The Influence of Early Aerobic Training on the Functional Capacity in Patients With Cerebrovascular Accident at the Subacute Stage

Michal Katz-Leurer, PhD, Mera Shochina, MD, Eli Carmeli, PhD, Yechiel Friedlander, PhD

ABSTRACT. Katz-Leurer M, Shochina M, Carmeli E, Friedlander Y. The influence of early aerobic training on the functional capacity in patients with cerebrovascular accident at the subacute stage. Arch Phys Med Rehabil 2003;84:1609-14.

Objective: To investigate the effect of early aerobic training on the aerobic and functional abilities of patients in the subacute stage of cerebrovascular accident (CVA).

Design: Randomized controlled trial.

Setting: Rehabilitation unit in Israel.

Participants: Ninety-two patients who had a first CVA were randomly assigned to an exercise-training group or to a control group.

Intervention: Aerobic training with a leg cycle ergometer for 8 weeks.

Main Outcome Measures: Workload, exercise time, resting and submaximal blood pressure and heart rate, and functional abilities.

Results: A trend toward improvement was found in all aerobic parameters for the experimental group, but only heart rate at rest (P=.02), workload, and work time (P<.01) improved significantly. A trend for improvement was also found in all parameters of function for the experimental group, but only stair climbing was significantly better (P<.01). An interaction (95% confidence interval, 1.7–17.21) was found between age and aerobic training on walking distance. Although no significant effect was found in the group of younger patients (aged <65y), a significant difference in favor of training was noted in the group of older patients.

Conclusions: Patients with CVA in the subacute stage improved some of their aerobic and functional abilities after submaximal aerobic training.

Key Words: Cerebrovascular accident; Exercise; Rehabilitation.

From the Rehabilitation Department, Hadassah University Hospital, Jerusalem (Katz-Leurer, Shochina); Sackler Faculty of Medicine, School of Health Professions, Dept of Physical Therapy, Tel-Aviv University, Ramat Aviv (Katz-Leurer, Carmeli); Hebrew University–Hadassah Medical School, Jerusalem (Shochina); and Department of Social Medicine, Hebrew University–Hadassah School of Public Health, Jerusalem (Friedlander), Israel.

Supported in part by the Chief Scientific Ministry of Health, Jerusalem, Israel.

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 Michal Katz-Leurer, PhD, Sackler Faculty of Medicine, Sch of Health Professions, Tel-Aviv University, Ramat Aviv 69978, Israel, e-mail: *michalkz@post.tau.ac.il.*

0003-9993/03/8411-7798$30.00/0

doi:10.1053/S0003-9993(03)00344-7

IT IS ESTIMATED that more than 60% of survivors of cerebrovascular accident (CVA) will have some permanent deficit affecting functional ability.[1] The main aim of rehabilitation is to optimize patients' ability to function, to improve their quality of life. There are different techniques for achieving this goal. The superiority of no particular treatment approach has yet been proven in terms of activities of daily living, including general mobility, tone, or function.[2]

It is known that stroke patients have low endurance during exercise both due to the event and as a secondary reaction to forced inactivity.[3,4] It is also known that there is a positive connection between aerobic capacity and functional performance.[5] Even so, aerobic exercise training is not regularly included in rehabilitation programs after CVA.

The main aims of this clinical trial were to test (1) whether aerobic training at the subacute stage in CVA patients' rehabilitation can preserve and improve their aerobic capacity and (2) whether this intervention improves function and walking ability of stroke patients at the end of the rehabilitation period.

METHODS

Study Population

Ninety-two patients, who were hospitalized up to 48 hours after the initiation of clinical signs of their first stroke, were included. Patients were excluded from the study if they had brainstem lesions and/or bilateral signs; had no lower-limb paralysis on admission; were unconscious and/or totally incontinent after the event; had been admitted to the rehabilitation department more than 30 days after the acute hospitalization; had an electrocardiogram (ECG) that showed pathologic change at rest and/or during their first stress test on admission to the rehabilitation department; presented with a significant change in blood pressure on exertion, a resting systolic blood pressure (SBP) of more than 200mmHg, or a resting diastolic blood pressure (DBP) higher than 100mmHg; had arrhythmia or heart failure; were taking β-blockers; or had inflammatory or degenerative joint diseases. The hospital ethics committee approved the study. Each patient gave informed consent.

The patients (N=92) were randomly assigned to the study groups by using a block sampling method. Separate sampling was taken of patients with lesions in the right and left hemisphere. At the beginning of the study, all patients were inpatients in the rehabilitation department and, according to their abilities, were transitioned to the outpatient clinic at the same center (fig 1).

Stress Test

Physical fitness was evaluated according to a graded stress test.[6] The test consisted of an exercise protocol on a leg cycle ergometer while patients sat in their own wheelchairs. For patients to become familiar with the device, the exercise protocol began with 2 minutes of unloaded pedaling with the help of the cycle's motor, which moved the flywheel at 20rpm at minute 1 and 50rpm at minute 2. During minute 3, patients

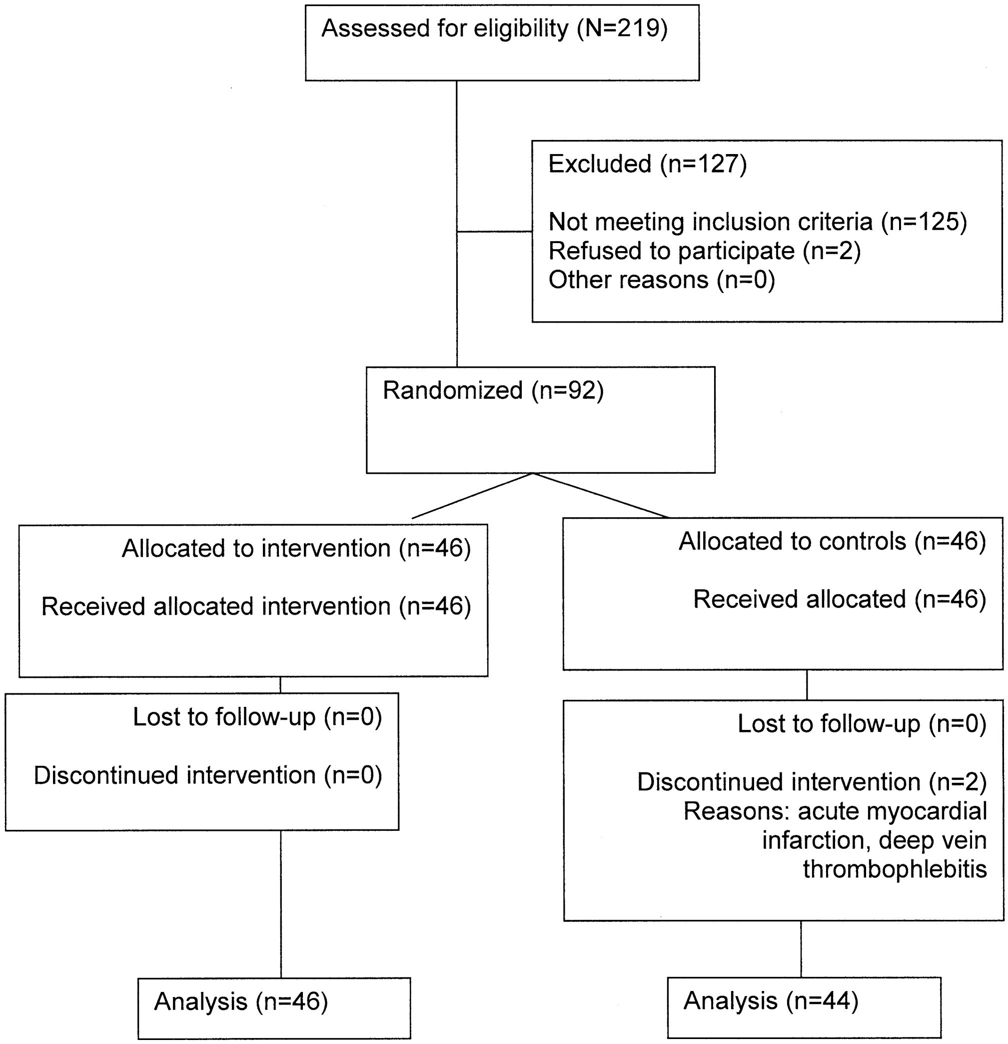

Fig 1. Flowchart of participants through each stage of the trial.[24]

were asked to maintain 50rpm while the accessory motor was shut down. At minute 4, resistance exercise began at 2W; at minute 5, it continued at 4W; at that point, workload was increased by 4W each minute for the next 6 minutes, and then by 8W until the end of the test.

The criterion for maximal effort was 85% of age-predicted maximal heart rate ([220−age]×.85). The exercise protocol ended when the subject was exhausted (when subjects could no longer continue pedaling, they were asked to stop), when the researcher saw that the patient could no longer pedal at 50rpm (without the patient asking to stop), or when pathologic findings were noticed in the ECG (eg, heart rate irregularity, ST depression). At that point, final measurements were taken, and subjects completed cool-down and recovery periods.

Heart rate, monitored and recorded every minute during exercise and recovery, was obtained from the relative risk interval on the ECG. Resting heart rate was determined after subjects sat for 20 minutes at rest before getting on the ergometer. Maximal heart rate was the average heart rate during the last 30 seconds of exercise.

Blood pressure was measured in the nonparetic arm with a standard mercury sphygmomanometer. Resting blood pressure was determined after the subject sat for 20 minutes at rest before starting the test. Working (maximum) blood pressure was determined immediately after the last session of exercise. At test completion, subjects were instructed to continue cycling against zero resistance for 2 to 3 minutes (cool-down and recovery).

To determine the reliability of the test, a random sample of 6 patients performed the test 2 times separated by 48 hours. All patients finished the test at the same workload and for the same reason: reaching the target heart rate or for the other reasons mentioned above (test-retest agreement=100%).

Training Protocol

The training program lasted 8 weeks. All patients trained on a leg cycle ergometer (Active/Passive Trainer[a]). A physical therapist constantly supervised the training. At the beginning of each exercise session, patients' diet, medication use, muscle tone, blood pressure, and heart rate were recorded.

On the basis of the initial stress test results, each patient assigned to the exercise group was prescribed an individualized exercise program. The training period was divided into 2 parts. The first part lasted 5 days a week for 2 weeks and started with multiple 2-minute intervals, according to patient tolerance, with 1-minute rest periods interposed for up to 10 minutes of work in the first day. The patient was instructed to add 1 minute to 1 or more interval working periods each day so that by the end of week 2, he/she could work continuously for 20 minutes at the low level. The second part of the training period lasted the next 6 weeks, during which patients exercised 3 times a week for 30 minutes. Intensity was limited to 60% of heart rate reserve as determined in the preliminary test. Throughout the training period, heart rate was monitored continuously by a pulse watch.[b]

Measurements

Evaluation of neurologic deficits. Neurologic deficits were scored according to the Scandinavian Stroke Scale[7] (SSS) on admission to the hospital and once weekly in the rehabilitation department until the patient was released or died. The overall score ranges from 0 to 58, subdivided as follows: 0 to 14, extremely severe; 15 to 29, severe; 30 to 44, moderate; and 45 to 58, mild.

Motor capacity. Motor capacity was evaluated once a week by a physiotherapist (blinded to patient group) according to the Motor Assessment Scale.[8] In the study group, muscle tone was tested by passive movement of the knee and elbow and was scored according to the Modified Ashworth Scale[9] before and after each aerobic training session.

Independent function level. The level of independent function was assessed by the rehabilitation patient's nursing staff (blinded to patient group) every 2 weeks from admission to the department, according to the FIM™ instrument.[10]

Functional walking parameter: walking time. Speed was tested by asking the patients to walk 12m, using any assisted device needed, at their own comfortable speed of walking. Speed was derived from timing walking over the middle 10m with a stopwatch.

Functional walking parameter: walking distance until fatigued. Patients were asked to walk as far as they could. Patients walked using any assisted device they wanted and at a self-chosen speed. The endpoint was when the patients felt (subjectively) too tired to continue.

Functional walking parameter: number of stairs climbed. Patients were requested to climb as many stairs as possible (up to 60), using any assisted device they wanted and at a comfortable speed. The endpoint was when the patient felt (subjective) fatigue.

To evaluate the reliability of the functional walking parameters, 2 physiotherapists separately evaluated a random sample of 22 patients from the study. A strong linear relationship (Pearson correlation, .96–.99) was found between the testers' results.

Data Analysis

Descriptive analysis of the demographic and medical characteristics are presented in table 1 by using frequency distribution for categorical data and mean and standard deviation (SD) for continuous variables. The quality of the randomization was examined by *t* test (for continuous variables) and chi-square test (for categorical variables) for all the potential confounders of the relation between stroke characteristics and aerobic capacity. Treatment effect on heart rate, blood pressure (resting and maximal), workload, and exercise time was tested with *t* tests and with the Cox model as a multiple-variable analysis for stress test survival time.[11] Cox regression is a method for modeling time-to-event data in the presence of censored cases. We defined the survival time as stress test time in minutes; event was defined as reaching target heart rate; censors were all the other reasons for test termination. Point estimates and 95% confidence intervals (CI) for the hazard ratios were calculated from the regression coefficients. The

Table 1: Demographic and Medical Characteristics of the Study Population

Variable	Control Group (n=46)	Exercise Group (n=46)	*P**
Demographic characteristics			
Age (y)	65±11	62±11	.19
Sex (%)			
Male	50	56.6	
Female	50	43.5	.40
Nationality (%)			
Jew	69.4	71.7	
Arab	30.4	28.3	.81
Baseline functional parameters			
Outdoor independent walking, n (%)	40 (86.9)	43 (93.4)	.29
FIM score	83.5±17.2	85±16.8	.87
Employment, n (%)	10 (21.7)	12 (26.1)	.63
Risk factor for event, n (%)			
CAD	14 (30.4)	8 (17.4)	.14
Diabetes	16 (34.7)	20 (43.4)	.39
Hypertension	24 (52.2)	25 (54.3)	.84
Smoking	8 (17.4)	15 (32.6)	.09
Neurologic score (SSS)	31.0±8.5	31.0±8.6	.99
Type of event (%)			
Hemorrhagic	13.1	13.1	
Ischemic	86.9	86.9	1.00

NOTE. Values are mean ± SD or n (%).
Abbreviation: CAD, coronary artery disease.
*Significant values were obtained from *t* tests or χ^2 tests.

Table 2: Stress Test Parameters at the Initiation and Termination of the Intervention

Parameter	Program	Control Group (n=44)	Exercise Group (n=46)	*P*
Resting heart rate (bpm)	Start	80.7±11.3	77.7±10.0	.10
	End	79.5±10.2	74.95±8.8	.02*
Resting SBP (mmHg)	Start	139.0±24.6	136.0±15.2	.71
	End	136.2±19.5	130.3±15.7	.20
Resting DBP (mmHg)	Start	83.1±13.7	82.2±9.4	.47
	End	80.8±10.2	79.0±9.7	.40
Highest test stage completed	Start	5.6±1.71	6.2±2.0	.28
	End	6.9±2.2	9.6±2.5	<.01*
Maximal workload (W)	Start	7.8±10.8	9.1±13.0	.22
	End	12.9±12.6	25.2±14.9	<.01*
Maximal heart rate (bpm)	Start	107.9±11.7	109.84±11.4	.43
	End	108.0±11.6	111.5±11.2	.14

NOTE. Values are mean ± SD.
*Significance obtained by *t* test.

log-rank test was used to detect a difference between survival curves.

The logistic regression was performed with the multivariable analysis method for the functional parameters. Those outcome variables were dichotomized as either independent (climbing 1 floor[10]; gait speed >.55m/s[12]; the ability to walk 100m[13]) or dependent. Results were considered statistically significant when the *P* value was less than .05.

RESULTS

Descriptive data for the study and control groups are listed in table 1. Ninety-two patients were followed up. The sample consisted of 50 men and 42 women (mean age, 63.3±10.9y). Of the participants, 90 had been functionally independent before the event, and 22 had worked on a regular basis. Exactly 13.1% of the events were caused by hemorrhage and 86.9% by infarction.

There were no statistically significant baseline differences in demographic or clinical parameters between study groups. Two subjects from the control group dropped out—1 because of an acute myocardial infarction and the other after deep venous thrombosis.

The baseline and posttreatment stress test measurements are listed in table 2. Low endurance capacity was shown in all parameters tested. A trend of improvement between groups was found in all parameters in favor of the experimental group, but only heart rate at rest, workload, and stress test stage reached a statistically significant level.

Table 3 shows the distribution of the reasons for test termination at the end of the intervention in the exercise and control groups. About 55% of all patients reached the submaximal heart rate as determined for each individual before the test. At every stage (when working against resistance, from stage 4), the dropout of individuals from the study group was lower than in the control group (fig 2). The log-rank test statistic with 1 degree of freedom was 15.75 ($P=.01$). As described in figure 3, when stratification was applied to severity level, it was found that there was a statistically significant difference between the survival curves (log-rank test, $P=.01$). After adjusting for the influence of gender, age, and severity of the event (table 4), there was a significant difference in survival time between study groups—estimated as 4.52 minutes—with the Cox model.

Table 5 shows a trend of improvement in all parameters of functional ability in favor of the experimental group, but only stair climbing was significantly better ($P=.01$). Table 6 presents the variables related to walking parameters that influenced the independence of a patient at the end of the program (walking faster than .55m/s, walking 100m, climbing 1 flight of stairs). A positive (but not significant) association was indicated between treatment and independent walking distance (result not shown), yet a significant interaction between age and aerobic training on independent walking distance was noted. Whereas no improvement was found in the group of younger patients (age <65y), a significant difference in favor of training was noted in the group of older patients.

Table 3: Reasons for Test Termination at the End of the Study Period

Reason for Test Termination	Control Group (n=44)	Exercise Group (n=46)
Reaching target heart rate (%)	56.8	54.0
Cranking rate declining (%)*	20.5	26.1
Weakness of lower limb (%)*	15.9	8.7
Increased muscle tone (%)	6.8	10.9

NOTE. $P=.63$ ($\chi^2_3=1.70$).
*Cessation of test due to subjective exhaustion (the patient asked to stop the test—"weakness of lower limb") or because researcher noted a decline in cranking rate ("cranking rate declining").

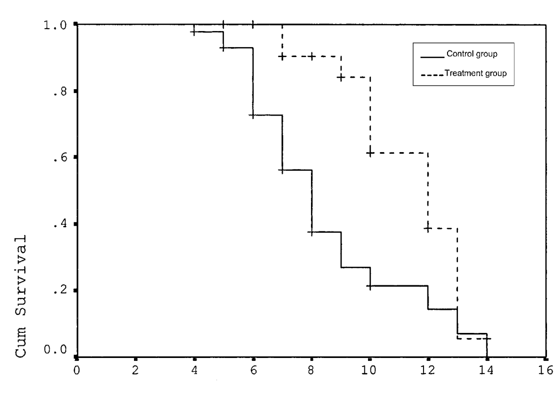

Fig 2. Survival functions. Stress test survival curve by treatment groups at the end of the program. Abbreviation: Cum survival, cumulative survival probability.

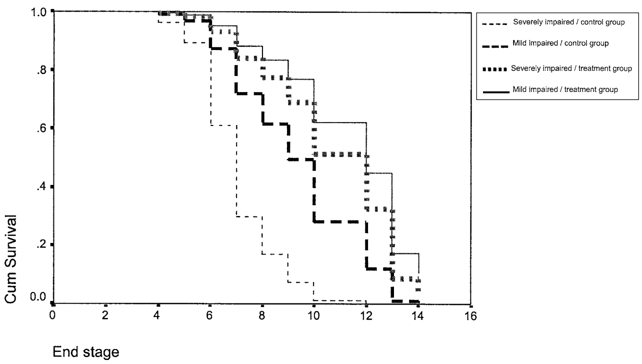

Fig 3. Survival function for patterns 1–4. Stress test survival curve by treatment groups and severity of events at the end of the program.

A model without interaction showed a nonsignificant association between treatment and independent walking speed. No significant interaction between age and aerobic training on independent walking speed was indicated (table 6). The only 2 variables that explained the ability to climb at least 1 flight of stairs were treatment (odds ratio [OR]=4.27, $P<.05$) and the severity of the event (OR=3.12, $P<.05$) (table 6).

Table 6 shows a significant difference in mobility level between groups. Study group patients needed less support while walking than controls. Even after adjusting for the influence of the severity of the event, there was a significant difference between exercise groups (OR=7.99; see table 6).

DISCUSSION

At the subacute stage, patients with CVA can improve some aerobic and functional abilities with moderately intense aerobic exercise. Parameters of heart rate at rest, workload, work time, and stair climbing improved significantly. A significant interaction was found between treatment and age on independent walking distance. Although no effect was found in younger patients, a significant difference in favor of training was noted in the group of older patients.

Subjects studied were CVA patients with mildly to severely impaired hemiparesis an average of 15.4 days after the event. The baseline aerobic capacity of the subjects was very low compared with healthy persons of the same age[14] or compared with spinal cord injury patients.[15] Similar findings have been reported elsewhere[4] for patients with chronic hemiparesis. The reduction in the number of active motor units and the reduced oxidative capacity of paretic muscles are the usual explanations for low aerobic capacity in stroke patients. This decreased ability after stroke can also be related to the reduced efficiency of motion and to the presence of spasticity and cocontraction.

Table 4: A Multivariate Cox Model for Testing Survival Time at the End of the Program

Variable	β	SE	Hazard Ratio	95% CI*
Treated/control	1.50	.34	4.52	2.29–8.90
Sex	−.95	.33	.38	.19–.75
Age	−.57	.31	.56	.30–1.04
Neurologic score	1.14	.36	3.22	1.56–6.67

Abbreviation: SE, standard error.
*95% CI for the hazard ratio.

Table 5: Functional Parameters at the End of the Intervention in Exercise and Control Groups

Parameter	Control Group (n=44)	Exercise Group (n=46)	P*
Walking distance (m)	107.6±94.8	143.0±122.8	.12
Walking speed (m/s)	.45±.16	.51±.18	.10
Stair climbing (n)	18.1±14.4	25.4±14.1	.01
FIM score	101.4±16.0	105.8±12.5	.12

NOTE. Values are mean ± SD.
*Derived from the *t* test.

The increased energy cost of spastic muscle has also been reported in subjects with spasticity resulting from cerebral palsy[16] and multiple sclerosis.[17]

Exercise training enabled patients to significantly increase work time and work load. As reported elsewhere,[4] those improvements were greater than cardiorespiratory aerobic parameters such as heart rate and blood pressure as reported in our study and greater than oxygen consumption as reported elsewhere.[4] It has been suggested[4] that cycling activity influences motion efficiency, as reflected by improving workload and time.

Participants in the study group improved in functional parameters such as step climbing (significantly) and walking time and distance (nonsignificantly). This greater improvement in step climbing over walking speed and distance may be due to the type of training—leg cycling activity while sitting. The patient performed repeated movements that included remarkable knee flexion-extension motion—movements that are more similar to step climbing. Compared with level walking, stair climbing produces greater forces and moments, for example, the significant knee flexion during ascent, which is necessary to lift the foot onto the next step.[18] Another possible explanation as to why only step walking improved significantly may be that step walking was the most energy-consuming activity of those tested.

When looking at the distribution of independent walking distance, we found a positive interaction between the age of the patient and the impact of treatment on this variable. With increasing age, there is a loss of muscle volume due to reduced fiber size, particularly in the fast-twitch (type IIB) fibers. A reduced size of these specific fibers would result in an increase in the ratio of slow-twitch (type I) to fast-twitch muscle fiber in an older person.[19] After CVA, there is a reduction in the proportion of slow-twitch fibers as compared with normal muscle.[20] Because aerobic training influences more slow-twitch than fast-twitch fibers,[19] there is an advantage for older patients in this program.

Another possible reason for increased improvement from aerobic training in elderly than in younger patients could be the phenomenon of cocontraction, which increases with age.[21] CVA reduces muscular coordination, which appears as cocontraction. Aerobic training improves movement efficiency. Therefore, young people with little cocontraction will improve less with aerobic training than elderly people with much more cocontraction.

The study group showed better balance while standing and walking ("can or can not walk five meters without support," as evaluated with the SSS) compared with the control group. We assumed that this difference in balance was due to the early and prolonged reciprocal pedaling stimuli. Walking is a function that requires a reciprocal movement. Training in an activity that is similar to walking could be a reason for improved balance while walking. The patients worked early—2 weeks

Table 6: Prediction of Functional Walking Parameters and Mobility by Using a Logistic Regression Model

Variable	β	SE	OR	95% CI
Distance*				
Treatment/control	0.78	.49	2.19	0.3–5.75
Age	−1.08	.52	0.33	0.12–0.94
Sex	1.71	.54	0.18	0.06–0.52
Neurologic score	1.69	.57	5.50	1.78–20
Age by treatment interaction	1.94	.43	8.16	1.7–17.21
Speed†				
Treatment/control	0.70	.49	2.03	0.76–5.39
Age	−1.51	.54	0.22	0.07–0.64
Sex	−1.31	.54	0.26	0.09–0.77
Neurologic score	1.77	.59	5.88	1.85–20
Age by treatment interaction	1.76	1.05	5.83	0.83–18.38
Stair climbing‡				
Treatment/control	1.45	.47	4.27	1.68–10.88
Neurologic score	1.12	.48	3.12	1.19–8.33
Mobility score‖				
Treatment/control	2.07	.85	7.99	1.51–31.09
Neurologic score	0.20	.05	1.25	1.09–1.38

*Walking 100m (yes/no).
†Walking .55m/s (yes/no).
‡Climbing 1 flight of stairs (14 steps) (yes/no).
‖Walking 5m without aids (SSS).

after the event (as compared with the conventional treatment of these patients)—and for an extended period in an upright sitting position. In another study[22] with CVA patients, which demanded an early upright position (treadmill walking with suspension), patient balance also improved. In addition, while pedaling, the patients have to perform continuous trunk muscle activity for stabilizing the dynamic activity of the lower extremities. As previously published, trunk muscles appear to perform a balancing function during standing and walking.[23] All of these factors contribute to the advanced balance ability while standing in trained subjects compared with the controls at the end of the study.

CONCLUSION

The results of this study show that early aerobic training at the subacute stage of CVA improved some aerobic and functional abilities in severely to moderately impaired stroke patients. Improved aerobic capacity and walking performance are essential for independent living in these patients. Reduction of cardiovascular risk factors (elevated blood pressure, resting heart rate) is another important consequence of the program for these patients.

Acknowledgments: We thank Dr. J. Leurer and the physiotherapy staff of the Rehabilitation Department, Hadassah University Hospital, for their support and insight.

References

1. Dobkin B. The economic impact of stroke. Neurology 1995;45 (2 Suppl 1):S6-9.
2. Dickstein R, Hocherman S, Pillar T, Shaham R. Stroke rehabilitation. Three exercise therapy approaches. Phys Ther 1986;66: 1233-8.
3. Landin S, Hagenfeldt L, Saltin B, Wahren J. Muscle metabolism during exercise in hemiparetic patients. Clin Sci Mol Med 1977; 53:257-69.
4. Potempa K, Lopez M, Braun LT, Szidon JP, Fogg L, Tincknell T. Physiological outcomes of aerobic exercise training in hemiparetic stroke patients. Stroke 1995;26:101-5.
5. Binder EF, Birge SJ, Spina R, et al. Peak aerobic power is an important component of physical performance in older women. J Gerontol A Biol Sci Med Sci 1999;54:M353-6.
6. Wasserman K, Hansen JE, Sue DY, Whipp BJ, Casaburi RC editors. Principles of exercise testing and interpretation. Philadelphia: Lea & Febiger; 1994.
7. Multicenter trial of hemodilution in ischemic stroke—background and study protocol. Scandinavian Stroke Study Group. Stroke 1985;16:885-90.
8. Carr JH, Shepherd RB, Nordholm L, Lynne D. Investigation of a new motor assessment scale for stroke patients. Phys Ther 1985; 65:175-80.
9. Gregson JM, Leathley M, Moore AP, Sharma AK, Smith TL, Watkins CL. Reliability of the Tone Assessment Scale and the modified Ashworth scale as clinical tools for assessing poststroke spasticity. Arch Phys Med Rehabil 1999;80:1013-6.
10. Keith RA, Granger CV, Hamilton BB, Sherwin FS. The functional independence measure: a new tool for rehabilitation. Adv Clin Rehabil 1987;1:6-18.
11. Cox DR. Regression models and life tables. J R Stat Soc B 1972;34:187-220.
12. Potter JM, Evans AL, Duncan G. Gait speed and activities of daily living function in geriatric patients. Arch Phys Med Rehabil 1995;76:997-9.
13. Kent P, Hill K, Bernhardt J. Functional prediction post-stroke. Aust Physiother 1993;39:281-9.
14. Stratton JR, Levy WC, Cerqueira MD, Schwartz RS, Abrass IB. Cardiovascular responses to exercise. Effects of aging and exercise training in healthy men. Circulation 1994;89:1648-55.
15. Haas F, Axen K, Pineda H. Aerobic capacity in spinal cord injured people. Cent Nerv Syst Trauma 1986;3:77-91.
16. Unnithan VB, Clifford C, Bar-Or O. Evaluation by exercise testing of the child with cerebral palsy. Sports Med 1998;26:239-51.
17. Olgiati R, Burgunder JM, Mumenthaler M. Increased energy cost of walking in multiple sclerosis: effect of spasticity, ataxia, and weakness. Arch Phys Med Rehabil 1988;69:846-9.
18. Costigan PA, Deluzio KJ, Wyss UP. Knee and hip kinetics during normal stair climbing. Gait Posture 2002;16:31-7.
19. McArdle WD, Katch FI, Katch VL. Exercise physiology. Philadelphia: Lea & Febiger; 1991.
20. Jakobsson F, Edstrom L, Grimby L, Thornell LE. Disuse of anterior tibial muscle during locomotion and increased proportion of type II fibres in hemiplegia. J Neurol Sci 1991;105:49-56.
21. Clarkson PM. The effect of age and activity level on simple and choice fractionated response time. Eur J Appl Physiol Occup Physiol 1978;15:17-25.
22. Nugent JA, Schurr KA, Adams RD. A dose-response relationship between amount of weight-bearing exercise and walking outcome following cerebrovascular accident. Arch Phys Med Rehabil 1994;75:399-402.
23. Winter DA, MacKinnon CD, Ruder GK, Wieman C. An integrated EMG/biomechanical model of upper body balance and posture during human gait. Prog Brain Res 1993;97:359-67.
24. Moher D, Schulz KF, Altman DG. The CONSORT statement: revised recommendations for improving the quality of reports of parallel-group randomised trials. Lancet 2001;14:1191-4.

Suppliers

a. Tzora Active Systems Ltd, Kibbutz Tzora, 99803 Israel.
b. Polar Electro Oy, Professorintie 5, FIN-90440 Kempele, Finland.