination and articulate their use in concussion diagnosis and prognosis.
3. Describe the evidence base behind cognitive and physical rest after pediatric mild traumatic brain injury and explain appropriate return to activity guidelines to patients and families.

Pediatric mild traumatic brain injuries (mTBIs), most of which are concussions, are an increasingly common reason for presentation to medical care. Over the past decade, the incidence of diagnosed pediatric mTBI has increased exponentially in the acute and primary care settings, likely due to increased awareness and recognition. Our understanding of the pathophysiology and optimal management of concussed patients has also rapidly evolved. As more and more children present to emergency departments (EDs) across the country, acute care providers must remain current with the diagnosis and management of mTBI. This article will review the definition, epidemiology, pathophysiology, diagnosis, and management of mTBI in the acute setting.

DEFINITION AND EPIDEMIOLOGY

The most widely accepted definition of concussion comes from the "Consensus statement on concussion in sport," revised every 4 years by an international workgroup. The latest revision occurred in 2016 and defines a concussion as a complex pathophysiological process induced by biomechanical forces, the features of which include the following: "(1) an injury resulting from either a direct blow to the head, face, or neck, or other part of the body with an impulsive force transmitted to the head; (2) the development of short-lived impairment in neurologic function that resolves spontaneously, though symptoms and signs may evolve over a number of minutes to hours; (3) neuropathological changes, though the acute symptoms largely reflect a functional disturbance rather than a structural injury, and, as such, no abnormality is seen on standard neuroimaging studies; and (4) a range of clinical signs and symptoms that may or may not involve loss of consciousness and typically follows a sequential course, however, in some cases may be prolonged."[1] Although most concussions in the pediatric population are the result of sport,[2,3] other mechanisms of injury include trauma such as falls, road traffic injuries, and assaults.

Because of expanded awareness, as well as a likely increase in true incidence, the diagnosis of concussion has increased dramatically over the past decade. Recent studies estimate that concussion diagnosis rates have doubled over the past 10 years.[4] There are nearly 1 million ED visits per year for mild traumatic brain injury (mTBI) for patients of all ages, with the highest reported rates in patients aged 12 to 17 years.[5] Most ED visits for pediatric concussion are from male patients (estimates between 55% and 60%).[2,3] The true incidence of concussion, however, is likely significantly higher than estimated, as studies have shown that most pediatric concussion is diagnosed and treated outside an ED.[6] The reported incidence will likely continue to rise as, between 2009 and 2014, all 50 states and the District of Columbia enacted legislation mandating that after a concussion, children be cleared by a health professional before returning to sport. Studies have shown that such laws have led to increasing health care utilization for concussed patients.[7]

PATHOPHYSIOLOGY

Multiple basic science and animal models of mTBI have demonstrated the metabolic cascade that occurs after a concussion. Sheer force and rotational deformity, rather than direct trauma, lead to mechanical damage to neurons and axons.[8] Excitatory neurotransmitter release then leads to ion flux and membrane depolarization (Fig. 1). An influx of calcium interferes with mitochondrial function and causes temporary cell dysfunction. Repair mechanisms, using adenosine triphosphate–fueled sodium/potassium pumps, attempt to restore intracellular balance.[9] During the early stages of the injury, glucose utilization

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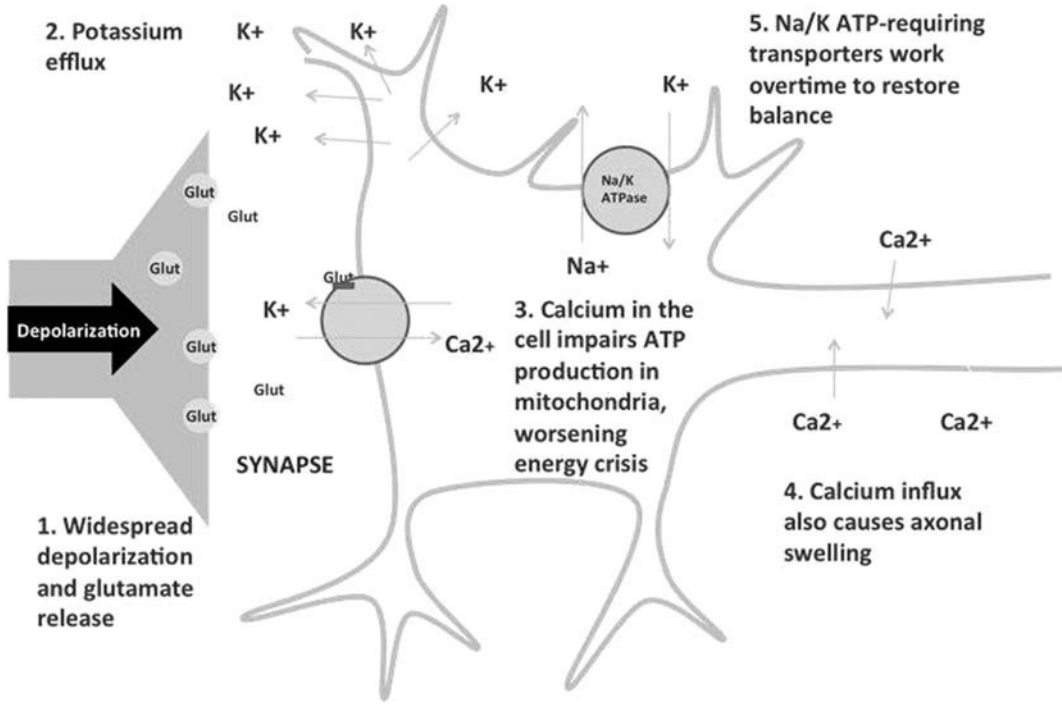

FIGURE 1. Biochemical cascade after concussion. Adapted with permission from McGinley AD, Master CL, Zonfrillo MR. Sports-related head injuries in adolescents: a comprehensive update. *Adolesc Med*. 2015; 26: 491–506.

to generate adenosine triphosphate is very high,[10] ultimately increasing neuronal energy demand.[9] Simultaneously, both pediatric and adult studies have shown that cerebral blood flow, which delivers glucose, decreases in response to injury, leading to an imbalance in energy supply and demand.[11,12] This creates a metabolic mismatch almost immediately after injury and forms the basis for cognitive and physical rest recommendations very early in the injury process. Finally, axons themselves have been shown to undergo structural damage, because disturbances in membrane homeostasis cause cytoskeletal injury.[13]

ACUTE HISTORY: SIGNS AND SYMPTOMS OF CONCUSSION

Concussion symptoms can be classified into 3 domains: physical, cognitive, and emotional (affective; Table 1).[1] Physical symptoms include headache, nausea, vomiting, dizziness, balance problems, vision problems, photophobia, and phonophobia. Cognitive symptoms include difficulty concentrating, difficulty remembering, and feeling mentally slow and foggy. Affective symptoms include emotional lability, irritability, depression, and anxiety. Physical symptoms tend to present earlier than cognitive or emotional symptoms and also tend to resolve sooner.[2,14] There seems to be a distinct entity, posttraumatic migraine, which encompasses prolonged headache, nausea, photophobia, and phonophobia[15] and can last for several months after the injury. This can occur both in migraine-prone children and in children without a history of migraine headaches. The acute care provider should be aware of the evolution of symptoms in both history taking and anticipatory guidance.

In addition, during history taking, the provider must examine elements of the patient's medical history pertinent to concussion recovery. Several populations have been shown to be at risk for prolonged recovery, including females, teenagers, those with prior concussion, those with underlying attention-deficit/hyperactivity disorder (ADHD) or a learning disability, and those with an underlying mood disorder (see the Special Populations section). A social history should ascertain the patient's current status in school to give the provider a sense of the cognitive demand that will be required of the patient during recovery (eg, a child in elementary

TABLE 1. Signs and Symptoms of Concussion

Physical Symptoms	Cognitive Symptoms	Emotional/Sleep Symptoms
Headache	Difficulty concentrating	Irritability
Nausea/vomiting	Difficulty remembering	Mood changes
Balance problems	Feeling foggy	Anxiety
Dizziness	Feeling slowed down	Depression
Vision problems		Emotional lability
Sensitivity to light/sound		Sleep disturbance

TABLE 2. Vestibulo-Ocular Examination for Concussion

Physical Examination Element	How to Perform Examination	Abnormal Findings
Dysmetria	Finger-nose-finger, examiner's finger moving horizontally, 10 repetitions	Slow reaction time, past-pointing, intention tremor
Nystagmus	Examiner's finger moving horizontally, progressively more rapidly, stopping centrally	>1 beat of nystagmus at center of visual field
Smooth pursuits	Examiner's finger moving horizontally, progressively more rapidly	Red/watering eyes, symptom provocation (headache, dizziness, eye fatigue)
Fast saccades	Examiner's fingers shoulder-width apart (horizontal) and forehead-chin distance (vertical), 30 repetitions	Red/watering eyes, symptom provocation (headache, dizziness, eye fatigue, fogginess)
Gaze stability	Patient fixes gaze on examiner's thumb while nodding yes and then shaking head no side to side, 30 repetitions	Red/watering eyes, symptom provocation (headache, dizziness, eye fatigue, fogginess)
Near-point convergence	Patient holds pen with letters at arm's length, brings toward nose until becomes double	Letters become double at >6 cm from the tip of the nose
Gait/balance testing	Tandem heel-toe gait forward and backward with eyes open and closed	Raises arms for stability or widens gait, extreme truncal swaying

school has a very different cognitive demand compared with a teenager preparing for college entrance examinations).

PHYSICAL EXAMINATION

In addition to a standard neurologic examination, there are specialized physical examination maneuvers to evaluate for vestibular and oculomotor dysfunction, very common postconcussive deficits. One version of the vestibular and oculomotor examination for concussion, the modified vestibular/oculomotor screening examination for concussion, described in Table 2 and Figure 2, includes tests for (1) nystagmus, (2) smooth visual pursuits, (3) fast saccades in both the horizontal and vertical directions, (4) gaze stability testing (the vestibulo-ocular reflex), (5) near-point convergence, (6) monocular accommodation, and (7) balance/gait stability. This test has been standardized across providers in primary care, emergency medicine, and sports medicine at one large, tertiary care pediatric institution and takes approximately 2 to 3 minutes to complete.[16] It can be performed in children as young as 6 years. A similar version of this examination, the vestibular/oculomotor screening examination, has been shown to positively correlate with symptom scales, with each individual element showing high predictive value in identifying concussed patients.[17] The examination has shown excellent sensitivity for concussion, because in specialty clinics, nearly 80% of concussed patients show at least 1 vestibular or oculomotor abnormality.[18,19] In addition to its use in concussion diagnosis, the specialized examination also shows potential for helping prognosticate for patients with mTBI, because those with abnormalities are at risk for prolonged recovery from concussion,[18,20] and vestibular deficits are more prevalent in children with prolonged symptoms.[21] Finally, this examination has functional implications, because it mimics the eye-tracking demands of children in the school classroom; vestibular and oculomotor deficits can impact school reentry and allow the provider to predict potential areas of difficulty in the school-aged population. It should be noted that although performing a version of the examination is feasible in the office or emergency setting, and the 2016 International Consensus Statement on Concussion recommends performing a version of vestibular and oculomotor testing in this setting,[1] currently, administration of the full spectrum of testing is not widespread and is yet to become a standard of care. We do anticipate that because of its use for diagnosis and its prognostic value, more and more clinicians will perform vestibular and oculomotor examinations over the coming years in children with concussion.

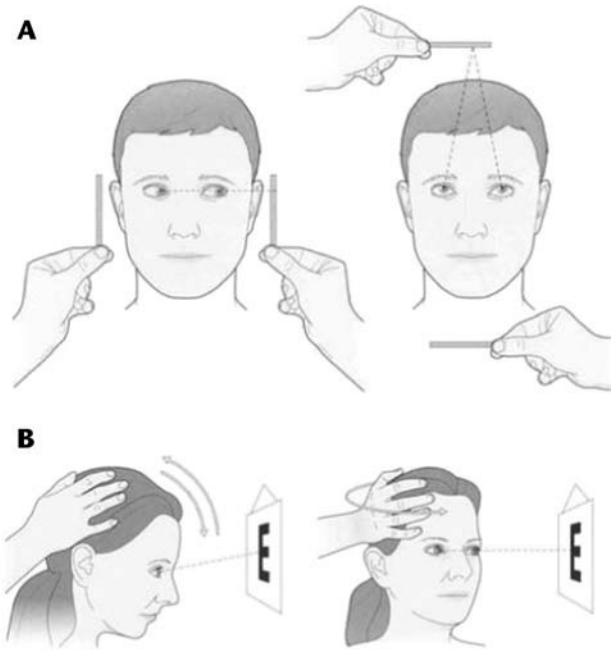

FIGURE 2. Demonstration of saccadic and gaze stability testing in the vestibular and oculomotor examination for concussion. A, To test horizontal saccades, the examiner's fingers are placed shoulder-width apart (horizontal) or forehead-chin distance (vertical), and the patient is asked to look between them for 30 repetitions. B, To test gaze stability, the patient fixes gaze on an object (or the examiner's thumb) while nodding yes and then shaking head no side to side for 30 repetitions. Adapted with permission from Plant G, Splaton D. Chapter 19: neuro-ophthalmology. In: Spalton D, Hitchings R, Hunter P, eds. *Atlas of Clinical Ophthalmology*, 3rd ed. Elsevier Limited. Oxford, Great Britain. 2005).

NEUROIMAGING AND LABORATORY TESTING

Diagnosis of mTBI is made by history and physical examination, and in general, it does not require neuroimaging. Consensus statements agree that imaging via either computed tomographic (CT) scan or magnetic resonance imaging (MRI) of the head contributes little to the diagnosis of concussion.[1] In the ED, CT scan

should be used when the clinician has suspicion for skull fracture or intracranial hemorrhage. Multiple studies have developed decision models to help rule out clinically significant intracranial hemorrhage, the largest and most widely used of which was published by Kuppermann et al[22] in 2009. Of note, there is overlap between the higher-risk features of traumatic brain injury in this study and symptoms of concussion, and not all patients who fail to meet the very low risk criteria in this study require a head CT.

Like CT, MRI has little role in the immediate diagnosis of concussion. Most MRI findings obtained on patients with mTBI are normal.[23] In patients with prolonged symptoms, MRIs are useful if the clinician is entertaining alternative diagnoses beyond postconcussive syndrome (eg, a space-occupying lesion). More recently, functional MRI (fMRI) has been used in patients recovering from mTBI, to show subtle abnormalities, even in asymptomatic patients.[24,25] In the future, fMRI may play a role in helping rehabilitate patients with prolonged recovery but currently does not play a role in the acute management of concussion.

Previously, there was little role for laboratory testing in the setting of mTBI, although more recently, several serum biomarkers have been studied. Glial fibrillary acidic protein (GFAP), an intermediate filament expressed by astrocytes, has been shown to correlate with CT findings in those with more severe TBI in pediatric patients.[26] Recently, a pilot study in children with mTBI demonstrated that levels of GFAP in the serum drawn shortly after the injury correlate with symptom burden both initially and 1 month after the injury.[27] This suggests that there may be a role in the future for GFAP, among other potential candidate markers (including S100 calcium binding protein B, myelin basic protein, and ubiquitin C-terminal hydrolase-L1), as potential indicators for more severe concussion.[28]

NEUROCOGNITIVE TESTING

Many computerized neurocognitive testing batteries are available for children experiencing concussion, which can be completed in a relatively short period. Prior studies have shown that such testing is feasible in an ED setting,[29] although one must keep in mind that many acutely concussed children are too symptomatic to complete neurocognitive testing, and exposing children to these batteries in the acute setting may solely serve to exacerbate symptoms. The utility of neurocognitive testing acutely is somewhat controversial; some studies have shown that patients with mTBI perform worse on computerized testing when compared with healthy controls,[29,30] even when asymptomatic, whereas other studies have shown that lower raw scores on neurocognitive testing in the ED do not predict prolonged recovery.[31] Likely, more useful than raw data is comparison between a patient's baseline testing and his or her performance after an mTBI. However, even with patients who have baseline testing available, there are limitations; for example, studies show that patients do worse on baseline testing with less sleep,[32] so a similar score between baseline and after a potential injury would not necessarily rule out concussion. The most important use of such testing is likely in trending scores as a patient recovers and determining clearance for return to sports.[33] Ultimately, neurocognitive testing, in conjunction with history and physical examination findings, may play a role in concussion diagnosis but should serve as an adjunct and not a primary diagnostic tool.

MANAGEMENT: COGNITIVE AND PHYSICAL REST

On the basis of consensus statements and expert opinion, both from the International Conference on Concussion[1] and the American Academy of Pediatrics Council on Sports Medicine and Fitness,[34] the standard of care for treatment of mTBI in children and youth is cognitive and physical rest. Given the pathophysiology of concussion and the metabolic mismatch that occurs early in the course of injury, some degree of rest is likely beneficial during the early recovery phase. However, the optimal dose and duration of rest remain controversial, with equivocal findings in the literature.

Early studies showed improvement in symptoms among those who rested at least 1 week after injury, although in the largest early study, there was no comparison group.[35] More recent studies have demonstrated that prolonged rest may actually be detrimental. Thomas et al[36] randomized a group of patients aged 11 to 22 years to either 5 days of strict rest or 1 to 2 days of rest followed by a stepwise return to activity, and the strict rest group had an increased number and a slower resolution of symptoms. Buckley et al[37] randomized 50 college-aged athletes either to strictly rest for 48 hours or to not receive specific postinjury instructions, and the "no-rest" group was symptom-free sooner (5.2 vs 3.9 days). The provider must consider the psychological consequences of prescribing physical and cognitive rest; DiFazio et al[38] have described an "Activity Restriction Cascade," whereby removing a child from validating life activities, combined with physical deconditioning, contributes to the development of persistent postconcussion symptoms and lengthens recovery. In addition, in contrast to prior recommendations that suggested complete abstinence from physical exercise while symptomatic, recent studies have also shown that early exercise may not only reduce symptoms but also reduce abnormalities in brain activity on fMRI imaging.[39]

At the same time, the provider must be cautious in recommending early return to full activity, as too much activity too soon may prolong recovery. Brown et al[40] recently showed that those in the highest quartile of cognitive activity within the first 3 weeks after injury had a more prolonged recovery, and Silverberg et al[41] showed that sharp increases in mental activity lead to an increased risk of symptom spikes (it should be noted, however, that symptom spikes in and of themselves were not a risk factor for a prolonged recovery). In addition, early cognitive and physical activity should not be equated with early return to activities that may result in another head injury. A second injury, before the full recovery of the first injury, may have severe consequences. Both basic science and animal models have shown a reinjury during a vulnerable window, usually within 1 to 2 weeks of injury, and may result in persistent and possibly permanent injuries,[42,43] including ion channel dysfunction, structural neuronal damage, and cognitive impairments.[44–46]

In recommending return to activity in the acute setting, the acute care provider must consider the eye-tracking demands required in the classroom. Reading, using a computer screen, taking notes, and viewing objects close to one's face can be difficult if the child still has abnormalities in the vestibular and oculomotor examination (eg, horizontal saccades mimic reading a book, and vertical saccades mimic looking up at a board or screen and taking notes).

The optimal duration of rest after concussion remains unclear, but there is enough evidence to recommended period of 24 to 48 hours of rest, followed by graduated return to activity in concert with a primary care provider, a recommendation supported by the International Consensus Statement.[1] Clinicians can expect these recommendations to be refined in the coming years as more research on the treatment of concussions is undertaken.

MANAGEMENT: MEDICATIONS

In the acute setting, analgesics including acetaminophen and ibuprofen can provide some pain relief (especially in the setting of a contact-related injury); however, they generally are not helpful during the recovery phase and should not be continued after ED

discharge. Often, such symptoms occur as a result of excessive cognitive activity and usually only improve with rest. If, during the acute stages of concussion, patients are requiring pain medication to enable participation in physical and cognitive activities, they are likely overexerting themselves. Sleep disturbances, which can occur shortly after a concussion, can be treated with melatonin in the acute setting.[47] Other medications have been trialed outside the acute setting for those patients with persistent postconcussive syndrome, including gabapentin, topiramate, and amitriptyline. Although a complete discussion of their efficacy is beyond the scope of this review, amitriptyline has been shown to be most effective for postconcussive headaches.[48]

SPECIAL POPULATIONS

Numerous studies have shown that certain populations are at risk for a prolonged recovery from concussion and therefore may require closer follow-up.

Age

Compared with college-aged athletes and adults, adolescents have demonstrated prolonged recovery time.[49,50] Among school-aged children and teenagers, there is controversial evidence regarding which patients are at the highest risk for prolonged symptoms. Some studies show that the youngest patients take longer to recover,[3] whereas others indicate that teenagers are predisposed to a longer duration of symptoms than younger children.[51,52] There are likely some confounding factors in the differential recovery by age, because younger children may be inclined to report symptoms less frequently than older teenagers; in addition, older teenagers experience a larger cognitive burden upon return to school. In terms of neurocognitive testing, there seems to be a trend of prolonged recovery time by age: adults (older than 22 years) have been found to return to baseline in 3 to 5 days; college-aged young adults (age, 18–22 years) recover in 5 to 7 days; and high school students (age, 14–17 years) recover in 10 to 14 days.[53,54] It has been hypothesized that the pediatric brain may have increased susceptibility to neurotransmitter-mediated excitotoxicity as mechanism for the longer recovery time when compared with adults.[55]

Sex

Multiple studies have shown the females take longer to recover compared with males.[51,56] Although females do report more baseline symptoms compared with males, they take longer to return to their baseline after an mTBI.[57] After concussion, females have been shown to score more poorly on neurocognitive testing.[58]

Prior Concussions

Many studies have shown that a history of multiple (>2) prior concussions is an independent risk factor for a prolonged recovery.[59,60] More recent studies have suggested that any prior concussion may predispose children to prolonged duration of symptoms.[56] On neurocognitive testing, those with a history of at least 1 concussion perform worse when recovering from a second injury compared with those who have never experienced a prior concussion.[61]

Mood Disorder and Learning Disabilities

Mood disorders (both anxiety and depression) have been shown to increase the risk of development of postconcussive syndrome, as well as the risk for prolonged duration of symptoms and recovery.[3,62] Children after concussion report significant mood-related symptoms and can develop novel psychiatric diagnoses,[63] although it is unclear if these come about as a result of the mTBI or represent an underlying diagnosis that is unmasked by the injury. Those with a strong family history of mood disorders are likely at higher risk to develop depression and anxiety after an injury. In addition, those children with ADHD have been shown to be at risk for prolonged recovery.[56] Interestingly, those with ADHD are actually at higher risk to sustain a concussion, in addition to their risk for prolongation of symptoms.[64]

Prolonged Recovery or More Likely to Report Symptoms?

Some researchers have proposed that several of these underlying conditions may not necessarily predispose children to a prolonged recovery but rather represent conditions whereby children are simply more likely to report symptoms. Iverson et al[65] examined symptom reporting in nonconcussed children and found that girls, those with mood disorders, and those with migraine headaches were more likely to endorse symptoms resembling concussion than those without these conditions. Although a propensity to overreport symptoms may partially explain the prolonged recovery in these specific groups, there likely is also an element of true prolongation of symptoms. Regardless, the acute care provider must be cognizant of the risks in concussed patients with the aforementioned underlying conditions.

FOLLOW-UP AND REFERRAL

Prior research has estimated that symptoms in most mTBI patients (as high as 80%–90%) will resolve within 4 weeks.[66] Both studies and position statements have emphasized that most concussions can be managed by primary care providers.[16] Referral to concussion specialists is indicated for patients who experience symptoms unresponsive to traditional rest after 3 weeks. These specialists can help coordinate education and neuropsychological resources, as well as facilitate referral to specialized physical therapists. Studies have proven that visual and oculomotor therapy can be successful for those with prolonged visual and vestibular complaints.[67]

In providing referral and follow-up, the acute care provider should be aware of the specialized populations mentioned previously, as, given their risk to prolonged recovery, they likely will require closer follow-up. Tools exist to aid the clinician in helping prognosticate for families. For example, recently, the Pediatric Emergency Research Canada Concussion Team published a clinical risk score for predicting persistent postconcussive symptoms from the ED, which includes points for being teenage, female sex, prior concussion history, migraine history, answering questions slowly, errors in balance testing, and reported symptoms of headache, sensitivity to noise, and fatigue.[52]

CONCLUSIONS

Pediatric mTBI is an increasingly common reason for presentation to medical care. As the incidence of concussion diagnosis continues to rise, it is imperative for acute care providers to have an understanding of the epidemiology and pathophysiology of concussion, an awareness of specialized elements of the history and physical findings when evaluating the potentially concussed patient, a knowledge of appropriate recommendations for rest and rehabilitation, and an appreciation of special, vulnerable populations at risk for a prolonged recovery.

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