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Active Rehabilitation of Concussion and Post-concussion Syndrome

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KEYWORDS

• Rehabilitation • Concussion • Post-concussion syndrome • Active
• Physiology • Treatment

KEY POINTS

- Patients with concussion are advised to rest until all symptoms resolve. Recent research suggests that a more active approach to concussion management may be beneficial.
- Practitioners should perform a physical examination in patients with concussion and PCS to try to identify one or more potentially treatable post-concussion disorders.
- Active treatments (e.g., subthreshold aerobic exercise and/or cervical, vestibular, cognitive behavioral, and vision therapy) may improve recovery from concussion if implemented at the right time.

INTRODUCTION

Rest has been the mainstay of the treatment for concussion.[1] Research based on animal physiological concussion studies suggests that the concussed human brain is in a vulnerable state that places it at increased risk of more debilitating injury should it sustain more trauma or experience undue stress before metabolic homeostasis has been restored.[2,3] This vulnerable state can be inferred to exist in humans after concussion from the rare but devastating (and controversial) phenomenon of second impact syndrome,[4,5] from data that concussion risk increases after having had one or more concussions[6] and from retrospective data suggesting that high levels of physical and/or cognitive activity soon after concussion delay recovery.[7] The timing and amount of rest after concussion have not been established; as such, the most recent world consensus concussion statement recommends that an initial period of rest in the acute symptomatic period following injury (24–48 hours) may be beneficial, followed by gradual return to school and social activities (before contact sports) in a manner that does not result in a significant exacerbation of symptoms.[8] The concept of

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"rest until asymptomatic" is also recommended by some clinicians when advising patients with prolonged recovery after concussion, which is called post-concussion syndrome (PCS).[1,9] Recent clinical and experimental studies are, however, beginning to challenge the utility of prolonged rest as treatment of concussion and PCS.[1,10] The purpose of this article is to review the emerging evidence for the active, nonpharmacologic rehabilitation of concussion and PCS.

DEFINITION OF CONCUSSION

- Concussion is a brain injury that involves a complex pathophysiological process induced by biomechanical forces.[8]
- This complex pathophysiological process includes metabolic,[2] physiological,[11] and microstructural[12] injury to the brain that produces excitatory neurotransmitter release, abnormal ion fluxes, increased glucose metabolism, lactic acid accumulation, and inflammation.
- The macrophysiological insult to the brain affects the autonomic nervous system (ANS) and its control of both cerebral blood flow (CBF) and cardiac rhythm.[13]
- The majority (80%–90%) of sport-related concussions (SRC) in adults resolve in a short (7–10 days) period, although the recovery time frame may be longer in children and adolescents.[8]
- Recent research that accounts for vestibular-oculomotor problems that often accompany SRC suggests that recovery time for adolescents after SRC may take 3 to 4 weeks, which is longer than the commonly reported 7 to 14 days.[14]

DEFINITION OF POST-CONCUSSION SYNDROME

In some cases, concussion symptoms are prolonged.[8] Persistence of symptoms beyond the generally accepted time frame for recovery is called "post-concussion syndrome."

- PCS is not a single pathophysiological entity. It is a term used to describe a constellation of nonspecific symptoms (eg, headache, fatigue, sleep disturbance, vertigo, irritability, anxiety, depression, apathy, and difficulty with concentration and exercise) that are linked to several possible causes that do not necessarily reflect ongoing physiological brain injury.[9]
- The differential diagnosis of PCS includes depression, somatization, chronic fatigue, chronic pain, cervical injury, vestibular dysfunction, ocular dysfunction, or some combination of these conditions.[15]
- The challenge for clinicians is to determine whether prolonged symptoms after concussion reflect a prolonged version of the concussion pathophysiology versus a manifestation of a secondary process such as premorbid clinical depression, a cervical injury, or migraine headaches.[16,17] It is therefore essential that the clinician obtain a history of prior affective or medical problems, perform a careful physical examination, and consider the response to exertion (ie, whether exertion reliably exacerbates symptoms)[18] when developing the differential diagnosis of persistent post-concussion symptoms. Through this process, the clinician may be able to link symptoms of post-concussion "syndrome" to one or more definable post-concussion "disorders."[19] For example, establishing a premorbid history of migraine headaches, depression, anxiety, attention deficit hyperactivity disorder, or learning disability is crucial because concussion can exacerbate these conditions, and they in turn can be responsible for ongoing symptoms.[17]

The accepted time frame for recovery after concussion is not scientifically established and depends on the circumstances of the clinical scenario.

- Persistent symptoms (>10 days) are, for example, generally reported in 10% to 15% of SRC.[8]
- In patients with non-SRC, however, PCS is defined as symptoms persisting for more than 3 months.[20,21]
- Some studies have identified risk factors for persistent symptoms, such as age (younger), sex (female), and history of (multiple) prior concussions.[6,22,23]
- The Zurich Consensus Guidelines state that, in general, symptoms are not specific to concussion, and it is important to consider other abnormalities.[8] This statement was confirmed in a recent study of patients with persistent symptoms for more than 3 weeks after head injury, which included cognitive symptoms that traditionally have been ascribed to brain injury. In this study, cognitive, somatic, and behavioral symptoms did not reliably discriminate between patients with physiological post-concussion disorder (defined as those with persisting symptoms who demonstrated exercise intolerance on a treadmill test) from patients with cervicogenic and/or vestibular post-concussion disorders (defined as those with persisting symptoms who had normal exercise tolerance but abnormal cervical and/or vestibular physical examinations).[19]

NONPHARMACOLOGIC TREATMENT APPROACHES

Acute Concussion

Rest

- The most recent Zurich Consensus statement on concussion in sport recommends that patients should rest for 24 to 48 hours after concussion.[8] This recommendation is reasonable because symptoms can increase with cognitive and physical exertion shortly after concussion.[7,24]
- Rest is also one of the most common recommendations patients who sustain non-SRC receive following head trauma.[25] There are experimental human data to support this recommendation. Functional MRI (fMRI) studies in those performing cognitive tasks have reported that excessive (compensatory) brain activation (as measured by fMRI blood flow) is a feature of concussion, suggesting that the brain should be rested after concussion because the threshold for physical exertion may also be lowered.[26,27]
- There are emerging data that excessive cognitive activity soon after concussion exacerbates symptoms and may delay recovery.[28]

What remains to be scientifically established, however, is just what “rest” means in the setting of concussion (eg, physical? cognitive? both?) and for how long it should be prescribed. “Rest” may be interpreted to include anything from strict bedrest to relative rest from intense athletic activity.

- The duration of rest after SRC is generally interpreted to mean “until asymptomatic” (the 2012 Zurich Consensus statement says “The cornerstone of concussion management is physical and cognitive rest until the acute symptoms resolve”).[8]
- Symptoms after head injury are not specific to the brain (eg, they can originate from the cervical spine[19]) and healthy, nonconcussed persons report some degree of symptoms on traditional concussion symptom checklists.[29]
- The use of symptom resolution to define an optimally therapeutic amount of rest is therefore fraught with difficulty, and how patients interpret “rest” is

inconsistent. In a prospective study, de Kruijk and colleagues[30] randomized adults discharged from the emergency department (ED) with acute mild traumatic brain injury (mTBI) to usual care or strict bedrest and found no significant differences in actual amounts of reported rest or in outcomes at 2 weeks, 3 months, and 6 months after injury.

It is clear that some rest, both physical and cognitive, is beneficial to allow the brain to recover from the acute metabolic crisis of concussion. Conversely, too much rest after concussion may have adverse physiological and psychological consequences and contribute to prolonged symptoms.

- Abnormal control of CBF appears to be a fundamental physiological disturbance after concussion.[31–33] Physical inactivity negatively affects CBF control,[34] whereas regular physical activity enhances CBF control.[35]
- Exercise intolerance is a sign of ongoing physiological dysregulation after concussion.[36]
- Exercise intolerance as a result of abnormally elevated CBF during physical exertion has been associated with prolonged inactivity in female athletes with persistent symptoms after concussion.[31] In this study, a program of individualized subthreshold aerobic exercise treatment restored the control of CBF to normal in association with return of exercise tolerance and with symptom resolution.

It is generally accepted that children and adolescents require more cognitive and physical rest in the acute phase of concussion recovery, theoretically because of the unique requirements of the developing brain.[8]

- Recent evidence suggests, however, that children may recover faster than adolescents from concussion.[37] This evidence may relate to the widely variable nonlinear trajectories in CBF evolution that have been observed during adolescent development.[38]
- In adults who sustain a concussion, there is no evidence that complete rest beyond 3 days is beneficial to their recovery.[1] In athletes, prolonged rest after concussion can lead to physical deconditioning and secondary symptoms such as fatigue and reactive depression.[39]
- The challenge to clinicians is therefore to use rest to aid in the recovery from the acute effects of concussion but to avoid “rest until asymptomatic” as a long-term prescription for those patients whose symptoms persist for weeks or months.

Return to normal activity

The most recent Zurich Consensus statement on concussion in sport recommends that patients should gradually return to school and social activities in a manner that does not result in a significant exacerbation of symptoms.[8]

- In a prospective study of concussed patients in a pediatric ED, Thomas and colleagues[10] randomly assigned patients aged 11 to 22 years within 24 hours of concussion to strict rest for 5 days versus 1 to 2 days of strict rest followed by stepwise return to regular daily activities. Consistent with their recommendation, the intervention (strict rest) group reported significantly less school and after-school attendance for days 2 to 5 post-concussion (3.8 vs 6.7 hours total). There were no clinically significant differences in neurocognitive or balance outcomes. Interestingly, however, the strict 5 days rest group reported more daily post-concussive symptoms and slower symptom resolution than the group who rested for 1 to 2 days. The investigators concluded that recommending strict rest for

adolescents immediately after concussion offered no added benefit over usual care.

- A recent prospective study evaluated a prescribed day of cognitive and physical rest after concussion. Patients in the rest group were withheld from activities, including classes, for the remainder of the injury day and the following day, whereas patients in the no-rest group were not provided any after-injury accommodations. Prescribed rest did not reduce post-concussion recovery time, suggesting that light activity after concussion may not be deleterious to recovery.[40]
- In a retrospective study of student athletes, those who reported engaging in a medium level of physical and cognitive activity (ie, school activity and light activity at home, such as slow jogging or mowing the lawn) had fewer symptoms and performed better on neurocognitive testing than those who reported engaging in high levels of activity (ie, school activity and sports practice or school activity and participation in a sports game) but also compared with those reporting very low levels of activity (ie, no school or exercise activity or school activity only),[7] suggesting that participation in typical daily activities soon after concussion is associated with better recovery. These findings should be cautiously interpreted because activity was self-reported recall, and it is not known at what point after injury the athletes began physical activity.
- In a prospective study of activity reports after brain injury,[1] just more than 20% of 126 mTBI subjects recruited from an ED reported symptoms consistent with PCS at 3 and 6 months. Negative mTBI perceptions, stress, anxiety, depression, and all-or-nothing behavior were associated with the risk of PCS. Multivariate analysis revealed that all-or-nothing behavior, which was defined as either excessive activity ("pushing through") or complete rest ("crashing") over the first 2 weeks following injury, was the key predictor for the onset of PCS at 3 months after injury. Negative mTBI perceptions best predicted PCS 6 months after injury. The investigators concluded that patients' perceptions of their head injury and their behavioral responses play important roles in the development of PCS.

Post-concussion Syndrome

Rest

The primary forms of PCS treatment have traditionally included a recommendation for rest until symptoms subside along with other interventions, such as education, coping techniques, support and reassurance, neurocognitive rehabilitation, and antidepressants.[41] With respect to rest versus activity, long-term adverse consequences of early activity sufficient to provoke or exacerbate symptoms have been hypothesized in humans because animal studies have shown negative effects of exercise shortly after concussion.

- Griesbach and colleagues[42] reported that premature voluntary exercise within the first week after rodent concussion impaired cognitive performance, whereas aerobic exercise performed 14 to 21 days after concussion improved performance and showed that cardiac and temperature autonomic regulation were compromised during exercise within the first 2 weeks after injury.[43]
- In a subsequent study, they analyzed the effects of voluntary versus forced exercise after concussion. Rats *forced* to exercise 28 to 32 days and 35 to 39 days after mTBI markedly stimulated the corticotropic axis and did not increase brain-derived neurotrophic factor (BDNF), which is involved in neuron repair after injury, whereas BDNF levels increased following *voluntary* exercise.[44]

- In another study, rats forced to exercise after mTBI/concussion increased the cortisol/corticotropin stress response, whereas rats allowed to voluntarily exercise did not, suggesting that exercise regimens with strong stress responses (ie, forced exercise) may not be beneficial during the early posttraumatic brain injury (TBI) period.[45] Thus, the motivation and circumstances surrounding exercise appear to be important after mTBI.
- Other animal researchers have identified beneficial effects of early exercise shortly after mTBI on various measures of brain neuroplasticity.[46–49]
- The bulk of the animal data suggests that uncontrolled or forced activity too soon after concussion is detrimental to recovery, but that voluntary exercise is not and may enhance recovery.

Athletes

- Prolonged rest, especially in athletes, can lead to physical deconditioning,[39] metabolic disturbances,[50] and secondary symptoms, such as fatigue and reactive depression.[51]
- As stated above, there are some retrospective human data showing that athletes who reported quite high levels of activity soon after concussion had worse neurocognitive performance than those who reported moderate levels of activity.[7]
- In athletes who remain symptomatic for weeks to months after concussion, it has been shown that symptom-limited exercise testing using a predetermined stopping criterion (symptom exacerbation) is safe.[52] The data are used to prescribe individualized progressive subthreshold aerobic exercise treatment that has been shown to be effective and safe and that can positively affect outcome at 1 year after injury.[18,53,54]
- Inactivity has been shown to prolong recovery from many health conditions, including those most often comorbid with mTBI/concussion, such as vestibular disorders, depression, posttraumatic stress disorder, chronic fatigue, and pain disorders.[1] It is therefore essential to establish the differential diagnosis of prolonged symptoms after concussion because postconcussion disorders will often respond to active intervention.

Active rehabilitation for post-concussion syndrome

Psychosocial factors and cognitive rehabilitation The empirical support for active psychological and neuropsychological rehabilitation specifically for PCS is somewhat limited.[55] Several recent review articles have noted the importance of addressing concussion knowledge, symptom interpretation, recovery expectations and other thought patterns, and activity levels, in preventing and managing persistent symptoms after concussion.[9,56,57] The potential benefit of integrating cognitive behavioral therapy (CBT) to address thoughts and activities with cognitive rehabilitation to address difficulties with cognitive abilities, such as attention and memory, has also been noted.[58] These approaches to active rehabilitation are grouped into psychoeducational, psychological, and cognitive interventions and reviewed in later discussion. A comprehensive and multidisciplinary approach to treatment, consistent with the concept that PCS can involve more than one disorder, appears promising.

Psychoeducational intervention

- Reassurance, discussing expected recovery time, and educating about compensatory strategies early on can improve symptoms of PCS.[59] Two controlled adult

studies have shown that brief, early education (an information booklet)[60] and psychological intervention[61] can reduce PCS symptoms at 3 to 6 months after injury.

- With respect to functional outcome in PCS, there are 3 randomized controlled trials (RCTs) that used education (for example, that problems after injury were common and would probably disappear within a few months), support/reassurance, coping strategies (for example, introduction of structured daily activities and keeping a diary), information sheets on gradual return to normal activities, ongoing advice (over a period of 6–12 months), and regular follow-up visits. Wade and colleagues[62] found that this approach improved daily social functioning and reduced PCS symptoms at 6 months in adults, whereas others found that education and early treatment inadvertently enhanced patients' consciousness of their symptoms and increased disability.[63,64] Thus, results of this form of treatment are mixed.

Psychological intervention

- A systematic review in 2010 of psychological interventions for the treatment of PCS concluded that there was limited evidence so far in the existing literature of benefit from rehabilitation programs with a psychotherapeutic element.[15] This review also discussed CBT, which 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 RCTs and 7 other studies of CBT all found some benefit, although there were limitations in study design.[9,15] Since that review, a pilot clinical trial with 28 participants at risk for PCS compared treatment as usual (education, reassurance, and symptom management strategies) from an occupational therapist to this treatment plus CBT from a psychologist.[65] Participants at risk for PCS were identified based on a multivariate prediction model that included symptom severity and the beliefs that symptoms will persist and will have catastrophic life consequences.[66] Fewer at-risk participants who received CBT had a diagnosis of PCS at follow-up (54% vs 91%, $P<.05$). Treatment effect sizes were moderate for symptoms (Cohen d = 0.74) and moderate to large for most other secondary outcome measures (Cohen d = 0.62–1.61).
- A recent RCT of group-based CBT for chronic posttraumatic headache after mTBI showed a minor effect on quality of life, psychological distress, and overall experience of symptoms, and no effect on headache and pressure pain thresholds.[67]
- In children, most post-concussion symptoms resolve within a month after injury, the exception being children who have a history of previous head injury, learning difficulties, or family stressors, who are more likely to experience ongoing problems.[68] Ponsford and colleagues[69] demonstrated that an information booklet of strategies for dealing with posttraumatic symptoms resulted in fewer symptoms and less behavioral changes in children 3 months after injury.[9]

Cognitive rehabilitation

- Studies of interventions to specifically improve cognition have indicated improvement in performance on selected neuropsychological (NP) test scores and cognitive functions following neurocognitive rehabilitation in patients with mild or mild-to-moderate TBI.[57,70,71] 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.[9] Empirical support varies for neurocognitive rehabilitation of different cognitive processes. Neurocognitive rehabilitation of

attention processes, which can affect memory, executive functioning, and other cognitive processes, has received the most empirical support with mTBI[57,70,72] and all severity levels of TBI.[73]

- A small RCT in mildto-moderate TBI of an 11-week program of combined neurocognitive rehabilitation and CBT improved divided auditory attention and levels of anxiety and depression in subjects who were symptomatic for 5 years.[74]
- Another recent trial compared supported employment along with a 12-week psychoeducation and compensatory cognitive training program to supported employment alone among veterans with mild to moderate TBI. The intervention group showed symptom reduction (Cohen d = 0.97) and improvement in prospective memory functioning (Cohen d = 0.72). Small-to-medium effect sizes were also found for posttraumatic stress disorder symptoms, depressive symptom severity, and attaining competitive work (Cohen d = 0.35–0.49).[75]

Physical therapy Symptoms after head injury are not specific to the brain.

- Concomitant injury to the cervical spine resembling whiplash may occur as a result of the acceleration-deceleration forces sustained in concussive trauma.[76]
- 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.[77]
- Leslie and Craton[78] hypothesize that concussion is a syndrome that does not require brain involvement in all cases and that concussion-like symptoms can emanate from the cervical spine. In support of this, cervical spine injury has been associated with prolonged symptoms of headache, dizziness, blurred vision, and vertigo[79,80] as well as cognitive complaints, such as poor concentration and memory deficits.[81] Symptoms of headache, dizziness, poor concentration and memory, and vertigo may therefore result from either a brain injury, an injury to the cervical spine, or an injury to both.
- It is important for the clinician to establish as much as possible the mechanism of injury and perform a careful physical examination of the neck in all patients with PCS. If a cervical source is suspected to contribute to ongoing symptoms, it is recommended that therapy be instituted to treat abnormal neck position and movement sense as well as cervicogenic oculomotor disturbance, postural stability, and cervicogenic dizziness.[77] This recommendation is supported by 2 recent studies in SRC.
  - In a case series of elite athletes with persistent symptoms of dizziness, neck pain, and headaches after SRC, Schneider and colleagues[82] showed that a course of combined cervical spine manual therapy, neuromotor retraining, sensorimotor retraining, and vestibular physiotherapy produced functional and symptomatic improvements in all participants.
  - The same research group then performed an RCT of individuals with persistent symptoms of dizziness, neck pain, and headaches following SRC and found that participants undergoing the same active treatments were far more likely to be medically cleared to return to sport within 8 weeks of initiating treatment than the control group (risk ratio 10.3; 95% confidence interval 1.51–69.6).[82] Thus, active cervical and vestibular physical therapy can improve symptoms in patients suffering from prolonged symptoms after SRC and speed their return to sport.

Vestibular therapy Vestibular dysfunction is very common after concussion.

- The vestibular system is responsible for integrating information from head movements and limb position to maintain visual and balance control. It is a complex network that includes the inner ear, brainstem, cerebellum, cerebral cortex, ocular system, and postural muscles.[83]
- There are 2 basic divisions: the vestibulo-ocular system, which maintains visual stability during head movements, and the vestibulospinal system, which is responsible for postural control.[83]
- Injury or disease of the vestibulo-ocular system commonly manifests as symptoms of dizziness and visual instability. Conversely, vestibulospinal system dysfunction interferes with balance.[84] Vestibular dysfunction is commonly associated with TBI[85] and has been reported to delay recovery from concussion.[86,87] Dizziness, which may represent an underlying impairment of the vestibular and/or ocular motor systems, is reported by 50% of concussed athletes[88] and is associated with a 6.4 times greater risk, relative to any other on-field symptom, for predicting protracted recovery (ie, >21 days).[89]
- In a recent retrospective study of children and adolescents referred to a multidisciplinary pediatric concussion program, 28.6% with acute SRC and 62.5% of those with PCS met the clinical criteria for vestibulo-ocular dysfunction, which was a significant risk factor for the subsequent development of PCS in pediatric patients acutely after SRC.[90]
- Vestibular suppressants may delay recovery and have been supplanted by vestibular rehabilitation in the management of post-traumatic vertigo.[91] Vestibular rehabilitation can reduce dizziness and improve gait and balance function after concussion in both children and adults and should be considered in the management of individuals who have vestibular dysfunction after concussion.[85]
- As noted above, an RCT of individuals with persistent symptoms following SRC, including dizziness, found that participants were more likely to be medically cleared to return to sport within 8 weeks of initiating treatment with combined vestibular and cervical physiotherapy.[82]

Ocular therapy Ocular motor dysfunction is very common after concussion.

- The cognitive control of eye movements requires pathways involving fronto–parietal circuits and subcortical nuclei, many of which are particularly vulnerable to concussion.[92]
- Common neuro-ophthalmic findings in concussion include abnormalities in saccades (the eye's ability to quickly and accurately shift from one target to another); antisaccades (voluntary control over saccade direction to make the response in the opposite direction); smooth pursuits (slower tracking movements to keep a moving stimulus centered on the fovea); vergence (turning motion of the eyeballs toward or away from each other to maintain single binocular vision); accommodation (the ability of the eye to adjust its focal length and maintain focus); the vestibular–ocular reflex (reflex eye movement that stabilizes images on the retina during head movement), and photosensitivity.[92]
- Nearly 30% of concussed athletes report visual problems during the first week after injury,[88] and a recent study showed that 69% of adolescents after concussion (from within 1 month to more than 3 months from injury) had one or more of the following vision diagnoses: accommodative disorders (51%), convergence insufficiency (49%), or saccadic dysfunction (29%).[93]

- Symptoms of oculomotor dysfunction include double vision, blurry vision, headache, or difficulty with reading or other visual work, such as the use of a tablet, smartphone, or computer monitor in the school setting.[93]
- RCTs in the general population without concussion have demonstrated the effectiveness of vergence/accommodative therapy for the treatment of convergence insufficiency and accommodative insufficiency.[94–96]
- With respect to the treatment of visual symptoms after concussion in adults, a preliminary placebo controlled trial showed that oculomotor training (OMT) therapy improved rhythmicity, accuracy, and sequencing of saccades following mTBI (as a result of oculomotor learning).[97] There was also a significant reduction in near vision-related symptoms, increased visual attention, and improved reading ability in the OMT but not the placebo arm of the study.

Aerobic exercise therapy Autonomic dysfunction is present after concussion.[13]

- The Zurich Guidelines advise that when asymptomatic at rest, concussed patients should progress stepwise from light aerobic activity such as walking or stationary cycling up to sport or work-specific activities.[8] Athletes should not return-to-sport (RTS) until they can participate to the full extent of their sport without symptoms.
- Exercise intolerance may be a physiological sign or biomarker of ongoing concussion and the return of normal exercise tolerance may serve as a physiological biomarker to establish physiological recovery from concussion and readiness to RTS.[98]
- Leddy and colleagues[52] have applied this principle to those with persistent symptoms. Their preliminary studies show that individualized subthreshold aerobic exercise treatment improved symptoms in PCS subjects in association with improved fitness and autonomic function (ie, better heart rate [HR] and blood pressure [BP] control) during exercise and, when compared with a period of no intervention, safely sped recovery and restored function (ie, sport and work).[52,54]
- A similar rehabilitation program has been effective for children with PCS.[99]
- Recent fMRI imaging data suggest that some concussion symptoms may be related to abnormal local CBF regulation that is amenable to individualized aerobic exercise treatment. In a small placebo-controlled trial of PCS patients, subthreshold aerobic exercise treatment restored exercise tolerance to normal and brain fMRI activation patterns to controls levels, whereas subjects who received a placebo intervention did not.[100] The mechanisms for concussion-related exercise intolerance and for the effect of subthreshold exercise treatment in patients with concussion and PCS require further study.

The Buffalo Concussion Treadmill Test

- The Buffalo Concussion Treadmill Test (BCTT) is a standardized exercise test that is based on the Balke cardiac protocol. It imparts a gradual increase in workload and is the only functional test thus far shown to safely[52] and reliably[53] reveal physiological dysfunction in concussion, assist in the differential diagnosis of concussion from other diagnoses (eg, cervical injury, depression, migraines),[98] and quantify the clinical severity and exercise capacity of concussed patients.[52]
- The starting speed is 3.2 to 3.6 mph (depending on patient's age and height) at 0% incline. The incline is increased by 1% at minute 2 and by 1% each minute thereafter while maintaining the same speed until the subject cannot continue.
- The BCTT is stopped at the subjective report of significant symptom exacerbation (defined as $\geq$3 point increase over the pretreadmill test resting overall

symptom score on a 1- to 10-point visual analog scale, where a point is given for each increase in a symptom or the appearance of a new symptom) or at exhaustion (rating of perceived exertion [RPE] $\geq$17).[18] The HR recorded at the threshold of symptom exacerbation forms the basis for the individualized exercise prescription (see later discussion).

- Testing requires some experience because neurologic symptoms have been reported by healthy individuals following intense exercise,[101] and cervical symptoms and migraine headaches occasionally become exacerbated during the final stages of the test. The onset of symptom exacerbation in patients with physiological concussion occurs, however, much earlier in the test protocol and well short of predicted maximum exercise capacity.[18]
- The contraindications to performing the BCTT are those that would typically contraindicate the performance of a cardiac stress test and are presented in **Table 1**. Using the BCTT, the author has shown that it is safe for adult PCS patients to exercise up to 74% of maximum predicted capacity,[36] which provides an evidence base for stage 2 (light aerobic exercise) of the Zurich Conference Guidelines' graduated RTP protocol.[8]
- If a submaximal symptom exacerbation threshold is identified, patients are given a prescription to perform aerobic exercise (on a stationary cycle at first, to avoid the vestibular aspects of running) for 20 minutes per day at an intensity of 80% (90% in elite athletes) of the threshold HR achieved on the BCTT (this becomes the target HR) once per day for 5 to 6 days per week using an HR monitor.
- Patients are advised to terminate exercise at the first sign of symptom exacerbation or after 20 minutes, whichever comes first.
- Athletes should use an HR monitor so that they do not exceed the target HR exercise "dose."

Table 1
Absolute and relative contraindications to the Buffalo Concussion Treadmill Test

Absolute Contraindications	
History	Unwilling to exercise
	Increased risk for cardiopulmonary disease as defined by the American College of Sports Medicine[a]
Physical examination	Focal neurologic deficit
	Significant balance deficit, visual deficit, or orthopedic injury that would represent a significant risk for walking/running on a treadmill
Relative contraindications	
History	β-Blocker use
	Major depression (may not comply with directions or prescription)
	Does not understand English
Physical examination	Minor balance deficit, visual deficit, or orthopedic injury that increases risk for walking/running on a treadmill
	Resting systolic BP >140 mm Hg or diastolic BP >90 mm Hg
	Obesity: body mass index $\geq$30 kg/m^2

[a] Individuals with known cardiovascular, pulmonary, or metabolic disease; signs and symptoms suggestive of cardiovascular or pulmonary disease; or individuals $\geq$ age 45 who have more than one risk factor to include: (1) family history of myocardial infarction, coronary revascularization, or sudden death before 55 years of age; (2) cigarette smoking; (3) hypertension; (4) hypercholesterolemia; (5) impaired fasting glucose; or (6) obesity (body mass index $\geq$30 kg/m^2).

From Leddy JJ, Willer B. Use of graded exercise testing in concussion and return-to-activity management. Curr Sports Med Rep 2013;12(6):372; with permission.

- The BCTT can be repeated every 2 to 3 weeks to establish a new target HR until symptoms are no longer exacerbated during exercise. A more cost-effective approach, however, is simply to establish the subthreshold HR on the initial test and increase the exercise target HR by 5 to 10 bpm every 2 weeks (via phone call or e-mail), provided the patient is responding favorably.[98]
- More fit patients and athletes generally respond faster[52] and can increase their HR by 10 bpm every 1 to 2 weeks, whereas nonathletes typically respond better to 5 bpm increments every 2 weeks. Rate of exercise intensity progression varies, and some patients may have to stay at a particular HR for more than 2 weeks.
- Physiological resolution of concussion is defined as the ability to exercise to voluntary exhaustion at 85% to 90% of age-predicted maximum HR for 20 minutes without exacerbation of symptoms for several days in a row.[52] Patients can then begin the Zurich RTP program.
- Exercise testing should only be considered for patients without orthopedic or vestibular problems that increase the risk of falling and only in those patients who are at low risk for cardiac disease.[18] In those patients who have a different cause of persistent symptoms (eg, cervical or vestibulo-ocular disorders), or a combination of disorders (patients with physiological post-concussion disorder can also have a neck injury), the author has found that subthreshold exercise along with specific treatment of the concomitant disorder enhances recovery as well.[98]

SUMMARY

Traditionally, patients have been advised to restrict physical and cognitive activity after concussion until all symptoms resolve. Recent research, however, suggests that prolonged rest beyond the first couple of days after concussion might hinder rather than aid recovery and that a more active approach to concussion management should be considered. Humans do not respond well to removal from their social and physical environments. Sustained rest adversely affects the physiology of concussion and can lead to physical deconditioning and reactive depression. New research suggests that patients after concussion can safely engage in controlled physical activity below the symptom threshold and that controlled activity may even be beneficial to recovery. Practitioners should always take a careful history and perform a physical examination in patients with concussion and in those with delayed recovery to try to identify one or more potentially treatable post-concussion disorders. Several active treatments (eg, subthreshold aerobic exercise, cervical, vestibular, cognitive behavioral, and/or vision therapy) may improve recovery from concussion if they are implemented at the right time. The principle of exercise tolerance can be used to help with the differential diagnosis of PCS, and return of normal exercise tolerance can serve as a physiological biomarker of readiness to return to sport in athletes. Additional research should determine the appropriate timing, mode, duration, intensity, and frequency of exercise during the acute recovery phase of concussion before making specific exercise recommendations. Subsymptom threshold aerobic exercise improves activity tolerance and is an appropriate treatment option for patients with prolonged symptoms after concussion.

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