ORIGINAL ARTICLE

Evolution of Cardiorespiratory Fitness After Stroke: A 1-Year Follow-Up Study. Influence of Prestroke Patients' Characteristics and Stroke-Related Factors

Ilse Baert, PT, MSc, Daniel Daly, PhD, Eddy Dejaeger, MD, PhD, Christel Vanroy, PT, MSc, Yves Vanlandewijck, PT, PhD, Hilde Feys, PT, PhD

ABSTRACT. Baert I, Daly D, Dejaeger E, Vanroy C, Vanlandewijck Y, Feys H. Evolution of cardiorespiratory fitness after stroke: a 1-year follow-up study. Influence of prestroke patients' characteristics and stroke-related factors. Arch Phys Med Rehabil 2012;93:669-76.

Objectives: To examine changes in cardiorespiratory fitness over the first year poststroke and explore the effect of prestroke patients' characteristics and stroke-related factors on this evolution.

Design: Descriptive, longitudinal study with repeated measures of exercise capacity at 3, 6, and 12 months poststroke.

Setting: Rehabilitation center and exercise testing laboratory.

Participants: Consecutive sample of patients with stroke (N=33; mean age ± SD, 59.0±11.3y).

Interventions: Not applicable.

Main Outcome Measures: Peak oxygen consumption ($\dot{V}O_2$peak) and oxygen uptake efficiency slope (OUES) were determined during a symptom-limited graded cycle ergometer test at 3, 6, and 12 months poststroke. Age, sex, premorbid physical activity level, clinical history (smoking, diabetes mellitus, chronic pulmonary diseases, cardiovascular diseases, overweight, and hypertension), stroke type and area, side of lesion, and assessments of stroke severity were evaluated at intake.

Results: Mean $\dot{V}O_2$peak ± SD was $18.1\pm6.6mL\cdot kg^{-1}\cdot min^{-1}$, $19.8\pm8.0mL\cdot kg^{-1}\cdot min^{-1}$, and $19.7\pm8.4mL\cdot kg^{-1}\cdot min^{-1}$ at 3, 6, and 12 months poststroke. Values for OUES were 1575.3±638.3, 1710.7±710.3, and 1687.2±777.5, respectively. Mixed models showed no significant difference over time for $\dot{V}O_2$peak (P=.10), nor for the logarithm of OUES (P=.09). Stroke survivors at risk of deconditioning were premorbidly less active at work or in sport activities, diabetic, or initially more severely impaired. Combination of factors revealed that older patients with stroke and diabetes were less likely to improve on $\dot{V}O_2$peak and that older, women, diabetic nonsmokers improved less on log OUES.

Conclusions: Cardiorespiratory fitness was reduced from 3 to 12 months poststroke and on average did not significantly change over time. Further studies should elucidate methods of increasing cardiorespiratory fitness during stay in the rehabilitation center and how community-based aerobic exercise training postrehabilitation can be organized.

Key Words: Cerebrovascular accident; Exercise; Rehabilitation.

CARDIORESPIRATORY FITNESS (CRF) is poor in persons with stroke,[1] with previous studies reporting a mean peak oxygen consumption ($\dot{V}O_2$peak) (an indicator of aerobic capacity) that ranged from 11.4±3.7[2] to $17.3\pm7.0mL\cdot kg^{-1}\cdot min^{-1}$.[3] This is 50% to 60% of the age- and sex-matched normative values in healthy persons. Low exercise capacity may be compounded by the increased energy cost of movement associated with residual functional deficits and may therefore contribute to low social participation[4] and poor quality of life. In addition to disease prevention, enhanced aerobic capacity also has beneficial effects on functional abilities and independent living.[5] A recent meta-analysis[6] supported the use of aerobic exercise training to improve CRF in mildly or moderately impaired stroke survivors and suggested that aerobic exercise is an important component of stroke rehabilitation. It is nevertheless unclear if current stroke rehabilitation programs induce an aerobic training effect and if long-term benefits are retained. Although previous studies[2,3,6-19] have documented the reduced CRF, these studies were mostly interventions and focused on either the subacute or chronic phase. To our knowledge, the longitudinal evolution of physical fitness over the first year poststroke has not been previously studied.

It remains to be seen if prestroke health-related conditions and if stroke-related factors (eg, stroke type, area, and initial

From the Department of Rehabilitation Sciences, Faculty of Kinesiology and Rehabilitation Sciences, Katholieke Universiteit Leuven, Leuven (Baert, Daly, Vanroy, Vanlandewijck, Feys); Department of Geriatric Medicine, University Hospital Pellenberg, Leuven (Dejaeger); and Artesis University College of Antwerp, Faculty of Medicine, University of Antwerp, Antwerp (Vanroy), Belgium.

Supported by the National Association for Support to Persons with a Disability (Nationale Vereniging voor Steun aan Gehandicapte personen) and the Van Goethem-Brichant Foundation.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit on the authors or on any organization with which the authors are associated.

Clinical Trial Registration No.: ML3617.

Reprint requests to Ilse Baert, PT, MSc, Katholieke Universiteit Leuven, Faculty of Kinesiology and Rehabilitation Sciences, Tervuursevest 101, 3001 Heverlee (Leuven), Belgium, e-mail: *Ilse.Baert@faber.kuleuven.be*.

In-press corrected proof published online on Feb 15, 2012, at www.archives-pmr.org.

0003-9993/12/9304-00345$36.00/0
doi:10.1016/j.apmr.2011.09.022

List of Abbreviations

BI	Barthel Index
CRF	cardiorespiratory fitness
FAC	Functional Ambulation Categories
MMSE	Mini Mental State Examination
NIHSS	National Institutes of Health Stroke scale
OUES	oxygen uptake efficiency slope
RMA-GF	Gross Motor Function of the Rivermead Motor Assessment
RPE	Ratings of Perceived Exertion scale
TIS	Trunk Impairment Scale
V_E	minute ventilation
$\dot{V}O_2$	oxygen consumption
$\dot{V}O_2$peak	peak oxygen consumption

severity) influence recovery of CRF. Knowledge of the influencing factors on CRF would enable identification at intake in the rehabilitation center of those at higher risk of (further) deconditioning. As a consequence, cardiovascular exercise training should be a therapeutic goal for these patients at risk and be started as early as possible. In the healthy population, CRF has been related to several factors, such as age, sex, level of physical activity, smoking, obesity, cardiovascular diseases, chronic diseases, and resting heart rate.[20,21] It is unclear whether these factors, many of which are also risk factors for stroke, are of similar importance in the stroke population. Only a few studies have looked into determinants of CRF poststroke.[11,13,16,18] Age was found to be negatively associated with Vo_2peak.[11,13] Significant positive relationships were also found between Vo_2peak and the Fugl-Meyer test,[18] the Berg Balance Scale,[16] and the Barthel Index (BI),[11] indicating that less disabled persons have a better CRF. These studies assessed CRF in either the subacute or chronic phase and samples were usually small, including only mild to moderately impaired patients with a mean age >50 years. Testing protocols varied from treadmill walking with and without body-weight support to semirecumbent or upright stationary cycling. No studies examined factors influencing the evolution of CRF. Furthermore, factors such as sex, clinical history, stroke type, stroke area, and side of lesion have never been investigated.

The purpose of this study was (1) to examine changes in CRF between 3, 6, and 12 months poststroke and (2) to explore the effect of prestroke patients' characteristics and stroke-related factors on this evolution. This information would aid in developing more individualized rehabilitation programs.

METHODS

Participants

Fifty stroke patients consecutively admitted to the stroke rehabilitation unit in the University Hospital, Leuven, Belgium, were recruited for the study on a volunteer basis. Screening was done by the physician of the unit. The inclusion criteria were (1) first-ever stroke as defined by the World Health Organization,[22] (2) age <75 years, and (3) able to comprehend simple test instructions. The exclusion criteria were (1) other neurologic disorders with permanent damage, (2) prestroke BI score[23] <50, (3) unable to perform a maximal exercise test in accordance with absolute contra-indications for exercise testing by the American College of Cardiology Foundation/American Heart Association,[24] and (4) unable or refusal to provide informed consent. Eligible participants were verbally informed, received written information, and signed an informed consent form. The study was approved by the Medical Ethical Committee of the Leuven University Hospital.

Assessments

Exercise testing. CRF was assessed at 3, 6, and 12 months poststroke. Three months was chosen as the initial measurement moment as spontaneous recovery of lower-limb function occurred by 10 weeks poststroke.[25] Participants were asked to avoid heavy exertion or exercise/sport on the day of testing. CRF was assessed during a symptom-limited graded cycle ergometer test on an electronically braked, upright stationary bicycle[a] under the supervision of a physician and with continuous 10-lead electrocardiogram.[b] The test procedure was explained to the participants and they were then familiarized with the testing equipment. After this, after 3 minutes of seated rest on the stationary bicycle, the participants started to pedal at 10W, with workload increments of 10W/min until voluntary cessation. Participants were instructed to pedal at a comfortable rate between 30 and 60 revolutions per minute and verbally encouraged to continue as long as possible to reach maximal effort. Exercise tests could also be terminated based on the American College of Sports Medicine criteria.[26] During cycling, expired air was collected breath-by-breath and analyzed at 10-second intervals with computerized open-circuit spirometry.[c] Volume and gas calibrations were done before each test. Peak Vo_2 was determined as an average of values recorded between 20 and 50 seconds of the last fully completed increment. Although this parameter is most frequently used as a measure of CRF, it is influenced by the patient's motivation. Therefore, the oxygen uptake efficiency slope (OUES) developed by Baba et al[27] was used as a second outcome measure. The OUES is an estimation of cardiopulmonary function even at submaximal exercise and is determined using the equation $\dot{V}O_2 = a \log_{10} V_E + b$, where $\dot{V}O_2$ is oxygen consumption and V_E is minute ventilation. When $\dot{V}O_2$ in mL/min is plotted on the *y* axis and V_E in L/min is plotted on the semilog transformed *x* axis, the slope of this linear relationship, "a," represents the rate of increase in $\dot{V}O_2$ in response to V_E and is defined as the OUES, whereas b is the intercept. As such, OUES provides an estimation of the efficiency of ventilation with respect to $\dot{V}O_2$, with greater slopes indicating greater ventilatory efficiency. The first 30 seconds and last 10 seconds of the ergometer test were omitted to calculate OUES values. Other descriptive measures of exercise testing were maximal workload, peak heart rate, respiratory exchange ratio peak, and Borg's 16-point Ratings of Perceived Exertion (RPE) scale.[28] Intake of beta-blocker medication was recorded.

Prestroke patients' characteristics. Patients' characteristics were age at stroke onset, sex, premorbid physical activity level, and clinical history. Participants were questioned on their premorbid physical activity level with the Baecke Physical Activity Questionnaire, which is composed of 3 distinct dimensions: work, sport, and leisure activity.[29] The clinical history of each participant was recorded by the physician of the stroke unit based on the patients' general medical record, including smoking habits and comorbidities such as diabetes mellitus, chronic pulmonary diseases (eg, chronic obstructive pulmonary disease), cardiovascular diseases (eg, myocardial infarction, atrial fibrillation, coronary heart disease), overweight (body mass index >25), and hypertension. The latter was defined as systolic blood pressure >160mmHg and/or diastolic blood pressure >95mmHg based on several measurements or a 24-hour registration. Patients treated with antihypertensives were considered to have high blood pressure.

Stroke-related factors. Stroke severity on admission to the rehabilitation center was assessed by the National Institutes of Health Stroke Scale (NIHSS),[30] Mini Mental State Examination (MMSE),[31] Trunk Impairment Scale (TIS),[32] Gross Motor Function of the Rivermead Motor Assessment (RMA-GF),[33] Functional Ambulation Categories (FAC),[34] and BI.[23] Type of stroke (ischemic or hemorrhagic), stroke area (cortical, subcortical, cerebellum-brainstem, or subarachnoidal), and side of lesion (left, right, or both) were also recorded.

Treatment characteristics. To describe the rehabilitation program undertaken by the participants in the current study, length of stay at the stroke rehabilitation unit, time between

stroke onset and admission to the stroke rehabilitation unit, number of patients returning home at 3, 6, and 12 months poststroke, and therapy received were documented. The information on therapy received was based on registered therapies during the stay at the stroke rehabilitation unit and questioning in the home situation. At discharge, the patients were given a written prescription for specific therapies. Because nursing therapy was not registered during the stay at the stroke rehabilitation unit, this type of therapy was not retained. The types of therapy prescribed were physiotherapy, occupational therapy, speech therapy, neuropsychology, medical care, and exercise-sport activities. Frequency (times/wk) and duration (min/wk) of therapy received were averaged for the periods admission to the stroke rehabilitation until 3 months poststroke, 3 to 6 months poststroke, and 6 to 12 months poststroke.

Data Analysis

Descriptive statistics were calculated for prestroke patients' characteristics and stroke-related factors. Only participants who could execute the exercise test at least twice were retained for the analyses. Differences between the included and excluded patients were verified with *t* tests, Median tests, or chi-square tests, as appropriate. To evaluate the differences for change in CRF (VO_2peak and OUES), repeated-measures regression models (proc mixed) were used. Mixed models allow handling of missing data. In these models, the intercept varied between subjects, and the regression slopes were assumed to be fixed effects. OUES values underwent logarithmic transformation to obtain normative distribution.

To further explore the evolution of CRF, patients were also subdivided into 3 categories (improved, remained stable, and deteriorated), separately for the periods 3 to 12 months, 3 to 6 months, and 6 to 12 months poststroke. The criterion for improvement or deterioration was based on the standard error of measurement of VO_2peak ($\pm$2.0mL·kg^{-1}·min^{-1}) given in a reliability study by Eng et al.[3]

To determine which factors have an effect on the evolution of CRF, interactions between time and covariates were univariately entered in mixed models. Covariates of interest were prestroke patients' characteristics (age at stroke onset, sex, prestroke Baecke work, sport and leisure index, smoking habits, presence of diabetes mellitus, chronic pulmonary diseases, cardiovascular diseases, overweight, and hypertension) and stroke-related factors (stroke type, stroke area, side of lesion, NIHSS, MMSE, TIS, RMA-GF, FAC, and BI). Only categorical variables with at least 5 patients in each category (15%) were retained. Multivariate analyses were then applied to evaluate if combinations of factors have an influence on the evolution of CRF. Interactions with a $P\leq.10$ in the univariate models were entered in a multivariate mixed model, for the prestroke patients' characteristics and stroke-related factors separately. The remaining interactions with a $P\leq.10$ of both categories were then included in a final model. Age and sex were always kept in the model. In all analyses, $P<.05$ was considered significant. Data were analyzed with SAS 9.2.[d]

RESULTS

Participants

One hundred thirty patients, under the age of 75 years, were admitted to the stroke rehabilitation unit during the study period. Of these, 80 patients did not fulfill the inclusion criteria (not the first stroke: n=14; no recent stroke: n=18; not able to comprehend simple oral instructions: n=3; other neurologic impairment: n=7; refused consent: n=29; unable to perform an exercise test: n= 9). Of the 50 remaining patients with stroke included in this study, 17 patients were assessed only once (n=7) or not at all (n=10) and were therefore excluded. Of the 7 who were assessed only once, 3 withdrew and 4 were incapable of performing the cycle ergometer test because of medical complications (eg, hip fracture, pneumonia), no sitting balance, or no selective leg movement. Of the 10 who were not assessed at all, 2 withdrew and 8 were incapable of performing the cycle test. There were no significant differences between the 33 patients that remained in the study and the 17 excluded patients with respect to age (P=.35), sex (P=.72), stroke type (P=.28), side of lesion (P=.91), and comorbid conditions prestroke (except cardiovascular disease, P=.03). In the exclusion group, significant higher values for NIHSS (P=.03) and significant lower values for TIS (P=.04) and FAC (P=.01) were found. Prestroke patients' characteristics and stroke-related factors of included patients are presented in table 1.

Table 1: Prestroke Patients' Characteristics and Stroke-Related Factors (N=33)

Variables	Values
Prestroke patients' characteristics	
Age at stroke onset, mean ± SD	59.0±11.3
Sex, men/women, n (%)	23 (70)/10 (30)
Comorbid conditions	
Smoking, n (%)	15 (45.5)
Overweight, n (%)	16 (48.5)
Cardiovascular disease, n (%)	11 (33.3)
Pulmonary disease, n (%)	3 (9.1)
Diabetes mellitus, n (%)	5 (15.2)
High blood pressure, n (%)	19 (57.6)
Physical activity level	
BPAQ work index, mean ± SD	2.7±0.6
BPAQ sport index, mean ± SD	2.3±0.8
BPAQ leisure index, mean ± SD	2.4±0.8
Stroke-related factors	
Stroke type	
Ischemic, n (%)	26 (79)
Hemorrhagic, n (%)	7 (21)
Stroke area	
Cortical, n (%)	20 (61)
Subcortical, n (%)	5 (15)
Cerebellum-brainstem, n (%)	6 (18)
Subarachnoidal, n (%)	2 (6)
Side of lesion	
Left, n (%)	17 (53)
Right, n (%)	10 (31)
Both, n (%)	5 (16)
Stroke severity outcomes on admission	
NIHSS, mean ± SD	4.5±4.0
MMSE, mean ± SD	25.9±4.0
TIS, mean ± SD	16.8±3.9
RMA-GF, median (IQR)	8 (5–12)
FAC, median (IQR)	3 (1–5)
BI, mean ± SD	66.7±26.7

Abbreviations: BPAQ, Baecke Physical Activity Questionnaire; IQR, interquartile range.

Treatment Characteristics

Treatment characteristics are presented in table 2. The majority of patients were still residing in the rehabilitation center at 3 months poststroke, while at 12 months poststroke almost all had returned home. Frequency and duration of therapies received decreased over time, except for exercise-sport activities. Nevertheless, the number of patients actually participating in exercise-sport activities decreased.

Evolution of CRF

Outcome variables of exercise testing at 3, 6, and 12 months poststroke are summarized in table 3. Individual performance on Vo_2peak and OUES at 3, 6, and 12 months poststroke is presented in figure 1. On the RPE scale, 88%, 87%, and 97% of the participants exerted themselves at least "somewhat hard" during the exercise testing at 3, 6, and 12 months poststroke, respectively. Mixed models showed no significant difference over time for Vo_2peak (P=.10), nor for log OUES (P=.09) (table 4).

Changes in Vo_2peak between 3 and 6 months and between 6 and 12 months poststroke are shown in figure 2. Between 3 and 6 months poststroke, 46% of patients improved, 33% remained stable, and 21% deteriorated. Between 6 and 12 months poststroke, 26% improved, 48% remained stable, and 26% deteriorated. Over the entire 1-year follow-up period (3–12mo poststroke), 46% improved, 27% remained stable, and 27% deteriorated. Only 6 of the patients who improved over 3 to 6 months poststroke further improved or remained stable between 6 and 12 months poststroke. Four patients began to improve only after 6 months poststroke.

Influencing Factors on the Evolution of CRF

Stroke area and pulmonary diseases were not retained as covariates, as <15% of patients were found in either category. Results of the univariate and multivariate mixed model analyses are shown in tables 4 and 5. Univariate analysis revealed significant interactions with Baecke work and sport indexes, diabetes, TIS, and BI for Vo_2peak. For log OUES Baecke work, diabetes, side of lesion, TIS, RMA-GF, FAC, and BI were significant covariates. Multivariate mixed model showed significant interactions between time and the covariates age, diabetes for Vo_2peak and age, diabetes, sex, and smoking habits for log OUES.

DISCUSSION

The primary aim of this study was to examine changes in CRF between 3, 6, and 12 months poststroke. Neither Vo_2peak nor log OUES changed significantly over time, implying that on average CRF did not change during and after stay in the rehabilitation center. Figures 1 and 2 also show the wide range of exercise capacity and great diversity in evolution of CRF between participants. This may even be underestimated, as those with the most significant disability after stroke were removed or were unable to complete the study. MacKay-Lyons and Makrides[14] also found no significant difference in Vo_2peak, measured during treadmill walking with 15% body-weight support, between 3 and 6 months poststroke. Although nearly half of the therapy received was spent in physiotherapy and exercise-sport until 6 months poststroke, this seemed insufficient to significantly change CRF between 3 and 6 months poststroke. Previous studies[35,36] documented the duration and intensity of therapy in patients with stroke. MacKay-Lyons and Makrides[35] stated that the time per physiotherapy session spent in activities capable of inducing a cardiorespiratory training

Table 2: Treatment Characteristics During the 1-Year Follow-Up Period (N=33)

Parameters	Days (median [IQR])
Time between stroke onset and admission to the stroke rehabilitation unit	23 (17–28)
Length of stay at the stroke rehabilitation unit	109 (52–137)

Current Residence	At 3 Months Poststroke, n (%)	At 6 Months Poststroke, n (%)	At 12 Months Poststroke, n (%)
Home	9 (27)	25 (76)	31 (94)
Rehabilitation center	24 (73)	8 (24)	2 (6)

Therapy Received	Intake to 3 Months Poststroke (Mean ± SD)		3 Months to 6 Months Poststroke (Mean ± SD)		6 Months to 12 Months Poststroke (Mean ± SD)	
	Frequency (times/wk)	Duration (min/wk)	Frequency (times/wk)	Duration (min/wk)	Frequency (times/wk)	Duration (min/wk)
Physiotherapy	4.11±1.13	247.66±86.31	3.22±1.67	159.37±112.20	2.70±1.93	107.01±90.39
Occupational therapy	3.20±1.35	176.29±85.53	1.41±1.85	75.93±108.10	0.26±0.82	11.16±40.10
Speech therapy	1.88±1.53	58.12±47.94	1.46±1.71	44.83±55.11	0.87±1.54	27.17±46.70
Neuropsychology	0.86±0.97	51.02±67.46	0.72±1.52	49.29±117.17	0.01±0.06	0.48±2.56
Medical care	0.85±0.33	23.52±10.92	0.50±0.42	9.70±10.73	0.25±0.03	4.64±6.31
Exercise-sport	0.47±0.70	27.91±42.31	0.74±2.16	36.27±93.18	0.91±2.24	38.97±83.17
Total	11.35±3.87	584.5±221.06	8.05±4.57	375.1±285.30	5.01±3.96	189.57±175.14

Abbreviation: IQR, interquartile range.

Table 3: CRF at 3, 6, and 12 Months Poststroke (N=33)

Variable	3 Months	6 Months	12 Months
Vo_2peak ($mL \cdot kg^{-1} \cdot min^{-1}$)	18.1±6.6	19.8±8.0	19.7±8.4
Men (n=23)	19.6±7.2	20.6±9.0	21.0±9.3
Women (n=10)	14.9±3.4	17.6±4.2	16.8±5.4
OUES (mL/min O_2)/(L/min V_E)	1575.3±638.3	1710.7±710.3	1687.2±777.5
Men (n=23)	1801.4±650.2	1846.5±757.5	1917.7±832.2
Women (n=10)	1098.2±214.6	1260.3±288.3	1202.9±302.7
Workload peak (W)	112.9±55.0	121.9±60.8	118.7±66.3
HR peak (bpm)	128.9±31.2	133.7±30.1	133.3±31.5
RER peak	1.02±0.11	1.06±0.07	1.07±0.07
RPE scale	13.5±1.4	14.4±1.8	14.3±1.6

NOTE. Data are presented as mean ± SD. Abbreviations: bpm, beats per minute; HR, heart rate; O_2, oxygen; RER, respiratory gas exchange ratio.

effect was low (2.8±0.9min), and was negligible (0.7±0.2min) per occupational therapy session between 2 and 14 weeks poststroke. Kuys et al[36] showed a mean intensity of 24% heart rate reserve during standing and walking activities, which was insufficient to cause a cardiorespiratory training effect. Clarification is needed on how stroke rehabilitation could be adapted to obtain a greater cardiorespiratory training effect.

Beyond 6 months, on average CRF did not change significantly and individual exploration showed that only one fourth improved their fitness. A recent meta-analysis[6] supported the use of aerobic exercise training to improve CRF in mildly or moderately impaired stroke survivors. Improvements in Vo_2peak from 8%[9] to 17%[15] have been reported in aerobic training studies involving patients with chronic hemiparesis. Although data are lacking on follow-up to evaluate long-term benefits and future studies should explore the effect of dose (intensity, frequency, and duration) and type (aerobic training, muscle strengthening, or a combination) of training, a systematic offering of functional exercise programs and sport activities in the community seems worthwhile. We should also develop motivational strategies for patients with stroke to encourage a more active lifestyle.

Mean ± SD values of Vo_2peak at 3, 6, and 12 months were 18.1±6.6mL·kg^{-1}·min^{-1}, 19.8±8.0mL·kg^{-1}·min^{-1}, and 19.7±8.4mL·kg^{-1}·min^{-1}, which is between 63% to 70% of that of the age-matched, healthy sedentary men and 65% to 79% of women.[26] Yates et al[2] reported a mean Vo_2peak ± SD of 11.4±3.7mL·kg^{-1}·min^{-1} at 70±27.8 days poststroke, and Duncan et al[12] reported 11.5±3.1mL·kg^{-1}·min^{-1} at 76±28 days poststroke. This is clearly lower than the 18.1±6.6mL·kg^{-1}·min^{-1} found in this study at a similar measurement time. In both studies,[2,12] exercise testing continued until maximal effort, defined as 90% of maximal predicted heart rate. In our study approximately one third exceeded this limit, which may contribute to the higher Vo_2peak. MacKay-Lyons and Makrides[14] found a mean Vo_2peak of 17.3±7.0mL·kg^{-1}·min^{-1} at 6 months poststroke. Inclusion of sport activities in the rehabilitation program might explain our slightly higher value. Previous studies[1,3,7,9,10,14-17,19] evaluating CRF in the chronic phase (>6mo poststroke) showed Vo_2peak values from 11.7±2.8 to 17.3±7.0mL·kg^{-1}·min^{-1}, all below 19.7±8.4 as found in our study. The upper age limit of 75 years and the presence of chiefly men participants in our study may have contributed to this higher value. To our knowledge, the present study is the first in which OUES values were calculated in the stroke population. Values were 77% to 82% of healthy men and 69% to 79% of healthy women.[37] In the present study, Spearman correlations between Vo_2peak and OUES were high (.78, .72, and .86) at 3, 6, and 12 months poststroke. Even higher correlations were found (.89, .91, and .94 at 3, 6, and 12mo poststroke, respectively) when OUES was expressed per kilogram body weight. As most patients did not reach a respiratory gas exchange ratio value of 1.1 or

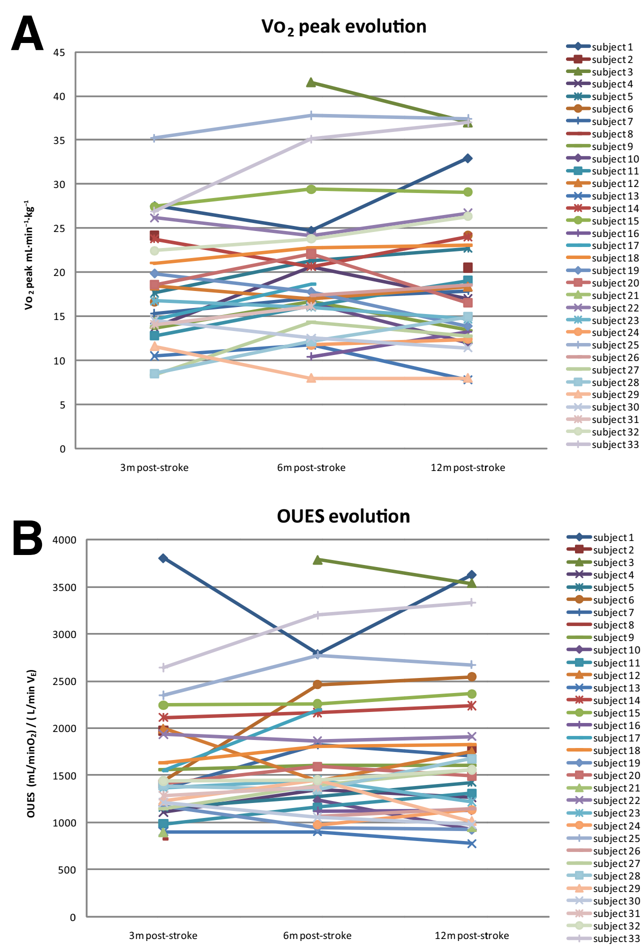

Fig 1. Individual performance on Vo_2peak (A) and OUES (B) at 3, 6, and 12 months poststroke (N=33).

Table 4: Univariate Mixed Model Analyses for Evolution of Cardiorespiratory Fitness and Its Influencing Factors

Outcome	Effect*	n	F	*P*	Estimate
VO_2peak ($mL \cdot kg^{-1} \cdot min^{-1}$)	Evolution				
	Time	33	2.72	.10	.004
	Prestroke patient characteristics				
	Time × BPAQ work	13	5.23	.03	.003
	Time × BPAQ sport	31	3.86	.05	.002
	Time × diabetes				
	No	33	5.11	<.01	.006
	Yes				−.009
	Stroke-related factors				
	Time × TIS	33	4.36	.04	<.001
	Time × BI	33	4.01	.05	<.001
Log OUES (mL/min O_2)/(L/min V_E)	Evolution				
	Time	33	3.02	.09	<.001
	Prestroke patient characteristics				
	Time × BPAQ work	13	4.88	.04	<.001
	Time × diabetes				
	No	33	3.54	.04	<.001
	Yes				<−.001
	Stroke-related factors				
	Time × side of lesion				
	Left	32	4.61	<.01	<.001
	Right				<−.001
	Both				<.001
	Time × TIS	33	5.27	.03	.006
	Time × RMA-GF	33	4.47	.04	<.001
	Time × FAC	33	3.29	<.01	<.001
	Time × BI	33	5.18	.03	.002

Abbreviations: BPAQ, Baecke Physical Activity Questionnaire; O_2, oxygen.
*Only significant interactions are retained.

more, the parameter OUES, which is a reflection of submaximal exercise, might be more appropriate.

Our second aim was to explore the effect of prestroke patients' characteristics and stroke-related factors on the evolution of CRF. Although some differences exist between factors influencing the evolution of VO_2peak and log OUES, general conclusions could be drawn. Univariate analysis revealed that stroke survivors at risk of deconditioning were premorbidly less active at work or in sport activities, diabetic, or initially more severely impaired. These results suggest that present rehabilitation therapies are not sufficient to change CRF for premorbidly less active persons, and that extra stimulation may be required to change their sedentary lifestyles. Guidance postrehabilitation will be essential to retain long-term benefits. Although optimal recovery of functional performance is a prerequisite to improve CRF, additional aerobic training for initially more severe stroke patients is needed. A multivariate approach highlighted that older patients with stroke and diabetes were less likely to improve their VO_2peak value while older, women, diabetic nonsmokers improved less on log OUES. Clearly, patients with stroke with diabetes, especially if elderly, should participate in aerobic exercises. The fact that older, women, diabetic smokers improved more than older, women, diabetic nonsmokers on log OUES is probably caused by cessation of smoking habits. No other study investigated factors influencing the evolution of CRF after stroke, and therefore comparison with the literature was not feasible.

Study Limitations

Some methodologic issues have to be considered when interpreting the data. Of the 50 recruited patients, only 33 were included for further analysis. The 17 excluded patients were more severely impaired. Results of the present study should not be generalized because of the small sample recruited from 1 institution and exclusion of severe stroke patients. Further research should explore the evolution of fitness in this group by adapting the cycle ergometer test (eg, broad seat with backrest, foot fixation, calf assists). Secondly, some factors, such as residence and intake of beta-blocker medication, may have changed during the 1-year follow-up period and may have influenced fitness. These confounders were not controlled. However, only 1 patient changed beta-blocker intake over time. Exploratory correlation analysis revealed no significant relation ($r<.30$) between CRF and residence at 3, 6, and 12 months poststroke.

Nonetheless, this study provided an insight into the longitudinal evolution of CRF over the first year after stroke and the possible risk factors of deconditioning. Moreover, a new index of CRF, the OUES, was introduced in this population. This index was more sensitive in detecting risk factors and may as such be promising as an alternative measure in intervention studies. Future research should evaluate the evolution of CRF in a larger stroke sample with a wide range of disability to confirm current results and should monitor fitness after 1 year poststroke.

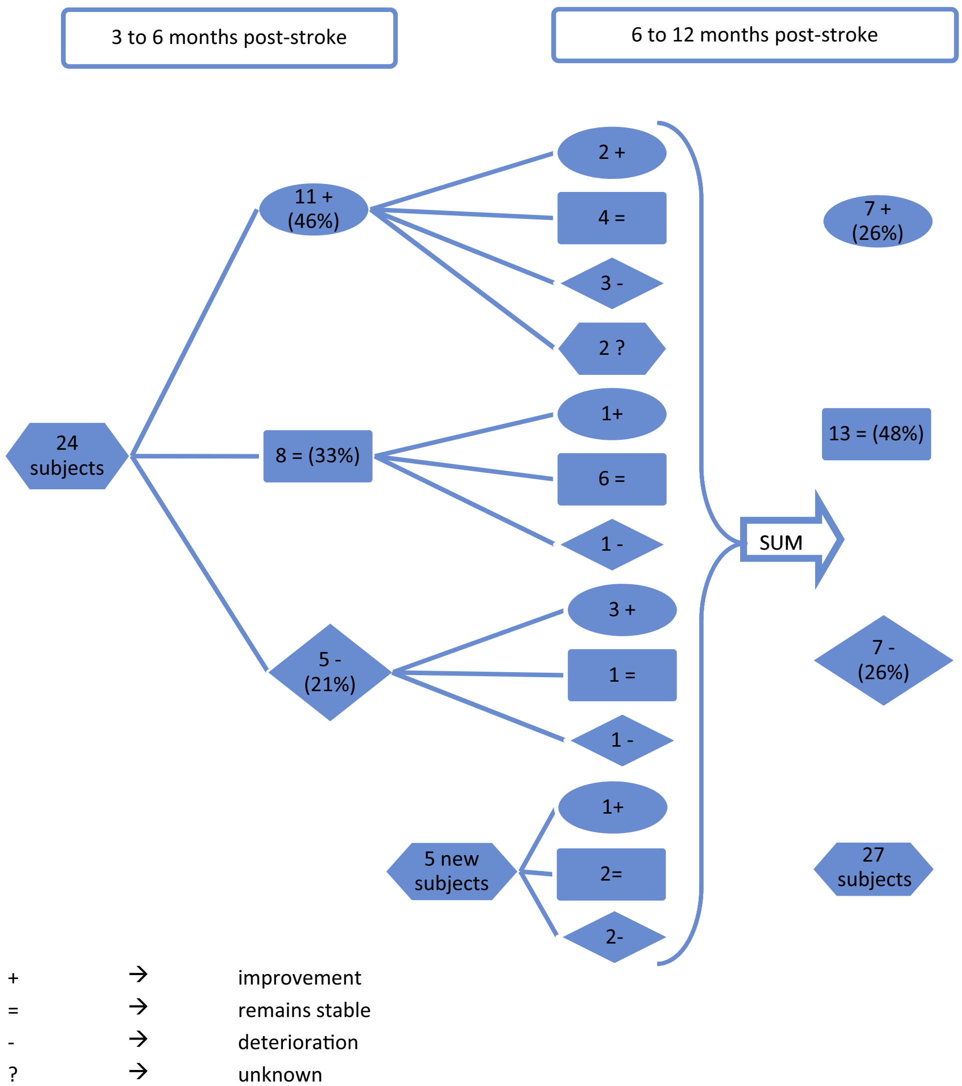

Fig 2. Individual changes in Vo_2peak between 3 and 6 months and between 6 and 12 months poststroke.

CONCLUSIONS

CRF was reduced from 3 to 12 months poststroke and did not on average significantly change during and after stay in the rehabilitation center. Individual data exploration showed that less than half of the sample improved their fitness from 3 to 12 months poststroke and only one fourth improved beyond 6 months. Exercise-based interventions of sufficient intensity, frequency, and duration should be initiated in the rehabilitation center and continued in the community. Stroke survivors at risk of deconditioning were premorbidly less active at work or in sport activities, diabetic, or initially more severely impaired. Combining factors revealed that older patients with stroke with diabetes were less likely to improve on Vo_2peak, and older, women, diabetic nonsmokers improved less on log OUES. This study provided a better understanding of fitness recovery after stroke.

Table 5: Multivariate Mixed Model Analyses for Influencing Factors on the Evolution of Cardiorespiratory Fitness

Outcome	n	χ^2	*P*	Effect*	F	*P*
Vo_2peak ($mL\cdot kg^{-1}\cdot min^{-1}$)	33	78.90	<.001	Time × age	14.26	<.001
				Time × diabetes	11.31	<.001
Log OUES (mL/min O_2)/(L/min V_E)	33	42.66	<.001	Time × age	43.12	<.001
				Time × diabetes	8.28	<.001
				Time × sex	6.01	.02
				Time × smoking	4.54	.04

Abbreviation: O_2, oxygen.
*Only significant interactions are retained.

References

1. Ivey FM, Hafer-Macko CE, Macko RF. Exercise rehabilitation after stroke. NeuroRx 2006;3:439-50.
2. Yates JS, Studenski S, Gollub S, et al. Bicycle ergometry in subacute-stroke survivors: feasibility, safety, and exercise performance. J Aging Phys Act 2004;12:64-74.
3. Eng JJ, Dawson AS, Chu KS. Submaximal exercise in persons with stroke: test-retest reliability and concurrent validity with maximal oxygen consumption. Arch Phys Med Rehabil 2004;85: 113-8.
4. Mayo NE, Wood-Dauphinee S, Ahmed S, et al. Disablement following stroke. Disabil Rehabil 1999;21:258-68.
5. Cress ME, Meyer M. Maximal voluntary and functional performance levels needed for independence in adults aged 65 to 97 years. Phys Ther 2003;83:37-48.
6. Pang MY, Eng JJ, Dawson AS, Gylfadottir S. The use of aerobic exercise training in improving aerobic capacity in individuals with stroke: a meta-analysis. Clin Rehabil 2006;20:97-111.
7. 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.
8. Fujitani J, Ishikawa T, Akai M, Kakurai S. Influence of daily activity on changes in physical fitness for people with post-stroke hemiplegia. Am J Phys Med Rehabil 1999;78:540-4.
9. Rimmer JH, Riley B, Creviston T, Nicola T. Exercise training in a predominantly African-American group of stroke survivors. Med Sci Sports Exerc 2000;32:1990-6.
10. Macko RF, Smith GV, Dobrovolny CL, Sorkin JD, Goldberg AP, Silver KH. Treadmill training improves fitness reserve in chronic stroke patients. Arch Phys Med Rehabil 2001;82:879-84.
11. Mackay-Lyons MJ, Makrides L. Exercise capacity early after stroke. Arch Phys Med Rehabil 2002;83:1697-702.
12. Duncan P, Studenski S, Richards L, et al. Randomized clinical trial of therapeutic exercise in subactue stroke. Stroke 2003;34: 2173-80.
13. Kelly JO, Kilbreath SL, Davis GM, Zeman B, Raymond J. Cardiorespiratory fitness and walking ability in subacute stroke patients. Arch Phys Med Rehabil 2003;84:1780-5.
14. MacKay-Lyons MJ, Makrides L. Longitudinal changes in exercise capacity after stroke. Arch Phys Med Rehabil 2004;85:1608-12.
15. Macko RF, Ivey FM, Forrester LW, et al. Treadmill exercise rehabilitation improves ambulatory function and cardiovascular fitness in patients with chronic stroke: a randomized, controlled trial. Stroke 2005;36:2206-11.
16. Michael KM, Allen JK, Macko RF. Reduced ambulatory activity after stroke: the role of balance, gait, and cardiovascular fitness. Arch Phys Med Rehabil 2005;86:1552-6.
17. Michael K, Macko RF. Ambulatory activity intensity profiles, fitness, and fatigue in chronic stroke. Top Stroke Rehabil 2007; 14:5-12.
18. Tseng BY, Kluding P. The relationship between fatigue, aerobic fitness, and motor control in people with chronic stroke: a pilot study. J Geriatr Phys Ther 2009;32:97-102.
19. Sutbeyaz ST, Koseoglu F, Inan L, Coskun O. Respiratory muscle training improves cardiopulmonary function and exercise tolerance in subjects with subacute stroke: a randomized controlled trial. Clin Rehabil 2010;24:240-50.
20. Howley ET. Metabolic, cardiovascular, and respiratory responses to physical activity. In: Bouchard C, Blair SN, Haskell WL, editors. Physical activity and health. Champaign, IL: Human Kinetics; 2007. p 51-66.
21. Pathophysiology of disorders limiting exercise. In: Wasserman K, Hansen JE, Sue DY, Stringer WW, Whipp BJ. Principles of exercise testing and interpretation. Including pathophysiology and clinical applications. 4th ed. Philadelphia: Lippincott Williams & Wilkins; 2005. p 111-32.
22. World Health Organization. Cerebrovascular disease: a clinical and research classification. WHO Offset Series No. 43. Geneva: World Health Organization; 1978.
23. Mahoney FI, Barthel DW. Functional evaluation: the Barthel Index. Md State Med J 1965;14:61-5.
24. Gibbons RJ, Balady GJ, Bricker JT, et al. ACC/AHA 2002 guideline update for exercise testing: summary article: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1997 Exercise Testing Guidelines). Circulation 2002;106:1883-92.
25. Kwakkel G, Kollen B, Twik J. Impact of time on improvement of outcome after stroke. Stroke 2006;37:2348-53.
26. American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription. 4th ed. Philadelphia: Lippincott Williams & Wilkins; 1995.
27. Baba R, Nagashima M, Goto M, et al. Oxygen uptake efficiency slope: a new index of cardiorespiratory functional reserve derived from the relation between oxygen uptake and minute ventilation during incremental exercise. J Am Coll Cardiol 1996;28:1567-72.
28. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982;14:377-81.
29. Baecke JA, Burema J, Frijters JE. A short questionnaire for the measurement of habitual physical activity in epidemiological studies. Am J Clin Nutr 1982;36:936-42.
30. Brott T, Adams HP, Olinger CP, et al. Measurements of acute cerebral infarction: a clinical examination scale. Stroke 1989;20: 864-70.
31. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189-98.
32. Verheyden G, Nieuwboer A, Mertin J, Preger R, Kiekens C, De Weerdt W. The Trunk Impairment Scale: a new tool to measure motor impairment of the trunk after stroke. Clin Rehabil 2004;18: 326-34.
33. Lincoln N, Leadbitter D. The assessment of motor function in stroke patients. Physiotherapy 1979;62:48-51.
34. Holden MK, Gill KM, Magliozzi MR, Nathan J, Piehl-Baker L. Clinical gait assessment in the neurologically impaired. Reliability and meaningfulness. Phys Ther 1984;64:35-40.
35. MacKay-Lyons MJ, Makrides L. Cardiovascular stress during a contemporary stroke rehabilitation program: is the intensity adequate to induce a training effect? Arch Phys Med Rehabil 2002; 83:1378-83.
36. Kuys S, Brauer S, Ada L. Routine physiotherapy does not induce a cardiorespiratory training effect post-stroke, regardless of walking ability. Physiother Res Int 2006;11:219-27.
37. Hollenberg M, Tager IB. Oxygen uptake efficiency slope: an index of exercise performance and cardiopulmonary reserve requiring only submaximal exercise. J Am Coll Cardiol 2000;36: 194-201.

Suppliers

a. Excalibur; Lode BV, Zenikepark 16, 9747 AN Groningen, The Netherlands.
b. SE-PRO-600; Welch Allyn & Schiller, 7420 Carroll Rd, San Diego, CA 92121.
c. Metalyzer 3B; CORTEX Biophysik GmbH, Walter-Köhn-Str 2d, 04356, Leipzig, Germany.
d. SAS Inc, 100 SAS Campus Dr, Cary, NC 27513.