

[Orthopaedic Surgery]

Rehabilitation of Concussion and Post-concussion Syndrome

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Context: Prolonged symptoms after concussion are called *post-concussion syndrome* (PCS), which is a controversial disorder with a wide differential diagnosis.

Evidence Acquisition: MEDLINE and PubMed searches were conducted for the years 1966 to 2011 using the search terms *brain concussion/complications* OR *brain concussion/diagnosis* OR *brain concussion/therapy* AND *sports* OR *athletic injuries*. Secondary search terms included *post-concussion syndrome*, *trauma*, *symptoms*, *metabolic*, *sports medicine*, *cognitive behavioral therapy*, *treatment* and *rehabilitation*. Additional articles were identified from the bibliographies of recent reviews.

Results: Of 564 studies that fulfilled preliminary search criteria, 119 focused on the diagnosis, pathophysiology, and treatment/rehabilitation of concussion and PCS and formed the basis of this review. Rest is the primary treatment for the acute symptoms of concussion. Ongoing symptoms are either a prolonged version of the concussion pathophysiology or a manifestation of other processes, such as cervical injury, migraine headaches, depression, chronic pain, vestibular dysfunction, visual dysfunction, or some combination of conditions. The pathophysiology of ongoing symptoms from the original concussion injury may reflect multiple causes: anatomic, neurometabolic, and physiologic.

Conclusions: Treatment approaches depend on the clinician's ability to differentiate among the various conditions associated with PCS. Early education, cognitive behavioral therapy, and aerobic exercise therapy have shown efficacy in certain patients but have limitations of study design. An algorithm is presented to aid clinicians in the evaluation and treatment of concussion and PCS and in the return-to-activity decision.

Keywords: concussion; post-concussion syndrome; physiology; rehabilitation; cognitive behavioral therapy

Concussion, a form of mild traumatic brain injury (TBI), is a leading public health problem, with an estimated 1.6 to 3.8 million sport-related concussions each year in the United States.⁶³ The majority of patients with sport-related concussion recover within a 7- to 10-day period, although children and adolescents require more time to recover than do collegiate or professional athletes.^{8,75} Persistence of symptoms beyond the generally accepted time frame for recovery may represent a prolonged concussion or may herald the development of post-concussion syndrome (PCS).¹¹⁷ The accepted time frame for recovery is not scientifically established and is influenced by factors such as age, sex, and history of prior concussions.^{43,54,74} Approximately 10% of athletes have persistent signs and symptoms of concussion beyond 2 weeks.¹¹⁷ In non-sport-related concussion, most individuals recover completely within the first 3 months⁶⁸; however, up to 33%^{12,95} may exhibit symptoms beyond that.

There is some uncertainty about the definition of PCS, in part because it is diagnosed according to clinical criteria. PCS is defined by the fourth edition of the *Diagnostic and Statistics Manual* as (1) cognitive deficits in attention or memory and (2) at least 3 or more of the following symptoms: fatigue, sleep disturbance, headache, dizziness, irritability, affective disturbance, apathy, or personality change.¹³ However, these criteria are conservative. The broader definition of PCS is represented by clinical criteria of the World Health Organization's International Classification of Diseases, or ICD-10—namely, 3 or more of the following symptoms: headache, dizziness, fatigue, irritability, insomnia, concentration difficulty, or memory difficulty. Use of these criteria is 6 times more sensitive for identifying patients with PCS.¹³ After 3 weeks, patients (especially athletes) begin to worry about when they will recover, and by 6 weeks, if symptoms persist, PCS can alter their lives.¹¹⁷

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There is considerable controversy regarding PCS because of the nonspecificity of symptoms and the fact that most cognitive deficits resolve within 1 to 3 months after mild TBI in the majority of patients.^{2,16} The differential diagnosis includes depression, somatization, chronic fatigue and pain, cervical injury, vestibular dysfunction, visual dysfunction, or some combination of these conditions.² Patients often present with considerable insecurity about PCS symptoms: headache, fatigue, sleep disturbance, vertigo, irritability, anxiety, depression, apathy, and difficulty with concentration and exercise.¹¹⁷ The clinical challenge is to determine whether prolonged symptoms reflect a version of the concussion pathophysiology versus a manifestation of a secondary process, such as premorbid clinical depression or migraine headaches.^{21,62} If symptoms that were experienced early after the injury are exacerbated with exertion, but improved with rest, then the original concussion pathophysiology is likely persisting.⁶² If ongoing symptoms are exacerbated by even minimal activity and no longer respond to rest, this may represent psychologic symptoms related to prolonged inactivity and frustration with inability to return to usual activities.⁶² Data suggest that at least some patients with PCS have measurable pathophysiology. For example, concussed athletes with prolonged depressive symptoms showed reduced functional magnetic resonance imaging activation in the dorsolateral prefrontal cortex and striatum and attenuated deactivation in medial frontal and temporal regions accompanied by gray matter loss in these areas.¹⁸ Some PCS patients have persistent abnormalities of brain blood flow on single-photon emission computed tomography scan,¹ neurochemical imbalances (eg, serum S100B),¹⁰² and electrophysiologic indices of impairment.^{4,27} Postural instability is much more likely when other signs and symptoms are the result of organic-based PCS.⁴⁰

THEORY OF PROLONGED SYMPTOMS

Animal research suggests that the concussed brain is in a vulnerable state that places it at increased risk of more debilitating injury should more trauma occur before metabolic homeostasis is restored.^{32,70} This vulnerable state can be inferred in humans from data that concussion risk increases after having had 1 or more concussions⁴³ and from the second impact syndrome (SIS).¹⁵ SIS is based on rare and disputed cases in children and adolescents in which a second mild head injury is thought to occur before resolution of a concussion, with resulting malignant brain edema. McCrory⁷⁶ argues that rather than SIS being a complication of recurrent concussion, it represents “diffuse cerebral swelling,” which is a well-recognized complication of TBI in children. Additionally, a recent review of death caused by blunt trauma found subdural hematoma to be the cause of all 17 cases of SIS. It is unclear whether concussion may have increased the risk of bleeding or whether the initial injuries were occult subdural injuries diagnosed as concussions.¹⁰⁷ There is also accumulating evidence of potential long-term sequelae in humans from studies showing that previous concussions may

be associated with slower recovery of neurologic function⁴³ and that repeated concussions can result in permanent neurocognitive impairment^{41,43,53} and perhaps an increased incidence of depression.⁴² Predictors of PCS are not known with certainty, but some clinical variables appear to increase the risk. These include a history of prior concussions,^{42,43,90} female sex,^{90,93} younger age,^{71,90} history of cognitive dysfunction,¹⁰⁶ and affective disorders, such as anxiety and depression.^{17,72,74} Predictors related to injury severity, such as length of posttraumatic amnesia and cognitive difficulties, are clearly associated with symptoms at 1 month but less so at 6 months after injury.⁷ Interestingly, no study has identified injury severity as a factor contributing to the development of PCS.

Anatomic/Mechanical

The acceleration-deceleration forces applied to the moving brain cause shearing of neural and vascular elements⁵⁵ with sudden neuronal depolarization followed by a period of nerve cell transmission failure^{101,115} that can result in loss of consciousness.⁸⁴ Animal studies of concussion show neuropathologic changes in the hippocampus and diffuse axonal injury along with disruption of the blood-brain barrier and eventual neuronal loss.^{5,48,85,118} Diffusion tensor imaging of the corpus callosum within 6 days of concussion in adolescents showed white matter edema that correlated with symptom severity.¹¹⁶ Quantitative electroencephalography and single-photon emission computed tomography showed focal cortical dysfunction in conjunction with persistent blood-brain barrier disruption and reduced global and regional cerebral blood flow in patients with PCS for more than a month post-injury.⁶⁰

Neurometabolic

The neurometabolic basis for concussion and post-concussive symptoms has been described in animal models.⁵¹ Experimental brain injury induces a cascade of neurochemical, ionic, and metabolic changes that change cerebral glucose metabolism and blood flow and alter mitochondrial respiration.^{50,57,58,78} There is an initial phase of hyperglycolysis, followed by a prolonged phase of metabolic depression that can last 7 to 10 days in adult rats.⁵¹ This basic pathologic response has been reported after human brain injury in positron emission tomography studies showing a similar pattern of early hyperglycolysis, followed by glucose metabolic depression (Figure 1).^{9,10} In magnetic resonance spectroscopy studies of human concussion, athletes who reported being symptom free at 3 to 15 days did not demonstrate complete metabolic recovery until a mean of 30 days post-injury.¹¹¹ Mitochondrial metabolism took significantly longer (an additional 15 days) to recover in athletes with a second concussion.¹¹²

Physiologic

Concussion-induced mechanical changes coupled with the neurometabolic alterations can affect functional cerebral

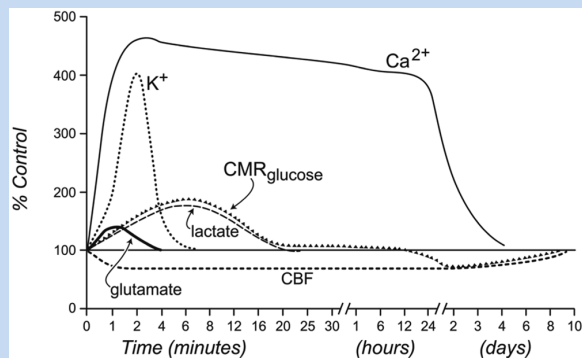


Figure 1. Neurometabolic cascade following concussion. K^+ , potassium; $CMR_{glucose}$, cerebral metabolic rate of glucose utilization; Ca^{2+} , calcium; CBF, cerebral blood flow. With permission (adapted from Hovda et al⁵⁰).

circulation.^{5,104,105} Concussion is also associated with metabolic and physiologic changes in organ systems outside the brain.⁶⁷ Concussed patients have higher heart rates at rest⁵⁹ and after cognitive⁴⁵ and physiological stress.³⁰ Autonomic nervous system (ANS) function may be disturbed after concussion.⁸⁸ Severe TBI,⁵⁹ cerebral infarction,¹¹³ and concussion in athletes²⁹ are associated with greater sympathetic nervous activity and lower parasympathetic activity when compared with controls. Autonomic dysregulation is proportional to TBI severity and improves during TBI recovery.³⁵ Increased sympathetic nervous activity may be due to an altered endocrine⁹⁹ or neuropeptide³⁶ milieu after TBI. Autoregulation, the maintenance of cerebral blood flow at appropriate levels during changes in systemic blood pressure, and cerebral blood flow are also disturbed after concussion,^{56,103} which may explain why symptoms often reappear or worsen with physical and/or mental exertion. Impairment of the cerebral vasculature after TBI sensitizes the brain to secondary insults, such as hypotension, intracranial hypertension, and dehydration.³³

Cerebral artery regulation is very sensitive to the arterial carbon dioxide tension ($PaCO_2$) and responds with vasoconstriction when $PaCO_2$ is low and vasodilation when it increases.⁶⁹ The major determinant of the blood $PaCO_2$ is pulmonary ventilation. This physiologic process is diminished in severely brain-injured humans²⁴ and is altered early after experimental concussive injury in animals.³⁴ If concussed patients have an altered ANS balance, pulmonary ventilation may be altered as well, especially during exertion.

It is not known how physiologic dysfunction develops and persists after TBI. The primary ANS control center is located in the brainstem.⁹⁸ Recent functional magnetic resonance imaging evidence⁸² suggests that the ANS is more diffusely distributed in the human brain beyond the brainstem to include higher cortical (eg, dorsolateral prefrontal, posterior insular, and middle temporal cortices) and limbic-related regions (eg, amygdala, hippocampus, and thalamus). A head

injury resulting from a twisting mechanism or direct trauma to the upper cervical/posterior skull region may damage this center. Thus, brain injury may alter central ANS regulation, disrupting cardiorespiratory control of ventilation and leading to the symptom exacerbation seen with physical exertion after concussion.⁶⁷

ASSESSMENT AND DIFFERENTIAL DIAGNOSIS

Patient history should include a description of the mechanism and force of the head trauma; the number and severity of symptoms, including retrograde and anterograde amnesia; and a history of any prior concussions, including mechanism, symptom type, and duration.⁷⁹ The nature, burden, and duration of symptoms appear to be the primary determinant of injury severity in concussion.⁷⁹ A history of multiple concussions appears to increase the risk for PCS.^{43,90} The older teenage or adult patient may be experiencing PCS if symptoms persist beyond 3 to 4 weeks, especially in athletes.¹¹⁷ A history of migraine headaches, depression, anxiety, attention-deficit/hyperactivity disorder, or learning disability is also crucial since TBI can exacerbate these conditions.⁶² Depression is an important differential diagnoses for PCS, in part because of overlapping symptoms. A study of physician-diagnosed depressive disorder found that 9 out of 10 patients met liberal criteria for PCS, whereas 5 out of 10 met more conservative criteria.⁵²

A detailed headache history is helpful because those with migraines may be at increased risk of concussion with severe and prolonged postconcussion symptoms.^{62,64} Upper cervical spine injury can also mimic the symptoms of concussion and PCS.^{23,109}

The physical examination should include an assessment of concentration (eg, drills such as stating the months of the year in reverse, a series of digits backward tests), memory (recall of 3 words at 5 minutes), and examination of the cranial nerves,⁷⁹ particularly extraocular motion, since PCS patients can have persistent abnormalities of smooth pursuit saccadic eye movements.⁴⁶ The Romberg test,²⁰ tandem gait, and vestibular testing should also be performed.⁸⁷ After the neurologic examination, the cervical spine should be carefully assessed for tenderness, spasm, and range of motion. Precipitation of headaches, dizziness, or vertigo should direct therapy to address a cervical injury.¹⁰⁹

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DIAGNOSTIC TESTING

A standardized treadmill test employing a Balke protocol⁶⁶ to determine physiologic recovery has very good interrater and sufficient retest reliability for identifying patients with symptom exacerbation from concussion.⁶⁵ Concussion symptoms are typically exacerbated by exercise,⁷⁷ while exercise may rapidly improve depression.²² If patients can exercise to exhaustion without reproduction or exacerbation of headache or other concussion symptoms, then the symptoms may be due to another problem.^{65,66} Computerized neuropsychological testing is widely employed in sport even though there are concerns with retest reliability and no data are available to suggest improved outcomes.^{14,94,100}

REHABILITATION OF CONCUSSION AND PCS

Current guidelines recommend a period of cognitive and physical rest in the early postinjury period because symptoms can increase with cognitive and physical exertion.^{73,77} Prolonged rest, especially in athletes, can lead to physical deconditioning,¹¹⁷ metabolic disturbances,⁴⁴ and secondary symptoms such as fatigue and reactive depression.¹¹ There is no scientific evidence that prolonged rest for more than several weeks in concussed patients is beneficial.

Reassurance, discussions of expected recovery time, and compensatory strategies can improve symptoms of PCS.^{80,114} An information booklet⁹² and psychological intervention⁸¹ can reduce PCS symptoms at 3 to 6 months after injury.

A recent systematic review of psychological interventions for PCS concluded that there was limited evidence of benefit.² Cognitive behavioral therapy is a form of psychological intervention that focuses on identifying and changing patterns of maladaptive thinking and behavior that can exacerbate—or, in some cases, even cause— affective symptoms often associated with persistent effects of direct brain injury, including depression and anxiety. Three randomized controlled trials and 7 other studies of cognitive behavioral therapy all found some benefit, although there were limitations in study design.²

In children, most post-concussion symptoms resolve within a month.⁸⁹ The exceptions are children who have a history of previous head injury, learning difficulties, or family stressors.⁸⁹ An information booklet on strategies for dealing with posttraumatic symptoms resulted in fewer symptoms and less behavioral changes in children 3 months after injury.⁹¹

Interventions to improve cognition have improved performance on selected neuropsychological test scores and cognitive function following neurocognitive rehabilitation in patients with mild or mild-to-moderate TBI.^{19,47,49} Neurocognitive rehabilitation uses cognitive tasks to improve cognitive processes, or it may involve developing compensatory strategies to address difficulties with aspects of cognition, such as attention, memory, and executive functioning. Empirical support varies for neurocognitive rehabilitation of different cognitive processes. Neurocognitive rehabilitation of attention processes

has received the most empirical support after TBI.^{19,47,86,96} A small randomized controlled trial of an 11-week program of combined neurocognitive rehabilitation and cognitive behavioral therapy in mild-to-moderate TBI improved divided auditory attention, anxiety, and depression in participants who were symptomatic for 5 years.¹⁰⁸

There is no scientific evidence that medication speeds recovery from concussion in humans. The most common medications prescribed for PCS are antidepressants.⁸⁰ Selective serotonin reuptake inhibitors have become the primary treatment for head injury–associated depression^{25,117} and can improve depression and the cognitive deficits associated with concussion.^{25,31,117} Tricyclic antidepressants such as low-dose amitriptyline¹¹⁰ are often used clinically to aid sleep and headaches in patients with PCS, but there are no controlled trials of their efficacy in restoring normal function.

The excitatory amino acids glutamate and aspartate may be important mediators of brain injury. NMDA and AMPA antagonists have been proposed for brain injury recovery.⁸³ The deficits in attention and memory seen after TBI mimic those in Alzheimer disease. There is some evidence that cholinergic agents (physostigmine and donepezil—acetylcholinesterase inhibitors that temporarily increase brain acetylcholine levels) and lecithin and CDP-choline (precursors of brain acetylcholine) alleviate some of the cognitive deficits suffered by brain injured patients.^{39,97}

Vestibular dysfunction is commonly associated with TBI.³ Vestibular suppressants may delay recovery and have been replaced by vestibular rehabilitation for posttraumatic vertigo.²⁶ Vestibular rehabilitation may reduce dizziness and improve gait and balance in children and adults.³

The upper cervical spine is particularly vulnerable to trauma because it is the most mobile part of the vertebral column, with a complex proprioceptive system that has connections to the vestibular and visual systems.⁶¹ Cervical vertigo or dizziness after whiplash injury can mimic the symptoms of PCS. It may be due to mechanoreceptor dysfunction¹⁰⁹ or posttraumatic vertebralbasilar circulatory insufficiency.²³

Physiologic disequilibrium may be a significant modulating factor in concussion and PCS.⁶⁷ Uncontrolled human activity too soon after concussion is detrimental to recovery.^{43,73} Experimental animal data show that premature voluntary exercise within the first week after concussion impairs recovery while aerobic exercise performed 14 to 21 days after concussion improves cognitive performance.^{37,38} Neurotrophins (brain-derived neurotrophic factor) promote neuronal recovery.⁶ Premature voluntary exercise within the first week after concussion interferes with the postconcussion rise of brain-derived neurotrophic factor and is associated with impaired cognitive memory task performance.^{37,38} Conversely, aerobic exercise performed 14 to 21 days after TBI upregulated brain-derived neurotrophic factor in association with improved cognitive performance.^{37,38}

The most recent consensus statement on concussion in sport advises that when asymptomatic at rest, concussed patients should progress stepwise from light aerobic activity, such as

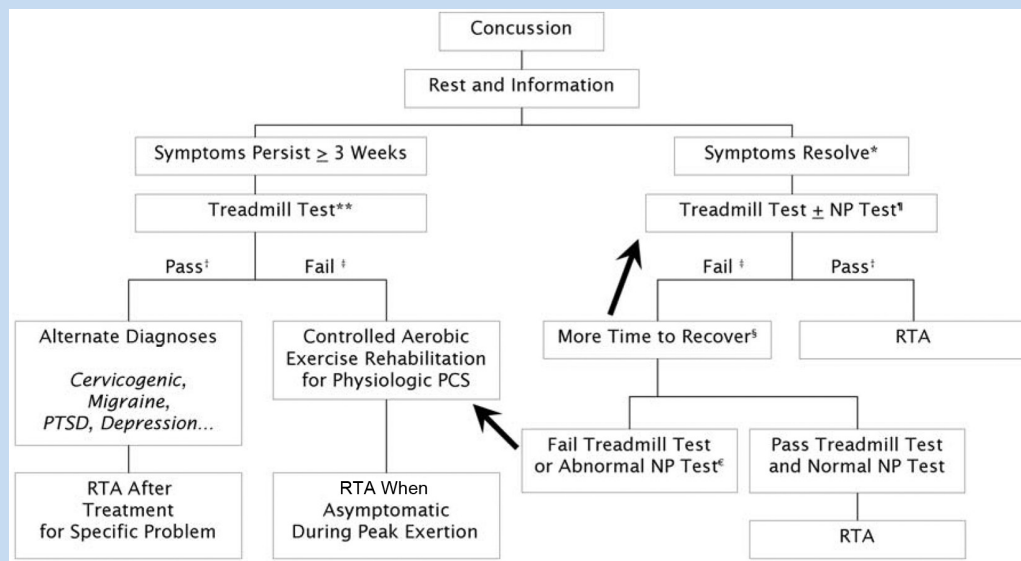


Figure 2. Return-to-activity algorithm for concussion and postconcussion syndrome. Time for symptom resolution will vary depending on clinical circumstances. Most athletes recover within 1 to 3 weeks. **Treadmill testing in patients with persistent symptoms should not be performed before 3 weeks after injury. Neuropsychological testing is not indicated, because the patient is still symptomatic. †If neuropsychological testing has been used, assume that there is a baseline preinjury test or valid normative data for the particular patient. ‡Exercise to exhaustion without exacerbation of symptoms. †Exercise stopped at a submaximal effort level because of symptom exacerbation. §Repeat testing interval will vary depending on clinical circumstances; it may be several days to several weeks. If athlete is not recovering, consider aerobic exercise rehabilitation. ¶If computerized neuropsychological testing has been used and remains abnormal, continue exercise treatment and consider consultation with a neuropsychologist to evaluate for a specific cognitive deficit. RTA, return to activity; PCS: postconcussion syndrome; NP, neuropsychological.

walking or stationary cycling, up to sport- or work-specific activities.⁷⁹ The guideline recognizes the important physiologic component of testing and recovery after concussion.

Controlled aerobic exercise rehabilitation after establishing symptom-free exercise capacity via treadmill testing has helped athlete and nonathlete PCS patients recover.⁶⁶ Exercise testing and rehabilitation should be employed only if patients have persistent symptoms for 3 to 6 weeks or more.^{38,65,66} A similar rehabilitation program has been established for children with PCS after sport-related concussion that combines gradual, closely monitored physical conditioning, general coordination exercises, visualization, education, and motivation activities.²⁸

Figure 2 presents a suggested progression for making the return-to-activity decision in patients who have recovered from the acute effects of concussion and in those whose symptoms persist beyond 3 weeks.^{65,66}

CONCLUSIONS

Rest is the primary treatment for the acute symptoms of concussion.⁷⁹ Ongoing symptoms reflect either a prolonged version of the concussion or a manifestation of other processes, such as cervical injury, migraine headaches, depression, chronic pain, vestibular dysfunction, visual dysfunction, or a combination of conditions.⁶² The pathophysiology of ongoing symptoms from the original concussion injury may reflect multiple causes: anatomic, neurometabolic, and physiologic.^{51,67,116} Treatment approaches depend on the clinician's ability to differentiate among the various conditions associated with PCS. Early education,^{80,114} cognitive behavioral therapy,² and aerobic exercise therapy⁶⁶ have been shown to be effective in certain patients.



Sort Recommendations

SORT: Strength of Recommendation Taxonomy

A: consistent, good-quality patient-oriented evidence

B: inconsistent or limited-quality patient-oriented evidence

C: consensus, disease-oriented evidence, usual practice, expert opinion, or case series

Clinical Recommendation	SORT Evidence Rating
Early education, ^{80,114} cognitive behavioral therapy, ² and aerobic exercise therapy ⁶⁸ have shown efficacy in certain patients	B

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