REVIEW

Physical fitness in persons with hemiparetic stroke

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Abstract. In persons with hemiparetic stroke, assessment and promotion of fitness have so far received limited attention, partly because of the lack of appropriate measures applicable to them. Because these mobility-impaired persons are prone to inactivity, disuse and insulin resistance are likely to occur, and can aggravate the already significant health and economic consequences that stroke entails. It is therefore important to assess objectively their fitness to devize effective and efficient fitness promotion programs. Because of physical limitations, however, many persons with stroke cannot perform traditional stress testing using a treadmill or a cycle ergometer, and maximal oxygen consumption, which is regarded as a gold standard, is not a practical measure. In this article, we reviewed the current status of research on fitness in persons with hemiparetic stroke from the perspectives of evaluation, structure analysis of fitness, and longitudinal changes during a rehabilitation program. As a measure of fitness, indices obtainable with a submaximal exercise are proposed, such as anaerobic threshold and heart rate oxygen coefficient. Protocols applicable to persons with hemiparetic stroke with a variety of functional limitations have been developed (basic bedside activities, bridging activity, or single arm ergometry). The structure of their fitness is demonstrated to be described by a fitness model of healthy persons (cardiopulmonary, muscular and metabolic dimensions) if the paresis/activities of daily living dimension is added. Several studies suggest that fitness improves during a conventional stroke rehabilitation program. Studying the changes of the above four dimensions can help develop more effective fitness training programs. (Keio J Med 52 (4): 211–219, December 2003)

Key words: cerebrovascular disease, immobilization syndrome, stress testing, oxygen consumption, rehabilitation

Introduction

As in other developed countries, stroke poses us important health and economic problems in Japan.[1] The annual medical expenditure generated by stroke was estimated at approximately ¥1,920 billion ($17.46 billion) in 1997, or about 6.6% of the total medical expenses. The number of persons left with stroke residuals was estimated as 1.7 million in 1996, and stroke is presumed to have caused about 30 to 40% of the bedridden population. It is the most frequent cause of disability, accounting for 12.2% of all causes in 1996 followed by bone and joint disease (12.1%) and heart disease (10.0%), and the most frequent reason for rehabilitation referrals.

In the rehabilitative management of persons with stroke, efforts have been made to predict their functional outcomes as early as possible after the onset using standardized functional instruments,[2,3] and to maximize their functional recovery and independence utilizing limited health care resources efficiently. However, compared with approaches to motor and cognitive impairments and limitations in activities of daily living (ADL), assessment and promotion of the fitness of stroke patients have so far received limited attention, partly because of the lack of appropriate measures of fitness applicable to this population. Because these mobility-impaired individuals are prone to inactivity in their daily lives, disuse-related changes of various organs and systems such as cardiovascular, bone-joint,

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muscular and metabolic systems, are likely to occur. This can hinder successful rehabilitation,[4] and can interfere with their reintegration into the community after medical rehabilitation.

Furthermore, these patients are also at higher risk of developing metabolic disorders such as adverse changes in body composition, glucose intolerance and/or hyperinsulinemia.[5,6] Recent studies strongly suggest that insulin resistance related to an inactive life style is a major risk factor of atherosclerotic diseases,[7,8] and this can have important implications for persons with stroke for whom secondary prevention of stroke recurrence as well as primary prevention of cardiac events should be given a high priority.

Therefore, disuse and insulin resistance brought about by inactivity can aggravate the already significant health and economic consequences that stroke entails, and it is important to assess objectively the physical fitness of patients with stroke to devise effective and efficient fitness promotion programs. In this article, we will review the current status of research on fitness in persons with stroke from the following perspectives: 1) how can we evaluate their fitness?; 2) what is the structure of their fitness?; and 3) what are the effects of rehabilitation programs on their fitness?

How Can We Evaluate Their Fitness?

Because of physical the limitations, many patients with stroke cannot perform the traditional stress testing using a conventional treadmill or a cycle ergometer exercise that are commonly practiced in healthy persons. Therefore, the first obstacle we are faced with is how we should evaluate their fitness. What are the appropriate and practical modes of stressing them? What indices of fitness can we employ for those who cannot perform maximal exercise? We will first discuss indices of fitness that can be used in patients with hemiparetic stroke, and then review modes of stressing them and introduce our experience of evaluating their fitness using basic bedside activities, bridging activity, and single arm ergometry.

The indices of fitness

Oxygen consumption ($\dot{V}O_2$) increases linearly with the increase in workload up to a certain point, and this is called maximal oxygen consumption ($\dot{V}O_2max$).[9] $\dot{V}O_2max$ indicates the maximum possible energy output produced by aerobic metabolism in a unit time, and it is regarded as a gold standard index of fitness. When $\dot{V}O_2$ measurement with a sophisticated equipment is difficult, the observed maximal heart rate (HRmax) can be used as a simple measure of aerobic capacity, because HR correlates well with $\dot{V}O_2$.[9] When performing maximum stress testing is impossible, $\dot{V}O_2$ is estimated by extrapolating the HR to the age-predicted HRmax to read the $\dot{V}O_2$ level corresponding to the predicted HRmax.

In persons with motor disability and older individuals, maximal or near maximal loading is usually difficult or impossible to achieve, and in general, $\dot{V}O_2max$ is not a practical index of fitness. Even the extrapolation method requires a relatively high workload. In this context, indices obtainable with submaximal exercises have been proposed as measures of fitness, such as the anaerobic threshold[10] and the HR oxygen coefficient (HR-O_2-coeff).[11–14]

Anaerobic threshold (AT): The AT is defined as the point where anaerobic metabolism becomes dominant and blood lactate begins to rise during a graded exercise.[10] It is obtained by measuring blood lactate levels (lactate threshold; LT). Alternatively, the ventilatory threshold (VT), or a point where a greater increase in ventilation is observed in comparison with the increase in $\dot{V}O_2$, is often used in clinical practice. The point where blood lactate equals 4 mmol/l is called the onset of blood lactate accumulation (OBLA), and this indicates that energy is produced predominantly by anaerobic metabolism. The AT usually corresponds to 55 to 65% of $\dot{V}O_2max$.

There are several studies measuring the AT in persons with stroke using a graded cycle ergometer,[15] treadmill,[16] or stand-up exercise,[17] and the AT is suggested as a useful index of aerobic capacity obtainable with submaximal exercises. However, we still need to stress the patients to a relatively high workload level to measure AT, and this limits its application to those who are at least functional ambulators. Also, questions are raised as to their physiological significance, method of determination, reproducibility, and the relationship between the LT and VT.[18,19]

HR-O_2-coeff: The HR-O_2-coeff is defined as the regression coefficient between $\dot{V}O_2$ and HR.[11] It is equivalent to the oxygen pulse ($\dot{V}O_2$/HR) when the HR is extrapolated to infinity, and signifies the oxygen supply capacity of the cardiopulmonary system. It is obtainable with submaximal exercise, and is therefore a useful measure of fitness in persons with disability who cannot perform maximal exercise. This index is reported to correlate well with activity levels[11] or ambulatory levels[13] in persons with hemiparetic stroke, and with measured $\dot{V}O_2max$ in healthy persons.[11]

Modes of stress testing

As for the modes of stress testing, investigators have tried various forms of modified stress testing such as single arm ergometry,[13] low-velocity graded treadmill,[20] cycle ergometer exercise,[15] graded stand-ups,[17]

Table 1 Stress Testing Protocols for Persons with Stroke

Author (year)	Mode of exercise	Protocol	Index of fitness	Criteria for stopping
Moldover (1984)	supine ergometer	20 W for 3 min, then increase by 20 W every 3 min. 1 min rest period between stages. Pedaling rate at 50 rpm.		subjective symptoms ECG abnormalities
Yoshida (1985)	treadmill	Change speed every 4 min (14 m, 22 m, 29 m, 37 m, 44 m, 51 m, 59 m–66 m/min) with a grade of 0%.	lactic threshold	fatigue, inability to walk
Majima (1985)	treadmill	Walk for 5 min at 50% of the patient's comfortable speed → at 120% for 5 min → at 100% for 5 min with an incline of 5°. Rest periods in between.	$\dot{V}O_2$-100, 120	
Sonoda (1989)	trunk flexion-extention	Sitting on a chair, flexes and extends trunk at a rate of 20, 35 and 50 rpm every 3 min.	HR-O_2 coeff	
Hiwatari (1989)	supine ergometer	At 200 kpm and 300 kpm, perform maximal exercise that can be done without discomfort for 3 min each.	HR, BP, DP, $\dot{V}O_2$	
Komuro (1992)	ergometer	10 W for 2 min, then increase by 15 W every min. Pedaling rate at 70 rpm.	AT	exhaustion, inability to maintain the pedaling rate.
Muraki (1992)	standing	Flex and extend upper extremities at 15 and 30 rpm with an incline of 0°, then at 15 and 30 rpm with an incline of 15°. 3 min for each step and 3 min rest in between.		
Tsukagoshi (1993)	treadmill	Walk at 5 m/min with 0% inclination, then increase the speed 5 m/min every 30 sec. After reaching maximum speed, the inclination is increased by 2% every 30 sec.	AT	unable to walk, leg fatigue, shortness of breath
Ohkuma (1994)	repetitive stand-ups	Stand up from a seat height of 60 cm at a rate of 10 rpm for 4 min, then at a rate of 20 rpm for 1 min. Lower the seat height by 5 cm every min.	AT	subjective symptoms, ≧90% HRmax unable to continue
Majima (1995)	ergometer	0 W for 3 min, then increase by 15 W/min. Pedaling rate at 40 rpm.	AT	fatigue, ECG abnormalities, systolic BP ≧ 200 mmHg
Mori (1995)	basic bedside activities	Rest → sitting → standing → arm elevation (10 rpm) → roll over (7 rpm) → bridging (13 rpm) → sit ups (5 rpm) → stepping (60 steps/min) → stand-ups (10 rpm). 4 min exercise and 2 to 4 min rest in between.	HR-O_2 coeff, $\dot{V}O_2$-100	subjective symptoms, ECG abnormalities, BP ≧ 200 mmHg
Hara (1996)	single arm ergometer	Start at 25 W, then increase by 5 W every min.	HR-O_2 coeff, $\dot{V}O_2$-100	subjective symptoms, ECG abnormalities, BP ≧ 200 mmHg
Macko RF (1997)	treadmill	Graded treadmill at gait velocities individualized to functional mobility observed during an initial zero-incline treadmill tolerance test.	HR, ECG	
Tsuji (1999)	bridging activity	3 rpm for 4 min, and the rate is increased to 6, 12, 18 and 24 rpm every 4 min.	HR-O_2 coeff	subjective symptoms, ECG abnormalities, BP ≧ 200 mmHg

W: Watt(s); rpm: repetition per minute, $\dot{V}O_2$-100, 120: oxygen consumption at the heart rate of 100 or 120 beats/min; BP: blood pressure; HR-O_2-coeff: heart rate oxygen coefficient; AT: anaerobic threshold; HRmax: maximal heart rate; ECG: electrocardiogram.

body bending,[11] graded basic activities,[12] and graded bridging activities.[14] The protocols reported so far are summarized in Table 1. Our group has studied extensively the possibility of applying basic bedside activities and single arm ergometry as graded testing protocols.[12–14,21]

Graded basic activities protocol: Patients with hemiparetic stroke routinely perform bedside activities such as roll-over, sit-ups and stand-ups, which play an important role in stroke rehabilitation. There have been, however, limited reports studying their cardiopulmonary stress levels in detail, except the study by Mori[12] who investigated the stress levels of basic bedside activities, and proposed a new stress testing protocol.

In his pilot study, 15 patients with hemiparetic stroke were asked to perform bedside activities at speeds which they found comfortable, and HR and $\dot{V}O_2$ were

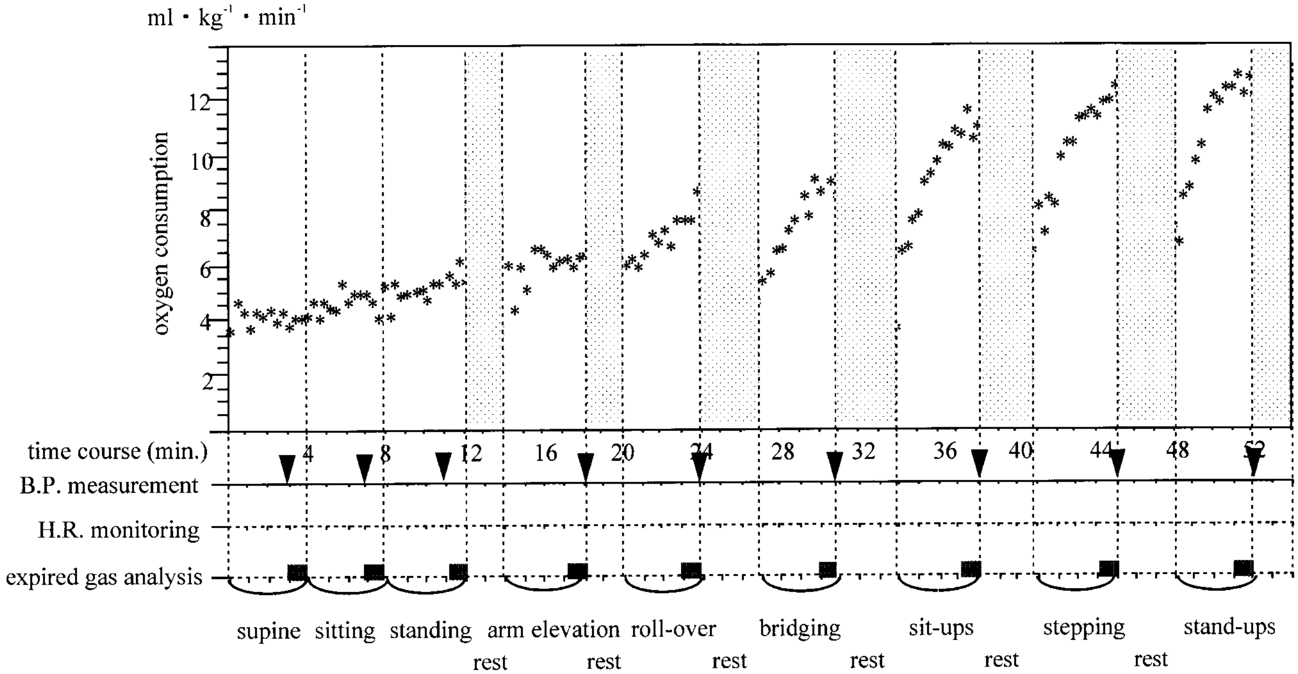

Fig. 1 The graded basic activities protocol. After 4 minutes of supine resting, the patient performs basic activities successively from sitting to stand-ups, each lasting 4 minutes with 2 or 4 minutes rest period in between. Blood pressure (BP), heart rate (HR) and oxygen consumption are continuously monitored. (Reproduced from Mori E: Jpn J Rehabil Med 1996; 33: 49–60 (in Japanese) Copyright © (1996), with permission from Japanese Association of Rehabilitation Medicine)

continuously monitored to determine the stress level of each activity. The $\dot{V}O_2$ increased in the following order; supine lying, sitting, standing, arm elevation, roll over, bridging, sit-ups, stepping and stand-ups. The HR demonstrated almost parallel changes. By analyzing the distribution of the repetitions per minute (RPM) for each activity, Mori determined the RPM-80%s or the RPMs that over 80% of the patients could follow. He proposed a graded basic activities stress testing protocol based on the RPM-80%s (Fig. 1).

The reproducibility of his protocol was studied in another 17 patients. The HRs were not significantly different between the two measurements for all activities, and the amounts of HR increase from resting were not statistically different except roll-over. For $\dot{V}O_2$, although the absolute values were significantly lower in the second examination for sitting, standing and stand-ups, the amounts of increase from the resting state were not statistically different for all activities. Also, the HR-O_2-coeff and predicted $\dot{V}O_2$max were not significantly different between the two examinations.

Using this protocol, Mori compared HR, $\dot{V}O_2$, HR-O_2-coeff and predicted $\dot{V}O_2$max in 52 patients with hemiparesis and 10 age-matched healthy persons. Most (83.8%) of the patients could complete the protocol with no serious complications. Absolute HR and HR increases from resting were significantly higher in the patient group than in the control group in sitting, standing, stand-ups and stepping. The $\dot{V}O_2$ was not significantly different from the controls except for standing and stepping, but when expressed in metabolic equivalent (MET), or the ratio of exercise $\dot{V}O_2$ to resting $\dot{V}O_2$,[9] it was significantly higher in the patient group for sitting, standing, roll-over, stepping and stand-ups. The HR and the $\dot{V}O_2$ increased linearly with each other, and linear regression lines for the two groups could be drawn (Fig. 2). The HR-O_2-coeff and the predicted $\dot{V}O_2$ max were significantly lower in the patient group (0.240 ± 0.080 vs. 0.362 ± 0.069 $ml \cdot kg^{-1} \cdot beats^{-1}$ for the HR-O_2-coeff and 24.34 ± 8.84 vs. 35.18 ± 7.86 $ml \cdot kg^{-1} \cdot min^{-1}$ for the predicted $\dot{V}O_2$ max; $P < 0.01$, Student t-test), indicating lower fitness level.

As far as we know, his study is the first that systematically examined stress levels of basic activities, and gives us valuable information when we try to prescribe a rehabilitation program for patients with stroke.

Graded bridging activity protocol: Based on the study by Mori,[12] we devised a simpler stress testing using a graded bridging activity applicable to a wider spectrum of patients with stroke (Fig. 3). In this protocol, a graded bridging activity, defined as a pelvic elevation to maximal hip extension at several predetermined rates, was used.[14] Patients performed the bridging activity

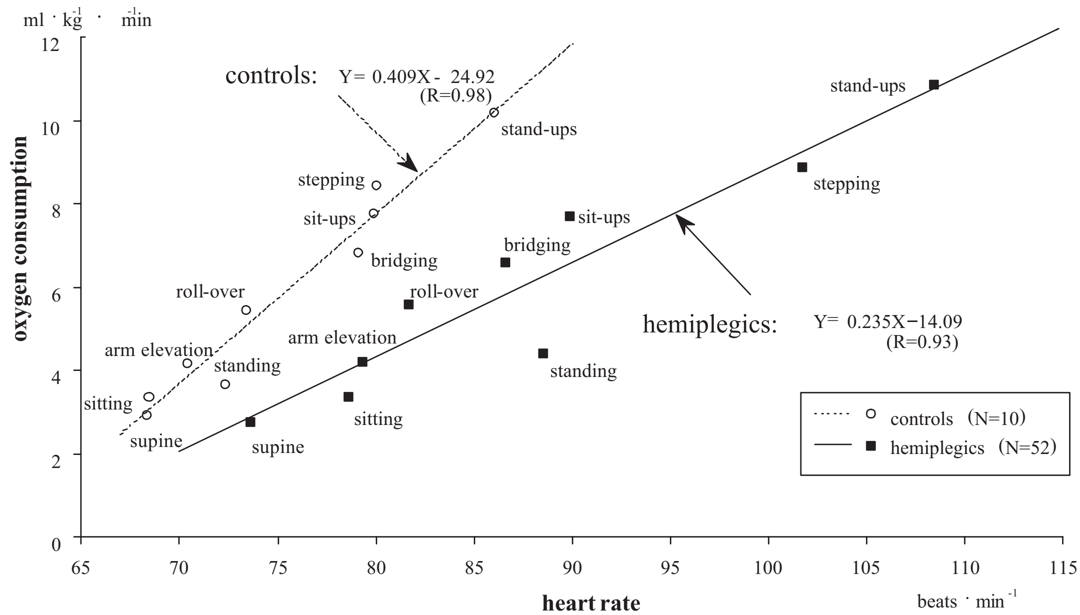

Fig. 2 The relationship between heart rate and oxygen consumption in 52 patients with hemiparetic stroke and 10 age-matched controls. The heart rate oxygen coefficient, or the regression coefficient between the heart rate and oxygen consumption is smaller in the patient group. (Reproduced from Mori E: Jpn J Rehabil Med 1996; 33: 49–60 (in Japanese) Copyright © (1996), with permission from Japanese Association of Rehabilitation Medicine)

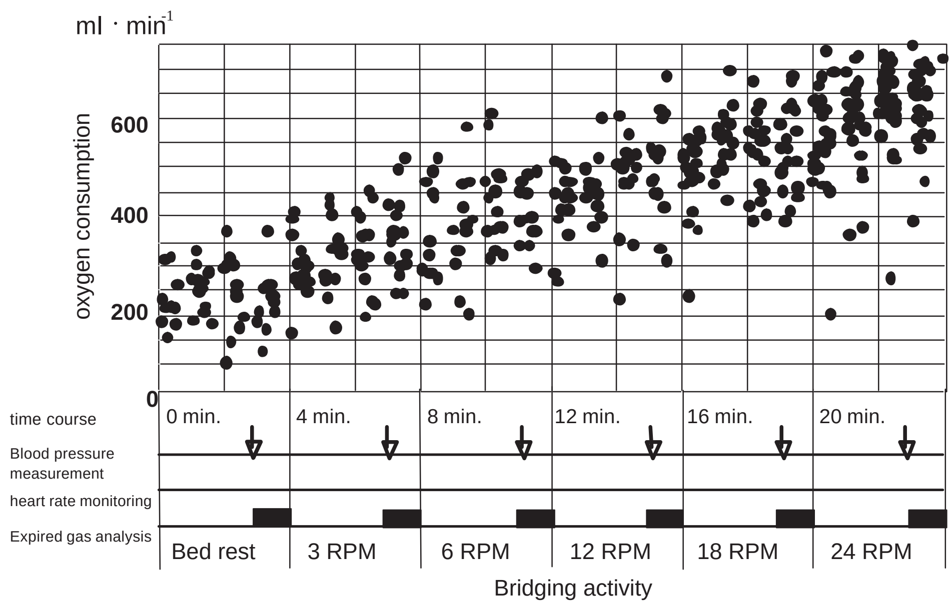

Fig. 3 Bridging activity exercise protocol. After 15 minutes of rest, the patient performs the bridging activity at a rate of 3 repetitions per minute (RPM) for 4 minutes, and the rate was increased to 6, 12, 18, and 24 RPM every 4 minutes. Heart rate and oxygen consumption are continuously monitored. (Reproduced from Tsuji T, *et al*: Arch Phys Med Rehabil 1999; 80: 1060–1064 Copyright © (1999), with permission from Elsevier Science)

at a rate of 3 RPM for 4 minutes, and the rate was increased to 6, 12, 18 and 24 RPM every 4 minutes. By continuously monitoring $\dot{V}O_2$, and HR, the HR-O_2-coeff was calculated.

When we repeated the testing twice within a week in 5 patients with hemiparesis who were over 3 months post stroke and 5 control persons, the intraclass correlation coefficients (ICC) were above 0.9 for HR, above 0.7 for $\dot{V}O_2$ at each stress level, and 0.75 in the controls and 0.98 in patients for the HR-O_2-coeff. Therefore, the

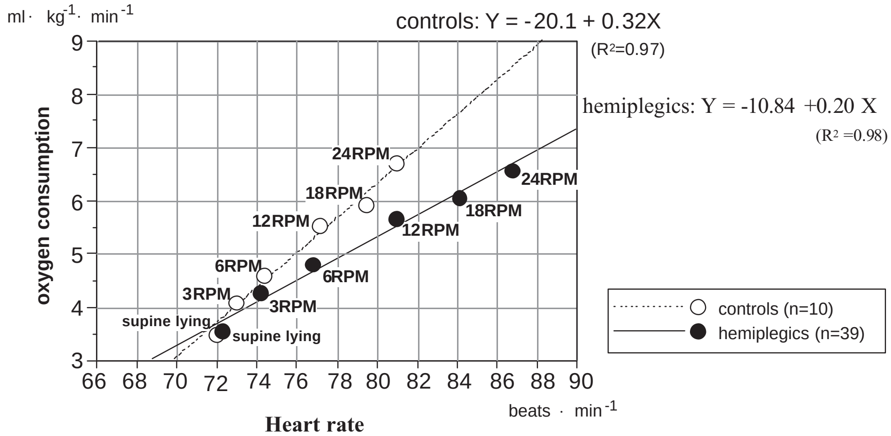

Fig. 4 Comparison of cardiopulmonary responses between 39 hemiplegic patients (●) and 10 age-matched controls (○). Heart rate (beat/min) and oxygen consumption (m $L \cdot kg^{-1} \cdot min^{-1}$) increased linearly with each other in the two groups. The heart rate oxygen coefficient was significantly less in the patient group. (Reproduced from Tsuji T, *et al*: Arch Phys Med Rehabil 1999; 80: 1060–1064 Copyright © (1999), with permission from Elsevier Science)

test-retest reproducibility of the protocol was satisfactory.

In 44 patients with hemiparesis who were within 2 weeks of a rehabilitation admission and 10 healthy age-matched controls, we compared HR, amounts of increase from the resting HR, $\dot{V}O_2$, METs, and HR-O_2-coeff for each RPM. All the control persons and 39 of the 44 patients (88.6%) completed the protocol from resting to 24 RPM. The amount of HR increase from the resting HR for each stress level was significantly greater in the patient group except at 3 RPM where no significant difference was found. The HR, $\dot{V}O_2$, and METs were not significantly different. However, the HR tended to be higher, and the HR-O_2-coeff was significantly lower in the patient group than in the control group (0.21 ± 0.08 vs. 0.29 ± 0.04 $ml \cdot kg^{-1} \cdot min^{-1}$, $P < 0.01$). As shown in Fig. 4, HR and $\dot{V}O_2$ increased linearly with each other in both groups, and two different linear regression lines could be drawn. Our newly developed bridging activity protocol proved to be a reliable and valid evaluation tool of physical fitness in patients with stroke.

Single arm ergometry protocol: Arm ergometry (AE) is more widely applicable to persons with lower limb disability than treadmill or cycle ergometer exercise. Hara[13] examined methodological issues of arm ergometry and compared the cardiopulmonary responses of patients with stroke to healthy persons. He studied the reproducibility of HR and $\dot{V}O_2$ during a graded arm ergometer exercise in 15 young adults (mean age: 27.7 yr, workload increment of 1 watt/3 sec) and 8 patients (mean age: 58.8 yr, workload increment of 5 watts/min), and reported that the ICCs of the two trials were over 0.83 for peak $\dot{V}O_2$ and 0.70 for peak HR. He also reported that in the young adult group, single AE $\dot{V}O_2$max corresponded to 70–80% of bilateral AE peak $\dot{V}O_2$.

When 87 patients with stroke (mean age: 58.4 yr) were compared with 35 age-matched controls (mean age: 59.9 yr) with a single AE protocol, $\dot{V}O_2$ max and HRmax were not significantly different, but the HR-O_2-coeff was lower in the stroke group (0.219 ± 0.063 vs. 0.258 ± 0.110 $ml \cdot kg^{-1} \cdot beats^{-1}$, Student t-test, $p < 0.05$). Among patients with stroke, $\dot{V}O_2$ max and the HR-O_2-coeff were the lowest in the wheelchair dependent group, followed by wheelchair independent, household ambulatory and community ambulatory groups (Kruscal-Wallis, $P < 0.05$). He also found that 61% of the variance of $\dot{V}O_2$ max could be explained by grip strength that can be easily measured in daily clinical practice.

With his protocol, most of the patients with stroke could be stressed to a relatively high level with no major complications, and it can be useful clinically as a mode of stress testing for these patients.

What Is the Structure of Fitness?

In healthy persons, physical fitness is commonly categorized by cardiopulmonary, muscular and metabolic factors,[9] but it is not known whether the same categorization applies to persons with stroke. To develop a rehabilitation program more targeted to the promotion of fitness in this population, it is necessary to clarify the dimensions of their fitness. To our knowledge, however, no studies are available in the literature investigating this problem except the study by our group.[21] In 107 patients with hemispheric stroke, we measured multiple parameters related to cardiopulmonary, muscular and metabolic functions as conceptualized in the fitness model in a healthy population, and also variables related to motor impairment and disability that could constitute another possible dimension of their fitness.

We used the Stroke Impairment Assessment Set (SIAS)[22,23] and the Functional Independence Measure (FIM^{SM})[24,25] that are standardized measures of impairment and disability. As for cardiopulmonary function, we measured the distance covered by 12-minute wheelchair propulsion or walking on an indoor running track,[26] and the HR-O_2-coeff derived by having the patients perform the graded bridging activity protocol. With regard to muscular function, we measured grip strength, the isometric torque of the knee extensors, and the cross-sectional area of the thigh muscles with CT images. As for metabolic factors, we calculated the body mass index (BMI) and visceral fat areas as measured with a CT scanner according to van der Kooy and Seidell.[27]

To study the statistical structure of fitness, the above variables were subjected to a principle component analysis (PCA) followed by an orthogonal rotation of the initially extracted components,[28] which produced four factors whose eigenvalues were greater than 1. The four factor solutions explained 78.1% of the total variance in the original 15 variables, and had a well-defined structure. These factors could be interpreted in clinically meaningful ways as conceptualized before the analysis. Factor I included grip strength, the unaffected side SIAS quadriceps manual muscle testing (MMT) score, isometric strength of the knee extensors, and cross-sectional area of the whole thigh muscles on the unaffected side. It represented the muscular function, and explained 24.4% of the variance. Factor II was comprised of the SIAS affected side lower extremity score, the FIM^{SM} motor score, the ambulatory score, the affected side SIAS quadriceps MMT score, and the isometric strength of the affected side knee extensors. It reflected lower extremity motor impairment and activities of daily living (ADL), and explained 24.3% of the variance. Factor III consisted of the BMI and fat accumulation that reflected metabolic function, explaining 14.7% of the variance. Factor IV included the HR-O_2-coeff representing the cardiopulmonary function, and explained 14.7% of the variance. PCA of the discharge data produced almost identical results, and the four factor solutions explained 69.6% of the total variance.

In this way, we could demonstrate that fitness in persons with hemiparetic stroke could be categorized on the basis of a conceptual model of fitness widely used among healthy persons if the paresis/daily living domain is also considered. Furthermore, the possibility was suggested that we could describe their fitness domains with variables easily measured in daily clinical practice, i.e., grip strength (factor I: muscular), the SIAS and the FIM^{SM} (factor II: paresis/ADL) and BMI (factor III: metabolic), except for factor IV (cardiopulmonary) that could only be explained by the HR-O_2-coeff which requires measurement with sophisticated equipment. This justifies the measurement of the HR-O_2-coeff with an HR monitor and expired gas analyzers using a graded bridging activity protocol to better understand the fitness of patients with stroke.

What Are the Effects of Rehabilitation Programs on Fitness?

There are several studies that examined the effects of muscle strengthening,[29–31] aerobic training[15,32,33] or a combination of these[34–36] in patients with stroke. Muscle strengthening exercise of the affected lower extremity with isokinetic strength training and progressive resistive exercise is effective to improve muscle strength and physical functioning such as basic activities and ambulation.[30,31] Eccentric contraction is more effective than concentric contraction in improving the affected to unaffected side knee extensor muscle strength ratio and symmetric weight distribution.[29] Aerobic training in the chronic phase of stroke improves aerobic capacity ($\dot{V}O_2$max) and systolic blood pressure response during a submaximal exercise.[32] Low-level treadmill aerobic exercise training increases peak $\dot{V}O_2$ and decreases energy consumption during ambulation, and is effective to improve cardiovascular fitness.[33] A combination of aerobic exercise and lower extremity muscle strengthening improves affected side muscle strength, gait speed, physical activity and quality of life.[34] Task-related circuit training focusing on lower extremity muscle strength and functional tasks improves performance of locomotor tasks in chronic stroke.[35] A health promotion program consisting of aerobic exercise, muscle strengthening and flexibility exercise improves general fitness.[36]

The above studies are targeted to training muscular and/or cardiopulmonary components of fitness. What about the effects of a conventional inpatient stroke rehabilitation program on fitness? Mori[12] followed the longitudinal changes of the exercise parameters obtained with basic bedside activities protocol in 13 patients involved in an inpatient stroke rehabilitation program over a period of 4 weeks. The HRs tended to be lower in the second examination for all activities. The absolute values were significantly lower for bridging and stand-ups, and the amounts of increase from the resting values were significantly lower for arm elevation, roll-over, bridging and stand-ups. In contrast, the $\dot{V}O_2$ values were not significantly different between the two measurements both for the absolute and the relative values. The indices of cardiopulmonary fitness were significantly higher in the second examination (0.214 ± 0.069 vs. 0.257 ± 0.091 $ml \cdot kg^{-1} \cdot beats^{-1}$ for the $HR\text{-}O_2$-coeff and 22.47 ± 7.49 vs. 26.93 ± 10.02 $ml \cdot kg^{-1} \cdot min^{-1}$ for predicted $\dot{V}O_2max$; $P < 0.05$, paired t-test).

In another study, we studied the longitudinal changes in fitness parameters in 30 patients with hemiparesis undergoing a conventional stroke rehabilitation program 5 days a week using the graded bridging activity protocol.[14] The absolute HR was significantly lower at each RPM level and the $HR\text{-}O_2$-coeff was significantly greater in the 2nd examination.

Thus, fitness appears to improve during a conventional rehabilitation program, but few studies have so far analyzed systematically the changes of various dimensions of fitness. We therefore examined in 107 patients with hemiparetic stroke whether the principle component (PC) scores of the four components of fitness described above can be used to document changes of fitness level after an inpatient stroke rehabilitation program.[21] As a result, the PC score for Factor I (muscular) decreased and those for factor II (paresis/ADL) and IV (cardiopulmonary) increased significantly at discharge, indicating improvement in these domains of fitness. In contrast, the PC score for Factor III (metabolic) did not change significantly. Fig. 5 shows scatter graphs of the PC scores for each patient at admission and at discharge. An ellipse contains 95% of the scatter plots, and all the ellipses moved in the directions of more normal areas at discharge, suggesting improvement. In this way, we could demonstrate that PC scores were useful not only to characterize but also to follow longitudinal changes of individual patients. In the fu-

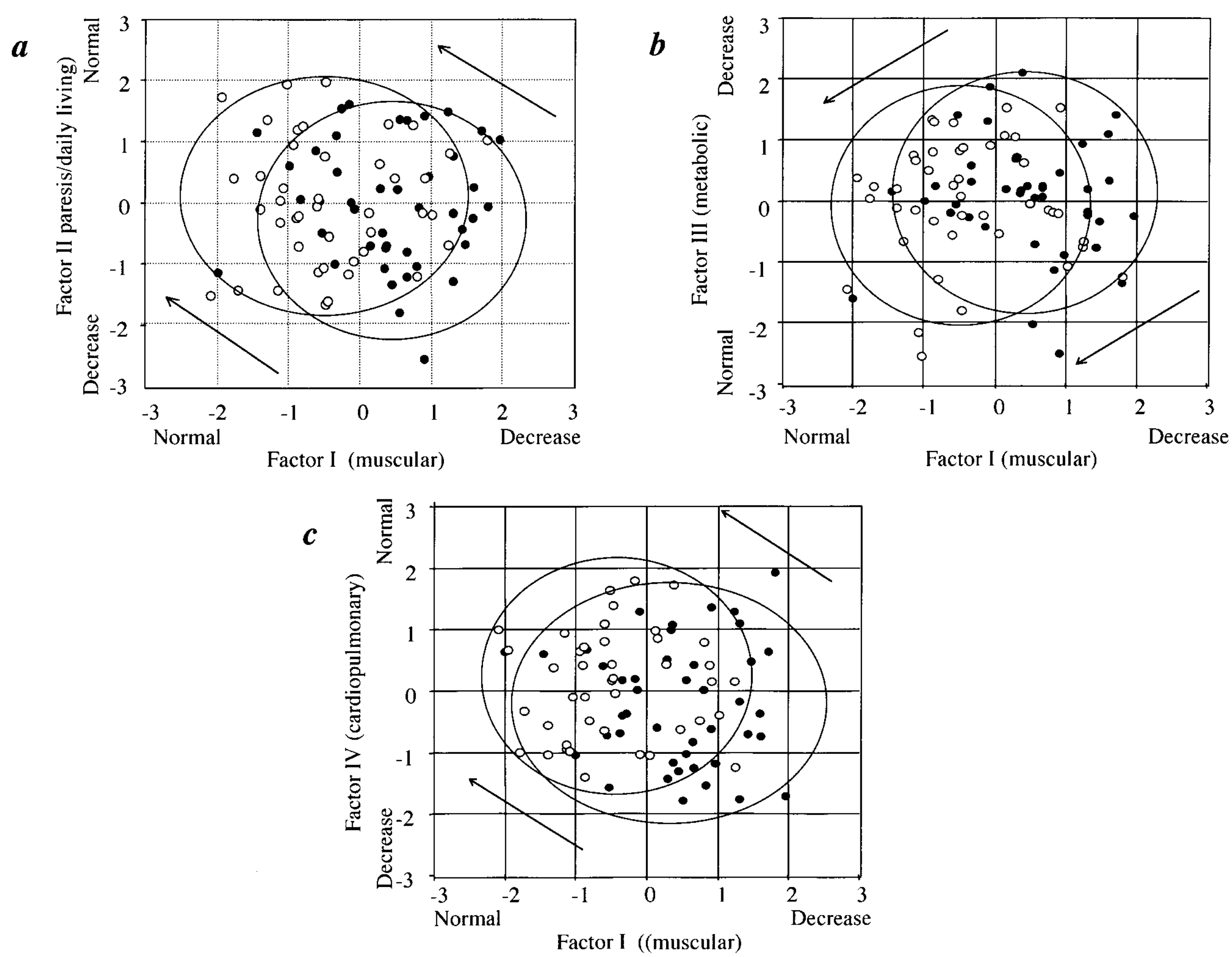

Fig. 5 a) A scatter graph of the principle component scores of Factor I (muscular) and Factor II (paresis/activities of daily living; ADL) at admission and at discharge. 95% of the scatter plots are concentrated statistically in an ellipse. b) A scatter graph of the principle component scores of Factor I (muscular) and Factor III (metabolic function) at admission and at discharge. c) A scatter graph of Factor I (muscular) and Factor IV (cardiopulmonary function) at admission and at discharge. ●, admission; ○, discharge. All the ellipses moved in the directions of more normal areas at discharge, indicating improvement. (Reproduced from Tsuji T, *et al*: Clin Rehabil 2003 (in press), with permission from Arnold Publishers)

ture, it would be necessary to prescribe a more specific training program to improve the fitness dimensions with lower scores on an individual basis.

References

1. Liu M, Chino N, Takahashi H: Current status of rehabilitation, especially in patients with stroke, in Japan. Scand J Rehabil Med 2000; 32: 148–158
2. Heinemann AW, Linacre JM, Wright BD, Hamilton BB, Granger C: Prediction of rehabilitation outcomes with disability measures. Arch Phys Med Rehabil 1994; 75: 133–143
3. Sonoda S, Saitoh E, Domen K, Chino N: Prognostication of stroke patients using the stroke impairment assessment set and functional independence measure. In Chino N, Melvin JL, eds, Functional Evaluation of Stroke Patients. Tokyo, Springer-Verlag, 1996; 103–114
4. Halar EM, Bell KR: Rehabilitation's relationship to inactivity. In: Kottke FJ, Lehmann JF, eds, Krusen's Handbook of Physical Medicine and Rehabilitation, 4th Ed, Philadelphia, WB Saunders, 1990; 1113–1133
5. Roth EJ: Heart disease in patients with stroke. Part II: Impact and implications for rehabilitation. Arch Phys Med Rehabil 1994; 75: 94–101
6. Chimowitz MI, Poole RM, Starling MR, Schwaiger M, Gross MD: Frequency and severity of asymptomatic coronary disease in patients with different causes of stroke. Stroke 1997; 28: 941–945
7. Prevalence of cardiovascular disease risk-factor clustering among persons aged > or = 45 years-Louisiana, 1991–1995. MMWR Morb Mortal Wkly Rep 1997; 46: 585–588
8. Montani JP, Antic V, Yang Z, Dulloo A: Pathways from obesity to hypertension: from the perspective of a vicious triangle. Int J Obes Relat Metab Disord 2002; 26: S28–38
9. Åstrand PO, Rodahl K: Textbook of Work Physiology, 3rd Ed, New York, McGraw-Hill, 1986; 295–353
10. McArdle WD, Katch FL, Katch VL: Exercise Physiology, 4th Ed, Baltimore, Williams & Wilkins, 1995; 122–124, 254–255
11. Sonoda S, Okajima Y, Tsubahara A, Chino N: Graded body bending exercise to measure endurance in hemiplegics. Jpn J Rehabil Med 1989; 26: 93–96 (in Japanese)
12. Mori E: Exercise physiology of basic bedside activities in hemiplegics. Jpn J Rehabil Med 1996; 33: 49–60 (in Japanese)
13. Hara Y: Arm ergometry in stroke patients: evaluation of fitness with single arm ergometry and its relation to grip strength. Jpn J Rehabil Med 1996; 33: 24–32 (in Japanese)
14. Tsuji T, Liu M, Tsujiuchi K, Chino N: Bridging activity as a mode of stress testing for persons with hemiplegia. Arch Phys Med Rehabil 1999; 80: 1060–1064
15. Majima M, Kondoh T, Eguchi K, Fujii H, Komiyama G, Suzuki E, Sowa K: Effect of endurance exercise at intensity corresponding to anaerobic threshold on improvement of cardiorespiratory fitness in stroke patients aged below 59 and over 60 years. Jpn J Rehabil Med 1998; 35: 485–490 (in Japanese)
16. Tsukagoshi K, Iida K, Takagi H, Odajima N, Ohkubo H, Kizawa T, Maruyama K, Yamanobe K: Evaluation of general endurance in the hemiplegic patients, utilizing anaerobic threshold. Sogo Rihabiriteshon 1993; 21: 585–591 (in Japanese)
17. Okuma H, Ogata H, Mizushima T, Tsutusi Y, Nagayoshi M: The availability of stand-up exercise for the detection of AT in hemiplegic patients. Jpn J Rehabil Med 1994; 31: 165–172 (in Japanese)
18. di Prampero PE: The anaerobic threshold concept: a critical evaluation. Adv Cardiol 1986; 35: 24–34
19. Myers J, Ashley E: Dangerous curves. A perspective on exercise, lactate, and the anaerobic threshold. Chest 1997; 111: 787–795
20. Macko RF, Katzel LI, Yataco A, Tretter LD, DeSouza CA, Dengel DR, Smith GV, Silver KH: Low-velocity graded treadmill stress testing in hemiparetic stroke patients. Stroke 1997; 28: 988–992
21. Tsuji T, Liu M, Hase K, Masakado Y, Chino N: Physical fitness in persons with hemiparetic stroke. Clin Rehabil 2003 (in press)
22. Tsuji T, Liu M, Sonoda S, Domen K, Chino N: The stroke impairment assessment set: its internal consistency and predictive validity. Arch Phys Med Rehabil 2000; 81: 863–868
23. Liu M, Chino N, Tuji T, Masakado Y, Hase K, Kimura A: Psychometric properties of the Stroke Impairment Assessment Set (SIAS). Neurorehabil Neural Repair 2002; 16: 339–351
24. Linacre JM, Heinemann AW, Wright BD, Granger CV, Hamilton BB: The structure and stability of the Functional Independence Measure. Arch Phys Med Rehabil 1994; 75: 127–132
25. Tsuji T, Sonoda S, Domen K, Saitoh E, Liu M, Chino N: ADL structure for stroke patients in Japan based on the functional independence measure. Am J Phys Med Rehabil 1995; 74: 432–438
26. Franklin BA, Swantek KI, Grais SL, Johnstone KS, Gordon S, Timmis GC: Field test estimation of maximal oxygen consumption in wheelchair users. Arch Phys Med Rehabil 1990; 71: 574–578
27. van der Kooy K, Seidell JC: Techniques for the measurement of visceral fat: a practical guide. Int J Obes Relat Metab Disord 1993; 17: 187–196
28. Armitage P, Berry G: Statistical Methods in Medical Research, 3rd Ed, Oxford, Blackwell Scientific Publications, 1994
29. Engardt M, Knutsson E, Jonsson M, Sternhag M: Dynamic muscle strength training in stroke patients: effects on knee extension torque, electromyographic activity, and motor function. Arch Phys Med Rehabil 1995 May; 76 (5): 419–25
30. Sharp SA, Brouwer BJ: Isokinetic strength training of the hemiparetic knee: effects on function and spasticity. Arch Phys Med Rehabil 1997; 78: 1231–1236
31. Weiss A, Suzuki T, Bean J, Fielding RA: High intensity strength training improves strength and functional performance after stroke. Am J Phys Med Rehabil 2000; 79: 369–376
32. 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: 101–105
33. 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: 879–884
34. Teixeira-Salmela LF, Olney SJ, Nadeau S, Brouwer B: Muscle strengthening and physical conditioning to reduce impairment and disability in chronic stroke survivors. Arch Phys Med Rehabil 1999; 80: 1211–1218
35. Dean CM, Richards CL, Malouin F: Task-related circuit training improves performance of locomotor tasks in chronic stroke: a randomized, controlled pilot trial. Arch Phys Med Rehabil 2000; 81: 409–417
36. 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: 1990–1996