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Postconcussion Syndrome: A Review

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Abstract

Postconcussion syndrome is a symptom complex with a wide range of somatic, cognitive, sleep, and affective features, and is the most common consequence of traumatic brain injury. Between 14% and 29% of children with mild traumatic brain injury will continue to have postconcussion symptoms at 3 months, but the pathophysiological mechanisms driving this is poorly understood. The relative contribution of injury factors to postconcussion syndrome decreases over time and, instead, premorbid factors become important predictors of symptom persistence by 3 to 6 months postinjury. The differential diagnoses include headache disorder, cervical injury, anxiety, depression, somatization, vestibular dysfunction, and visual dysfunction. The long-term outcome for most children is good, although there is significant morbidity in the short term. Management strategies target problematic symptoms such as headaches, sleep and mood disturbances, and cognitive complaints.

Keywords

mild traumatic brain injury, children, pathophysiology, outcome, management

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One in 7 children will have postconcussion syndrome for 3 months or longer after a mild traumatic brain injury.[1] Postconcussion syndrome is a symptom complex with a wide range of somatic, cognitive, sleep, and affective features and is the most common consequence of traumatic brain injury.[2,3] It is a significant public health concern as up to 1 in 5 children will sustain a traumatic brain injury by the age of 16 years.[4] Postconcussion syndrome is associated with significant disability in the child and his or her family, and yet there are few evidence-based medical treatments available.[5-8] Substantial controversy exists because of a lack of consensus regarding diagnostic criteria, symptoms that are common in normal populations, the contribution of sociological, psychological, and medicolegal factors to outcomes and, until recently, a failure to identify any abnormal pathophysiology.[9] This review will focus on pediatric postconcussion syndrome, what is known about its neurobiological underpinnings, and then highlight the clinical features, differential diagnoses and atypical presentations, and finally provide some strategies for the treatment of this complex disorder.

Diagnostic Criteria

There are 2 commonly used sets of diagnostic criteria for postconcussion syndrome, and both are usually modified to suit clinical practice.

- The International Classification of Diseases–10th Edition defines postconcussion syndrome as a condition that occurs in the setting of a history of traumatic brain injury and with 3 or more of the following 8 symptoms: headache, dizziness, fatigue, irritability, insomnia, difficulty concentrating, memory problems, and/or intolerance of stress, emotion, or alcohol. The International Classification of Diseases–10th Edition lacks "mood disturbance" as a symptom, does not specify a minimum length of symptom presence, and can begin any time within 1 month of the injury. The latter makes it difficult to apply causality.
- The *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition*, has very specific diagnostic criteria: (*a*) a history of traumatic brain injury; (*b*) evidence from neurobehavioral testing of cognitive deficits in attention and/or memory; (*c*) 3 or more of the following symptoms that appear after injury and persist for *3 months or more*: fatigue, headaches, dizziness, sleep disturbance, irritability, apathy or affective disturbance, or personality changes; (*d*) the symptoms in (*b*) and (*c*) begin or worsen after injury; (*e*) interference with social or occupational functioning; and (*f*) are not better explained by other mental disorders. The

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Table 1. Postconcussion Symptoms at 1 Month Postinjury in Symptomatic Children With Mild Traumatic Brain Injury and Extracranial Injury.[a]

Postconcussion symptom	Mild traumatic brain injury (n = 138)	Extracranial injury (n = 49)	Odds ratio (95% CI)	*P* value
Headaches	43.4*	16.3	3.9 (1.7-9.0)	.001
Dizziness	24.6*	10.2	2.88 (1.05-7.86)	.033
Fatigue	42.8*	18.4	3.32 (1.49-7.37)	.002
Irritability	47.4*	20.4	3.52 (1.63-7.62)	.001
Difficulty falling asleep	35	20.4	2.10 (0.97-4.58)	.058
More emotional	40.9*	12.2	4.96 (1.98-12.42)	.001
Concentration difficulties	31.3*	1.2	3.26 (1.28-8.28)	.010
Memory problems	28.2*	10.2	3.44 (1.26-9.38)	.011
Mood disturbance	33.3*	14.3	3.0 (1.25-7.20)	.011

[a]Groups differed in all of the symptoms except in sleep dysfunction.
*$P < .05$.

symptom onset must be contiguous with traumatic brain injury, distinguishable from preexisting conditions, and be of a minimum 3 months' duration. In practice, the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition* is usually modified as most physicians do not have access to neurobehavioral testing, and in any case standard neuropsychological tests are usually normal by 3 months postinjury even though patients continue to complain of cognitive deficits.[10,11] The International Classification of Diseases–10th Edition criteria result in 5 to 6 times the incidence rates of postconcussion syndrome than when the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition*, criteria are used.[11,12]

Postconcussion syndrome criteria have not been validated in children. We investigated the accuracy of a modified version of the International Classification of Diseases–10th Edition and *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition*, postconcussion syndrome criteria in a cohort of children with persistent symptoms following a mild traumatic brain injury. This longitudinal controlled cohort study has been reported previously and follows the outcome of children attending the emergency department.[1] A total of 350 children following mild traumatic brain injury were symptomatic at 1 month, 52% (95% CI: 54.8-62.2) in comparison to 38.5% (95% CI: 31.7-45.3) of extracranial injury controls. The postconcussion syndrome diagnostic criteria were evaluated by comparing symptom endorsement rates in symptomatic children with mild traumatic brain injury to those symptomatic children with extracranial injury at 1 month (KM Barlow, Personal communication, March 2014). The following criteria were used: (*a*) mild traumatic brain injury with symptom onset within 7 days of injury; (*b*) any of the following 9 symptoms: headache, dizziness, fatigue, irritability, insomnia, difficulty concentrating, memory problems, emotional labiality, and mood disturbance; and (*c*) persistent symptoms at 4 weeks postinjury (as clinically individuals become concerned when symptoms persistent beyond 4 weeks).

Mild traumatic brain injury and extracranial injury groups were comparable in age, sex, and family income although the injury severity was greater in the extracranial injury group ($P < .001$). All symptoms in this cohort began within 72 hours of the injury. Mild traumatic brain injury and extracranial injury groups differed in all of the symptoms at 1 month postinjury except in sleep dysfunction (Table 1). Receiver operating curve analysis using *all* symptoms revealed that the modified postconcussion syndrome symptoms significantly classified the mild traumatic brain injury and control participants into their respective groups at 1 month postinjury; the area under the curve was 0.889 ($P < .001$, SE 0.029; see Figure 1). The quality of the receiver operating curve can be therefore classified as good.[13] Postconcussion syndrome is likely to be present in a child with mild traumatic brain injury if 3 of these 9 symptoms are present, with a positive predictive value of 86.7% and negative predictive value of 79.6%.

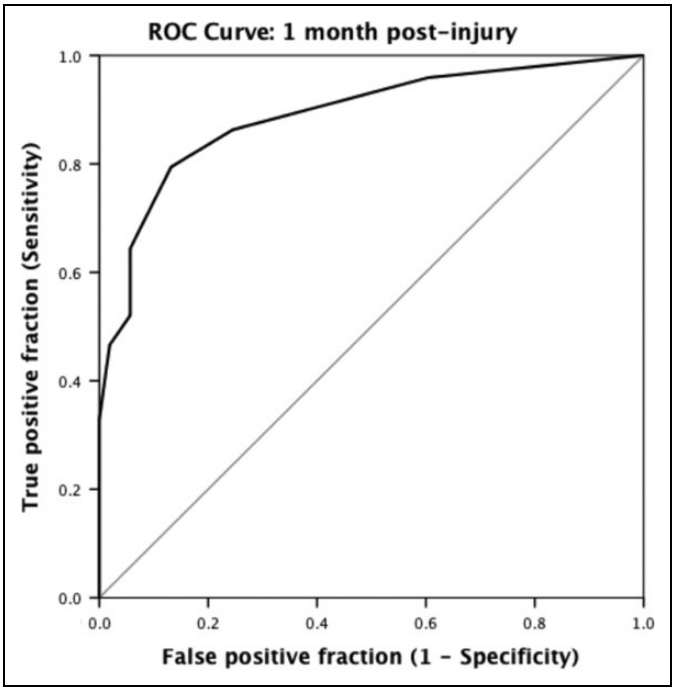

Figure 1. Receiver operating curve obtained at 1 month postinjury.

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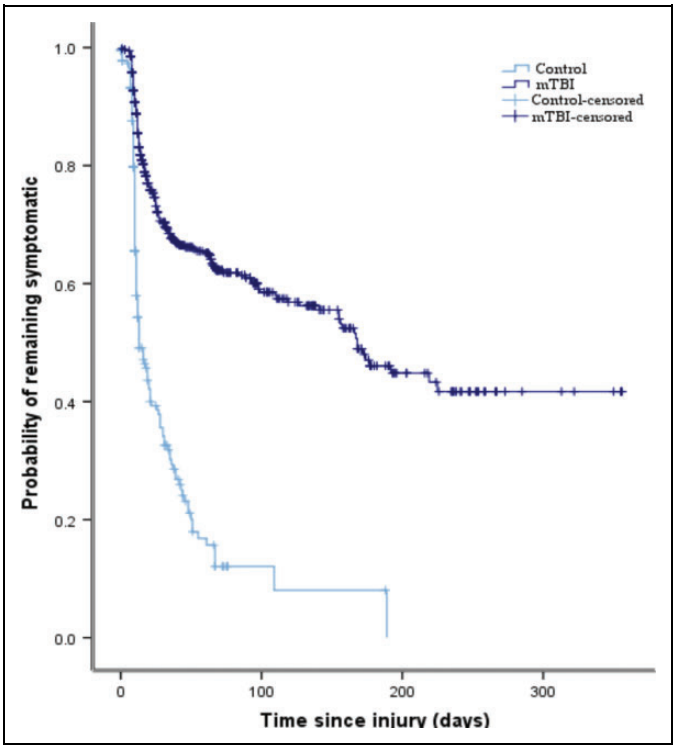

Figure 2. Survival curves demonstrating persistence of symptoms in children (age 0-18 years) with mild traumatic brain injury compared with children with extracranial injuries (log rank [Mantel-Cox] = 11.15; $P < .001$).[1]

A proposed pediatric definition of *postconcussion syndrome following mild traumatic brain injury* is (*a*) a history of mild traumatic brain injury with an onset of symptoms or signs within 72 hours of the injury, (*b*) the presence of at least 3 of the following symptoms: headache, dizziness, fatigue, irritability, insomnia, difficulty concentrating, memory problems, emotional labiality, and mood disturbance, (*c*) symptoms have been present for at least 4 weeks postinjury, and (*d*) symptoms are not better explained by another disorder.

Epidemiology of Postconcussion Syndrome

The incidence of postconcussion syndrome varies according to diagnostic criteria used, time postinjury, age, injury severity, presence of assault, and the population studied. The 2 main populations reported in the literature are emergency department and sport-related concussion cohorts, which are likely to have inherent differences. The emergency department cohorts include both sport-related and non-sport-related concussion.

- Postconcussion syndrome rates at 1 month postinjury vary between 24.5% and 52.5% in the emergency department population follow-up cohorts.[1,14] Symptom survival decays exponentially (Figure 2).
- At 3 months postinjury, 11% of all children and 13.7% to 29.3% of school-aged children remain symptomatic.[1,15] Symptoms gradually resolve but a small percentage of children, 2.3%, continue to be symptomatic at 1 year.[1,16]

Falls and recreational and sports-related accidents are the most common cause of injury.[1,15] Assault and motor-vehicle-related trauma are less common, accounting for less than 5% of injuries, but are an important cause of mild traumatic brain injury because of frequent associations with persistent postconcussion syndrome.

Predictors of Recovery

Many factors are important contributors to symptom persistence including injury severity, previous traumatic brain injury, premorbid sociological and psychological factors, as well as the presence of medicolegal issues (eg, litigation, assault). The role of repeated injuries in recovery is under investigation and is of particular relevance in sport-related concussion. National sport organizations are placing increasing importance on stressing full recovery before returning to play, and the implementation of strategies to prevent concussion in at-risk populations. Improvements in methodologies have enabled researchers to gain a better understanding of these factors at various time points in recovery.[17,18]

- *Injury severity:* Injury severity is a significant factor in predicting *acute* outcomes following mild traumatic brain injury, that is, 1 to 3 months postinjury in emergency department cohorts.[1,18-20] These factors include loss of consciousness, amnesia, admission to hospital, degree of the acute symptoms, and the presence of other injuries.[1,15,18,21] Teenagers are more likely than younger children or adults to develop postconcussion syndrome.[1,15] Although there is evidence to suggest that adult females are more likely to develop postconcussion syndrome,[22-26] female children and adolescents do not differ in their likelihood to have persistent symptoms, especially when premorbid factors and preinjury symptoms are taken into account.[1,21,27,28] However, further studies addressing the role of gender in recovery are still ongoing.[1,15]
- *Genetic factors:* Genetic factors have not been associated in children with prolonged outcomes, for example, apolipoprotein E rare alleles, serotonin receptor alleles HTR1A C(-1019)G.[29-31] There is some evidence that rare ApoE genotypes do influence the outcome following adult mild traumatic brain injury.[30,32,33]
- *Premorbid factors:* The relative contribution of injury factors to postconcussion syndrome decreases over time and premorbid factors become important predictors of symptom persistence.[18,34,35] After 3 to 6 months postinjury, premorbid child and family factors such as school difficulties, parental preinjury anxiety, coping strategies, adverse life events, and stressors make increasing contributions to persistent postconcussion syndrome, and injury-related factors are less important.[18,31,36] Children

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with lower IQs and premorbid learning difficulties such as attention-deficit disorder are more likely to be injured and are prone to postconcussion syndrome, perhaps because of differences in cognitive reserve capacity.[37] Thus, when evaluating and treating children with persistent postconcussion syndrome, clinicians should pay close attention to factors that may elicit symptoms for reasons other than an underlying brain injury.[38]

Controversies

Postconcussion syndrome has been a highly debated and questioned entity for several reasons, including absence of symptom specificity, premorbid influences on outcome, recall bias, and the influence of psychosocial factors. The symptoms are not specific to postconcussion syndrome alone but are present in normal and disease populations (eg, depression, chronic pain, and anxiety),[39-41] and involvement with litigation also influences symptom report.[42,43] When this is combined with the absence of an objective diagnostic test (at least in the chronic state), many begin to question the validity of postconcussion syndrome as a diagnosis. Furthermore, the cognitive and behavioral symptoms are often not prominent complaints acutely after injury but emerge between 1 and 3 months postinjury, perhaps perpetuating the misperception that the whole condition is solely due to a mood disturbance.[9,44,45]

A recall bias, known as the ''good old days'' bias, is a phenomenon seen in the normal and pathologic states and is the tendency to underreport the degree and severity of baseline symptoms over time.[46,47] We examined the effects of this phenomenon prospectively in 412 children with mild traumatic brain injury.[35] Parent and child ratings of premorbid symptoms were provided in the emergency department (parent only), and at 1 and 3 months postinjury (parent and child). Parental ratings of premorbid symptoms decreased by 80% from the emergency department to 1 month postinjury ($P < .001$) but were stable from 1 to 3 months postinjury ($P < .05$). Adolescents' premorbid ratings also declined from 1 to 3 months postinjury. Slow recovery did not have a differential impact on premorbid reporting over this period. This demonstrates that the ''good old days'' bias is relevant in pediatric mild traumatic brain injury and is potentially making significant contributions to reported outcomes by 1 month postinjury. Further research is necessary to investigate this and whether attempts to mitigate this bias may decrease parent and child anxiety concerning their ongoing symptoms and perception of brain injury.

Pathophysiology

A brain injury in childhood occurs at a maximal time of brain development. Children and adolescents are more susceptible to trauma.[4] Children's brains have different mechanical and compositional properties (eg, increased water content, decreased myelin, and increased translation of acceleration-deceleration forces due to decreased neck strength), which results in an increased potential for shear injury and brain tissue displacement during trauma. An injury during a period of critical brain maturation (eg, myelination, dendritic arborization, synaptic refinement) is more likely to alter and impair outcome. Children probably also have different pathophysiologic responses to a concussion.[48-50] Although the pathophysiology of mild traumatic brain injury is well described, the explanations for prolonged postconcussion syndrome in children were lacking until recent advances in neuroimaging.[50,51] The pathophysiological literature reviewed subsequently focuses on that pertaining to persistent symptoms in children and adolescents.

There are relatively few neuroimaging studies to provide insight into the pathophysiology of *postconcussion syndrome* in children. Conventional magnetic resonance imaging is usually normal (80%-90% of magnetic resonance imaging in acute mild traumatic brain injury) and rarely influences acute management but nearly all standard magnetic resonance images are normal in postconcussion syndrome following an uncomplicated mild traumatic brain injury. The use of special sequences increases the likelihood of detecting abnormality, for example, susceptibility weighted imaging, diffusion tensor imaging, functional magnetic resonance imaging.[52]

- Diffusion tensor imaging is sensitive to detecting changes in white matter tracts although the findings are variable. Diffusion tensor imaging abnormalities may correlate with postconcussion syndrome symptoms and cognitive outcome,[53,54] although not all studies report this finding.[55] The anatomic areas of abnormality vary; common sites of abnormalities are in the corpus callosum, frontal white matter, and internal capsule.[56-58]
- Functional magnetic resonance imaging also provides some useful information. Adult athletes with postconcussion syndrome and higher ratings of mood disturbance showed reduced activation in the dorsolateral prefrontal cortex and striatum, and attenuated deactivation in medial frontal and temporal regions similar to individuals with a major depression.[59] In children and young adults, working memory or spatial memory tasks are associated with increased activation of multiple cortical networks, even though the performance on the task is similar to controls.[60-62] This suggests that other brain networks are recruited in order to perform the task, that is, decreased efficiency. This may be why children with postconcussion syndrome are so fatigued after a full day of school and complain that it is harder to perform cognitive tasks.

A state of decreased brain energy is another potential mechanism that could explain the discordance between the lack of abnormality on conventional imaging and the extent of neurocognitive complaints in postconcussion syndrome. There has been much interest in the use of *N*-acetylaspartate as a surrogate marker for brain energy state.[63] In a promising

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study by Vagnozzi et al,[48] *N*-acetylaspartate levels were decreased at 72 hours and did not reach normal values until 30 days postinjury in all athletes, suggesting that the brain was in a state of energy depletion (perhaps because of mitochondrial dysfunction). The explanation is likely to be more complex, however, as *N*-acetylaspartate levels in subsequent studies have been variable, ranging from persistently decreased levels, decreasing levels during the season in women hockey athletes, and normal levels in adolescents.[49,56,64]

Cerebral blood flow and cerebral autoregulation is frequently altered in traumatic brain injury (usually severe forms), and disturbed autoregulation is more likely to occur in children and is a potential contributor to persistent symptoms. Maugans et al[49] found significant alterations in cerebral blood flow in mild traumatic brain injury, and interestingly 36% of children still had abnormal cerebral blood flow values at 30 days postinjury. Cerebrovascular reactivity is altered in young adult mild traumatic brain injury, especially with exercise, but this resolves very quickly (usually by 4 days).[65,66] Although it is unlikely that autoregulation alone explains postconcussion syndrome, impairments of the cerebral vasculature may increase cerebral sensitivity to common activities, for example, decreases in blood pressure with neurogenic syncope or dehydration, and increases in intracranial pressure associated with straining, weight lifting, and strenuous exercise.

Transcranial magnetic stimulation can measure discrete cortical functional areas, offering noninvasive, painless mapping of motor systems. Advanced paradigms can now explore real-time intracortical physiology in mild traumatic brain injury, particularly GABAergic systems.[67-69] Although none have been conducted in children, a few studies have used transcranial magnetic stimulation to demonstrate acute and long-term dysfunction in the primary motor cortex neurophysiology in adult mild traumatic brain injury.[69-71] A prolonged cortical silent period, thought to represent abnormal GABAergic cortical inhibition, correlates with injury severity in athletes and is related to sleep-wake disturbances in traumatic brain injury.[69-73]

Another area of interest is the accumulating evidence that neuroinflammation plays a key role in the outcome of traumatic brain injury and may well play a role in persistent postconcussion syndrome. Traumatic brain injury (especially the release of adenosine triphosphate from damaged cells) initiates the activation of the innate immune system (predominantly microglia), resulting in the release of inflammation-promoting mediators (eg, cytokines, chemokines, and reactive oxygen and nitrogen species). Proinflammatory processes are intended to clear the central nervous system of potentially harmful substances. Anti-inflammatory processes follow this, performing reparative and regenerative functions considered to be beneficial to neuronal survival. An imbalanced or prolonged inflammatory response is harmful and is associated with many central nervous system diseases, for example, neurodegenerative diseases (see review by Mayer et al[74]). In traumatic brain injury, there is strong pathologic evidence of a prolonged immune response, with microglial activation, astrocyte activation, and microvascular changes in the blood-brain barrier, and evidence of these changes can be found months and years after injury.[75,76] Further studies elucidating the mechanisms and cell signaling pathways involved in neuroinflammation in persistent postconcussion syndrome are warranted and may offer future treatment options.

Very few potential biomarkers have been assessed in postconcussion syndrome in children. The Tau protein has been implicated in mild traumatic brain injury secondary injury and has been found elevated in the serum of adult mild traumatic brain injury patients, but this has not been found in children.[77,78] The term *tauopathy* has been associated with other neurologic disorders such as Alzheimer and Parkinson disease, and is thought to be involved in the etiology of chronic traumatic encephalopathy.[79] Although a recent study demonstrated increased Tau deposits in retired football players with mood disturbance and cognitive dysfunction similar to postconcussion syndrome, there is no evidence to support or refute its role in pediatric persistent postconcussion symptoms or syndrome.[80]

Clinical Assessment

A comprehensive assessment is necessary to evaluate a child with postconcussion syndrome and it should pay particular attention to risk factors for poor recovery and mimics. The differential diagnosis includes headache disorder, cervical injury, anxiety, depression, somatization, vestibular dysfunction, and visual dysfunction. Beware of the tendency for patients to attribute problems to a mild traumatic brain injury, when clearly the problems were preexisting. The history and examination should assess

- Preinjury details including factors indicating severity of injury, the presence of litigation, and mechanism of injury (eg, high velocity/energy insult, elite athlete, assault)
- Medication use (screening for medication overuse), alternative therapies, use of other substances, for example, marijuana. Many teenagers use marijuana recreationally but may begin to use it to treat their headaches, and it will also improve their anxiety. Unfortunately, few pharmacotherapies are likely to be of benefit where there is significant substance use and the involvement of psychological and psychiatric services will be necessary.
- Current functioning, for example, mood and sleep disturbance, school performance, presence of social isolation (a frequent consequence of prolonged absence from school and sport).
- Current activity, for example, type and amount of exercise especially weight training, and boxing, which may exacerbate symptoms.
- Past medical history, for example, migraine, exercise-induced headaches, previous concussion, and the time taken to recover. A prolonged recovery from one concussion should alert the clinician to the high likelihood that this recovery will be protracted.
- Preexisting traits or disorders, for example, anxiety, depression, current learning difficulties, and/or attention

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deficits as well as the past school history (including learning assistance in early school years).
- Family history, for example, migraine, hemiplegic migraine, depression, anxiety, attention deficits, learning disorders, etc.
- Psychosocial history, for example, recent stressors such as loss of a family member or friend, change of school, conflicts with friends/family, etc, and the child's reaction to these.
- Evidence to support cervicogenic headache, for example, neck pain, facet joint pain, occipital neuralgia, decreased range of movement of neck, and muscle tenderness
- Vestibular dysfunction (using the head impulse test, Dix Hallpike maneuver, dynamic visual acuity testing).
- Convergence insufficiency, asymmetrical refractive errors.

Outcome Measures in the Clinic

Questionnaires to explore current symptoms as well as function are very useful. A postconcussion symptom scale, for example, Post Concussion Symptom Scale,[81] Rivermead Post Concussion Questionnaire[82] helps to track symptoms and monitor treatments. As symptoms become chronic, these measures have to be used with caution and avoid using the total score as a marker for recovery. Instead, use individual symptoms scores in conjunction with clinical impression and other measures.[83] A quality of life measure, for example, PedsQL,[84] Child Health Questionnaire,[85] can be particularly useful to assess overall function. Posttraumatic headaches are one of the commonest problems encountered in postconcussion syndrome affecting over half of children with persistent symptoms.[86] See the review of posttraumatic headaches in this issue. When headaches are a significant problem, a headache diary is highly recommended to help track frequency and severity, as well as medication overuse and lifestyle issues that may contribute to the headaches. Other useful tools include questionnaires to help evaluate mood, anxiety, and sleep dysfunction in the clinic. Several readily available ones are the Mood and Feelings Questionnaire,[87,88] SCARED questionnaire,[89] Child Sleep Habits Questionnaire (ages 6-10 years)[90] and Adolescent Sleep Habits Questionnaire.[91]

Investigations

Investigations do not play a large role in postconcussion syndrome. Laboratory investigations should be considered where there is concern for endocrine dysfunction. After 2 to 3 months, hypersomnia is unusual and raises concerns for other medical disorders (eg, hypothyroidism, anemia, depression, and idiopathic hypersomnia). Neuroimaging is generally not warranted. Specialized clinics may offer dynamic balance assessments as well as computerized assessments of vestibular and cognitive function but their use in persistent symptoms has not been validated.

Management

Postconcussion syndrome is managed somewhat differently to the acute and subacute phases following mild traumatic brain injury. Rather than focusing on rest, the focus switches to strategies to improve general functioning, increase activities of daily life, and returning the child to school. This is done in a graduated fashion supporting the child/adolescent in his/her environment. Prolonged absence from school is not recommended, and should not be longer than 2 to 4 weeks as this often leads to more problems when the children become isolated from their peers and lose their self-confidence. Often adolescents need significant reassurance and encouragement in this process, especially when their symptoms have been present for several months.

Once the clinician has a clear understanding of the various factors contributing to symptom persistence, it is advisable to address 1 or 2 of the most problematic symptoms and the other symptoms will often improve. Participation in school and social activities should be encouraged while this occurs. Referral to a specialist should be made for children with persistent vertigo and balance problems, or persistent visual complaints. Peripheral vestibular dysfunction should be treated with specialized physiotherapy initially; migrainous vertigo may be treated with prophylactic agents for migraine.[7,92] Convergence insufficiency and persistent reading dysfunction may respond to oculomotor neurorehabilitation.[93] The commonest problems, however, are usually sleep disturbance, headaches, and cognitive and mood disturbance. (See the review of posttraumatic headaches by Blume[87] in this issue.) Addressing sleep disturbance is usually the first step. As sleep improves, children find it easier to cope at school, and often mood disturbance will also improve.

Sleep Disturbance

Sleep disturbances are common in childhood and adolescence, and occurs in 50% of young adults and children following mild traumatic brain injury.[94-96] Correct treatment of the sleep disturbance associated with postconcussion syndrome is rewarding as it results in a rapid improvement in quality of life. In a local cohort study, preinjury "difficulty falling asleep" was the most common sleep disturbance affecting 31% of all children ($n = 410$) in the emergency department with mild traumatic brain injury (KM Barlow, Personal communication, March 2014). The type of sleep disturbance seen following mild traumatic brain injury is time dependent. Initial hypersomnia is gradually replaced by delayed sleep onset and frequent arousals. Hypersomnia was the most frequent sleep complaint at 7 to 10 days postinjury (43.6% vs 12% at base-line, $P < .001$), similar to Blinman et al.[95] As hypersomnia resolved, it was replaced by problems of sleep initiation. This was problematic for 44% of symptomatic children (vs 16% in these children at baseline, $P = .046$). There is a trend for these sleep onset difficulties to continue at 3 months ($n = 88$, 38%, $P = .083$), when it is now combined with "sleeping

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less'' and frequent awakenings ($P = .008$) (KM Barlow, Personal communication, March 2014).

Although sleep problems are a major concern for children and their parents, there are few studies exploring this.[94,95,97] Persistent postconcussion syndrome sleep disturbance is associated with lower sleep efficiency, more wake time, and more nocturnal awakenings when assessed using polysomnography.[98] The pathogenesis for sleep disturbance is multifactorial. It may correlate with increased abnormalities on magnetic resonance imaging and a longer tentorial length (implicating susceptibility to pineal trauma).[99,100] Psychological factors definitely play a role (especially anxiety) as well as the potential for decreased melatonin production.[98,101]

The clinician should always examine other factors that affect sleep, including sleep hygiene, pain, anxiety, and depression.[102] Medications that interfere with sleep (especially those used to treat any concomitant attention problems) should be examined, as well as the use of substances and caffeine. A sleep questionnaire can often be helpful. Any relevant factors should be addressed, including the treatment of pain.[103] Sleep diaries should be used, and actigraphy can be used to help delineate the type of sleep disorder (usually delayed sleep phase syndrome). Melatonin and amitriptyline can be used to treat delayed sleep phase syndrome,[104] and may be particularly useful in the setting of headaches.[86,105,106] Non-benzodiazepine sedative hypnotics can be used in the short term (eg, Zopiclone, Zolpidem). Cognitive-behavioral therapy provides more benefit than pharmacotherapy alone in chronic insomnia.[107]

Mood Disturbance

A range of psychiatric problems can be seen following traumatic brain injury in children, including anxiety, depression, personality change disorder, posttraumatic stress disorder, attention-deficit hyperactivity disorder (ADHD), and substance abuse. Mood disturbance is common after any traumatic injury in the first few weeks.[108] Novel psychiatric disorders are seen more frequently as the severity of injury increases, occurring in 36% of a *hospitalized group* of children with mild traumatic brain injury within 6 months of injury. These children were more likely to have preinjury social factors, neurocognitive deficits, and frontal white matter lesions.[109]

A multidisciplinary team including a psychiatrist is necessary to manage severe depression or anxiety in childhood following mild traumatic brain injury. Any sleep and pain disorders should be concurrently managed. The use of methylphenidate in adult mild-moderate traumatic brain injury may have similar efficacy to sertraline for treating depressive symptoms and is associated with improvement in cognition and alertness.[110,111] Behavioral modification therapies, including cognitive behavioral therapy, are often beneficial to treat anxiety[112] and it is sometimes combined with a selective serotonin uptake inhibitor. Addressing the needs of the whole family are important pediatric psychiatric constructs to maximize the effectiveness of treatments.

Cognitive Difficulties

Whether neuropsychological impairment can persist in pediatric mild traumatic brain injury is still debated. Satz et al found no adverse effects on academic-psychosocial outcome across the spectrum of mild traumatic brain injury in a comprehensive systematic review.[113] Most children with uncomplicated mild traumatic brain injury do well.[114] However, children that sustain *complicated mild traumatic brain injury* may have subtle deficits on long-term follow-up.[115] Risk factors for this in one study were posttraumatic amnesia longer than 30 minutes and an EEG abnormality within 24 hours after traumatic brain injury (a likely surrogate for injury severity).[115] There are also concerns about the long-term impact of repetitive concussions, especially in professional contact sports where repeated concussions and subclinical concussive events are common.[116] As yet, there are no conclusive data in children, but animal studies do suggest vulnerability in repeated episodes of concussion, especially if this occurs before the time of neurometabolic recovery.

In clinical practice, for most children with persistent postconcussion syndrome where baseline values are not available, the value of neuropsychological testing is unknown. It is useful for identifying preexisting learning difficulties and attention problems that were ''unmasked'' by a mild traumatic brain injury. This may be because children with lower cognitive ability have a reduced capacity to cope with neurologic insults.[37] Neuropsychological testing frequently identifies mood disorders and somatizing behaviors, which can lead to the implementation of helpful therapies.[117] Unless any of these factors are suspected, it is usually better to address problems with sleep, headaches, and mood disturbance (as all of these can interfere with cognitive performance) and then reassess the need for neuropsychological testing later. Any abnormalities identified, such as attention-deficit hyperactivity disorder (ADHD), should be addressed were possible. Although there is currently little evidence to support the use of stimulants for secondary attention deficits, future studies are addressing this question,[118] and until the results are available, a trial of stimulants is probably warranted. Drugs such as memantine are not warranted in postconcussion syndrome (especially outside of a clinical trial) given the good long-term prognosis.

Supporting children as they return to school, regardless of the time postinjury, is key. Parents and adolescents should be encouraged to talk to the school before their child returns and an individualized educational plan should be developed. Where possible, exemptions should be made so that the student does not have to ''catch up'' on all assignments or work missed, but instead priority projects or key areas should be identified. Exemption from examinations and tests should be made during the first phase of return to school, and accommodations such as a quiet environment for taking tests should be arranged. A gradual return to full participation is recommended. Sometimes psychological support is necessary during this time, especially if plans for graduation or university hopes have to be put on hold.

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Summary

Postconcussion syndrome is a complex disorder involving somatic, mood, cognitive, and sleep difficulties. The reasons for persistent symptoms vary considerably between children. The traumatic brain injury is the initial insult, but many preexisting or environmental factors influence outcome. Although the mechanisms by which these preexisting factors "drive" biological outcomes are poorly understood, successful management of the child and his/her family needs to address them. Early reassurance is a key part of the rehabilitation process, and problematic symptoms should be treated promptly, paying particular attention to sleep, headaches, and mood disturbance. Most of these problems will respond well to targeted management strategies. Referral to a multidisciplinary specialized rehabilitation center is warranted when symptoms persist.

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