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CONCUSSION (C SENTER AND M KAPADIA, SECTION EDITORS)

Current Concepts in the Evaluation of the Pediatric Patient with Concussion

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Abstract

Purpose of the Review A concussion is a mild traumatic brain injury (mTBI) that results in a change in how a person feels or functions after a force transmitted to the head. Nearly 10% of all sports-related injuries are mild traumatic brain injuries. Concussion/mTBIs have accounted for more than 3 million emergency department visits between 2005 and 2009 and present as an important public health concern.

Recent Findings Physical, cognitive, and psychological functioning are known to be affected by concussion/mTBI, and various tools are readily available to guide clinicians through the initial evaluation.

Summary Evaluation of patients with concussion/mTBI should include symptom report and balance, vestibular-ocular, and neurocognitive testing. Awareness of past medical history and pre-injury history of social, behavioral, and emotional functioning is essential to better understand the injury and to predict the expected course of recovery. No tool available can be used alone to diagnose concussion/mTBI or evaluate for recovery.

Keywords Concussion evaluation · Concussion · Mild traumatic brain injury · Post-concussion symptoms · Sideline concussion testing

Introduction

A concussion is a mild traumatic brain injury (mTBI) that results in a change in how a person feels and/or functions after biomechanical forces are transmitted to the head. As defined in the 5th International Conference on Concussion in Sport, published in 2017, concussion results from a direct or indirect impulsive force to the head leading to a rapid onset of short-lived neurologic impairment. Concussion largely reflects a functional disturbance rather than a structural injury and symptoms cannot be explained by drug, alcohol or medication use, other injuries, or comorbidities [1••]. The Center for Disease Control and Prevention Guideline on Mild Traumatic Brain Injury Among Children recommends using the term mild traumatic brain injury instead of concussion [2••].

mTBI is known to result in somatic complaints and changes in cognition, mood, visual-motor functioning, and balance. Recovery typically follows a sequential course, although in children, the patterns of recovery are variable. Given that injury recovery is defined by one's return to their pre-injury baseline, without symptom provocation, understanding their baseline is paramount to successfully evaluate and manage an individual with mTBI.

mTBI results in an immediate onset and/or delayed onset of symptoms (physical, cognitive, mood, and sleep-related). Immediate onset signs/symptoms include headache, dizziness, unsteadiness, feeling confused, anterograde or retrograde amnesia, loss of consciousness, visual disturbance, nausea/vomiting, and rarely tonic posturing/seizure. Delayed onset symptoms begin hours to days after injury and typically involve physical symptoms, mood symptoms, and cognitive symptoms (Table 1). mTBI may also result in vestibular-ocular changes and/or balance abnormalities. Even in the absence of cognitive symptoms, changes in performance on testing may be seen.

This article is part of the Topical Collection on *Concussion*

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Table 1 Commonly reported post-concussion symptoms

Physical	Cognitive	Emotional	Sleep
Headache	Difficulty thinking clearly	Irritable	Difficulty initiating sleep
Dizziness	Difficulty concentrating	More easily frustrated	Sleeping more
Balance problems	Difficulty remembering	Sad	Sleeping less
Light sensitivity	Feeling more slowed down	Nervous	Waking more frequently during the night
Noise sensitivity	Feeling sluggish, hazy, foggy, or groggy	More emotional than usual	Drowsy
Fatigue	Problems in school		
Blurry or double vision	Longer to complete assignments		
Nausea/vomiting			

Although many tools for concussion evaluation have been studied, no single tool in isolation can be used to define injury or define recovery. In clinical practice, it is a combination of readily available tools that is most beneficial [2••].

The goals of evaluation of the concussed child, student, or athlete vary depending on the location and the timing of the evaluation. At the time of injury/event, the first question that needs to be asked is "did this person sustain a concussion," with important implications for removal from play and the potential need for further evaluation. In the emergency department, the medical evaluation includes recognizing the presence or absence of concussion with additional focus on the concern for clinically important intracranial injury, the need for observation, neuroimaging, or neurosurgical intervention. Once the diagnosis of mTBI has been made, the goals of evaluation shift to assessing for areas affected by the injury and the evaluation for readiness for return to learn and return to play [3].

The Field

For individuals with suspected head or neck trauma, the initial assessment should always include the basics—airway, breathing, and circulation. In addition, when the individual experiences trauma with loss of consciousness or change in mental status, cervical spine injury should be suspected until proven otherwise.

In the sideline setting, there are age-appropriate assessment tools that can be used to aid in the diagnosis of concussion. The most commonly used validated tools are the Sideline Concussion Assessment Tool (SCAT 5) [4••], for individuals older than 13 years and the Child Sideline Concussion Assessment Tool (ChildSCAT 5), for children age 5–12 years [5]. The cognitive screening included in the Standardized Assessment for Concussion (SAC) is inadequate to distinguish between individuals with mTBI and those without and therefore should not be used in isolation to diagnose mild TBI in children and adolescents [6••].

Sideline testing can also include the Balance Error Score System, a test of postural stability, and the King-Devick test, a test of visual-motor function. Each of these tools relies on an accurate understanding of the individual's pre-injury baseline which is often unavailable. No tool can be used in isolation to define injury or to make a return to play determination [6••].

The Emergency Department

Referral to an emergency department (ED) for evaluation is based on the likelihood of significant injury other than a concussion and the need for neuroimaging and possible neurosurgical intervention. Indications for immediate ED evaluation include prolonged loss of consciousness (greater than 1 min), concern for cervical spine injury, high-impact or high-risk mechanism for intracranial bleed, examination findings suggestive of skull fracture, post-traumatic seizure, or any significant acute worsening in the patient's condition (i.e., focal neurologic deficits, worsening mental status, persistent nausea, and vomiting). Numerous studies have demonstrated that multiple risk factors in combination were most predictive of identifying children at high risk for clinically important intracranial injury [6••]. The Pediatric Emergency Care Applied Research Network (PECARN) pediatric head injury prediction rule is a widely used algorithm to identify children at very low risk for clinically important intracranial injury, for whom CT scan can be avoided. The PECARN clinical decision rule for children 2 years and older with normal mental status, no loss of consciousness, no vomiting, nonsevere injury mechanism, no signs of basilar skull fracture, and no severe headache had a negative predictive value of 99.95% [7]. (Fig. 1).

Avoiding a head CT in children at very low risk for clinically significant intracranial injury is important due to the amount of radiation delivered when undergoing a head CT. The ionizing radiation doses delivered for a head CT is 20 times more than a conventional chest radiograph [8]. There has been a significant association between the estimated radiation doses provided by CT scans to the brain and the

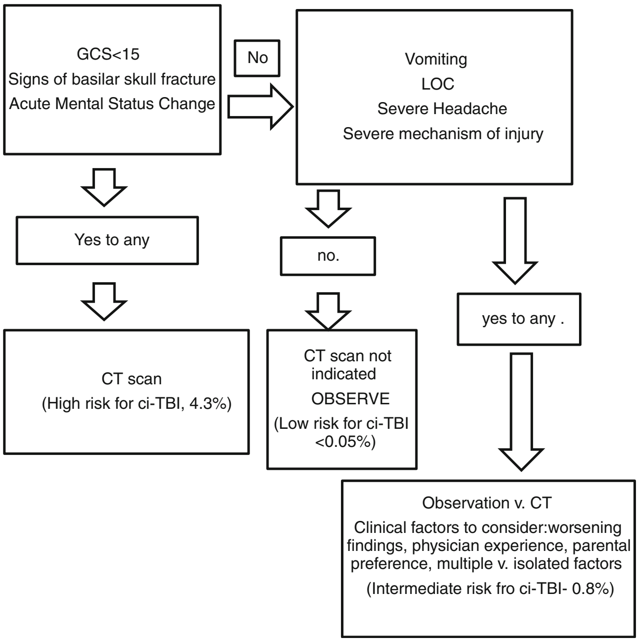

Fig. 1 PECARN pediatric head trauma CT decision guide (> 2 years old). Kuppermann N. et al. "Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study.". *The Lancet*. 2009. 374(9696):1160–1170

subsequent incidence of brain tumors. Although the brain tumor risk remains extremely low, assuming typical doses for scans were performed after 2001 in children aged younger than 15 years, cumulative ionizing radiation doses from 2 to 3 head CTs (i.e., ~ 60 mGy) nearly triple the risk [9].

The Office Evaluation

The office evaluation of the concussed student/athlete should be designed with the intent of confirming that the individual sustained a concussion and a comprehensive evaluation to appropriately initiate a management plan. As of 2017, all 50 states and the District of Columbia have laws regarding concussion that require evaluation by a health care provider prior to consideration of return to play [10]. A comprehensive concussion evaluation includes details of the initial injury, assessment of symptom burden, a complete neurologic exam, cognitive and mood evaluation, visual motor screening evaluation, balance assessment, and assessment for premorbid risk factors for slower recovery.

Injury Details

Mechanism of injury, presence of immediate onset symptoms, and whether or not the athlete was pulled from a play contribute to an understanding of the likelihood of important intracranial injury and/or the likelihood of a prolonged recovery course. Of note, loss of consciousness occurs in fewer than 10% of injuries and brief loss of consciousness has little prognostic value [11–13]. Motor changes including tonic posturing or a brief seizure in the immediate post-injury time frame are rare and do not usually require more than usual concussion management [3]. Athletes not removed from play, who sustain another injury to the head, are at risk for increased symptom burden and longer recovery times [14].

Symptom Scales

Validated and age-appropriate symptom scales should be utilized by health care providers to assess symptoms as part of a more comprehensive evaluation [2••]. Several checklists are available that can be used to monitor and measure self-reported symptoms of mTBI including the Graded Symptom Checklist (GSC), Post-Concussion Symptoms Survey (PCSS), and Rivermead Post-Concussion Symptom Questionnaire [15]. The Post-Concussion Symptom Inventory (PCSI) has been validated for use with children and adolescents ages 5–18 [16]. There are two self-report versions for ages 5–12 and ages 13–18, and one parent/guardian version. The parent/guardian report and the adolescent self-report (ages 13–18) provide an opportunity for the reporter to rate pre-injury symptoms, along with the current symptoms. While it is important to have a good understanding of a patient's pre-injury symptoms in order to better understand their reported post-injury symptoms, research suggests that athletes may under-report their post-injury symptoms in hopes of returning to play sooner [17]. Relying solely on questionnaires is discouraged and providers should follow up with both the patient and their parent or guardian about the endorsed symptoms. Additionally, we have observed in clinic that patients and their parent/guardian often complete rating scales incorrectly due to a misunderstanding of directions, and clarification is often needed. If ratings of current emotional symptoms are high, additional more specific assessments of mood and anxiety using validated questionnaires or interview may be useful to guide further treatment options. It is important to also assess pre-injury concerns such as attention-deficit hyperactivity disorder, learning disability, anxiety, depression, and headache/migraine, which can affect the recovery process.

Neurologic Exam

A comprehensive neurologic exam including mental status/orientation, fundoscopic exam, cranial nerve testing, strength, sensory testing, reflexes, coordination testing, and gait is usually normal in the individual with mTBI; however, a thorough exam helps to identify other injuries or more significant injury. For example, the presence of brisk reflexes or ankle clonus may be indicative of a more severe TBI, or sensory deficits may suggest a plexopathy, stinger, or spinal cord damage.

Vestibular-Ocular Evaluation

Over the past few years, visual motor screening evaluation has been recognized as an important component of the concussion evaluation [18]. The cognitive control of eye movements is complicated and utilizes about half of the brain's pathways involving the frontoparietal circuits and subcortical nuclei. These pathways are particularly susceptible to injury in concussion. The most commonly observed abnormalities are seen in saccades, smooth pursuits, and convergence. Saccades are of particular interest as they have been shown to be abnormal in acute and subacute mTBI with persistence in individuals with slower recovery. The vestibular-ocular motor examination takes a few minutes to perform and consists of smooth pursuits, saccadic or rapid eye movements, near the point of convergence, vestibular-ocular reflex, and visual motion sensitivity. Movement abnormalities and symptom provocation are both considered [18] (see Table 2).

Vestibular-ocular motor abnormalities have been associated with slower recovery from concussion [2••, 19]. In our concussion program, patients who presented with vestibular-ocular motor abnormalities—including smooth pursuits, horizontal and vertical saccadic abnormalities, abnormal vestibular-ocular reflex, abnormal visual motion sensitivity/optokinetic response, and/or abnormal convergence, experienced a statistically significant, longer recovery course. Each component of the exam was predictive of slower recovery—most notably smooth pursuits, saccades, optokinetic/visual motion sensitivity, and convergence [19].

The King-Devick test has been used in both the sideline and office setting to assess for visual motor changes post-concussion. The King-Devick test, which measures visual tracking and attention, may be useful in confirming concussion in individuals suspected of sustaining a concussion, but should not be used as a standalone test [20]. Lack of age-matched, gender-matched normative data in children, and the low incidence of available baseline tests for comparison have made the incorporation of the King-Devick test into the office setting a challenge.

Table 2 Vestibular-ocular motor screen

- Smooth pursuits—test the ability to follow a slowly moving target.
- Saccades (horizontal and vertical)—test the ability of the eyes to move quickly between targets.
- Convergence—measures the ability to view a near target without double vision
- Vestibular-ocular reflex (VOR) test—assesses the ability to stabilize vision as the head moves.
- Visual motion sensitivity (VMS) test—test visual motion sensitivity and the ability to inhibit vestibular-induced eye movements using vision.

**Abnormal findings or provocation of symptoms (headache, dizziness, fogginess, or nausea) with any test may indicate dysfunction

Mucha A, Collins MW, Elbin RJ, et al. A brief vestibular/ocular motor screening (VOMS) assessment to evaluate concussions: preliminary findings. *Am J Sports Med*. 2014;42(10):2479–86

Balance Testing

Balance abnormalities are commonly present in concussed individuals and an objective assessment is a mainstay of the evaluation [21]. Key features of the balance exam include gait evaluation, tandem gait, single foot stance eyes open, single foot stance eyes closed, and tandem stance eyes open and closed. Attention to footwear is important because the individual with hiking boots will have more balance support than the individual wearing flip flops. Because balance deficits should not be defined by footwear, we recommend that patients remove their footwear prior to testing.

Office-based tools for balance assessment include the SCAT5 and the Balance Error Scoring System (BESS). The SCAT5 requires patients to perform double leg stance, single leg stance, and tandem stance, eyes open and eyes closed on a firm or foam surface. The BESS measures postural stability in 3 positions on firm and foam surfaces. The setting of testing and proximity to exercise may affect results and repeated assessment can have a practice effect. With access to more elaborate technology and software, balance can also be assessed using mobile applications that measure postural stability and reaction time as well as force plate testing.

Cognitive Screen

The in-office cognitive screen has been a mainstay of concussion evaluation for more than a decade. The Acute Concussion Evaluation (ACE) tool [22] and the SCAT5 [4••, 5] both have cognitive screens that are easily performed in the office. Maddocks questions evaluate orientation and memory but do not assess multistep thinking or attention, which are known to be affected after mTBI. In children and adolescents, computer-based screening can be performed, but the effects of vestibular-ocular motor evaluation on computer-based testing have not yet been evaluated. Individuals with poor performance on screening are at risk for slower recovery and may warrant referral to a neuropsychologist.

Computerized Neurocognitive Testing

Standard of care dictates assessing cognitive function in patients with mTBI. Optimally, the assessments should be administered and interpreted by a mTBI-trained neuropsychologist; however, due to limitations in the availability of trained neuropsychologists, computerized neurocognitive measures are commonly used as screening tools [1••]. Commonly available computerized neurocognitive assessment tools include ImPACT, Cogsport, and Headmider. These tools are intended to be used as a screen, but the findings are not considered diagnostic of specific cognitive deficits [15]. Validated computerized cognitive testing can be used serially in the acute period following mTBI to assess cognitive recovery [2••, 6]. While there was a greater emphasis on the need for baseline neurocognitive testing previously, the most recent guidelines developed by the 5th International Conference on Concussion in Sport indicate that it is not mandatory, but may provide helpful information in order to interpret post-injury neurocognitive measures [1••].

Neuropsychological Evaluation

Neuropsychologists play a valuable role as part of a multidisciplinary team to assess cognitive recovery and manage mTBI, including important clinical decision making such as the timing of return to play (RTP) [1••]. A neuropsychological evaluation is used to assess components of learning and memory, processing speed and efficiency, reaction time, and attention in order to identify the current cognitive status of the patient and assess improvement over time [15]. A neuropsychological evaluation can help to identify and predict protracted recovery and provide an opportunity for early intervention if needed. Given that symptom resolution may predate cognitive return to baseline, assessment of neuropsychological functioning can also be utilized once the patient is asymptomatic and returned to full academic functioning to ensure cognitive recovery.

In addition to more common neuropsychological measures administered by a neuropsychologist, evaluation of neurocognitive functioning and recovery of the pediatric population with mTBI should include use of standardized performance validity tools, such as the Medical Symptom Validity Test (MSVT) [23]. This measure has good empirical support for use with the pediatric population and can help to ensure that the results are valid [24]. In our concussion clinic, we have found significant utility for use of performance validity testing, related to better understanding sub-optimal effort and/or symptom magnification independent of concussion.

This information guides the interpretation of the test results and serves as a measure of need for referral to psychology services to address underlying mood/anxiety concerns that may be interfering with recovery. Furthermore, assessing the degree of symptom exacerbation with cognitive exertion is necessary in order to guide treatment recommendations, particularly when determining the timing and intensity of reintegration back into activities such as return to learn. One tool that can be utilized is the Children's Exertional Effects Rating Scale (ChEERS) [25].

Risk Factors for Protracted Recovery

The symptoms and findings of mTBI are temporary, with 70% of pediatric patients recovering within the first 4 weeks and 90% in the first 3 months (https://www.cdc.gov/traumaticbraininjury/PediatricmTBIGuideline.html). Premorbid and demographic features may identify those individuals at risk for protracted (> 4-week) recovery. Properly identifying individuals at risk for slower recovery allows for targeted anticipatory guidance and should be included in the initial evaluation. Based on review of the literature, identified premorbid and historic risk factors for slower recovery include history of mTBI, lower cognitive ability, neurological or psychological disorder, learning difficulties, ADHD, headaches/migraines, family and social stressors, lower socioeconomic status, Hispanic ethnicity, older child/adolescent, and severe symptom burden [2••, 6]. The persistent post-concussion symptom (PPCS) risk score has been developed to predict individuals at risk for slower recovery; however, further research is needed to validate its utility in clinical practice [26].

Neuroimaging

Patients and parents often request neuroimaging as part of the initial or follow-up mTBI evaluation. Based on current data available, there is no neuroimaging tool that clearly identifies mTBI or defines injury recovery. The use of advanced neuroimaging, including diffusion tensor imaging (DTI), functional MRI (fMRI), SWI (susceptibility-weighted imaging), magnetoencephalography, anatomic MRI, resting-state functional MRI (rsfMRI), and magnetic resonance spectroscopy (MRS), has been a topic of ongoing research. DTI, a form of MR imaging that measures the diffusion of water molecules, has been the most frequently used and correlates significantly with symptom report, emotional issues, arithmetic problem-solving, and concussion outcome scores [27].

Serum Biomarkers

Serum biomarkers including S100B, tau proteins, serum potassium, glucose, or white blood cell count, autoantibodies against glutamate and oxide metabolites, and multiplex bead array biomarkers are actively being studied. To date, none have demonstrated a clear, validated role in the management of mTBI injury in children [2••, 6••].

Conclusion

mTBI is an injury that results in temporary changes in multiple domains: physical, cognitive, emotional, and functional. No single tool is adequate for a complete evaluation. Evaluation of patients with mTBI should be multimodal and include symptom report, balance, vestibular-ocular, and neurocognitive testing. Obtaining a pre-injury history of medical, social, behavioral, and emotional, as well as current psychosocial stressors, is essential to better understand the injury and to predict the expected course of recovery. In patients with ongoing symptoms, a multidisciplinary approach to management should be utilized to optimize physical and cognitive recovery.

Compliance with Ethical Standards

Conflict of Interest Rochelle Haas, Maya Zayat, and Amanda Sevrin declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent All reported studies/experiments with human or animal subjects performed by Rochelle Haas and Amanda Sevrin have been previously presented and complied with all applicable ethical standards (including the Helsinki declaration and its amendments, institutional/national research committee standards, and international/national/institutional guidelines).

This article does not contain any studies with human or animal subjects performed by Maya Zayat.

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