Exercise Prescription in Subjects With Spinal Cord Injuries

Emiliana Bizzarini, MD, Marsilio Saccavini, MD, Federica Lipanje, MD, Paolo Magrin, MD, Cristina Malisan, PT, Agostino Zampa, MD

ABSTRACT. Bizzarini E, Saccavini M, Lipanje F, Magrin P, Malisan C, Zampa A. Exercise prescription in subjects with spinal cord injuries. Arch Phys Med Rehabil 2005;86:1170-5.

Objective: To evaluate the effect of training with ergometers on subjects with spinal cord injury (SCI) in the postacute phase.

Design: Cohort study.

Setting: A spinal unit at a physical medicine and rehabilitation institute.

Participants: Twenty-one subjects with SCI in the postacute phase as a consecutive sample were chosen on a strict first-come, first-chosen basis. All patients completed the study.

Interventions: A 6-week (5d/wk, 90min/d) program consisting of exercises with the ergometers formulated (as intensity and duration) for each patient on the basis of the results obtained in specific cardiovascular tests.

Main Outcome Measures: Parameters of workload levels, as well as hematologic and hormonal parameters, recorded during the first 6 weeks of training.

Results: The workload performed during the training showed an initial increase, but it reached a plateau in week 4. No statistically meaningful variations in the workload emerged between the fourth and the sixth weeks of monitoring. There were no hematologic or hormonal signs of overtraining.

Conclusions: Strengthening and aerobic rehabilitation programs for patients with subacute SCI should be limited to 4 weeks, followed by an independent maintenance exercise program. The strengthening program is safe for these patients.

Key Words: Ergometry; Exercise; Hematology; Rehabilitation; Spinal cord injuries.

IT IS HIGHLY DESIRABLE THAT spinal cord injury (SCI) patients begin active physical therapy programs as soon after injury as possible. However, 2 important problems should be addressed when dealing with SCI patients in the subacute phase—namely, the reduction in cardiovascular fitness and in work capacity, by loss of sympathetic control and functional muscle mass. The sympathetic innervation of the heart derives from the spinal cord segments between T1 and T4, so a lesion above T1-4 could seriously compromise an increase in heart rate at the beginning of the exercise, as well as heart output, final diastolic volume, and stroke volume. However, in subjects with higher levels of injury, the primary mechanism for heart rate increase during exercise is withdrawal of vagal inhibition, in the absence of sympathetic innervation.[1] Sympathetic nervous system impairment limits control of regional blood flow and cardiac output, and maximal heart rate may be reduced to 110 to 130 beats/min. It should be remembered that, often in the recovery phase, subjects with SCI are candidates for immediate and serious hypotension.[2] Issues of concern in an exercise program for people with SCI in the subacute phase include the inability to respond to the training program (bedrest syndrome), because the heart, lung, and muscles above the lesion are not conditioned to exercise. After spinal cord trauma, muscles beneath the lesion are affected by morphologic, metabolic, and contractile alterations. Nevertheless, what is known is that a rise in mechanical power is also caused by a correct recruitment of the paretic muscles. To assess the effect of exercise on muscle, the first step is to measure the increase in workload. To be able to quantify the workout, the mechanical energy produced by the human body could be applied to instruments capable of measuring the amount of work exerted: the ergometers.

No other studies have examined the amount of increase attainable in muscle strength and the appropriate duration of training in subjects with SCI in the subacute phase. In addition, no other studies monitored the rehabilitation program effect on hormonal and metabolic parameters used to signal an overtraining syndrome.[3] Moreover, no consensus about a specific training program has been reached for the SCI population.[4]

The aim of our study was to assess the effectiveness of an "enhanced" 6-week rehabilitation program in newly injured paraplegic and tetraplegic patients.

Various combinations of training intensity, duration, and frequency are often proposed to people with SCI in order to improve fitness. We devised a rehabilitation program based on stress arm crank tests. Metabolic parameters (lactate, testosterone, cortisol, creatine phosphokinase [CPK], luteinizing hormone [LH], urea, blood iron, transferrin, ferritin, blood glucose) were used as reliable indicators of the conditioning levels of exercise.[3]

METHODS

Participants

Twenty-one subjects (mean age, 33.81±14.83y) were examined. We enrolled the first 21 patients admitted to the Spinal Unit of the Institute of Physical Medicine and Rehabilitation of Udine. They all had SCI in the postacute phase (6 cervical lesions, 15 thoracic and lumbar lesions). The demographic data referring to the SCI and the American Spinal Injury Association (ASIA) motor score are shown in table 1. The level of SCI for each participant was determined by a physician through myotomal and dermatomal testing. The ASIA system for classification of SCI was used, and each individual was categorized as being either tetraplegic (with an injury to the spinal cord between the levels of C4 and C8) or paraplegic (injury at T1 or below). Eight patients had ASIA Impairment Scale (AIS) score B, and 13 patients had AIS score C. Patients were divided into

From the Ergonomics & Occupational Therapy, Spinal Unit, Department of Rehabilitation Medicine, Physical Medicine and Rehabilitation Institute, Udine (Bizzarini, Saccavini, Malisan, Zampa); School of Physical Medicine and Rehabilitation, University of Trieste, Trieste (Lipanje); and School of Sport Medicine, University of Udine, Udine (Magrin), Italy.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the author(s) or upon any organization with which the author(s) is/are associated.

Reprint requests to Emiliana Bizzarini, M. Ergonomia & Terapia Occupazionale; Unità Spinale; Istituto di Medicina Fisica e Riabilitazione, Azienda per i Servizi Sanitari No. 4 Medio Friuli, via Gervasutta 48, 33100 Udine, Italia.

0003-9993/05/8606-8910$30.00/0
doi:10.1016/j.apmr.2004.11.014

Table 1: Demographic Data

Patient	Sex	Age (y)	Lesion Type	Lesion Level	AIS Score	ASIA Motor Score	Lesion From t0 (d)
Tm1	M	19	Dislocation	C4	C	24	153
Tm2	M	65	Ependymoma	C5	C	53	49
Tm3	M	33	Frac-dis	C5	C	13	96
Tm4	M	25	Contusion	C4	C	44	50
Tm5	M	25	Fracture	C6	C	18	183
Tm6	M	29	Fracture	C7	B	40	38
PHm1	M	54	Frac-dis	T2	C	50	158
PHm2	M	29	Fracture	T4	C	50	65
PHm3	M	22	Frac-dis	T3	C	50	59
PHm4	M	16	Frac-dis	T5	B	50	94
PHm5	M	31	Fracture	T6	B	50	63
PHm6	M	66	Fracture	T6	B	50	91
PLm1	M	24	Fracture	T11	B	50	24
PLm2	M	49	Fracture	T12	B	54	213
PLm3	M	22	Frac-dis	T10	C	57	91
PLm4	M	32	Fracture	T7	B	50	103
PLm5	M	22	Fracture	L2	C	68	23
PLm6	M	38	Ependymoma	T8	C	85	18
PLf1	F	21	Fracture	L1	C	50	225
PLf2	F	51	Fracture	T7	B	50	41
PLf3	F	37	Fracture	T8	C	50	110

Abbreviations: AIS, ASIA Impairment Scale; f, female; F, female; Frac-dis, fracture-dislocation; m, male; M, male; PH, high paraplegic lesion; PL, low paraplegic lesion; T, tetraplegic lesion.

subgroups according to sex (male, female) and level of lesion (tetraplegic lesion level C4-8, high paraplegic lesion level T1-6, low paraplegic lesion level T7-L2). None of these subjects was affected by significant cardiovascular and respiratory diseases. The training began, on average, 92.71±14.83 days after the day of the spinal cord lesion and lasted 60 days at the most. Informed consent was obtained from all participants before the study.

Training Sessions

Patients were monitored every 2 weeks for 42 days. The first rehabilitation session was performed in our gym. Each patient undertook and completed a daily training session for approximately 90min/d, including during the recovery periods. The exercise program covered 5d/wk. The training consisted of exercises on the ergometers (cranking ergometer, wheelchair ergometer) based on discontinuous protocols and formulated for each patient on the basis of the results obtained in specific cardiovascular tests performed every 2 weeks. Each test was preceded by a 1-minute warm-up. During the test, resistance was increased by 12.5W every 2 minutes. The test could be interrupted for any of the following reasons: personal decision, symptoms of cardiopulmonary abnormality, electrocardiogram alterations, or attaining of the maximum expected level of proficiency. Because of the difficulty in achieving small enough workload grades for tetraplegic participants, the protocol was modified so that workload increments would be more gradual. Initially, this was accomplished by increasing only the rate at which the subjects were working, as opposed to the resistance on the flywheel. The training was then modulated with the aim of maintaining the target heart rate between 70% and 80% of the maximal heart rate. The heart rate was determined by using the following formulas: reserve of heart rate = maximal heart rate (reached at the stress test) – heart rate at rest; training heart rate = (reserve of heart rate × % of desirable intensity) + heart rate at rest. Additionally, patients rated their subjectively perceived effort on the Borg 20-point scale, which during the training session was maintained between score 12 and 16.

Training to improve upper-limb strength was performed by using pulley machines and with exercises concentrating on the main muscle groups (latissimus dorsi, deltiformis, pectoralis, triceps brachii, biceps brachii). A pyramidal protocol based on maximal tests (single maximal repetition reached during an increasing number of pounds lifted), repeated every 10 training sessions, was drawn up for this purpose. The exercises were then performed 8 times for 3 sets at an intensity of 40% to 60% of the single maximal repetition.

The workout with the ergometers and pulley machines was evaluated every 2 weeks, and a new training program was then proposed. The average value of the total workout at t0 (first day of training in our gym), t14, t28, and t42, by every group of subjects, was recorded. The average value was calculated as the total workout in newtons done in 2 weeks divided by 10 training sessions, the number of training sessions performed in 2 weeks.

Patients with AIS score C also undertook exercises to increase lower-limb strength (leg press). These exercises were also performed on a single maximal repetition basis (which was reached during an increasing number of pounds lifted). For these patients, a specific resistance workout was devised by using bicycle ergometers for the lower limbs and modulating the intensity and the duration of the training on previous cardiovascular tests.

Body mass index (BMI) was calculated for each individual by using the formula: BMI = weight (in kilograms)/height^2 (in meters). The body composition of the patients was estimated from measurements of skinfold thickness. The skinfold was estimated, by the same operator, entirely from the nondominant side of the body, taking the average of 3 measurements. A Harpenden caliper was used for the evaluation. The percentage of total body fat (table 2) was calculated on the basis of the sum of skinfold thickness from 4 locations (biceps, triceps, subscap-

Table 2: Anthropometric Parameters

Parameters	Average Male Tetraplegia ± SD	Average Male High Paraplegia ± SD	Average Male Low Paraplegia ± SD	Average Female Low Paraplegia ± SD
t0				
Stature (m)	1.85±0.09	1.77±0.08	1.75±0.05	1.59±0.12
Weight (kg)	67.13±10.80	70.40±8.17	65.00±11.75	53.00±4.24
BMI (kg/m²)	19.92±4.29	22.59±3.84	21.06±3.45	21.15±1.51
Waist/hip ratio	0.93±0.04	0.94±0.02	0.92±0.03	0.87±0.09
Sum of the 4 skinfold	31.85±13.76	37.02±12.03	35.73±7.22	56.45±1.48
FM (kg)	9.39±5.69	13.35±2.62	11.83±5.01	13.43±3.10
FFM (kg)	57.74±5.70	57.05±6.27	53.17±7.29	39.58±1.13
FFM/FM ratio	8.96±6.78	4.36±0.72	4.86±1.16	3.02±0.62
FM (%)	13.26±6.67	18.90±2.34	16.48±1.89	25.18±3.85
t42				
Stature (m)	1.85±0.09	1.77±0.08	1.75±0.05	1.59±0.12
Weight (kg)	66.50±11.21	71.00±7.71	61.00±9.54	55.00±7.07
BMI (kg/m²)	19.71±4.24	22.80±3.88	19.78±2.33	21.87±0.49
Waist/hip ratio	0.93±0.03	0.95±0.02	0.93±0.03	0.83±0.00
Sum of the 4 skinfold	25.83±7.65	39.15±10.62	33.77±5.81	51.77±14.18
FM (kg)	8.62±5.01	13.97±2.06	8.90±3.58	15.84±3.88
FFM (kg)	57.88±6.40	57.03±6.29	52.10±6.16	39.17±3.19
FFM/FM ratio	9.01±5.66	413±0.56	6.50±2.50	2.53±0.42
FM (%)	12.30±5.65	19.68±2.00	14.22±4.00	28.57±3.38

Abbreviations: FFM, fat-free mass; FM, fat mass; SD, standard deviation.

ular, suprailiac) by using the Durnin and Womersley equations[5] specific for sex and age.

The intensity of each single training session was estimated according to the values of lactate produced after exertion, whereas the CPK value was adopted to assess training load.

During monitoring, we also evaluated some specific metabolic parameters, which are considered to be clear indicators of overtraining in sports medicine, to test the safety of the program.[3]

Laboratory Testing

Blood tests were performed on all patients on the same day of the week (Thursday). The first blood test (t0) was always taken within 3 days of the patient's admission to our gym. Blood samples were drawn in the morning after overnight fasting and were used to study the baseline levels at rest for blood urea nitrogen (BUN), blood iron, blood transferrin, ferritin, blood glucose, CPK, testosterone, and cortisol. All samples collected were stored below 0°C until centrifugation, at which time the supernatant was separated. Glucose, iron, and CPK were measured with a routine clinical chemistry analyzer.[a] Ferritin, LH, and CPK of the muscle band were assayed with the microparticle immunoassay.[b] Cortisol and testosterone 12 were measured with competitive luminescence assays,[c] transferrin with an immunonephelometric method on BN-II automatic analyzer.[d] Lactate was determined with the manual photometric method.[e]

Data Analysis

For the data analysis, the nonparametric Wilcoxon signed-rank test was used to compare the numeric variables obtained during exercise. We considered *P* less than .05 to be statistically significant. To study and compare the differences in the values of the specific metabolic parameters at the different times of assessment (t0, t14, t28, t42), the Spearman rank-order correlation test was used.

RESULTS

The workload performed was evaluated during the first 6 weeks of "enhanced" training in subjects with SCI in the subacute phase by using an ergometer for training and evaluation. After an initial increase in workload performed, a plateau was reached on week 4 (fig 1). After that, the monitoring of subjects revealed no statistically significant variations in the total newtons achieved during a single rehabilitation session (table 3).

No statistically significant difference was found between the patients' initial and final weight as the percentage of body fat remained stable, except for low paraplegic male subjects (see table 2).

A few hematologic and hormonal parameters were tested to verify whether the subjects were in a so-called overtraining phase, but we failed to detect any such indications of overtraining.[3]

In particular, with respect to the values of testosterone (figs 2, 3), the results recorded do not highlight any statistically

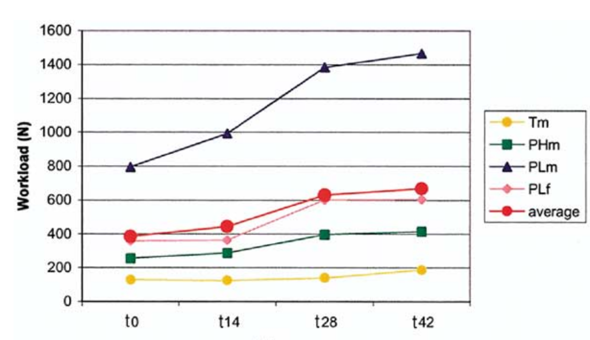

Fig 1. Workload from t0 to t42 for 21 subjects. Abbreviations: f, female; m, male; PH, high paraplegic lesion; PL, low paraplegic lesion; T, tetraplegic lesion.

Table 3: Workload (in watts)

	Male Tetraplegia	Male High Paraplegia	Male Low Paraplegia	Female Low Paraplegia
Time	Average ± SD	Average ± SD	Average ± SD	Average ± SD
Week 1	128.33±84.30	257.10±57.26	794.97±713.93	358.33±211.80
Week 2	124.58±101.17	288.44±66.78	994.46±918.64	363.33±206.48
Week 4	140.50±107.17	395.83±72.77	1383.56±1690.45	602.78±517.32
Week 6	186.75±148.81	415.06±60.61	1466.54±1698.30	605.00±515.34

significant differences between the data obtained at t0, t14, t28, or t42. However, they did seem to suggest a tendency to increase, particularly in the final phase of the monitoring (42d). Cortisol, whose values at t0 are higher than normal, in support of the integrity of the hypothalamus-pituitary-adrenal axis after a spinal cord lesion, did not seem to change significantly from the initial values. This increase was not, however, statistically significant. LH showed a different course for each patient examined; however, by analyzing the average values, a progressive decrease was recorded during monitoring. This was even more evident between t0 and t42, although this decrease was not statistically significant.

The blood level of CPK, which was evaluated at rest (fig 4) never more than 24 hours after the previous training session, failed to show any significant variations, nor did it show a proportional increase as the training load progressively increased. However, a general tendency toward a decrease was noticed during the last 2 weeks of monitoring as compared with the previous training sessions. Along with the hematologic parameters, consideration was also given to parameters such as BUN, to plasmatic iron—namely, the concentration of iron in the organism; to transferrin, the concentration of protein that carries it through the blood; and to ferritin, which determines the amount of deposit. The statistical analysis of these parameters, however, did not detect any significant variation between the 4 measurements taken during the 6 training sessions.

DISCUSSION

Health promotion strategies, such as fitness and activity programs, may improve quality of life for this population.[6] Exercise can improve resistance and muscular strength in people with paraplegia.[7] Durán et al[8] evaluated in a primary rehabilitation program the effects of an exercise program on the rehabilitation of patients with thoracic level lesions caused by gunshot. Subjects in that study were at a median of 10 months between the injury and the beginning of the study (range, 2–120mo), and in most patients the injuries were more than 6 months old.

There is agreement about the statement that, in people with SCI, physical activity correlates positively with the domains of physical independence[9]; however, specific recommendations about the type, intensity, and frequency of the training program have not been established. There is a discrepancy among the various training programs proposed for SCI persons.[10] For the prescription of exercise, the following specific parameters are fundamental: frequency of movements, intensity, and duration. About duration, in particular, Tordi et al[4] investigated the effects of a short-interval training program specifically designed for patients with SCI. Tordi studied the effect, in SCI persons, of a specific interval training that has been successfully performed in patients with chronic airway obstruction and in patients after heart transplantation.

Training on the ergometers allows one to monitor cardiovascular capacities and to evaluate objectively how much they increase. Other previous studies[10,11] have analyzed training on the arm-crank ergometer. According to these studies, exercise duration ranged from 4 to 24 weeks, with a frequency of 2 to 3 sessions per week. Although the duration of exercise varied inversely to intensity, the intensity threshold required to induce training benefits with wheelchair users was determined at 70% of the maximal heart rate and for a minimal duration of 20 minutes.[10,11] We agree that the intensity threshold of exercise should be set at 70% of the maximal heart rate, but we also believe that a single test performed at the beginning of the training in patients in the subacute phase is not sufficient, because of the different levels of cardiovascular conditioning of the subjects in this rehabilitation phase. As for strength, a test was performed every 2 weeks. In our study, a significant increase in workload was found at the end of the 6-week exercise program.

Our study did not find any significant changes in the percentage of lean body weight or adiposity, as reported in the study by Midha et al.[12] Use of the Durnin and Womersley[5] method for such measurements can underestimate the average percentage of fat, according to Spungen et al,[13] because lower-limb tissues, which will have more significant changes after an SCI, are not taken into account.

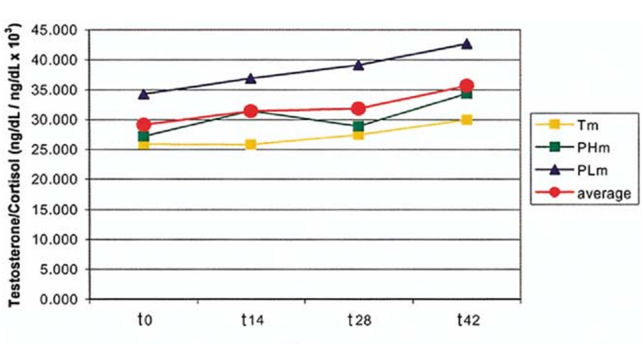

Fig 2. The testosterone/cortisol ratio during t0 to t42 monitoring for male subjects.

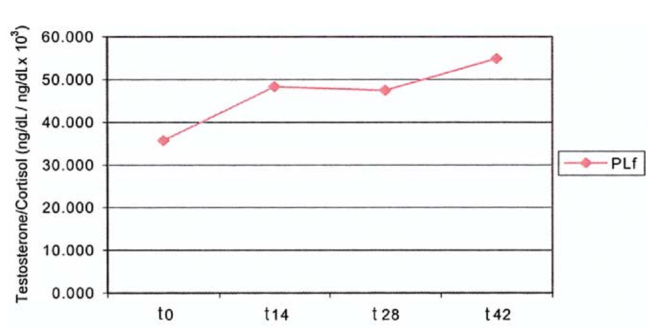

Fig 3. The testosterone/cortisol ratio during t0 to t42 monitoring for female subjects.

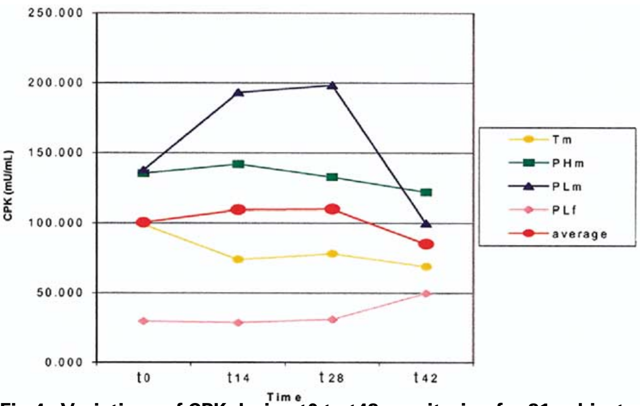

Fig 4. Variations of CPK during t0 to t42 monitoring for 21 subjects.

It was observed that patients with SCI in the postacute phase responded differently to exercise than did healthy subjects.[14] Among the many factors that complicate the response to exercise[15] is the apparent involvement of the endocrine system. It has been noted that hormonal parameters in blood and urine are affected because their values show an inadequate response to stress agents.[12,15,16] The primary factor that causes such altered results is the interruption of the neural pathways and specifically the drop in the values of the catecholamines.[17,18] Nerves, in fact, can influence the concentration of testosterone, perhaps also through the circulating catecholamines, given that exercise in particular can immediately affect the secretion of blood-free testosterone, cortisol, and catecholamines. Finsen et al[19] shows that, once the situation is stabilized, the levels of testosterone return to their normative range. Several studies[20,21] have shown that, subsequent to an SCI, some neuroendocrine alterations occur that suggest a deficiency in the function of the hypothalamus-pituitary-adrenal axis, despite the normative levels of cortisol recorded at rest and an adequate response to the adrenocorticotropic hormone.

We tested some metabolic parameters used to verify the overtraining syndrome, a condition that occurs when a subject has undergone an intense and heavy training load without stopping to adequately recover. For a subject to recover, a few weeks of rest, or at least a drastic reduction in the training load, is required.[22] The overtraining syndrome determines an increase in basal metabolism, a loss of weight, and a negative nitrogenous balance with a slow return to basic conditions. Moreover, it may also affect the nervous system, the endocrine system, and hypothalamus control.[22-25] In cases of overtraining syndrome,[3] testosterone levels adjust rapidly to endurance exercises, whereas hormonal plasmatic levels decrease if the patient's workload increases. By and large, the values of testosterone at rest decrease with either an increase in workload or overall workout intensity, even in cases in which the overtraining syndrome is not clearly present. Cortisol-increased circulating levels may be associated with psychologic depression, a condition sometimes associated with forms of overtraining.[3]

The quite high levels of plasmatic cortisol in our patients with SCI in the postacute phase do not contradict the hypothesis of the deficiency of the hypothalamus-pituitary-adrenal axis. The lack of an increase in the cortisol levels, despite the intervention of a systemic stimulus such as exercise, could be the result of either the lack of a real catabolic phase in response to a high workload or the lack of a metabolic adjustment to the induced stimulus, together with the inability to adjust to the training itself.

Because the overall testosterone/cortisol ratio, which is nowadays considered a clear marker of overtraining, seemed to increase slightly in the last weeks of training, it is possible to confirm the absence of a catabolic phase in response to exercise in our patients. Although a greater number of subjects is needed to generalize our findings, the parameters used to confirm a condition of overtraining did not show any statistically significant variations in our patients, despite an intense and progressively heavier workload.

CONCLUSIONS

In our population of subjects with SCI, the workload performed increased during the first 4 weeks of enhanced training. But the actual workload performed reached a plateau between weeks 4 and 6, with no sign of any increase in the parameters that normally signal an overtraining syndrome. This leads to the following conclusions. A 6-week enhanced training program in the SCI population is effective; however, a plateau occurs between weeks 4 and 6. Therefore, we believe that strengthening and aerobic rehabilitation programs for subacute SCI patients should be limited to 4 weeks, followed by an independently maintained exercise program.

Although more subjects are needed for generalization of the findings, we found that there is no laboratory evidence of overtraining. We, therefore, suggest that this type of exercise program is safe for this population.

References

1. Birk TJ, Nieshoff E, Gray G, Steeby J, Jablonski K. Metabolic and cardiopulmonary responses to acute progressive resistive exercise in a person with C4 spinal cord injury. Spinal Cord 2001;39:336-9.
2. Shepard RJ. Sports medicine and the wheelchair athlete. Sports Med 1988;5:226-47.
3. Fry AC, Kraemer WJ. Resistance exercise overtraining and overreaching. Sports Med 1997;23:106-29.
4. Tordi N, Dugue B, Klupzinski D, Rasseneur L, Rouillon JD, Lonsdorfer J. Interval training program on a wheelchair ergometer for paraplegic subjects. Spinal Cord 2001;39:532-7.
5. Durnin JV, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurement on 481 men and women aged from 16 to 72 years. Br J Nutr 1974;32:77-97.
6. Noreau L, Shephard RJ. Spinal cord injury, exercise and quality of life. Sports Med 1995;20:226-50.
7. Gass GC, Camp EM, Davis HA, Eager D, Grant L. The effect of prolonged exercise on spinally injured subjects. Med Sci Sports Exerc 1981;13:277-83.
8. Durán FS, Lugo L, Ramírez L, Eusse E. Effects of an exercise program on the rehabilitation of patients with spinal cord injury. Arch Phys Med Rehabil 2001;82:1349-54.
9. Manns PJ, Chad KE. Determining the relation between quality of life, handicap, fitness, and physical activity for persons with spinal cord injury. Arch Phys Med Rehabil 1999;80:1566-71.
10. Hooker SP, Wells CL. Effects of low and moderate intensity training in spinal cord-injured persons. Med Sci Sports Exerc 1989;21:18-22.
11. Crane L, Klerk K, Ruhl A, Warner P, Ruhl C, Roach KE. The effect of exercise training on pulmonary function in persons with quadriplegia. Paraplegia 1994;32:435-41.
12. Midha M, Schmitt JK, Sclater M. Exercise effect with the wheelchair aerobic fitness trainer on conditioning and metabolic function in disabled persons: a pilot study. Arch Phys Med Rehabil 1999;80:258-61.

13. Spungen AM, Bauman WA, Wang J, Pierson RN. Measurement of body fat in individuals with tetraplegia: a comparison of eight clinical methods. Paraplegia 1995;33:402-8.
14. Capodaglio P, Grilli C, Bazzini G. Tolerable exercise intensity in the early rehabilitation of paraplegic patients. A preliminary study. Spinal Cord 1996;34:684-90.
15. Claus-Walker J, Halstead LS. Metabolic and endocrine changes in spinal cord injury: I. The nervous system before and after transection of the spinal cord. Arch Phys Med Rehabil 1981;62:595-601.
16. Claus-Walker J, Halstead LS. Metabolic and endocrine changes in spinal cord injury: II (section 1). Consequences of partial decentralization of the autonomic nervous system. Arch Phys Med Rehabil 1982;63:569-75.
17. Frey GC, McCubbin JA, Dunn JM, Mazzeo RS. Plasma catecholamines and lactate relationship during graded exercise in men with spinal cord injury. Med Sci Sports Exerc 1997;29:451-6.
18. Schmid A, Huonker M, Barturen JM, et al. Catecholamines, heart rate, and oxygen uptake during exercise in persons with spinal cord injury. J Appl Physiol 1998;85:635-41.
19. Finsen V, Indredavik B, Fougner KJ. Bone mineral and hormone status in paraplegics. Paraplegia 1992;30:343-7.
20. Wheeler G, Cumming D, Burnham R, et al. Testosterone, cortisol and catecholamines responses to exercise stress and autonomic dysreflexia in elite quadriplegic athletes. Paraplegia 1994;32:292-9.
21. Wheeler GD, Ashley EA, Harber V, et al. Hormonal responses to graded-resistance, FES-assisted strength training in spinal cord-injured. Spinal Cord 1996;34:264-7.
22. Urhausen A, Gabriel HH, Kindermann W. Impaired pituitary hormonal response to exhaustive exercise in overtrained endurance athletes. Med Sci Sports Exerc 1998;30:407-14.
23. Hartmann U, Mester J. Training and overtraining markers in selected sport events. Med Sci Sports Exerc 2000;32:209-15.
24. Lehmann MJ, Lormes W, Opitz-Gress A, et al. Training and overtraining: an overview and experimental results in endurance sports. J Sports Med Phys Fitness 1997;37:7-17.
25. Lehmann M, Foster C, Dickhuth HH, Gastmann U. Autonomic imbalance hypothesis and overtraining syndrome. Med Sci Sports Exerc 1998;30:1140-5.

Suppliers

a. ILAB-900; Instrumentation Laboratory, 101 Hartwell Ave, Lexington, MA 02421.
b. AxSYM; Abbott Laboratories, 100 Abbott Park Rd, Abbott Park, IL 60064.
c. Immulite One; Diagnostic Products Corp, 5210 Pacific Concourse Dr, Los Angeles, CA 90045.
d. Dade Behring Holding GmbH, Höchster Str 70, 65835 Liederbach, Germany.
e. Sigma-Aldrich Corp, 3050 Spruce St, St. Louis, MO 63103.