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Early Aerobic Exercise for the Treatment of Acute Pediatric Concussions

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Sport-related concussion is a common injury that has garnered the attention of the media and general public because of the potential for prolonged acute symptoms and increased risk for long-term impairment. Currently, a growing body of evidence supports the use of various therapies to improve recovery after a concussion. A contemporary approach to managing concussion symptoms is to use aerobic exercise as treatment. To date, several studies on both pediatric and adult patients have established that controlled aerobic exercise is a safe and effective way to rehabilitate patients experiencing delayed recovery after concussion. However, less is known about the utility of an early exercise protocol for optimizing recovery after acute concussion and reducing the risk for persistent post-concussive symptoms, particularly in pediatric populations. Thus, the purpose of our paper was to review and evaluate the available literature on the implementation of aerobic exercise for the treatment of acute pediatric concussion.

Since 2000, the number of pediatric patients diagnosed with concussions in both outpatient and inpatient clinical settings has increased significantly.[1,2] Recent estimates suggest that between 1.1 to 1.9 million sport- and recreation-related concussions occur annually in the United States to children or youths who are 18 years of age or younger.[3] Pediatric patients who experience concussions may present with a variety of physical, cognitive, affective, and behavioral signs and symptoms, including headaches, nausea or vomiting, loss of consciousness, fatigue, confusion, and difficulty focusing or remembering.[2,4] Fortunately, most pediatric patients experience relief of symptoms in the first few weeks after injury, with only a small percentage of patients experiencing delays before making a complete recovery.[5] The earlier treatment paradigm for concussion management consisted of placing patients of all ages on strict physical and cognitive rest until the patient's symptoms resolved and before any return to physical activity would be considered.[6] Recent consensus-based recommendations[7,8] have instead advocated for a more active approach to concussion care. In fact, a growing body of evidence[9–16] suggests that the addition of symptom-limited aerobic exercise to the rehabilitation regimen is well tolerated by pediatric and adult patients and appears to improve self-reported symptoms without negative consequences. However, much of the research[9–19] performed to date on this topic has focused on symptom-limited aerobic exercise for improving recovery in pediatric and adult patients who specifically experienced chronic or prolonged concussion symptoms (>28 days).

Aerobic exercise can improve brain health by promoting brain vascularization and increasing levels of brain-derived neurotrophic factor.[20,21] Brain-derived neurotrophic factor is known to promote the growth of new neurons (*neurogenesis*) as well as help repair and protect neurons from degeneration or other adverse conditions.[20,21] Yet the chief physiological basis for recommending subsymptom aerobic exercise for the treatment of patients with prolonged or delayed recovery is to address the postinjury autonomic nervous system dysfunction and cerebral blood flow changes.[17] Patients with concussions are unable to properly regulate cerebral blood flow, which can exacerbate clinical symptoms during exercise.[10,15,17] Subsymptom aerobic exercise may, over time, help to correct impaired local blood flow in the brain and thereby reestablish normal control of cerebral blood flow.[10,15]

In light of the promising findings indicating that pediatric and adult patients who were slow to recover from concussion injury benefitted considerably from engaging in subsymptom aerobic exercise,[9–16] attention has turned to whether aerobic exercise can also be implemented as a rehabilitation strategy in the more acute stages of recovery as a way to optimize the recovery period or perhaps lessen the risk of developing persistent postconcussion symptoms. Emerging data[10,15,22–24] have shown that autonomic nervous system dysfunction and abnormal cerebral blood flow may develop soon after a concussion injury. Thus, it is believed the early introduction of aerobic exercise to the management plan may bestow positive benefits similar to those observed in patients with protracted recovery. Therefore, the goal of our review was to provide a summary of recently published research regarding early aerobic exercise (ie, exercise initiated in the acute stages of injury) and its efficacy for reducing acute concussion symptoms and facilitating recovery in the pediatric population.[25–29] In addition, we describe the exercise guidelines that have been used by investigators so as to allow clinicians to decide if

Table 1. Research Strategy Used to Select Articles for Review

Elements	Details
Clinical question	Patient group: pediatric patients with acute concussions Intervention: early aerobic exercise Comparison: current standard of care or other passive method of recovery Outcome(s): symptom improvement or readiness to return to activity Time: within 1 wk of injury
Databases searched	The Cochrane Library OVID Embase Google Scholar Web of Science (Web of Knowledge)
Inclusion criteria	Studies in which researchers investigated patients diagnosed with acute concussion or acute sport-related concussion Studies in which researchers investigated patients who began an aerobic exercise program (as a therapeutic intervention) during the acute stages of injury, generally within 7–10 d of a concussion Studies in which researchers investigated patients who were 5–20 y of age
Exclusion criteria	Studies designed to treat patients with prolonged concussion symptoms (>4 wk) or persistent postconcussion symptoms Studies published in a language other than English Studies published before 2015

and how to potentially incorporate these exercise protocols into their clinical practice.

METHODS

We used a deliberate and effective bibliographic research strategy to conduct this review in order to reduce bias in the selection of articles (Table 1). To find the best available evidence to influence practice, we formulated a well-constructed clinical question using the patient, intervention, comparison, outcome(s), time method. Using predetermined inclusion and exclusion criteria, we then performed several searches across multiple databases to obtain the best available evidence.

Search Results

The literature search yielded 1623 potential articles for analysis (Figure). The criteria for article selection were designed to target the most contemporary literature related to early aerobic exercise for the treatment of acute pediatric concussion. After the inclusion and exclusion criteria were applied, only 5 relevant studies[25–29] were identified based on their patient populations, interventions, and outcomes. The 5 studies have been categorized based on the Strength of Recommendation (SOR) Taxonomy (Table 2).[30] This framework allows for the grading of each article's methods to deliver an overall recommendation for incorporating this information into clinical practice. Of the 5 studies identified, 3 were classified as level 2 evidence and 2 as level 1 evidence. Level 1 studies demonstrate good quality in their design and methods.[30] The subsequent levels represent decreases in quality and applicability to a clinical

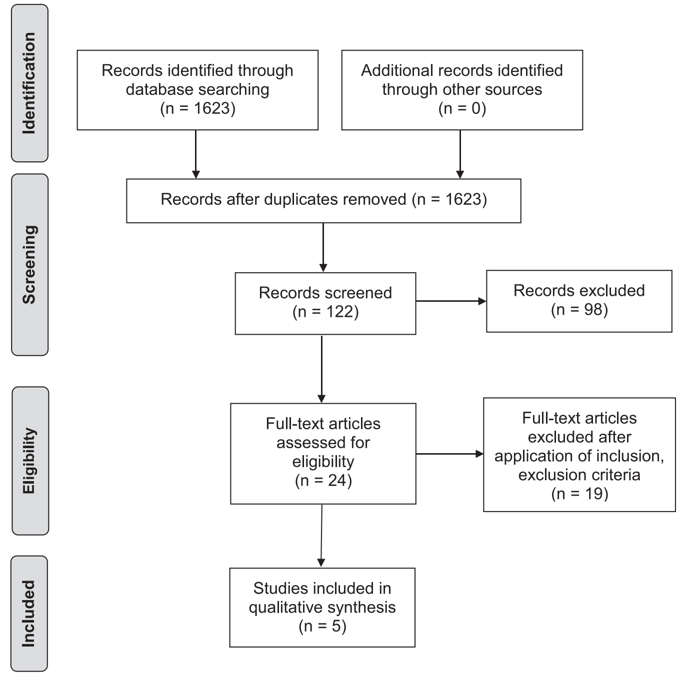

Figure. The literature review process.

recommendation.[30] The characteristics and critical appraisal of each of the applicable studies examined in this review are provided in Tables 2 and 3.

Feasibility and Safety of an Early Exercise Intervention Program After Concussion

Authors of preclinical studies[20,31] on rodents demonstrated that an exercise program that was implemented too soon after a concussion may have negative repercussions for recovery, yet a great deal of interest remains in assessing whether aerobic exercise can be recommended to humans in the early acute stages of injury. To ascertain the clinical utility of aerobic exercise as a treatment option for humans, the requisite first step is to establish whether this type of exercise can be safely tolerated without consequence so soon after a concussion. Fortunately, among the current evidence, investigators[25, 27–29] in 4 preliminary studies have directly (although not uniformly) addressed the feasibility or safety or both of prescribing aerobic exercise during the acute stages of recovery.

In 3 of the aforementioned studies,[25,27,28] the feasibility or tolerability of an exercise program was determined by assessing the number of patients who, by virtue of participating in an exercise program, experienced a delay in their recovery. In 1 study of male patients,[27] not a single person in the exercise group had a prolonged recovery, whereas 4 participants (13%) in the control group (ie, those who were asked to rest only) reported delays in their recovery that averaged 113 $\pm$ 73.6 days. Similarly, other researchers[28] reported that 2 patients (4%) in an aerobic exercise group had a delayed recovery (ie, recovery time >30 days) as compared with 7 patients (14%) in the control group who were engaged in a stretching regimen postinjury. In a third study, patients who initiated a self-selected exercise program were less likely to experience a delayed recovery—as determined by the incidence of persistent

Table 2. Study Details and Classification of Level of Evidence Continued on Next Page

Characteristic	Grool et al[25]	Lawrence et al[26]	Leddy et al[27]	Leddy et al[28]	Micay et al[29]
Study design	Prospective cohort study	Retrospective cohort study	Quasi-experimental	Prospective randomized clinical trial	Prospective randomized controlled trial
Participants	3063 children and adolescents aged 5.00–17.99 y with acute concussion	253 patients with acute concussions aged 15–20 y; 148 males, 105 females	Male adolescents (aged 13–18 y) who sustained concussion; exercise group (n = 24, age = 15.13 ± 1.4 y) and rest group (n = 30, age = 15.33 ± 1.4 y)	Male and female adolescent athletes (aged 13–18 y) presenting within 10 d of diagnosed concussion; experimental group = 52, control group = 51	15 adolescents who sustained concussion (aged 14–18 y); experimental exercise group (n = 8), usual care group (n = 7)
Time when patients began exercise program	≤7 d Postinjury	2–10 d Postinjury	≤10 d Postinjury (average <5 d from injury)	2–10 d Postinjury (average <5 d from injury)	6 d Postinjury
Intervention(s) investigated	Self-initiated early physical activity ≤7 d postinjury	Aerobic exercise, either self-initiated or physician prescribed	Subthreshold aerobic exercise or relative rest (ie, no structured exercise)	Progressive subsymptom threshold aerobic exercise or a progressive placebo-like stretching program	Progressive subsymptom standardized aerobic exercise program starting 6 d postinjury or usual care (rest followed by physician-advised progressions in activity levels in unsupervised setting)
Outcome measure(s)	Physical activity participation and postconcussive symptom severity 7 and 28 d postinjury; persistent postconcussion symptoms assessed 28 d postenrollment	Main outcomes evaluated for all participants were time (days from injury) to full return to (1) sport and (2) school or work	Days to recovery after treatment prescription; *recovery* defined as return to baseline symptoms, exercise tolerant, normal physical examination from physician, and normal cognitive performance on computer-based testing	Days from injury to recovery; *recovery* defined as being asymptomatic, having recovery confirmed through assessment by physician blinded to treatment group, and returning to normal exercise tolerance on treadmill testing. Participants were also classified as having normal (<30 d) or delayed (>30 d) recovery.	Intervention effectiveness evaluated via symptom status and time to medical clearance (d) compared with usual care group
Main findings	Early physical activity participants had lower risk of persistent postconcussion symptoms than those with no physical activity. Early physical activity was associated with lower persistent postconcussion symptom risk. Patients symptomatic at 7 d had ↑ rate of persistent postconcussion symptoms if they reported no physical activity versus light, moderate, and full-contact activity.	With each successive day before start of aerobic exercise, individuals had less favorable recovery trajectory. Initiating aerobic exercise at 3 and 7 d after injury was associated with 36.5% and 73.2%, respectively, ↓ probability of faster full return to sport versus initiating exercise ≤1 d, and 45.9% and 83.1%, respectively, ↓ probability of faster full return to school or work. Concussion history, symptom severity, and loss of consciousness negatively influenced concussion recovery.	Recovery time from initial visit shorter in exercise group; no delayed recovery (>30 d) in exercise group versus 13% (4/30) of rest group	Aerobic exercise participants recovered in median 13 d, whereas stretching participants recovered in 17 d (*P* = .009); nonsignificant lower incidence of delayed recovery in aerobic exercise group (2 participants [4%] in aerobic group versus 7 [14%] in placebo group; *P* = .08)	Aerobic exercise group experienced greater symptom resolution than usual care (control) group across recovery timeline. Structured aerobic exercise protocol appeared to be safe and feasible in postacute stage of concussion recovery in adolescents.

Table 2. Continued From Previous Page

Characteristic	Grool et al[25]	Lawrence et al[26]	Leddy et al[27]	Leddy et al[28]	Micay et al[29]
Level of evidence	2	2	2	1	1
Conclusion(s)	Among participants aged 5 to 18 y with acute concussion, physical activity $\leq$7 d of acute injury versus no physical activity was associated with ↓ risk of persistent postconcussion symptoms at 28 d.	Earlier initiation of aerobic exercise was associated with faster full return to sport and school or work. Insight into benefits and safety of aerobic exercise $\leq$1 wk postinjury provided.	Preliminary data suggest that early subthreshold aerobic exercise prescribed to symptomatic adolescent males $\leq$1 wk of concussion hastened recovery and might prevent delayed recovery.	Individualized subsymptom threshold aerobic exercise treatment prescribed to adolescents with symptoms during wk 1 of concussion speeded recovery and may reduce incidence of delayed recovery.	Structured aerobic exercise protocol appeared to be safe and feasible to administer in adolescents' postacute stage of concussion recovery.

Table 3. Appraisal of Research Studies

Characteristic	Grool et al[25]	Lawrence et al[26]	Leddy et al[27]	Leddy et al[28]	Micay et al[29]
Strengths	Very large sample size improved external validity; more information gathered on younger patients than other studies with prospective designs	Large sample size; population and intervention of interest were thoroughly explored and researchers were blinded while collecting data for main outcomes	Large sample showed differences between groups; quasi-experimental design yielded useful results, but interpretation should be cautious	Decent sample size; well-designed randomized clinical trial; blinded physicians determined recovery	Study design allowed cause-and-effect conclusions to be assessed; standardized protocol easy to implement in clinical practice
Weaknesses	No direct intervention from research group in observational study; physical activity rated via self-reported questionnaires; duration and frequency of exercise not determined; likely variations among the collection sites and treating physicians	Retrospective study design; some patients (No. unclear) self-initiated activity	Participants recruited in 2 time periods; no randomization or researcher blinding; only male athletes examined; activity levels outside of testing sessions not addressed	Participants not observed outside of testing, which could have influenced results; more varied patient population and age demographic needed to extrapolate results to other populations	Small sample size ($n = 15$), so results must be interpreted cautiously when trying to extrapolate to larger population; only males studied, so sex differences unknown

postconcussion symptoms—versus patients who stated they had not participated in any physical activity postinjury.[25]

Instead of using delayed recovery as the criterion for determining the feasibility of administering an aerobic exercise intervention postinjury, authors of a fourth study[29] defined their inclusion criteria as (1) symptoms not being exacerbated during or immediately after exercise compared with pre-exercise levels and (2) participants in the exercise group being able to complete the prescribed exercise program.[29] Symptom status did not worsen either during or immediately after any exercise session for any participant. Also, all participants were able to complete all requisite exercise sessions over the 11-day study period.

It is worth noting that a fifth set of investigators[26] did not explicitly address or disclose whether any of their participants who engaged in early aerobic exercise experienced any negative consequences (eg, worsening symptoms) during the study period. Interestingly, these patients began an exercise program sooner than any others: 3% (n = 8) within 2 days and 21% (n = 52) within 4 days. It is not clear, however, if any of the participants who began an exercise program had a setback as a result of such early intervention. Perhaps future authors should document and report data related to adverse outcomes. Nonetheless, the researchers[26] concluded, without any details or supporting evidence, that early initiation of exercise was safe.

Recommendation: The inclusion of an active intervention early in the treatment plan after pediatric concussion appears to be safe and well tolerated.

The relative safety of initiating an aerobic exercise program in the early stages of recovery after injury has been determined by noting if exercise participation resulted in the exacerbation of symptoms, the inability to complete the prescribed aerobic exercise program, or delayed recovery. Although most of the available evidence regarding the initiation of early aerobic interventions after concussion has been favorable,[24,26–28] feasibility and safety were not uniformly addressed among the studies that were evaluated and, in 1 study,[25] not directly addressed at all. Additional high-quality research studies in which this issue is addressed further using specific outcome measures would be helpful, but the initial body of evidence is good.

SOR: B

Symptom Resolution and Recovery Time

Despite considerable advances supporting the use of active rehabilitation strategies as a way to reduce the severity and prevalence of symptoms[12–14,16] and promote recovery in patients experiencing persistent postconcussive symptoms,[9,13–15] only recently have investigators begun to explore if similar benefits are conferred to patients with acute concussions. To date, all studies[25–29] of the efficacy of aerobic exercise initiated within the first week of injury have generally demonstrated positive benefits.

The first authors to examine the role of acute exercise in concussion recovery were Grool et al,[25] who reported in an observational cohort study that, of the 1677 children and adolescent patients who engaged in early physical activity, 48% (n = 803) had at least 3 persistent or worsening postconcussive symptoms at 7 days after enrollment, compared with 79.5% of patients who were not physically active. At 28 days postenrollment, 28.7% of those who were physically active reported persistent or worsening symptoms, compared with 40.1% of those who rested. Unfortunately, of all the relevant studies, this was the only one we evaluated that did not provide the average time to achieve a full recovery.

The remaining 4 studies[26–29] reviewed addressed the effects of early exercise on both symptom resolution and recovery time. In the first of 2 reports published by Leddy et al,[27] patient recovery was confirmed by physician examination and defined as a return to baseline symptoms. The total recovery time after the onset of injury was more than twice as long for those who had been prescribed rest only postinjury. More specifically, those who were prescribed aerobic exercise achieved recovery in an average of 13 days versus 28 days for the rest group ($P = .052$). At the end of the study, 8% of patients in the exercise group still reported symptoms as compared with 33% of patients in the rest group ($P = .028$).

In a second publication by Leddy et al[28] (a randomized clinical trial), *recovery* was defined as resolution of symptoms to normal levels, which was again confirmed by physician assessment and the ability to exercise to exhaustion. The median recovery period for participants who performed aerobic exercise was less: 13 days versus 17 days for those participants in a stretching group ($P = .009$). In addition, total symptom scores decreased at a much faster pace in the exercise group than in the stretching group, although this difference was not statistically significant.

In the only other randomized control study we reviewed, Micay et al[29] observed that an aerobic exercise group experienced greater resolution of symptom severity over the first 4 weeks postinjury than a control group that received the current standard of care for concussions at that time (ie, the usual recovery care the treating physician would normally prescribe). However, this finding was not different, as the investigation was statistically underpowered due to a small sample size. Interestingly, recovery, which was based on time to full medical clearance to return to play, was slower in the exercise group versus the control group (36.1 ± 18.5 days and 29.6 ± 15.8 days, respectively), but again, this result was not statistically significant. The researchers suggested that the acute symptom burden may have played a role in this conflicting outcome, as participants in the exercise group had higher (but not statistically significant) mean symptom severity scores than the control group at the beginning of the study. Supporting this claim was the significant correlation between acute symptom severity and the overall time to medical clearance.

Finally, in a retrospective report by Lawrence et al,[26] all participants were required to complete the same prescribed exercise program (ie, no control group was present), with the main difference between participants being the time (in days) from injury until the initiation of the exercise program. *Recovery* was defined as the time to full return to sport, school, or work, but the results were presented as the reduction in the probability of a faster full return to sport, school, or work as compared with starting the exercise program on day 1 postinjury. In general, the shorter the time to the initiation of aerobic exercise, the faster the return to sport, school, or work. Unfortunately,

Table 4. Exercise Protocols Used in Preliminary Studies[a]

Variable	Lawrence et al[26]	Leddy et al[27,28]	Micay et al[29]
Method of exercise	Stationary bike	Treadmill or stationary bike	Stationary bike
Variables measured	HR, symptom severity	HR, symptom severity (using VAS), rating of perceived exertion	HR, symptom severity
Exercise dosage	Stage 1: 15 min at 100–120 beats/min Stage 2: 30 min at 100–120 beats/min Stage 3: 30 min at 140 beats/min Stage 4: 1-min maximal sprint every 5 min for 30 min ≥2 sessions at each stage recommended before progression to next level 1 bout exercise/d	Buffalo Concussion Treadmill or Bike Test completed before initiating exercise program to establish safe exercise threshold Patients exercised at 80% of max HR as determined by Buffalo Concussion Treadmill Test Each exercise bout ≥20 min or until symptoms exacerbated (≥2-point increase in symptoms on VAS) 1 bout exercise/d and new exercise HR threshold established each wk Exercise program: 14 d[27]–30 d[28]	5-min Warmup and cool down for each stage Stage 1: 10 min at 50% (of max HR) Stage 2: 20 min at 50% Stage 3: 20 min at 55% Stage 4: 20 min at 60% Stage 5: 20 min at 65% Stage 6: 20 min at 70% Stage 7: 20 min at 70% Stage 8: 20 min at 70% 1 bout exercise/d, with 2 consecutive exercise days, then 1-d rest for total 11 d
End of test	Completion of stage or symptom exacerbation	Completion of stage or symptom exacerbation	Completion of stage or symptom exacerbation
Symptoms exacerbation described	Not applicable	≥2-Point change in VAS symptom score (each new symptom = 1 point)	≥3-Point change in symptom score (each new symptom = 1 point)

Abbreviations: HR, heart rate; VAS, visual analog scale.

[a] Grool et al[25] not included, as exercise protocol was not standardized. Instead, exercise completed by patients was self-initiated and self-selected.

without a control group, it is difficult to assess the actual benefits of an early exercise program versus not exercising.

Recommendation: Introducing aerobic exercise during the acute stage of injury (ie, within 1 week) may be useful for symptom improvement.

Four of the 5 studies showed that implementing an aerobic exercise program within the first week or so of concussion offered some degree of benefit related to symptom improvement, which included a reduction in symptom severity (symptom burden) and a faster resolution of symptoms. Additional work is needed to further strengthen this recommendation.

Also, although positive outcomes related to overall recovery time (ie, decreased time) occurred in 3 of the 4 studies,[26–28] time to recovery was increased among those who pursued an exercise program in a randomized controlled study.[29] Therefore, the ability of early aerobic exercise to optimize recovery and reduce recovery time after a concussion remains uncertain, and no recommendation is provided at this time. Further higher-quality research is needed to fully ascertain whether participation in an aerobic exercise program soon after concussion can consistently reduce the time needed to achieve full recovery.

SOR: B

Exercise Prescription

The exercise program used in 4 of the 5 studies reviewed[26–29] was typically well defined and prescribed by either a physician or the researchers. However, given the novelty of prescribing aerobic exercise as treatment for concussion in the early stages of recovery, it is not surprising that these exercise programs lacked uniformity because the topic had not been examined previously (Table 4). In particular, the exercise programs in these early investigations varied in the frequency, intensity, duration, and type of activities, as well as the time between the injury and when the exercise program was initiated. These components, many of which are elements of a framework for the frequency, intensity, time, and type of exercise prescribed, are important in determining the exercise dosage. As with any evaluation of exercise efficacy, the exercise dosage needs to be well defined so that the minimum level at which exercise begins to confer health benefits can be ascertained. The concept of exercise dosing is also important because it can affect the benefits achieved at various levels of prescribed exercise.

Authors of most of the investigations[26–29] to date have relied on either a stationary bike or treadmill as the preferred choice of aerobic exercise. These modes of exercise were likely chosen for convenience and perhaps as a way for participants to more easily control exercise intensity. Besides exercise mode, several other exercise factors have varied. For example, session durations lasted 10 to 20 minutes[29] or 15 to 30 minutes[26] or were maintained at 20 minutes.[27,28]

Exercise frequency varied to a lesser degree: sessions for 2 consecutive days followed by a day of rest for a total of 8 sessions over 11 days[29] or daily exercise sessions.[26–28]

Perhaps the most variable exercise factor was intensity. Typically, researchers based their exercise intensity on the age-predicted maximal heart rate (HR) or a subsymptom threshold aerobic exercise prescription target HR. In 1 experiment,[29] the exercise program began with the participants exercising on a stationary bike at 50% of their age-predicted maximal HR and steadily increased to 70% over the course of the study. In another,[26] exercise intensity was also initially set at approximately 50% of maximum HR but increased to 70% of maximum HR over time and ultimately progressed to maximal sprints (1 minute in length repeated every 5 minutes for 30 minutes). In contrast, authors of 2 other studies[27,28] set the initial intensity at 80% of the HR at which symptom exacerbation

Table 5. Sample Progression of Low- to Moderate-Intensity Exercise for a 15-Year-Old Patient Recovering From Concussion (Adapted From Micay et al[29])

Characteristic	Details
Exercise type	Stationary bike
Monitored variables	HR, symptom severity
Age-predicted max HR	$208-(0.7 \times \text{age}) = 208-(0.7 \times 15) = 197.5$
Starting intensity	99 beats/min (ie, 50% of age-predicted max HR for 15-year-old patient)
Start date	≤1st wk Postinjury (at physician direction)
Daily progression	Day 1: 10 min at 50% max HR Day 2: 20 min at 50% max HR Day 3: off Day 4: 20 min at 55% max HR Day 5: 20 min at 60% max HR Day 6: off Day 7: 20 min at 65% max HR Day 8: 20 min at 70% max HR Day 9: off Day 10: 20 min at 70% max HR Day 11: 20 min at 70% max HR Day 12: off Day 13: 20 min at 70% max HR Day 14: 20 min at 70% max HR
Symptom exacerbation and protocol modifications	≥3-point ↑ in postconcussion symptom score requires exercise session to cease and be repeated next day

Abbreviation: HR, heart rate; max, maximal.

Table 6. Sample Progression of Subsymptom Threshold Exercise for a 15-Year-Old Patient Recovering From Concussion (Adapted From Leddy et al[27,28])

Characteristic	Description
Exercise type	Stationary bike, treadmill, or swimming
Monitored variables	HR, symptom severity using visual analog scale
Symptom threshold	Exercising HR for symptom exacerbation as determined by Buffalo Concussion Treadmill Test; assume 140 beats/min
Starting exercise intensity	<112 beats/min (ie, 80% of HR level for symptom exacerbation [140 beats/min])
Start date	≤10 d Postinjury (physician discretion)
Daily progression	Week 1 (all + warmup and cool down) Day 1: 20 min at HR <112 beats/min or 80% max HR Day 2: 20 min at <112 beats/min Day 3: 20 min at <112 beats/min Day 4: 20 min at <112 beats/min Day 5: 20 min at <112 beats/min Day 6: 20 min at <112 beats/min Day 7: 20 min at <112 beats/min Week 2 (all + warmup and cool down) Buffalo Concussion Treadmill Test repeated to identify new threshold; assume revised symptom threshold = 160 beats/min, so revised maximum exercise intensity = 128 beats/min (or 80% of HR level for symptom exacerbation) Day 8: 20 min at HR <128 beats/min or 80% max HR Day 9: 20 min at <128 beats/min Day 10: 20 min at <128 beats/min Day 11: 20 min at <128 beats/min Day 12: 20 min at <128 beats/min Day 13: 20 min at <128 beats/min Day 14: 20 min at <128 beats/min
Symptom exacerbation and protocol modifications	If any postconcussion symptoms return during progression, the athlete must return to previous asymptomatic stage or max HR

Abbreviation: HR, heart rate; max, maximal.

occurred. This target HR was initially determined using the Buffalo Concussion Treadmill Test and adjusted thereafter, if needed, depending on the weekly reevaluations. It should be noted that the subsymptom threshold target HR may not parallel the age-predicted maximal HR and, therefore, these 2 strategies represent distinctly different approaches to establishing exercise intensity. (Tables 5 and 6 demonstrate how these 2 strategies differ and how they would be applied for a sample patient.)

Finally, in regard to the time from injury occurrence until the start of an exercise program (ie, start time postinjury), participants in 1 study[29] began exercise on day 6 postinjury, compared with days 2 to 6 in another (retrospective) study.[26] Results of the latter study indicated that the shorter the time to initiation of an exercise program postinjury, the faster the return to sport, school, and work. Although patients in the 3 remaining studies[25,27,28] began their exercise programs within the first 7 days after injury, the effect of the exercise start time on recovery from concussion was not examined.

Recommendation: Both subthreshold exercise and low- to moderate-intensity exercise programs (based on age-predicted maximum HR) performed either daily or intermittently may impart beneficial effects to pediatric patients recovering from concussion.

Individually, the various exercise programs that were examined all appear promising (ie, effective); however, a consensus on which exercise protocol or dosage provides the greatest benefit in terms of symptom resolution or time until recovery is lacking. Therefore, more high-quality (level 1), patient-oriented evidence obtained from larger prospective studies that further examine the role of relevant exercise factors on recovery from concussion are needed. Also, the clinician wishing to implement an exercise program with patients as part of a broader rehabilitation plan would, in all likelihood, prefer that a standardized exercise protocol be adopted or that greater conformity and agreement be reached on the specific exercise factors (as detailed by the frequency, intensity, time, and type of exercise training) that best facilitate recovery.

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CONCLUSIONS

Research that examined the effect of early aerobic exercise for the treatment of acute pediatric concussions has shown promising results, although more high-quality evidence to firmly support its implementation is needed. Data from early studies have provided limited but good-quality evidence that aerobic exercise, when appropriately prescribed during the acute stages of recovery (ie, within 7–

10 days of injury), is safe and well tolerated by pediatric patients. Additionally, introducing aerobic exercise early as part of a comprehensive treatment program does not appear to increase the risk of protracted recovery in this specific population. The emerging evidence also moderately supports the use of early subsymptom aerobic exercise as a way to either lessen the symptom burden or expedite symptom resolution. More consistent investigations are needed to assess the role of an early active intervention to accelerate the time needed by patients to fully recover from concussion. Furthermore, none of the authors who assessed the effectiveness of early active exercise on concussion recovery evaluated the influence of exercise on specific physiological measures of autonomic nervous system function or cerebral blood flow. Therefore, at present, the mechanism of action that appears to facilitate recovery in patients who engage in early active interventions has not yet been fully elucidated and requires additional attention. Finally, to attain the full benefits associated with administering early aerobic exercise in pediatric patients with concussion, clinicians should use a validated protocol that offers the greatest possible benefit. Currently, however, more research is needed to better establish the exercise factors, such as frequency, intensity, and duration of exercise, as well as the optimal timeframe for initiating an exercise program, that are most important for enhancing the recovery process after a concussion injury.

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