Evaluation and Management of Pediatric Concussion in the Acute Setting

Daniel J. Corwin, MD, MSCE, Matthew F. Grady, MD,† Christina L. Master, MD,† Mark D. Joffe, MD,* and Mark R. Zonfrillo, MD, MSCE‡*

Abstract: Concussion, a type of mild traumatic brain injury, is a common injury encountered by providers caring for pediatric patients in the emergency department (ED) setting. Our understanding of the pathophysiologic basis for symptom and recovery trajectories for pediatric concussion continues to rapidly evolve. As this understanding changes, so do recommendations for optimal management of concussed youth. As more and more children present to EDs across the country for concussion, it is imperative that providers caring for children in these settings remain up-to-date with diagnostic recommendations and management techniques. This article will review the definition, epidemiology, pathophysiology, diagnosis, and management of pediatric concussion in the ED setting.

Key Words: concussion, mild traumatic brain injury, visiovestibular examination, persistent postconcussion symptoms

(*Pediatr Emer Care* 2021;37: 371–381)

TARGET AUDIENCE

This continuing medical education activity is intended for physicians, advanced practice providers, and emergency medical service providers who care for pediatric patients with concussion.

LEARNING OBJECTIVES

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

1. Describe the pathophysiologic basis for concussion, including the metabolic mismatch, visiovestibular dysfunction, exercise intolerance, and autonomic dysfunction that can occur after injury.
2. Explain how to perform a concussion-specific history and physical examination, and articulate their utility in concussion diagnosis, prognosis, and return to activity recommendations.
3. Identify populations at highest risk for prolonged recovery from pediatric concussion and indications for referral to concussion specialists.
4. Design a rest and graduated return-to-activity strategy that is individualized to a concussed child or adolescent.

From the *Attending Physician, Division of Emergency Medicine, Children's Hospital of Philadelphia; †Attending Physician, Sports Medicine and Performance Center, Children's Hospital of Philadelphia, Philadelphia, PA; and ‡Attending Physician, Departments of Emergency Medicine and Pediatrics, Alpert Medical School of Brown University and Hasbro Children's Hospital, Providence, RI.

The authors, faculty, and staff in a position to control the content of this CME activity and their spouses/life partners (if any) have disclosed that they have no financial relationships with, or financial interest in, any commercial organizations relevant to this educational activity.

Reprints: Daniel Corwin, MD, MSCE, Children's Hospital of Philadelphia, Roberts Center for Pediatric Research, 2716 South St, Philadelphia, PA 19103, 215-590-1959 (e-mail: corwind@chop.edu).

ISSN: 0749-5161

Concussion, a type of mild traumatic brain injury, is a common injury encountered by providers caring for pediatric patients across multiple settings, including the emergency department (ED). Our understanding of the pathophysiologic basis for symptom and recovery trajectories for pediatric concussion continues to evolve rapidly. As this understanding changes, so do recommendations for optimal management of concussed youth. More and more children are presenting to EDs across the country for concussion, making it imperative that providers caring for children in these settings remain up-to-date on diagnostic recommendations and management techniques. This article will review the definition, epidemiology, pathophysiology, diagnosis, and management of pediatric concussion in the ED setting.

DEFINITION AND EPIDEMIOLOGY

Although there are several working definitions of concussion from various expert groups, the most widely accepted definition comes from the International Concussion in Sport Group, which had met every 4 years since 2000 to revise a consensus statement (the most recent meeting, scheduled for the calendar year 2020, was postponed until 2022 because of the coronavirus pandemic). The latest revision occurred in 2016, and defines a concussion as "a traumatic brain injury induced by biomechanical forces," which may include 1 or more the following features: "(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, although symptoms and signs may evolve over a number of minutes to hours; (3) neuropathological changes, although 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 this definition comes from the Concussion in Sport Group, it is important to note that concussions can occur from multiple mechanisms. The majority (approximately two thirds) of pediatric concussions evaluated in the ED are sustained through sport[2,3]; however, other mechanisms of injury, such as falls, road traffic injuries, and assaults, are important contributors to overall injury prevalence. As noted in *Special Populations* section, youth who sustain non–sport-related concussion may receive different care and have different recovery trajectories compared with those who sustain their injuries from sport, and thus warrant special consideration.[2–4]

Given concerns for under-reporting, the true incidence of pediatric concussion is unknown, although estimates from studies using national databases suggest between 1.1 million and 1.9 million sport-related concussions occur each year in children.[5] The incidence of diagnosed concussion rose rapidly in the first decade of the 21st century,[6,7] likely due to a combination of expanded awareness, state laws mandating children be cleared by a health

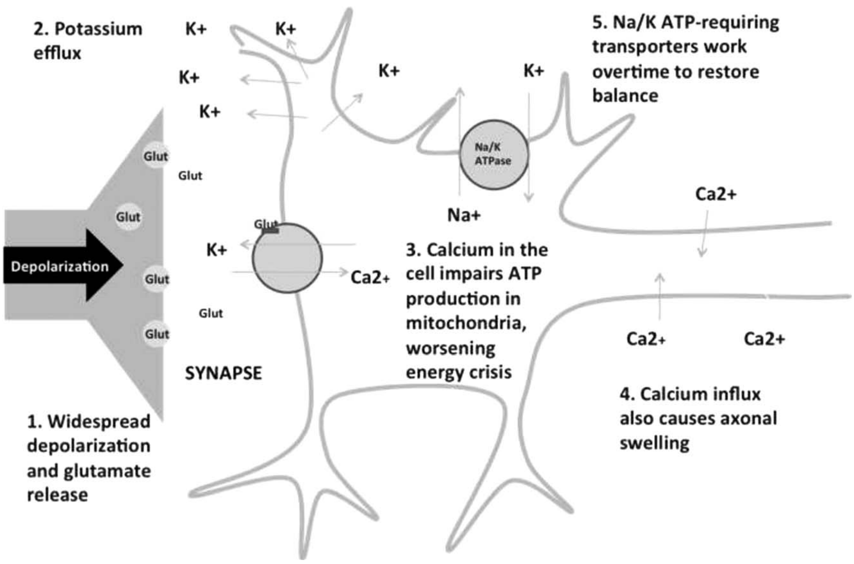

FIGURE 1. Biochemical cascade following concussion (adapted from Corwin DJ, Grady MF, Joffe MD, Zonfrillo MR. Pediatric Mild Traumatic Brain Injury in the Acute Setting. Pediatr Emerg Care. 2017; 33(9):643–649).

professional before resumption of organized sports activity,[8,9] and a possible increase in true incidence. Of ED visits for mild traumatic brain injury in patients of all ages, the highest reported rates occur in patients' aged 12 to 17 years.[10] Large observational studies have found more boys (approximately 60%) present to EDs for concussion in the pediatric population when compared with girls.[11,12]

PATHOPHYSIOLOGY

Several key physiologic changes underlie the clinical manifestations of pediatric concussion. A well-defined metabolic cascade that occurs after a concussion has been well-characterized in both basic science and animal models (see Fig. 1). Rather than due to directly applied forces from trauma, angular acceleration forces result in rotational deformity, leading to mechanical damage to neurons.[13] This is followed by widespread excitatory neurotransmitter release and temporary neuronal dysfunction, requiring increased intracellular energy utilization to restore intracellular balance.[14,15] Despite this increased energy demand, both pediatric and adult studies have shown cerebral blood flow is altered after injury, leading to an energy supply and demand mismatch.[16,17] As a result of injury, both vision and vestibular systems are also impacted after a concussion. The physiologic basis of vision and vestibular dysfunction is likely multifactorial, with contributions from both central (including the basal ganglia, cerebellum, thalamus, and cerebral context) and peripheral disruptions.[18,19] Finally, in addition to peripheral nervous system abnormalities contributing to vestibular dysfunction, autonomic nervous system dysfunction, with dysregulation of the cardiovascular system, appears to play a role in both acute and subacute physiology postinjury.[20–22] Autonomic dysfunction has been hypothesized to underlie several clinical manifestations of concussion, including exercise intolerance.[23] Understanding these various physiologic disturbances after concussion is important for clinicians, as they form the basis for acute concussion evaluation and management recommendations.

ACUTE HISTORY: SIGNS AND SYMPTOMS OF CONCUSSION

Concussion symptoms can be grouped into 4 domains: physical, cognitive, sleep, and emotional (see Table 1).[1,24,25] Physical symptoms can be further classified into somatic (headache, nausea, photophobia, phonophobia) and vestibular (visual problems, dizziness, balance problems, and clumsiness) categories.[26] Cognitive symptoms include difficulty concentrating, difficulty remembering, and feeling mentally slow and foggy. Sleep symptoms include difficulty falling asleep, difficulty staying asleep, and drowsiness. Emotional symptoms include emotional lability, irritability, depression, and anxiety. As more is understood regarding

TABLE 1. Signs and Symptoms of Concussion

Physical Symptoms	Cognitive Symptoms	Emotional Symptoms	Sleep Symptoms
Headache	Difficulty concentrating	Irritability	Sleeping more than normal
Nausea	Difficulty remembering	Anxiety	Sleeping less than normal
Light sensitivity	Feeling foggy	Depression	Difficulty falling asleep
Noise sensitivity	Feeling slowed down	Emotional lability	Drowsiness
Balance problems			
Dizziness			
Vision problems			
Clumsiness			

the pathophysiology of pediatric concussion, distinct phenotypes based on these symptom categories have emerged,[27–29] although any combination of symptoms can be present in any concussed child or adolescent. It is additionally important to note that these symptoms can evolve as recovery progresses, with physical symptoms seeming to present earlier than cognitive, sleep, or emotional symptoms.[24,25] Consensus recommendations for the management of pediatric concussion, including from the American Academy of Pediatrics (AAP) Council on Sports Medicine and Fitness and the Centers for Disease Control and Prevention (CDC), recommend assessing concussion symptoms in a standardized manner.[30,31] Although multiple symptom-based tools are available,[32] regardless of the tool used, systematic evaluation of symptoms has the potential to improve diagnostic accuracy and avoid diagnostic delays.[33]

In addition, during history-taking, it is important to assess comorbidities that may impact concussion recovery. Several populations have been shown to be at risk for prolonged recovery, including those with multiple prior concussions or previous concussions associated with a prolonged recovery, girls, teenagers, those with underlying mood disorders, those with learning disabilities, and those with a history of somatization (see *Special Populations* below).[34,35] A social history should ascertain the patient's current status in school, given the impact of concussion on school reentry.[36] Knowledge of the cognitive demand that will be required of the patient during recovery can be particularly helpful in tailoring anticipatory guidance. This is even more salient given the shift during the coronavirus pandemic to virtual school, leading a diversity of not only cognitive demands but also eye tracking, screen usage, and visual demands among children and adolescents.

PHYSICAL EXAMINATION

In addition to a standard neurologic examination, there are specialized physical examination maneuvers to evaluate for visual and vestibular dysfunction, common abnormalities which, when identified, can be useful both diagnostically and prognostically. Consensus statements recommend assessment of visiovestibular function as part of standard concussion assessment.[1,30,31] Several visiovestibular batteries have been developed, building on the Vestibular/Oculomotor Screening (VOMS) assessment.[18] One version of vestibular testing, the VisioVestibular Examination for Concussion (VVE), is described in Table 2 and Figure 2, and includes 9 test elements: (1) smooth pursuit, (2) horizontal and (3) vertical saccades; (4) horizontal and (5) vertical gaze stability (the angular vestibuloocular reflex), (6) near-point of convergence, (7) right and (8) left monocular accommodation; and (9) complex tandem gait.[37–39] The VVE has been standardized across providers in primary care, emergency medicine, and sports medicine at a large, tertiary-care pediatric institution, and has been shown to be reliable in multiple practice settings.[2,38,40] It takes approximately 3 to 5 minutes to complete, and can be performed in children as young as 6 years.[38] There are multiple benefits to performing visiovestibular testing in the acute setting. The testing is highly diagnostic, as previous work has found that each abnormal element of the 9 subtests of the VVE increases likelihood of a concussion diagnosis by 2.1 times,[38e] and that 10% of youth concussions will report minimal symptoms, but exhibit VVE abnormalities on physical examination.[2] The VOMS assessment was found to have an area under the receiver operating characteristic curve of 0.89 in distinguishing concussed youth from healthy controls.[18] Visiovestibular testing can help improve timeliness of diagnosis, as studies have found those children with more immediate diagnoses in the ED are more likely to have had visiovestibular testing performed as part of their ED care.[33] In addition to its diagnostic value, this specialized examination also has significant prognostic value. Each individual abnormal element of the VVE correlates with prolonged recovery times,[41] as do individual elements of the VOMS[42] and other vestibular testing maneuvers.[19] Finally, vestibular testing has functional implications, as the maneuvers performed mimic the eye tracking and vision demands of children in the school and sports setting. Visiovestibular deficits can impact school reentry, and recognizing these deficits allows the provider to anticipate potential areas of difficulty in the school-aged population. This is important for the acute care provider; as we note in *Management*, given recommendations for early return to light activity, it is possible that some children seen in the ED return to some school activity before a follow-up outpatient appointment occurs.

NEUROIMAGING AND LABORATORY TESTING

The mainstay of diagnosis for concussion remains history and physical examination maneuvers (including visiovestibular testing), and generally should not require neuroimaging. Consensus statements from the AAP, CDC, and International Concussion in Sport Group agree that standard imaging available in the ED setting, via either computed tomography (CT) scan or magnetic resonance imaging (MRI) of the head, does not currently contribute to the diagnosis of concussion.[1,30,31] When the clinician has suspicion for a gross structural intracranial process (such as hemorrhage), there exist multiple decision models to assist decision-making with regard to neuroimaging, with the largest and most widely utilized published by Kuppermann et al[43] in 2009 from the Pediatric Emergency Care Applied Research Network.

Beyond CT and MRI, several additional research imaging modalities have shown to be potentially discriminatory for concussion. Functional MRI (fMRI) and diffusion tensor imaging have shown alterations following concussion, with some findings persisting beyond the timepoint of symptom resolution.[44–46] As the equipment, personnel requirements, and space requirements to perform fMRI testing make it less practical clinically, another modality, functional near-infrared spectroscopy, has emerged as a more portable tool that correlates with fMRI deficits, and has been shown to demonstrate postinjury functional alterations.[47,48] Although currently, the use of these advanced imaging modalities is beyond the scope of the acute care provider's practice, over time they may play a larger role in acute diagnosis and prognostication.

Although standard laboratory testing also plays little role in the acute management of pediatric concussion currently, it is important to note that several blood-based biomarkers have shown promise in both diagnosing concussion and predicting prolonged recoveries. Although a full review of these biomarkers is outside the scope of this article, in the near future, these may play a role in clinical care. These blood-based biomarkers include enzymes such as ubiquitin c-terminal hydrolase-L1,[49] axonal proteins such as neurofilament light,[50] microtubule-associated proteins such as tau,[51] markers of neuronal injury including calpain-derived spectrin n-terminal fragment,[52] and astroglial markers such as glial fibrillary acidic protein.[49,53] Several comprehensive systematic reviews describing these biomarkers in more detail have recently been published.[54,55]

NEUROCOGNITIVE TESTING

Many computerized neurocognitive testing batteries are available for children, obtained with either baseline testing before a sport season or with assessment following a head injury. These are attractive, as they can be completed in a relatively short period of time and provide some objective data beyond symptom self-report. The utility of neurocognitive testing acutely, however, is

TABLE 2. Individual Elements of the VVE for Concussion

Examination Element	How to Perform Element	Abnormal Findings
Smooth pursuit	Examiner's finger moving horizontally, slowly from side to side stopping centrally 5 repetitions Examiner can increase speed to assess symptom provocation with "catch up saccades"	Signs: Right and left eye are not able to move together and stay on the target, jerky/jumpy eye movements (catch up saccades) while tracking slow target, >1 beat of nystagmus at center of visual field Symptom provocation: headache, dizziness, nausea eye fatigue, or eye pain
Fast saccades	Examiner's fingers shoulder-width apart (horizontal) and forehead-chin distance (vertical), patient looks back and forth between targets. 20 repetitions	Signs: inability to coordinate right and left eye to go from target to target, eyes slow because of fatigue with increasing repetitions Symptom provocation: headache, dizziness, eye fatigue, or eye pain
Gaze stability (angular vestibuloocular reflex)	Patient fixes gaze on examiner's thumb while nodding shaking head no side-to-side (horizontal) and then nodding head yes (vertical) *20 repetitions*	Signs: Unable to keep eyes fixed on target with head turning Symptom provocation: headache, dizziness, eye fatigue, or eye pain
Near-point convergence	Patient holds standardized 20/30 card with vertical letters at arm's length, brings toward face until becomes double	Letters become double at >6 cm forehead
Monocular accommodation	Patient holds same standardized card at arm's length with 1 eye covered, brings toward face until becomes blurry Repeat with contralateral eye covered	Rule of thumb: • For children aged 12 y and younger: ≥10 cm • For children aged 13 y and older: ≥12 cm
Complex tandem gait	Tandem heel-toe walk • Forward eyes open • Forward eyes closed • Backward eyes open • Backward eyes closed For 5 steps each	Steps off straight line, raises arms for stability or widens gait, extreme truncal swaying

uncertain. Prior studies have shown that such testing is feasible in an ED setting,[56] and although some studies have shown pediatric concussion patients perform worse on computerized neurocognitive testing when compared with nonconcussed subjects,[57] others have found that scores on neurocognitive testing obtained in the ED are not associated with recovery time.[58] In addition, many acutely concussed children are too symptomatic to complete neurocognitive testing while in the ED. Finally, there can be several factors impacting performance on neurocognitive testing (such as distractions or prior nights' sleep) beyond acute injury.[59] Taken together, these data suggest the most helpful use of neurocognitive testing in the management of concussion is likely in documenting score trends over the duration of recovery, rather than assessment at a single point-in-time in the ED.

MANAGEMENT: REST AND GRADUATED RETURN TO ACTIVITY

After confirming the diagnosis, the most important job of the ED provider caring for a concussed child or adolescent is to provide thorough and individualized anticipatory guidance. As noted in *Follow-up and Referral*, whereas primary care pediatricians and concussion specialists should play an active role in rest and graduated return to activity recommendations, multiple studies have shown that, for many children who are seen in EDs for concussion, the ED provider is their only contact with a medical provider.[60,61] In discussing rest and return-to-activity guidance, providers should keep in mind the pathophysiologic changes that can lead to the exacerbation of the clinical symptoms in concussion, including alterations in cerebral blood flow, metabolic mismatch, and impairment of visiovestibular function.

Based on consensus statements and expert opinion, including from the AAP, CDC, and the Concussion in Sport Group,[1,30,31] the standard of care for treatment of pediatric concussion begins with cognitive and physical rest. Although the optimal duration of rest after concussion remains unclear, current recommendations include a brief period of 24 to 48 hours of relative rest to allow symptoms to decrease, followed by graduated return to activity while avoiding activities that lead to significant symptom provocation or with risk of repeat head injury.[1] Historically, physical and cognitive rest were the sole treatment modality, oftentimes prescribed until symptoms completely resolved. More recently, several studies have demonstrated the potential harm of prolonged rest. Specifically, Thomas et al,[62] in a randomized controlled trial evaluating a group a adolescents and young adults, found that those prescribed 5 days of strict rest had an increased number and a slower resolution of symptoms compared with those prescribed 1 to 2 days of rest followed by graduated return-to-activity. Similarly, Buckley et al[63] randomized 50 college-aged athletes to either strict rest for 48 hours or usual care, finding longer recovery times in the strict rest group. Behind symptom exacerbation, there are psychological consequences of prolonged rest prescriptions. DiFazio et al[64] have described an "activity restriction cascade," where removing a child from validating life activities, paired with physical deconditioning, ultimately worsens symptoms and prolongs recovery.

In addition to recommendations to avoid prolonged rest, there is emerging evidence that early aerobic activity can improve outcomes,[46,65] including data from a randomized controlled trial of adolescent athletes prescribed subthreshold exercise protocols within the first week of injury.[66] Physiologically, given the alterations in cerebral blood flow and autonomic dysfunction that can accompany pediatric concussion, there is a strong evidence base to support prescribed aerobic activity as a treatment for pediatric concussion. Although structured exercise protocols may be out of the scope of practice for an ED provider, a recommendation

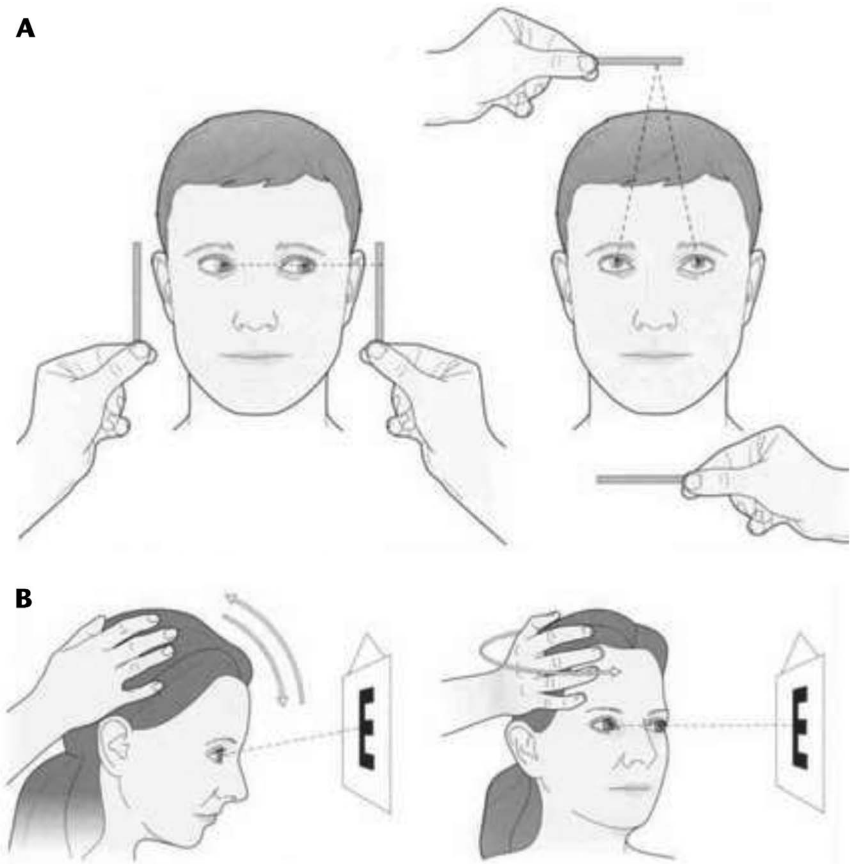

FIGURE 2. Demonstration of saccadic and gaze stability (angular vestibuloocular reflex) testing in the visiovestibular examination concussion (A) To test horizontal saccades, 2 fixed objects (usually the examiner's fingers) are placed shoulder-width apart (horizontal) or forehead-sternal notch distance (vertical), and the patient is asked to look rapidly between them for 20 repetitions. B, To test gaze stability (vestibuloocular reflex), the patient fixes their gaze on a fixed object (often the examiner's thumb) while shaking their head no (horizontal) or nodding their head yes (vertical) for 20 repetitions (adapted with permission, Plant G, Splaton D. Chapter 19: Neuro-ophthalmology. In: Spalton D, Hitchings R, Hunter P. Atlas of Clinical Ophthalmology, 3rd Edition. Elsevier Limited. Oxford, Great Britain. 2005).

of light activity that does not provoke severe symptom exacerbation is certainly appropriate given current evidence.

Although prolonged rest can be harmful, and early, subthreshold aerobic activity can speed recovery, it is important to note that too much activity too soon may also cause severe symptom exacerbation and prolong the recovery process, and providers should be cautious in recommending early return to full activity. First, immediate removal from athletic competition, for those who sustain sport- or recreation-related concussion, is critical, as multiple studies have found continued play following injury lengthens recovery.[67,68] In the acute recovery phase, Brown et al[69] demonstrated that following injury, those in the highest quartile of cognitive activity had a more prolonged recovery (without differences in recovery for those in the lowest, second, and third quartiles), and Silverberg et al[70] showed sharp increases in mental activity lead to an increased risk of symptom spikes (although the symptom spikes themselves were not associated with prolonged recovery). Finally, providers should caution concussed youth that early reentry into high-risk activities that carry the risk of additional head trauma. A second injury, while recovering from the primary injury, can lengthen recovery time, as has been demonstrated in basic science models, animal models, and observational human studies.[71–74]

Given the multiple physical, cognitive, and psychosocial benefits of being present in the school setting, the acute care provider should also discuss "return-to-learn" recommendations, as school reentry is a critical component of pediatric concussion guidance. Considering the pathophysiology of visiovestibular deficits following concussion, and the eye tracking demands required in the classroom (including reading, taking notes, and viewing visual targets close-up), children may require accommodations (such as decreasing reading requirements, providing preprinted class notes, and larger size font texts) to aid return to the school setting. Several return-to-learn guidelines exist for providers to refer to, but it is important to keep in mind that recommendations should be tailored to the individual patient, based on their symptoms and physical signs.[30,31]

MEDICATIONS

In the acute setting, analgesics can potentially provide short-term symptomatic relief, and there is some evidence that patients with features of posttraumatic migraine may benefit from standard ED migraine management (including intravenous therapy with nonsteroidal anti-inflammatory drugs and antiemetics).[75] However, over-the-counter analgesics are not helpful during recovery after discharge from the ED. Specifically, prolonged use of nonsteroidal anti-inflammatory drugs or acetaminophen has the potential to place adolescents at risk for medication overuse headaches following concussion with as little as twice per week use for 2 weeks.[76] Other medications may be used by concussion specialists to manage symptoms, which include amitriptyline to manage persistent posttraumatic headaches,[77] melatonin to manage postinjury sleep disturbances,[78] and amantadine as a potential treatment for prolonged postconcussion cognitive symptoms,[79] although these are unlikely to be prescribed from the ED setting.

SPECIAL POPULATIONS

Numerous studies have shown that certain populations are at risk for a prolonged recovery from concussion, and therefore may benefit from closer follow-up. In addition, results of standardized concussion batteries may differ among these groups, impacting interpretation of results by the acute care provider.

Age

Compared with college-aged athletes and adults, multiple studies have shown children and adolescents have longer recovery times.[80,81] Compared with their younger counterparts, adolescents in particular seem to be at-risk for longer recovery durations.[12,24] Beyond recovery differences, there are other age-related differences to consider in concussion management. Among both concussed and nonconcussed subjects, adolescents and older children are more likely to demonstrate symptom provocation with visiovestibular testing compared with younger children.[26,82] In addition, adolescents without concussion seem to be more prone to report concussion-like symptoms compared with their younger counterparts.[83] Finally, when discussing return-to-activity recommendations, the provider should keep in mind that older teenagers will experience a greater cognitive burden upon return to school compared with younger children.

Sex

Multiple observational studies have shown female children and adolescents may have prolonged recovery times when compared with boys.[24,35] Studies of nonconcussed adolescents have found girls report more concussion-like symptoms when compared with their male peers,[84] and also take longer to return to their baseline following injury.[85] As with age, there are also differences between sexes on visiovestibular testing, with both concussed and nonconcussed girls demonstrating more abnormalities on visiovestibular testing compared with boys.[82,86,87] Interestingly, although biological differences may drive some of these observed clinical findings, the disparities may also be the result of modifiable factors. In a population of children and adolescents aged 7 to 18 years, Desai et al[86] found that, although female subjects generally took longer to recover than male subjects, the differenced disappeared when controlling for time from injury to first specialist visit. In the college-aged population, 2 large-scale studies among athletes have shown no difference in overall time to return to play despite the fact that girls reported greater postinjury symptom burden and took longer than boys to return to academics.[88,89]

Prior Concussions

Many studies have shown that a history of prior concussions is a risk factor for a prolonged recovery.[35,36,90] In addition, a previous concussion associated with prolonged recovery is an independent risk factor for a longer duration of symptoms from the current concussion.[12] These differences extend to neurocognitive testing as well, as those with a prior history of at least 1 concussion perform worse when recovering from a second injury compared with those who have never suffered a prior concussion.[91] As noted in the *Management*, a second injury while recovering from an initial injury has the potential to lead to a more extended recovery time.[74]

Comorbidities: Mood Disorders, Somatization Disorders, and Learning Disabilities

Patients with underlying mood disorders (both anxiety and depression), somatization disorders, and learning disabilities are all at risk for prolonged recovery time.[34,36,92] In addition, children with concussion report significant mood-related symptoms and can develop novel psychiatric diagnoses.[93] Evidence regarding recovery time for children with attention-deficit hyperactivity disorder (ADHD) is less definitive, with some studies finding children with ADHD experiencing prolonged recovery time, and others not.[34,94] Interestingly, ADHD may be a risk factor for sustaining a concussion,[95] as those with ADHD have been found to be overrepresented in cohort samples of concussed youth.[96] In addition to recovery time implications, children with these comorbidities may be more likely to experience difficulty with school reentry, and therefore warrant specialized guidance regarding return-to-learn recommendations.

Non–Sport-Related Injury Mechanisms

As noted in *Definition and Epidemiology*, approximately one third of pediatric concussions are sustained by non–sport-related mechanisms[12,97]; however, the vast majority of research in pediatric concussions to date has focused on children who sustain their injuries via sport and recreation. Emerging evidence has shown that children who suffer concussions from motor vehicle collisions are at higher risk for prolonged recovery times compared with those who sustain their injuries from sport,[3,4] and it is possible that children who sustain concussion from mechanisms such as assault will experience additional psychosocial complications that impact concussion recovery.[98,99] Furthermore, children who are injured from nonsport mechanisms are less likely to receive concussion-specific care when being evaluated in EDs.[2] Acute care providers must pay special attention to these children to ensure that they are adequately screened for concussion, and receive appropriate anticipatory guidance once diagnosed.

FOLLOW-UP AND REFERRAL

As described in *Management*, although initial return-to-activity guidance can and should be provided by the acute care provider, follow-up through recovery is a critical element of pediatric concussion care. Consensus guidelines recommend that follow-up primarily occur through the primary care provider[30,31]; however, there is a role for referral to concussion specialists from the acute setting, particularly for patients already experiencing prolonged symptoms from their current injury. These specialists can help coordinate educational resources and facilitate referral to specialized physical therapists for rehabilitation. Emerging data has shown that, of those children and adolescents who ultimately seek care from concussion specialists, those who do so within the first week after injury have significantly improved recovery times,[86,100,101] suggesting that in the future, there may be a role for early, targeted referral of concussed youth to specialists from the acute setting. The acute care provider should also be aware of the specialized populations mentioned above, given their risk of experiencing prolonged recovery. To assist with prognosis and follow-up recommendations, a risk stratification tool has been developed by the Pediatric Emergency Research Canada Concussion Team. This clinical risk score, derived among a multicenter Canadian ED population, includes points for adolescent age, female sex, prior concussion history, migraine history, answering questions slowly, errors in balance testing, and reported symptoms of headache, sensitivity to noise, and fatigue,[12] and has subsequently been validated in a US population.[102]

CONCLUSIONS

Pediatric concussion is a common reason for presentation to EDs and other acute care settings. It is imperative for acute care providers to have an understanding of the epidemiology and pathophysiology of concussion, an awareness of specialized element of the medical history and physical examination findings, a knowledge of appropriate recommendations for initial relative rest and graduated return-to-activity, and finally, an appreciation of populations at risk for a prolonged recovery that require close follow-up.

REFERENCES

1. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport-the 5th international conference on concussion in sport held in Berlin, October 2016. *Br J Sports Med*. 2017;51:838–847.
2. Corwin DJ, Propert KJ, Zorc JJ, et al. Use of the vestibular and oculomotor examination for concussion in a pediatric emergency department. *Am J Emerg Med*. 2019;37:1219–1223.
3. Lumba-Brown A, Tang K, Yeates KO, et al. Post-concussion symptom burden in children following motor vehicle collisions. *J Am Coll Emerg Physicians Open*. 2020;1:938–946.
4. Seiger A, Goldwater E, Deibert E. Does mechanism of injury play a role in recovery from concussion? *J Head Trauma Rehabil*. 2015;30:E52–E56.
5. Bryan MA, Rowhani-Rahbar A, Comstock RD, et al. Sports- and recreation-related concussions in US youth. *Pediatrics*. 2016; 138:e20154635.
6. TBI-related Emergency Department Visits. Hospitalizations, and Deaths (EDHDs). *CDC Injury Center*. Available at https://www.cdc.gov/traumaticbraininjury/data/tbi-edhd.html. Accessed April 9, 2021.
7. Rosenthal JA, Foraker RE, Collins CL, et al. National high school athlete concussion rates from 2005–2006 to 2011–2012. *Am J Sports Med*. 2014; 42:1710–1715.
8. Baker DR, Kulick ER, Boehme AK, et al. Effects of the New York State Concussion Management and Awareness Act ("Lystedt Law") on Concussion-Related Emergency Health Care Utilization Among Adolescents, 2005–2015. *Am J Sports Med*. 2018;46:396–401.
9. Gibson TB, Herring SA, Kutcher JS, et al. Analyzing the effect of state legislation on health care utilization for children with concussion. *JAMA Pediatr*. 2015;169:163–168.
10. Zonfrillo MR, Kim KH, Arbogast KB. Emergency department visits and head computed tomography utilization for concussion patients from 2006 to 2011. *Acad Emerg Med*. 2015;22:872–877.
11. Arbogast KB, Curry AE, Pfeiffer MR, et al. Point of health care entry for youth with concussion within a large pediatric care network. *JAMA Pediatr*. 2016;170:e160294.
12. Zemek R, Barrowman N, Freedman SB, et al. Clinical risk score for persistent postconcussion symptoms among children with acute concussion in the ED. *JAMA*. 2016;315:1014–1025.
13. Giza CC, Hovda DA. The new neurometabolic cascade of concussion. *Neurosurgery*. 2014;75(0 4):S24–S33.
14. Barkhoudarian G, Hovda DA, Giza CC. The molecular pathophysiology of concussive brain injury—an update. *Phys Med Rehabil Clin N Am*. 2016;27:373–393.
15. Maugans TA, Farley C, Altaye M, et al. Pediatric sports-related concussion produces cerebral blood flow alterations. *Pediatrics*. 2012; 129:28–37.
16. Spain A, Daumas S, Lifshitz J, et al. Mild fluid percussion injury in mice produces evolving selective axonal pathology and cognitive deficits relevant to human brain injury. *J Neurotrauma*. 2010;27:1429–1438.
17. Meier TB, Bellgowan PSF, Singh R, et al. Recovery of cerebral blood flow following sports-related concussion. *JAMA Neurol*. 2015;72:530–538.
18. 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;42:2479–2486.
19. Ellis MJ, Cordingley D, Vis S, et al. Vestibulo-ocular dysfunction in pediatric sports-related concussion. *J Neurosurg Pediatr*. 2015;16:248–255.
20. Esterov D, Greenwald BD. Autonomic dysfunction after mild traumatic brain injury. *Brain Sci*. 2017;7:100.
21. Dobson JL, Yarbrough MB, Perez J, et al. Sport-related concussion induces transient cardiovascular autonomic dysfunction. *Am J Phys Regul Integr Comp Phys*. 2017;312:R575–R584.
22. Goldstein B, Toweill D, Lai S, et al. Uncoupling of the autonomic and cardiovascular systems in acute brain injury. *Am J Phys*. 1998;275: R1287–R1292.
23. Kozlowski KF, Graham J, Leddy JJ, et al. Exercise intolerance in individuals with postconcussion syndrome. *J Athl Train*. 2013;48:627–635.
24. Eisenberg MA, Andrea J, Meehan W, et al. Time interval between concussions and symptom duration. *Pediatrics*. 2013;132:8–17.
25. Blinman TA, Houseknecht E, Snyder C, et al. Postconcussive symptoms in hospitalized pediatric patients after mild traumatic brain injury. *J Pediatr Surg*. 2009;44:1223–1228.
26. Master CL, Curry AE, Pfeiffer MR, et al. Characteristics of concussion in elementary school-aged children: implications for clinical management. *J Pediatr*. 2020;223:128–135.
27. Craton N, Ali H, Lenoski S. COACH CV: The Seven Clinical Phenotypes of Concussion. *Brain Sci*. 2017;7:119.
28. Yeates KO, Tang K, Barrowman N, et al. Derivation and initial validation of clinical phenotypes of children presenting with concussion acutely in the emergency department: latent class analysis of a multi-center, prospective cohort, observational study. *J Neurotrauma*. 2019;36:1758–1767.
29. Maruta J, Lumba-Brown A, Ghajar J. Concussion subtype identification with the Rivermead Post-concussion Symptoms Questionnaire. *Front Neurol*. 2018;9:1034.
30. Halstead ME, Walter KD, Moffatt K. Sport-related concussion in children and adolescents. *Pediatrics*. 2018;142:e20183074.
31. Lumba-Brown A, Yeates KO, Sarmiento K, et al. Centers for Disease Control and Prevention Guideline on the diagnosis and management of mild traumatic brain injury among children. *JAMA Pediatr*. 2018; 172:1–13.
32. Sady MD, Vaughan CG, Gioia GA. Psychometric characteristics of the postconcussion symptom inventory in children and adolescents. *Arch Clin Neuropsychol*. 2014;29:348–363.
33. Corwin DJ, Arbogast KB, Haber RA, et al. Characteristics and outcomes for delayed diagnosis of concussion in pediatric patients presenting to the emergency department. *J Emerg Med*. 2020;59:795–804.
34. Morgan CD, Zuckerman SL, Lee YM, et al. Predictors of postconcussion syndrome after sports-related concussion in young athletes: a matched case-control study. *J Neurosurg Pediatr*. 2015;15:589–598.
35. Miller JH, Gill C, Kuhn EN, et al. Predictors of delayed recovery following pediatric sports-related concussion: a case-control study. *J Neurosurg Pediatr*. 2016;17:491–496.
36. Corwin DJ, Zonfrillo MR, Master CL, et al. Characteristics of prolonged concussion recovery in a pediatric subspecialty referral population. *J Pediatr*. 2014;165:1207–1215.
37. Corwin DJ, Wiebe DJ, Zonfrillo MR, et al. Vestibular deficits following youth concussion. *J Pediatr*. 2015;166:1221–1225.
38. Corwin DJ, Arbogast KB, Swann C, et al. Reliability of the visio-vestibular examination for concussion among providers in a pediatric emergency department. *Am J Emerg Med*. 2020;38:1847–1853.

39. Master CL, Scheiman M, Gallaway M, et al. Vision diagnoses are common after concussion in adolescents. *Clin Pediatr (Phila)*. 2016; 55:260–267.

40. Arbogast KB, Curry AE, Metzger KB, et al. Improving primary care provider practices in youth concussion management. *Clin Pediatr (Phila)*. 2017;56:854–865.

41. Master CL, Master SR, Wiebe DJ, et al. Vision and vestibular system dysfunction predicts prolonged concussion recovery in children. *Clin J Sport Med*. 2018;28:139–145.

42. Anzalone AJ, Blueitt D, Case T, et al. A positive vestibular/ocular motor screening (VOMS) is associated with increased recovery time after sports-related concussion in youth and adolescent athletes. *Am J Sports Med*. 2017;45:474–479.

43. Kuppermann N, Holmes JF, Dayan PS, et al. Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. *Lancet*. 2009;374:1160–1170.

44. Schmidt J, Hayward KS, Brown KE, et al. Imaging in pediatric concussion: a systematic review. *Pediatrics*. 2018;141:e20173406.

45. Johnson B, Hallett M, Slobounov S. Follow-up evaluation of oculomotor performance with fMRI in the subacute phase of concussion. *Neurology*. 2015;85:1163–1166.

46. Leddy JJ, Cox JL, Baker JG, et al. Exercise treatment for postconcussion syndrome: a pilot study of changes in functional magnetic resonance imaging activation, physiology, and symptoms. *J Head Trauma Rehabil*. 2013;28:241–249.

47. Urban KJ, Barlow KM, Jimenez JJ, et al. Functional near-infrared spectroscopy reveals reduced interhemispheric cortical communication after pediatric concussion. *J Neurotrauma*. 2015;32:833–840.

48. Kontos AP, Huppert TJ, Beluk NH, et al. Brain activation during neurocognitive testing using functional near-infrared spectroscopy in patients following concussion compared to healthy controls. *Brain Imaging Behav*. 2014;8:621–634.

49. Papa L, Zonfrillo MR, Welch RD, et al. Evaluating glial and neuronal blood biomarkers GFAP and UCH-L1 as gradients of brain injury in concussive, subconcussive and non-concussive trauma: a prospective cohort study. *BMJ Paediatr Open*. 2019;3:e000473.

50. McDonald SJ, dien WT, Symons GF, et al. Prolonged elevation of serum neurofilament light after concussion in male Australian football players. *Biomark Res*. 2021;9:4.

51. Gill J, Merchant-Borna K, Jeromin A, et al. Acute plasma tau relates to prolonged return to play after concussion. *Neurology*. 2017;88:595–602.

52. Siman R, Cui H, Wewerka SS, et al. Serum SNTF, a surrogate marker of axonal injury, is prognostic for lasting brain dysfunction in mild TBI treated in the emergency department. *Front Neurol*. 2020;11:249.

53. Mannix R, Eisenberg M, Berry M, et al. Serum biomarkers predict acute symptom burden in children after concussion: a preliminary study. *J Neurotrauma*. 2014;31:1072–1075.

54. Mannix R, Levy R, Zemek R, et al. Fluid biomarkers of pediatric mild traumatic brain injury: a systematic review. *J Neurotrauma*. 2020; 37:2029–2044.

55. Papa L, Ramia MM, Edwards D, et al. Systematic review of clinical studies examining biomarkers of brain injury in athletes after sports-related concussion. *J Neurotrauma*. 2015;32:661–673.

56. Brooks BL, Khan S, Daya H, et al. Neurocognition in the emergency department after a mild traumatic brain injury in youth. *J Neurotrauma*. 2014;31:1744–1749.

57. Nance ML, Callahan JM, Tharakan SJ, et al. Utility of neurocognitive testing of mild traumatic brain injury in children treated and released from the emergency department. *Brain Inj*. 2016;30:184–190.

58. Hang B, Babcock L, Hornung R, et al. Can computerized neuropsychological testing in the emergency department predict recovery for young athletes with concussions? *Pediatr Emerg Care*. 2015;31: 688–693.

59. McClure DJ, Zuckerman SL, Kutscher SJ, et al. Baseline neurocognitive testing in sports-related concussions: the importance of a prior night's sleep. *Am J Sports Med*. 2014;42:472–478.

60. Seabury SA, Gaudette É, Goldman DP, et al. Assessment of follow-up care after emergency department presentation for mild traumatic brain injury and concussion: results from the TRACK-TBI study. *JAMA Netw Open*. 2018;18:e180210.

61. Grubenhoff JA, Deakyne SJ, Comstock RD, et al. Outpatient follow-up and return to school after emergency department evaluation among children with persistent post-concussion symptoms. *Brain Inj*. 2015; 29:1186–1191.

62. Thomas DG, Apps JN, Hoffmann RG, et al. Benefits of strict rest after acute concussion: a randomized controlled trial. *Pediatrics*. 2015;135: 213–223.

63. Buckley TA, Munkasy BA, Clouse BP. Acute cognitive and physical rest may not improve concussion recovery time. *J Head Trauma Rehabil*. 2016;31:233–241.

64. DiFazio M, Silverberg ND, Kirkwood MW, et al. Prolonged activity restriction after concussion: are we worsening outcomes? *Clin Pediatr (Phila)*. 2015;55:443–451.

65. Lawrence DW, Richards D, Comper P, et al. Earlier time to aerobic exercise is associated with faster recovery following acute sport concussion. *PLoS One*. 2018;13:e0196062.

66. Leddy JJ, Haider MN, Ellis MJ, et al. Early subthreshold aerobic exercise for sport-related concussion: a randomized clinical trial. *JAMA Pediatr*. 2019;173:319–325.

67. Elbin RJ, Sufrinko A, Schatz P, et al. Removal from play after concussion and recovery time. *Pediatrics*. 2016;138:e20160910.

68. Charek DB, Elbin RJ, Sufrinko A, et al. Preliminary evidence of a dose-response for continuing to play on recovery time after concussion. *J Head Trauma Rehabil*. 2020;35:85–91.

69. Brown NJ, Mannix RC, O'Brien MJ, et al. Effect of cognitive activity level on duration of post-concussion symptoms. *Pediatrics*. 2014;133:e299–e304.

70. Silverberg ND, Iverson GL, McCrea M, et al. Activity-related symptom exacerbations after pediatric concussion. *JAMA Pediatr*. 2016;170:946–953.

71. Meehan WP, Zhang J, Mannix R, et al. Increasing recovery time between injuries improves cognitive outcome after repetitive mild concussive brain injuries in mice. *Neurosurgery*. 2012;71:885–891.

72. Mannix R, Meehan WP, Mandeville J, et al. Clinical correlates in an experimental model of repetitive mild brain injury. *Ann Neurol*. 2013; 74:65–75.

73. Prins ML, Alexander D, Giza CC, et al. Repeated mild traumatic brain injury: mechanisms of cerebral vulnerability. *J Neurotrauma*. 2013; 30:30–38.

74. Terwilliger VK, Pratson L, Vaughan CG, et al. Additional post-concussion impact exposure may affect recovery in adolescent athletes. *J Neurotrauma*. 2016;33:761–765.

75. Chan S, Kurowski B, Byczkowski T, et al. Intravenous migraine therapy in children with posttraumatic headache in the ED. *Am J Emerg Med*. 2015; 33:635–639.

76. Heyer GL, Idris SA. Does analgesic overuse contribute to chronic post-traumatic headaches in adolescent concussion patients? *Pediatr Neurol*. 2014;50:464–468.

77. Bramley H, Heverley S, Lewis MM, et al. Demographics and treatment of adolescent posttraumatic headache in a regional concussion clinic. *Pediatr Neurol*. 2015;52:493–498.

78. Barlow KM, Kirk V, Brooks B, et al. Efficacy of melatonin for sleep disturbance in children with persistent post-concussion symptoms: secondary analysis of a randomized controlled trial. *J Neurotrauma*. 2021; 38:950–959.

79. Reddy CC, Collins M, Lovell M, et al. Efficacy of amantadine treatment on symptoms and neurocognitive performance among adolescents following sports-related concussion. *J Head Trauma Rehabil*. 2013;28:260–265.
80. Field M, Collins MW, Lovell MR, et al. Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *J Pediatr*. 2003;142:546–553.
81. Sim A, Terryberry-Spohr L, Wilson KR. Prolonged recovery of memory functioning after mild traumatic brain injury in adolescent athletes. *J Neurosurg*. 2008;108:511–516.
82. Corwin DJ, Zonfrillo MR, Wiebe DJ, et al. Vestibular and oculomotor findings in neurologically-normal, non-concussed children. *Brain Inj*. 2018;32:794–799.
83. Hunt AW, Paniccia M, Reed N, et al. Concussion-like symptoms in child and youth athletes at baseline: What is "typical"? *J Athl Train*. 2016;51: 749–757.
84. Iverson GL, Silverberg ND, Mannix R, et al. Factors associated with concussion-like symptom reporting in high school athletes. *JAMA Pediatr*. 2015;169:1132–1140.
85. Zuckerman SL, Apple RP, Odom MJ, et al. Effect of sex on symptoms and return to baseline in sport-related concussion. *J Neurosurg Pediatr*. 2014; 13:72–81.
86. Desai N, Wiebe DJ, Corwin DJ, et al. Factors affecting recovery trajectories in pediatric female concussion. *Clin J Sport Med*. 2019;29:361–367.
87. Sufrinko AM, Mucha A, Covassin T, et al. Sex differences in vestibular/ocular and neurocognitive outcomes after sport-related concussion. *Clin J Sport Med*. 2017;27:133–138.
88. Master CL, Katz BP, Arbogast KB, et al. Differences in sport-related concussion for female and male athletes in comparable collegiate sports: a study from the NCAA-DoD Concussion Assessment, Research and Education (CARE) Consortium. *Br J Sports Med*. 2020; Online ahead of print.
89. Bretzin AC, Esopenko C, D'Alonzo BA, et al. Clinical recovery timelines following sport-related concussion in men's and women's collegiate sports. *J Athl Train*. 2021; [Online ahead of print].
90. Thomas DJ, Coxe K, Li H, et al. Length of recovery from sports-related concussions in pediatric patients treated at concussion clinics. *Clin J Sport Med*. 2017;28:56–63.
91. Colvin AC, Mullen J, Lovell MR, et al. The role of concussion history and gender in recovery from soccer-related concussion. *Am J Sports Med*. 2009;37:1699–1704.
92. Root JM, Zuckerbraun NS, Wang L, et al. History of somatization is associated with prolonged recovery from concussion. *J Pediatr*. 2016;174: 39–44.e1.
93. Ellis MJ, Ritchie LJ, Koltek M, et al. Psychiatric outcomes after pediatric sports-related concussion. *J Neurosurg Pediatr*. 2015;16:709–718.
94. Cook NE, Iverson GL, Maxwell B, et al. Adolescents with ADHD do not take longer to recover from concussion. *Front Pediatr*. 2021;8:606879.
95. Biederman J, Feinberg L, Chan J, et al. Mild traumatic brain injury and attention-deficit hyperactivity disorder in young student athletes. *J Nerv Ment Dis*. 2015;203:813–819.
96. Iaccarino MA, Fitzgerald M, Pulli A, et al. Sport concussion and attention deficit hyperactivity disorder in student athletes: a cohort study. *Neurol Clin Pract*. 2018;8:403–411.
97. Haarbauer-Krupa J, Arbogast KB, Metzger KB, et al. Variations in mechanisms of injury for children with concussion. *J Pediatr*. 2018;197: 241–248.e1.
98. Meiser-Stedman R, Yule W, Smith P, et al. Acute stress disorder and posttraumatic stress disorder in children and adolescents involved in assaults or motor vehicle accidents. *Am J Psychiatry*. 2005;162: 1381–1383.
99. Trickey D, Siddaway AP, Meiser-Stedman R, et al. A meta-analysis of risk factors for post-traumatic stress disorder in children and adolescents. *Clin Psychol Rev*. 2012;32:122–138.
100. Kontos AP, Jorgensen-Wagers K, Trbovich AM, et al. Association of time since injury to the first clinic visit with recovery following concussion. *JAMA Neurol*. 2020;77:435–440.
101. Pratile T, Marshall C, DeMatteo C. Examining how time from sport-related concussion to initial assessment predicts return-to-play clearance. *Phys Sportsmed*. 2021;1–9. Online ahead of print.
102. Howell DR, Zemek R, Brilliant AN, et al. Identifying persistent postconcussion symptom risk in a pediatric sports medicine clinic. *Am J Sports Med*. 2018;46:3254–3261.