Case Report

Aerobic Exercise During Early Rehabilitation for Cervical Spinal Cord Injury

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Background and Purpose. People with spinal cord injuries (SCIs), particularly those with injuries causing tetraplegia, are at risk for cardiovascular illnesses. There is a compelling need to address poor cardiovascular health as early as possible after cervical SCI. The purpose of this case report is to illustrate the process of aerobic exercise prescription during inpatient rehabilitation for cervical SCI.

Case Description. The patient was a 22-year-old man who had sustained a complete C5 SCI during a swimming accident 12 weeks before he participated in an aerobic exercise program. The program was developed to facilitate aerobic capacity while minimizing muscular fatigue. The patient attended 18 sessions over a 2-month period.

Outcomes. The patient's exercise tolerance increased in terms of both exercise duration and exercise intensity. Measurements of cardiovascular health, taken before and after training, revealed substantial increases in peak oxygen uptake (20%) and orthostatic tolerance over the course of the program.

Discussion. The patient experienced typical complications associated with acute SCI (eg, orthostatic hypotension, urinary tract infections). He exhibited several signs of improved exercise tolerance and wheelchair mobility during the 2-month program, indicating potential cardiovascular and functional improvements from the exercise training.

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Cervical spinal cord injuries (SCI) significantly disrupt connections in the spinal cord, causing severe muscle paralysis, loss of sensation, and autonomic dysfunction. People with cervical SCI are likely to become inactive[1] and exhibit low levels of cardiovascular fitness.[2] The latter significantly increases the risk of cardiovascular disease. Cardiovascular disease is the leading cause of death in both people who are able-bodied and people with SCI.[3] However, the disease occurs earlier and is more prevalent in the latter population, and tetraplegic injuries are associated with a 16% higher risk of developing the disease than paraplegic injuries.[4] Although reduced muscle mass is a fundamental factor contributing to inactivity, autonomic dysfunction compounds this problem. The failure of sympathetically driven cardiac acceleration and contractility mechanisms, combined with venous pooling, results in severely decreased cardiac output and therefore a reduction in the overall ability to transport oxygen to the exercising muscle. These factors lead to a vicious cycle of further decline because they can result in reduced functional capacity and, therefore, threaten the ability to live independently.

Physical inactivity directly predisposes people to metabolic syndrome.[5] Metabolic syndrome, a prediabetic state characterized by a group of metabolic risk factors (obesity, high blood pressure, insulin resistance, and atherogenic dyslipidemia[6]), is considered to be a major risk factor for heart disease[7]; its presence approximately doubles the risk of cardiovascular disease mortality.[4] Metabolic syndrome has been shown to be present in 23% of people with SCI (approximately double its presence in people who are able-bodied and of similar ages[6]); the highest incidence of the disease is apparent in people with tetraplegia.[4] The increased risk for metabolic syndrome in the latter population is likely multifactorial. A loss of muscle mass attributable to paralysis causes a shift in body composition from lean mass (composed of skeletal muscle and bone) to fat mass, thus promoting insulin resistance and physical inactivity.[4] Another cardiovascular dysfunction observed in people with SCI is orthostatic hypotension (OH), which is prevelant in both the acute[8] and the chronic[9] stages of SCI. Orthostatic hypotension can significantly complicate and delay rehabilitation for cervical SCI because 58.9% of patients experience symptomatic OH with mobilization.[10] It has even been suggested that OH can lead to neurological deterioration in people who may otherwise have stable SCI.[11] Because prolonged bed rest and cardiac insufficiency are 2 primary causes of OH in people who are able-bodied,[12,13] it is assumed that severe cardiovascular deconditioning in the initial months after SCI increases the risk of OH and, therefore, threatens efficient rehabilitation.

It is critical to address cardiovascular function as early as possible after newly sustained SCI. People with acute, motor-complete cervical SCI can spend up to 4 weeks in bed during acute care.[10] The negative cardiovascular consequences of such prolonged bed rest have been well documented for people who are able-bodied[14] and are particularly detrimental for people with cervical SCI. Thus, cardiovascular training, in addition to increasing sitting tolerance and functional ability, during subacute rehabilitation may halt the cardiovascular deterioration that results from prolonged immobility and reduce OH symptoms. Cardiovascular training is needed if people with SCI are to reach and maintain the level of cardiovascular fitness that is desirable for functioning in daily life. Thus, the effort to achieve optimal levels of fitness through sustained aerobic activity should start during primary rehabilitation.

Despite the compelling rationale to optimize physical fitness levels in people with SCI, research investigating conventional aerobic exercise (eg, sustained wheelchair propulsion [wheeling], arm ergometry) during subacute rehabilitation is scarce. There are currently no guidelines for prescribing aerobic exercise for people with cervical SCI, nor is it an integral part of subacute rehabilitation. To our knowledge, only 2 studies have explored the use of aerobic exercise as an adjunct to primary rehabilitation.[15,16] These studies aimed to maintain an exercise frequency of 3 to 5 days per week at an intensity of 70% to 80% of heart rate reserve (HRR). However, the 2003 study by De Groot et al[15] (n=6) included only 1 individual with cervical SCI, sustained more than 6 months before participation in the program, and the 2005 study by Bizzarini et al[16] did not include any people with complete cervical SCI and did not involve any cardiovascular assessments.

Although previous studies[17–19] demonstrated the beneficial effects of upper-extremity training on cardiovascular status in people with cervical injuries, no study has assessed the feasibility (or the effects) of an aerobic exercise program designed specifically for people with tetraplegia during inpatient rehabilitation. Because people with cervical SCI are severely limited by autonomic ner-

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vous system impairments and paralysis, they are not always able to participate in programs designed for people with full upper-body strength (force-generating capacity) and intact autonomic control of the cardiovascular system. The purpose of this case report is to outline the process used to develop an exercise program to enhance cardiovascular fitness in a patient undergoing primary rehabilitation for a motor-complete C5-C6 SCI. We used a novel upper-extremity circuit training program that aimed to minimize muscular fatigue to facilitate gains in aerobic capacity. Secondary outcomes included measures of OH, lipids, functional wheeling, and program satisfaction.

Patient History and Review of Systems

The patient was a 22-year-old man (weight=62 kg, height=188 cm) admitted for inpatient rehabilitation after a traumatic SCI sustained during a swimming accident. He spent 50 days in acute care before being transferred to the inpatient rehabilitation center.

Clinical Impression

The patient appeared to be a potential candidate for our novel treatment because he was highly motivated to work on his cardiovascular fitness. An American Spinal Injury Association Impairment Scale (AIS) examination[20] was planned to clarify the completeness and severity of the injury.

Examination

The patient rated his activity level before the injury as "very active." The AIS examination revealed a C5 sensory-C6 motor AIS-A SCI. The patient had full passive shoulder range of motion, with an overall motor score of 20/100, and was able to perform some activities of daily living (eg, brushing teeth, upper-body dressing) with assistance. He could tolerate a full day in his manual wheelchair and expressed no complaints of pain, shortness of breath, or cough. He was managing occasional OH with abdominal binders and thromboembolism deterrent stockings. He was participating in standard-of-care physical therapy (1 hour per day) and occupational therapy (1 hour per day), which addressed range of motion, functional mobility, activities of daily living, and wheelchair skills training.

Clinical Impression

The patient was diagnosed with motor-complete tetraplegia. He was a good candidate for our novel treatment because his motor function and strength were such that he was able to perform all exercises in the proposed aerobic exercise program (outlined below). Measurements of cardiovascular health (peak oxygen uptake [$\dot{V}O_2$], 6-minute arm ergometer test, lipid profile, sit-up test, and timed functional wheeling) were to be taken before the commencement of the exercise program, at the midpoint of the program, and at program completion. Because of the medical management of the patient's injury (cervical collar) and the development of deep vein thrombosis, baseline assessments for the case report were completed 6 weeks after admission to the rehabilitation center, and the exercise regimen commenced 3 months after the patient sustained his injury. The patient provided informed consent for the treatment program.

Intervention

The American College of Sports Medicine (ACSM) recommends a minimum exercise frequency of 3 times per week and a minimum duration of 20 to 30 minutes.[21] The ACSM suggests that an exercise intensity of 70% to 80% of HRR is necessary to produce training effects in deconditioned people.[21] Designing an effective aerobic exercise program for people with tetraplegia is challenging because of physiological and musculoskeletal considerations.

Cervical SCIs disrupt sympathetic outflow to the heart, resulting in a blunted chronotropic response to exercise. Normally, the adrenal medulla, which is innervated by cholinergic preganglionic sympathetic neurons originating between T5 and T9,[22] releases epinephrine and norepinephrine into the blood in response to stress or exercise, causing an increase in both heart rate (HR) and blood pressure as well as blood vessel constriction. Whereas people who are able-bodied will show exponential increases in free plasma epinephrine and norepinephrine levels during maximal effort, people with tetraplegia will exhibit only small increases in the levels of these same catecholamines, indicating no considerable stimulation of the sympathetic nervous system.[22] This loss of sympathetic outflow to the heart and adrenal glands results in bradycardia.[23] Consequently, people with tetraplegia show a blunted chronotropic response to exercise and are unable to attain their age-predicted maximal HR; the peak HR in people with cervical injuries rarely exceeds 120 bpm.[24] Thus, exercise intensity in this population cannot be monitored solely with HR and must include ratings of perceived exertion.

Because arm exercises involve a relatively small muscle mass, the primary factors limiting performance may be peripheral in nature; thus, local fatigue of the highly stressed arm musculature may occur despite sufficient systemic oxygen availability.[15] Accordingly, we used interval training to facilitate longer cumulative exercise durations and incorporated several activities to minimize muscle fatigue and boredom.

We developed a circuit that included 4 activities (arm ergometry, boxing,

Table 1.
Guidelines for Progression of Intermittent Exercise[a]

Level	Value on Borg Rating of Perceived Exertion (RPE)	Total Minutes at Indicated Value on Borg RPE	Minutes of Exercise	Minutes of Rest
1	12–14	18	3	2
2	12–14	21	3.5	1.5
3	12–14	24	4	1
4	14–16	24	4	1
5	14–16	27	4.5	0.5
6	14–18 ([1 min at RPE value of 14 + 1 min at RPE value of 18] × 2)	24	4	1

[a] Six repetitions were performed at each level. The patient was considered to be able to progress to the next level of exercise when both of the following criteria were met: first, the patient was able to complete the time goal (exercise minutes) at the current level without pain or overbearing fatigue (fatigue that interferes with activities of daily living or regular therapy, as reported by the patient), and second, the patient was able to complete the exertion goal at the current level without pain or overbearing fatigue.

sliding motion, and wheeling), 2 of which were repeated, for a total of 6 timed stations. The patient chose which 2 stations to repeat; these often were the boxing and sliding stations. Emphasis was placed on proper technique during all stations to minimize the risk of shoulder pain. The patient could perform all of the activities independently. Five minutes was allotted to each station, for a total session duration of 30 minutes. The patient began and finished each session with 2 minutes on the arm ergometer against no resistance. The circuit was to be performed 3 times per week. The exercise protocol was made more challenging throughout the treatment.

Arm ergometry was performed on an arm cycle ergometer (Monark Rehab Trainer 881E*) against 2 to 5 W of resistance. Upright hand cuffs were used so that the hand was placed with the thumb pointing upward, and the ergometer was positioned so that the arm never exceeded the height of the shoulder. A small boxing bag was positioned at shoulder height on the wall. The patient was encouraged to punch the bag with the thumb pointing upward to mitigate any potential shoulder impingement.[25] A VitaGlide wheelchair fitness machine† with Tri-Post Adaptors was used for sliding. The Tri-Post Adaptors provided support for the patient's limited gripping ability. Wheeling was performed forward and backward along a 20-m hallway.

Exercise intensity was monitored with an HR monitor and as perceived exertion. Both exercise duration and intensity progressed over the course of the program in accordance with the ACSM guidelines for exercise progression for individuals with chronic conditions[21]: (1) duration: stations initially consisted of 3 minutes of exercise followed by 2 minutes of rest (18 cumulative minutes of exercise) and gradually increased to 4.5 minutes of exercise followed by 30 seconds of rest (27 cumulative minutes of exercise); (2) intensity: target work rates (HR as determined from initial peak $\dot{V}O_2$ tests and corresponding values on the Borg Rating of Perceived Exertion [RPE][26]) were initially set to 50% of HRR and then gradually increased to 70% to 80% of HRR. The HRR was calculated from a resting HR of 73 bpm and a maximal HR of 109 bpm. Progression guidelines are shown in Table 1.

Outcome

All assessments were performed at 3 time points: baseline (before the exercise program), midpoint (40 days after the first training session, the point at which the patient could complete level 3 of the exercise program [Tab. 1]), and endpoint (80 days after the first training session). The patient did not wear thromboembolism deterrent stockings for any of the tests.

Primary Outcome Measure

Cardiopulmonary status: peak $\dot{V}O_2$. A maximal graded exercise test was performed before the initiation of training to assess cardiopulmonary status. The protocol for assessing peak $\dot{V}O_2$ in people with SCI is well established[27] and documented.[28] In brief, the test consisted of 1 minute of arm cycling against no resistance at a comfortable cadence (generally 50–70 rpm) and subsequent work load increases of 5 W/min[29] until volitional exhaustion. The test was performed on an electronically braked arm ergometer (Excaliber‡). Cardiovascular and metabolic measurements were collected with a 12-lead electrocardiograph (Quark C12§) and a non-rebreathing face mask (K4b2§). The patient rated his perceived exertion by using the Borg RPE immediately after the test.

Secondary Outcome Measures

Functional capacity: 6-minute submaximal arm ergometer task. As a measure of functional capacity, the patient completed a single-stage,

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‡ Lode BV Medical Technology, Zernikepark 16, Groningen, the Netherlands 9747AN.

§ COSMED Srl, Via dei Piani di Mt Savello 37, Pavona di Albano, Rome I-00041, Italy.

6-minute submaximal arm ergometer task shown to be valid and reliable in people with SCI.[28] He cycled against 5 W of resistance at a comfortable cadence (50–70 rpm) for 6 minutes on the arm cycle ergometer used in the training circuit. During arm cycling, the patient wore an HR monitor (Polar A3[‖]) and the non-rebreathing face mask used in the peak $\dot{V}O_2$ test. The HR was recorded every 5 seconds. An average HR over a 30-second period during the last minute of this test was used to determine functional capacity. Immediately after the test, the patient rated his perceived exertion by using the Borg RPE.

Lipid profile. Levels of total cholesterol, high-density lipoprotein (HDL), low-density lipoprotein (LDL), and triglycerides in serum were analyzed by use of fasting blood samples.

Orthostatic tolerance: sit-up test. The presence of OH was assessed with a sit-up test.[9] In the supine position, the patient was fitted with a 12-lead electrocardiograph. Systolic blood pressure, diastolic blood pressure, and mean blood pressure were measured with a calibrated DINAMAP 300 monitor.[#] This monitor accurately measures blood pressure (mean error=≤5 mm Hg, SD=8) and HR (±3.5%).[30] A cuff was placed on the patient's right bicep, and an oximeter was placed on his left index finger. Baseline HR and blood pressure recordings were made during a 10-minute supine rest period. The patient then was passively moved into an upright seated position by raising the head of the plinth by 90 degrees and dropping the base of the plinth by 90 degrees from the knees. This "sit-up" position is essentially the same as that of a patient seated in a wheelchair. The patient was informed about the importance of the sit-up maneuver being passive and was instructed not to assist during the procedure. The upright seated position was maintained for 10 minutes, during which HR and blood pressure recordings were continued. Values from minute 3 after the patient was moved into an upright posture are reported. Orthostatic hypotension was defined as a decrease in systolic blood pressure of ≥20 mm Hg or in diastolic blood pressure of ≥10 mm Hg in the upright position, whether or not symptoms occurred.[31] Visual signs of OH (eg, yawning, pallor) and patient-reported symptoms (eg, lightheadedness, dizziness) also were recorded.

Timed functional wheeling. The patient completed 2 items from the Functional Tasks for Persons Who Self-Propel a Manual Wheelchair.[32] Because the reliability of this measure is reported for each task individually (ie, single-item results can be used[32]), we used the timed forward wheeling (distance=23 m) and ramp ascent (10-m ramp, 1:12 grade) tasks in the treatment program.

Patient perception of the program. At 1 week after exercise completion, the patient completed a 7-item questionnaire regarding his satisfaction with the program (Appendix). We designed the questionnaire on the basis of a literature review of satisfaction criteria and input from 2 SCI rehabilitation researchers. The items in each category were rated on an ordinal scale from 1 to 5. A rating of 5 indicated that the patient was extremely satisfied with the program, and a rating of 1 indicated that he was not satisfied. We calculated a total score from this questionnaire; a higher score indicated a greater degree of satisfaction.

Training intervention. The patient had expressed interest in participating in the exercise program at admission to the rehabilitation center. Although he eagerly attended 18 of 35 scheduled exercise sessions over a 2-month period (average attendance=2 sessions per week), his participation in the program (and required assessment sessions) was disrupted by several common medical setbacks (Fig. 1). Seventeen sessions were rescheduled because of statutory holidays or recreational day trips outside the center (n=5), specialist appointments outside the center (n=4), illness (n=5), or fatigue associated with illness (n=3). During the course of the exercise program, the patient contracted 3 urinary tract infections (UTIs; confirmed by urine cultures), developed heterotopic ossification over his right hip (confirmed on radiographs and bone scans), and sustained a shear wound on his left ischial tuberosity. Although every effort was made to reschedule sessions when possible (eg, to compensate for recreational programs, holidays, or specialist appointments), rescheduling was not always feasible because the patient was very active in his rehabilitation program (he participated in most recreational opportunities) and enjoyed spending time with family and friends.

The progression of the exercise program with regard to percent of HRR and value on the Borg RPE is shown in Figure 1. During the program, exercise duration increased by 6 minutes (from 18 to 24 minutes), and exercise intensity increased in terms of both the average value on the Borg RPE (values of 10 ["light effort"]–18 ["very hard effort"]) and the average HRR (56%–106%). The average value on the Borg RPE in the first half of the program was 12 ("moderately hard"), and the average HRR was 65%. In the second half of the program, the average value on

‖ Polar Electro Inc, 1111 Marcus Ave, Suite M15, Lake Success, NY 11042-1034

Critikon Inc, 4110 George Rd, Tampa, FL 33634.

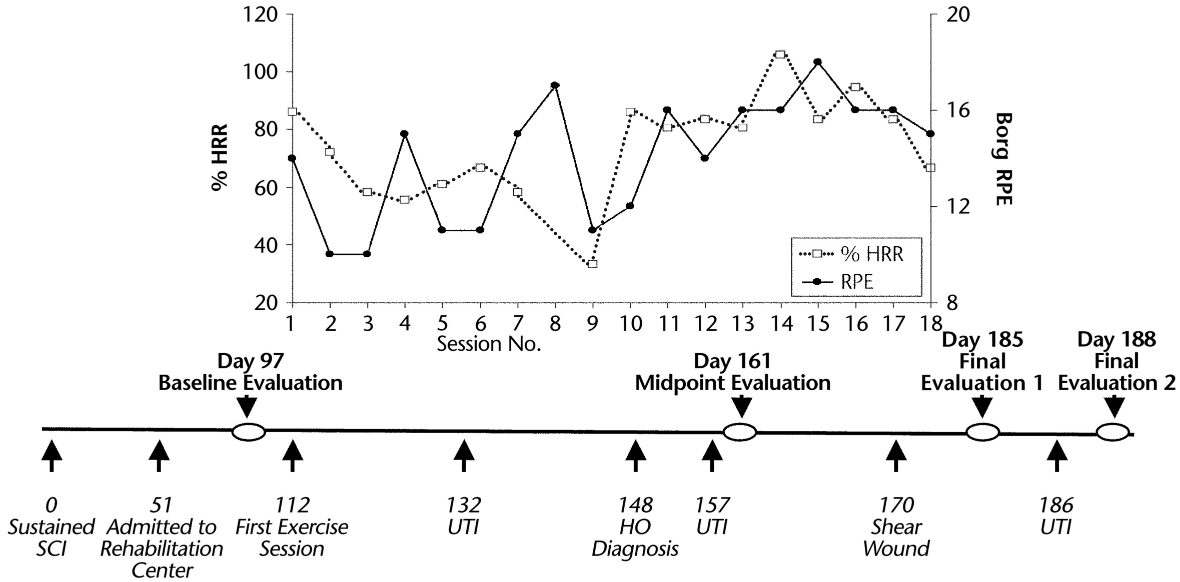

Figure 1.
Exercise program progression. The time course of the exercise program shows exercise intensity (HR reserve [HRR] and Borg Rating of Perceived Exertion [RPE]) over time. Two endpoint assessments were conducted because the patient felt too ill to continue with testing on day 182 (subsequent testing confirmed a urinary tract infection). Thus, the assessments were readministered once the patient felt well enough to perform the tests, and the results of this second endpoint evaluation (final evaluation 2) were analyzed. HO=heterotopic ossification (confirmed by radiography), SCI=spinal cord injury, UTI=urinary tract infection (confirmed by urine culture).

Table 2.
Results of Cardiovascular Assessments

Assessment	Value at: Baseline	Midpoint	Endpoint
Stress test (peak values)			
$\dot{V}O_2$ (mL/kg/min)	11.78	14.16	13.72
Heart rate (bpm)	109	115	117
Power output (W)	20	20	30
Value on Borg Rating of Perceived Exertion	19	19	19
Six-minute submaximal arm ergometer task (average values)			
$\dot{V}O_2$ (mL/kg/min)	8.47	8.68	7.59
Heart rate (bpm)	110	114	99
Value on Borg Rating of Perceived Exertion	11	16	11
Lipid profile, mmol/L (mg/dL)			
Triglycerides	0.41 (36.49)	0.50 (44.50)	0.41 (36.49)
High-density lipoprotein cholesterol	1.08 (42.12)	1.11 (43.29)	1.30 (50.70)
Low-density lipoprotein cholesterol	0.87 (33.93)	0.75 (29.25)	1.05 (40.95)
Ratio of triglycerides to low-density lipoprotein	1.98	1.88	1.95

the Borg RPE was 15 ("hard"), and the average HRR was 85%.

Cardiovascular Assessments

The results of the cardiovascular assessments are shown in Table 2.

Cardiopulmonary status: peak $\dot{V}O_2$. Peak HR increased from 109 bpm (baseline evaluation) to 117 bpm (endpoint evaluation). Peak $\dot{V}O_2$ increased from 11.78 mL/kg/min (baseline) to 13.72 mL/kg/min (endpoint). Power output, measured during the peak cardiovascular stress test, increased from 20 W (baseline) to 30 W (endpoint) during the 2-month period.

Functional capacity: 6-minute submaximal arm ergometer task. The $\dot{V}O_2$ and HR values were lower at the endpoint evaluation ($\dot{V}O_2$=7.59 mL/kg/min, HR=99 bpm) than at the baseline evaluation ($\dot{V}O_2$=8.47 mL/kg/min, HR=110 bpm); however,

Table 3.
Patient's Response to Orthostatic Challenge[a]

Evaluation	Supine Values (Average of First 10 Minutes)			Values at 3-Minute Mark			Final Values (Average of Last 3 Minutes)		
	SBP (mm Hg)	DBP (mm Hg)	HR (bpm)	SBP (mm Hg)	DBP (mm Hg)	HR (bpm)	SBP (mm Hg)	DBP (mm Hg)	HR (bpm)
Before program	107.3	58.2	72.8	75	37	87	86.7	49.3	90.7
Midpoint	124	75.6	59.6	112	72	67	98	66.7	87.7
After program	111.1	57.8	76.9	62	32	101	67.7	32	98.3

[a] Average values from 10-minute supine rest period at beginning of challenge, values at 3 minutes after sit-up maneuver, and average values from final 18 to 20 minutes of challenge are shown for systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR). bpm=beats per minute.

the values on the Borg RPE remained the same (ie, 11).

Lipid profile. Lipid changes were minimal. The patient's HDL values increased from the baseline evaluation (1.08 mmol/L, 42.12 mg/dL) to the endpoint evaluation (1.30 mmol/L, 50.70 mg/dL), whereas the ratio of total cholesterol to HDL decreased by 0.03 (baseline=1.98, endpoint=1.95) during the course of the exercise program.

Orthostatic tolerance: sit-up test. The patient's response to an orthostatic challenge improved from the baseline evaluation to the midpoint evaluation (Tab. 3, Fig. 2). During the baseline evaluation, at 3 minutes after passive movement of the patient from a supine position to a sitting position, his systolic blood pressure decreased from 107.3 mm Hg to 75 mm Hg and his diastolic blood pressure decreased from 58.2 mm Hg to 37 mm Hg, confirming the presence of OH. These decreases in blood pressure were accompanied by feelings of dizziness and lightheadedness. During the midpoint evaluation, blood pressure did not show a large decrease at the 3-minute mark (like that observed during the baseline evaluation), and the patient had no complaints of adverse symptoms. Because of an acute UTI, however, these improvements were not apparent during the endpoint evaluation. Two endpoint assessments were required because the patient felt too ill to continue with testing on day 182 (subsequent testing confirmed a UTI). Thus, the assessments were readministered once the patient felt well enough to perform the tests. The results of this second endpoint evaluation were analyzed and are presented in Table 3 and Figure 2. Dehydration and fatigue (common consequences of a UTI) likely impaired orthostatic tolerance.[12] However, the patient's HR at 3 minutes after the sit-up maneuver during the endpoint evaluation (101 bpm) was 14 beats higher than that at the baseline evaluation (87 bpm), suggesting an improvement in chronotropic compensation during the orthostatic challenge.

Timed functional wheeling. The patient showed improvements on the 2 wheeling tests during the course of the exercise program, with substantially faster times to cover the flat distance (from 19 seconds at the baseline to 12 seconds at the endpoint) and the ramp (from 23 seconds [with 4 rest breaks] at the baseline to 12 seconds [without stopping] at the endpoint).

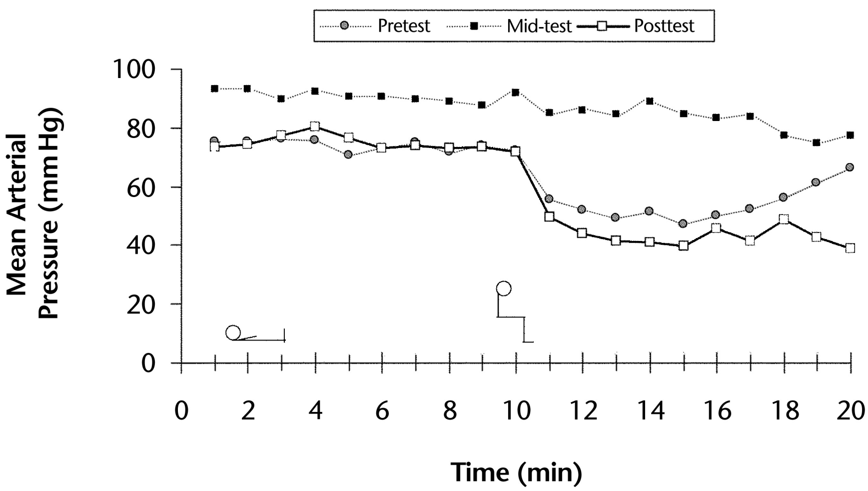

Figure 2.
Sit-up test. Minute-by-minute measurements of mean arterial blood pressure in response to an orthostatic challenge test before the program, at the midpoint, and after the program are shown. Two endpoint assessments were conducted because the patient felt too ill to continue with testing on day 182 (subsequent testing confirmed a urinary tract infection). Thus, the assessments were readministered once the patient felt well enough to perform the tests. The results of this second endpoint evaluation were analyzed and are shown in Table 3.

Patient perception of the program. The patient rated the program 31 out of a possible 35 points, with a score of 3 on items 3 and 5 (satisfaction with content and manageability of the program) and a score of 5 (extremely satisfied) on all other items. He stated that each station had its own unique challenges and functional outcomes. For example, he noticed and appreciated increases in hand-eye coordination, balance, and body awareness from practicing the boxing station. He also believed that using the arm ergometer was instrumental in alleviating some mild shoulder pain, stating that this was likely attributable to balanced strengthening from the push-pull motion. He also commented on the psychological benefits of exercise, reporting that the "biggest thing" about the program was that the exercise increased his mood, stating that "it [the exercise] is good for the body and, even more importantly, good for the mind."

Discussion

The aerobic exercise program appeared to be a feasible addition to the patient's inpatient rehabilitation schedule because he was able to participate without adverse effects, was able to increase his exercise tolerance, and reported that he enjoyed the program. The upper-extremity circuit that we developed is a unique alternative to a standard arm ergometry exercise program. It provides the opportunity to increase aerobic capacity while minimizing muscular fatigue and boredom. Increased exercise tolerance, evident during both training and testing sessions, suggested gains in aerobic capacity, and orthostatic testing indicated increased orthostatic tolerance. The patient also commented on the psychological benefits of aerobic exercise.

The activities and intensity used in our program were modified to continually challenge the patient's increasing capacity for exercise (as measured by changes in HR and value on the Borg RPE). Careful adjustment of exercise prescription is of utmost importance in people with SCI because training intensities must not compromise the muscles required for wheeling and transferring yet must be high enough to induce training effects.[33] The patient was able to sustain a relatively high level of physical effort during inpatient rehabilitation without compromising standard therapy or experiencing overbearing fatigue (fatigue that would consistently prohibit participation in regular therapy). Although the protocol of sessions on 3 days per week seemed to be relatively manageable at the outset of the program, participating in 3 sessions per week was often difficult. Medical complications and numerous specialist appointments outside the center impeded regular adherence to the program. These disturbances are commonly encountered during SCI rehabilitation[34] and need to be recognized and accounted for to achieve the realistic implementation of any program. Thus, although a frequency of 3 sessions per week often is thought to be optimal for exercise training, it has been noted that twice-weekly programs may be more suitable for people with SCI because they offer benefits similar to those of more frequent training yet provide a prescription to which it is easier to adhere.[33]

The patient exhibited several signs of increased exercise tolerance (eg, sustained increases in exercise duration and intensity) throughout the program, indicating potential cardiac or peripheral skeletal muscle adaptations to the exercise training. Aerobic changes during exercise (sustained elevation of HRR and values on the Borg RPE) seemed to occur during the second half of the program. This result was likely attributable to the fact that the patient was accustomed to the exercises and, therefore, could challenge himself with respect to intensity and his ability to sustain longer exercise durations. His peak $\dot{V}O_2$ changed by 2 mL/kg/min (with a corresponding 10-W increase in power output) from the baseline evaluation to the endpoint evaluation. Functionally, this result was previously shown to positively relate to wheeling performance; a change in the peak $\dot{V}O_2$ of 2 mL/kg/min was sufficient to increase the ability and decrease the time to complete a wheelchair circuit in 74 people with SCI.[35] Similarly, our patient showed improvements on the 2 wheeling tests, indicating a concomitant increase in functional wheeling ability.

We found that orthostatic tolerance in our patient improved after 6 weeks of aerobic exercise. Heart rate responses to orthostatic stress normally are attributable to baroreflex-mediated parasympathetic (vagal) withdrawal and sympathetic activation.[12] However, because of our patient's cardiovascular sympathetic insufficiency, it is likely that any increase in HR during the orthostatic challenge was predominantly attributable to baroreceptor reflex–mediated reductions in vagal tone. Although there is some evidence to support the role of exercise in increasing baroreceptor activity in people who are able-bodied,[36] similar research in people with SCI is scarce, although Engelke et al suggested that it may play a similar role in people with SCI.[37] They found that exercise induced a 4-fold increase in the cardiac baroreceptor reflex response, increased the sensitivity of the aortic baroreceptor reflex control of HR, and ultimately eliminated OH.[37]

The deterioration of the patient's orthostatic tolerance after an episode of UTI was likely multifactorial. On the one hand is the effect of deconditioning because the patient likely experienced a decrease in activity level subsequent to more time spent in bed as a result of increased spasticity (reflex activity) and discomfort. In fact, it was previously shown that 48 hours of bed rest can impair orthostatic tolerance in people during hospitalization.[38] On the other hand, increased sweating (because of the high temperature associated with a UTI) may have contributed to a loss of intravascular volume and dehydration, thereby resulting in decreased orthostatic tolerance.

Previous researchers reported unfavorable lipid profiles in people with SCI and suggested that low levels of HDL are mainly attributable to low physical activity secondary to wheelchair dependency.[39] Thus, HDL correlates positively with physical activity and negatively with the risk of cardiovascular disease.[15] Although De Groot et al[15] demonstrated that a physical activity program enhanced the lipid profiles of people undergoing primary rehabilitation for SCI,[15] Solomonow et al[40] found that people with normal cholesterol levels did not exhibit changes in HDL or LDL after a 14-week exercise program.[40] Because our patient's lipid profile was within normal guidelines,[41] minimal changes were observed. Like those of previously published work,[15] the results of this case report suggested that being physically active can increase HDL and that this mechanism may have decreased the risk for cardiovascular disease in our patient with tetraplegia.

The medical complications mentioned in this case report are common occurrences during inpatient rehabilitation for cervical SCI.[34] Clinicians and scientists performing research with inpatients who have SCI need to be aware of the typical interruptions during rehabilitation. Although participation in our exercise program was complicated by various medical setbacks, our patient was able to tolerate the training sessions, suggesting that this program is a feasible addition to standard therapy. Thus, it would appear, from the results of this case report, that a patient with a motor-complete C5 SCI is able to sustain a relatively high level of physical effort during initial rehabilitation without compromising standard therapy or experiencing overbearing fatigue. Early aerobic training has the potential to mitigate cardiovascular deterioration and metabolic alterations, thereby decreasing cardiovascular risk factors and achieving optimal physical fitness for function in daily life.

Limitations

The findings described in this case report have limitations that must be taken into consideration. First, our patient was a recently injured individual undergoing subacute rehabilitation; thus, physiologic changes may have been influenced by the typical rehabilitation program and natural processes of adaptation, recovery, or both. Adding elements of a controlled experiment is necessary to address internal validity concerns about the effects of history or maturation. Second, the difficulty in accurately measuring exercise intensity in people with tetraplegia cannot be overlooked. Although the Borg RPE is commonly used as an index of the physiologic response to exercise in people with SCI, no correlations have been found between workloads and HR or $\dot{V}O_2$ at high exercise intensities in people with tetraplegia.[42] However, HRR generally mirrored values on the Borg RPE throughout the program, indicating that the Borg RPE provided a reflection of our patient's exertion. Third, because we did not do any follow-up on exercise behavior after the termination of the program, we could not examine long-term exercise adherence after discharge from inpatient rehabilitation.

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References

1 Tawashy AE, Eng JJ, Lin KH, et al. Physical activity is related to lower levels of pain, fatigue and depression in individuals with spinal-cord injury: a correlational study. *Spinal Cord.* 2008;47:301–306.

2 Hoffman MD. Cardiorespiratory fitness and training in quadriplegics and paraplegics. *Sports Med.* 1986;3:312–330.

3 Garshick E, Kelley A, Cohen SA, et al. A prospective assessment of mortality in chronic spinal cord injury. *Spinal Cord.* 2005;43:408–416.

4 Myers J, Lee M, Kiratli J. Cardiovascular disease in spinal cord injury: an overview of prevalence, risk, evaluation, and management. *Am J Phys Med Rehabil.* 2007;86:142–152.

5 Dallmeijer AJ, Hopman MT, Angenot EL, van der Woude LH. Effect of training on physical capacity and physical strain in persons with tetraplegia. *Scand J Rehabil Med.* 1997;29:181–186.

6 Lee MY, Myers J, Hayes A, et al. C-reactive protein, metabolic syndrome, and insulin resistance in individuals with spinal cord injury. *J Spinal Cord Med.* 2005;28:20–25.

7 American Heart Association. Metabolic syndrome. Available at http://www.americanheart.org/presenter.jhtml?identifier=4756. Accessed October 30, 2009.

8 Sidorov EV, Townson AF, Dvorak MF, et al. Orthostatic hypotension in the first month following acute spinal cord injury. *Spinal Cord.* 2008;46:65–69.

9 Claydon VE, Krassioukov AV. Orthostatic hypotension and autonomic pathways after spinal cord injury. *J Neurotrauma.* 2006;23:1713–1725.

10 Illman A, Stiller K, Williams M. The prevalence of orthostatic hypotension during physiotherapy treatment in patients with an acute spinal cord injury. *Spinal Cord.* 2000;38:741–747.

11 El Masry WS. Physiological instability of the spinal cord following injury. *Paraplegia.* 1993;31:273–275.

12 Mathias CJ. Orthostatic hypotension: causes, mechanisms, and influencing factors. *Neurology.* 1995;45(suppl):S6–S11.

13 Claydon VE, Steeves JD, Krassioukov AV. Orthostatic hypotension following spinal cord injury: understanding clinical pathophysiology. *Spinal Cord.* 2006;44:341–351.

14 Saltin B, Blomqvist G, Mitchell JH, et al. Response to exercise after bed rest and after training. *Circulation.* 1968;38(5 suppl):VII1–VII78.

15 De Groot PCE, Hjeltnes N, Heijboer AC, et al. Effect of training intensity on physical capacity, lipid profile and insulin sensitivity in early rehabilitation of spinal cord injured individuals. *Spinal Cord.* 2003;41:673–679.

16 Bizzarini E, Saccavini M, Lipanje F, et al. Exercise prescription in subjects with spinal cord injuries. *Arch Phys Med Rehabil.* 2005;86:1170–1175.

17 DiCarlo SE. Improved cardiopulmonary status after a two-month program of graded arm exercise in a patient with C6 quadriplegia: a case report. *Phys Ther.* 1982;62:456–459.

18 DiCarlo SE. Effect of arm ergometry training on wheelchair propulsion endurance of individuals with quadriplegia. *Phys Ther.* 1988;68:40–44.

19 McLean KP, Skinner JS. Effect of body training position on outcomes of an aerobic training study on individuals with quadriplegia. *Arch Phys Med Rehabil.* 1995;76:139–150.

20 Marino RJ, Barros T, Biering-Sorensen F, et al. International standards for neurological classification of spinal cord injury. *J Spinal Cord Med.* 2003;26(suppl 1):S50–S56.

21 American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription.* 8th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2009.

22 Bravo G, Guizar-Sahagun G, Ibarra A, et al. Cardiovascular alterations after spinal cord injury: an overview. *Curr Med Chem Cardiovasc Hematol Agents.* 2004;2:133–148.

23 Krassioukov AV, Karlsson AK, Wecht JM, et al. Assessment of autonomic dysfunction following spinal cord injury: rationale for additions to International Standards for Neurological Assessment. *J Rehabil Res Dev.* 2007;44:103–112.

24 Freyschuss U, Knutsson E. Cardiovascular control in man with transverse cervical cord lesions. *Life Sci.* 1969;8:421–424.

25 Kirshblum S, Campagnolo DI, DeLisa JA. *Spinal Cord Medicine.* Philadelphia, PA: Lippincott Williams & Wilkins; 2001.

26 Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med.* 1970;2:92–98.

27 Lasko-McCarthey P, Davis JA. Protocol dependency of $\dot{V}O_2$max during arm cycle ergometry in males with quadriplegia. *Med Sci Sports Exerc.* 1991;23:1097–1101.

28 Hol AT, Eng JJ, Miller WC, et al. Reliability and validity of the six-minute arm test for the evaluation of cardiovascular fitness in people with spinal cord injury. *Arch Phys Med Rehabil.* 2007;88:489–495.

29 Lasko-McCarthey P, Davis JA. Effect of work rate increment on peak oxygen uptake during wheelchair ergometry in men with quadriplegia. *Eur J Appl Physiol Occup Physiol.* 1991;63:349–353.

30 Critikon. *DINAMAP Pro Series 100–400 Monitor Operation Manual.* Tampa, FL: Critikon, Inc; 1999.

31 Consensus Committee of the American Autonomic Society and the American Academy of Neurology. Consensus statement on the definition of orthostatic hypotension, pure autonomic failure, and multiple system atrophy. *Neurology.* 1996;46:1470.

32 May LA, Butt C, Minor L, et al. Measurement reliability of functional tasks for persons who self-propel a manual wheelchair. *Arch Phys Med Rehabil.* 2003;84:578–583.

33 Martin Ginis KA, Hicks AL. Considerations for the development of a physical activity guide for Canadians with physical disabilities. *Appl Physiol Nutr Metab.* 2007;32(suppl):S135–S147.

34 Chen D, Apple DF, Hudson LM, Bode R. Medical complications during acute rehabilitation following spinal cord injury: current experience of the model systems. *Arch Phys Med Rehabil.* 1999;80:1397–1401.

35 Kilkens OJ, Dallmeijer AJ, Nene AV, et al. The longitudinal relation between physical capacity and wheelchair skill performance during inpatient rehabilitation of people with spinal cord injury. *Arch Phys Med Rehabil.* 2005;86:1575–1581.

36 Convertino VA, Adams WC. Enhanced vagal baroreflex response during 24 h after acute exercise. *Am J Physiol Regul Integr Comp Physiol.* 1991;260:570–575.

37 Engelke KA, Shea JD, Doerr DF, Convertino VA. Enhanced carotid-cardiac baroreflex response and elimination of orthostatic hypotension 24 hours after acute exercise in paraplegics. *Paraplegia.* 1992;30:872–879.

38 Schneider SM, Robergs RA, Amorim FT, et al. Impaired orthostatic response in patients with type 2 diabetes mellitus after 48 hours of bed rest. *Endocr Pract.* 2009;15:104–110.

39 Dearwater SR, LaPorte RE, Robertson RJ, et al. Activity in the spinal cord-injured patient: an epidemiologic analysis of metabolic parameters. *Med Sci Sports Exerc.* 1986;18:541–544.

40 Solomonow M, Reisin E, Aguilar E, et al. Reciprocating gait orthosis powered with electrical muscle stimulation (RGO II), part II: medical evaluation of 70 paraplegic patients. *Orthopedics.* 1997;20:411–418.

41 Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults. Executive summary of the Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III). *JAMA.* 2001;285:2486–2497.

42 Lewis JE, Nash MS, Hamm LF, et al. The relationship between perceived exertion and physiologic indicators of stress during graded arm exercise in persons with spinal cord injuries. *Arch Phys Med Rehabil.* 2007;88:1205–1211.

Appendix.
Patient Satisfaction Scale

I am interested in how you feel about the exercise program you participated in over the past 2 months. Please tell me how you would rate the following (response categories: 1=not at all satisfied, 2=somewhat satisfied, 3=satisfied, 4=very satisfied, 5=extremely satisfied).

1. How satisfied were you with the frequency of the program (3 times per week)?
2. How satisfied were you with the duration of the program (30 minutes)?
3. How satisfied were you with the content of the program (6 stations)?
4. How satisfied were you with the intensity of the program (12–16 on the Borg Rating of Perceived Exertion)?

For each of the following statements, please tell me how manageable/beneficial/enjoyable you found the exercise program (response categories [eg, for question 1]: 1=not at all manageable, 2=somewhat manageable, 3=manageable, 4=very manageable, 5=extremely manageable).

1. How manageable is the program given an inpatient rehabilitation schedule?
2. How beneficial did you find the program?
3. How enjoyable did you find the program?