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 devise 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 residuais 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,
muscular and metabolic systems, are likely to occur. This can hinder successful rehabilitation, 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. Recent studies strongly suggest that insulin resistance related to an inactive lifestyle is a major risk factor of atherosclerotic diseases, 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 (VO₂) increases linearly with the increase in workload up to a certain point, and this is called maximal oxygen consumption (VO₂max). VO₂max 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 VO₂ 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 VO₂. When performing maximum stress testing is impossible, VO₂ is estimated by extrapolating the HR to the age-predicted HRmax to read the VO₂ 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, VO₂max 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 and the HR oxygen coefficient (HR-O₂-coeff).

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. 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 VO₂, 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 VO₂max.

There are several studies measuring the AT in persons with stroke using a graded cycle ergometer, or stand-up exercise, 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.

HR-O₂-coeff: The HR-O₂-coeff is defined as the regression coefficient between VO₂ and HR. It is equivalent to the oxygen pulse (VO₂/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 or ambulatory levels in persons with hemiparetic stroke, and with measured VO₂max in healthy persons.

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, low-velocity graded treadmill, cycle ergometer exercise, graded stand-ups, etc.
body bending,\textsuperscript{11} graded basic activities,\textsuperscript{12} and graded bridging activities.\textsuperscript{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.\textsuperscript{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\textsuperscript{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 VO\textsubscript{2} were...
continuously monitored to determine the stress level of each activity. The VO₂ 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 VO₂, 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-VO₂-coeff and predicted VO₂max were not significantly different between the two examinations.

Using this protocol, Mori compared HR, VO₂, HR-VO₂-coeff and predicted VO₂max 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 VO₂ was not significantly different from the controls except for standing and stepping, but when expressed in metabolic equivalent (MET), or the ratio of exercise VO₂ to resting VO₂, it was significantly higher in the patient group for sitting, standing, roll-over, stepping and stand-ups. The HR and the VO₂ increased linearly with each other, and linear regression lines for the two groups could be drawn (Fig. 2). The HR-VO₂-coeff and the predicted VO₂max were significantly lower in the patient group (0.240 ± 0.080 vs. 0.362 ± 0.069 ml·kg⁻¹·beats⁻¹ for the HR-VO₂-coeff and 24.34 ± 8.84 vs. 35.18 ± 7.86 ml·kg⁻¹·min⁻¹ for the predicted VO₂ 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, 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. Patients performed the bridging activity...
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 VO₂ and HR, the HR-O₂-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 VO₂ at each stress level, and 0.75 in the controls and 0.98 in patients for the HR-O₂-coeff. Therefore, the

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**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)

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**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)
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, V˙O₂, METs, and HR-O₂-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, V˙O₂, and METs were not significantly different. However, the HR tended to be higher, and the HR-O₂-coeff was significantly lower in the patient group than in the control group (0.21 ± 0.08 vs. 0.29 ± 0.04 ml·kg⁻¹·min⁻¹, P < 0.01). As shown in Fig. 4, HR and V˙O₂ 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. Hara13 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 V˙O₂ 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 V˙O₂ and 0.70 for peak HR. He also reported that in the young adult group, single AE V˙O₂ₘₐₓ corresponded to 70–80% of bilateral AE peak V˙O₂.

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, V˙O₂ₘₐₓ and HRₘₐₓ were not significantly different, but the HR-O₂-coeff was lower in the stroke group (0.219 ± 0.063 vs. 0.258 ± 0.110 ml·kg⁻¹·beats⁻¹, Student t-test, p < 0.05). Among patients with stroke, V˙O₂ₘₐₓ and the HR-O₂-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 V˙O₂ₘₐₓ could be explained by grip strength that can be easily measured in daily clinical practice.

With this 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)\textsuperscript{22,23} and the Functional Independence Measure (FIM\textsuperscript{SM})\textsuperscript{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,\textsuperscript{26} and the HR-O\textsubscript{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.\textsuperscript{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,\textsuperscript{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\textsuperscript{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\textsubscript{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\textsuperscript{SM} (factor II: paresis/ADL) and BMI (factor III: metabolic), except for factor IV (cardiopulmonary) that could only be explained by the HR-O\textsubscript{2}-coeff which requires measurement with sophisticated equipment. This justifies the measurement of the HR-O\textsubscript{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,\textsuperscript{29–31} aerobic training\textsuperscript{15,32,33} or a combination of these\textsuperscript{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.\textsuperscript{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.\textsuperscript{29} Aerobic training in the chronic phase of stroke improves aerobic capacity (V\textsubscript{O2max}) and systolic blood pressure response during a submaximal exercise.\textsuperscript{32} Low-level treadmill aerobic exercise training increases peak V\textsubscript{O2} and decreases energy consumption during ambulation, and is effective to improve cardiovascular fitness.\textsuperscript{33} A combination of aerobic exercise and lower extremity muscle strengthening improves affected side muscle strength, gait speed, physical activity and quality of life.\textsuperscript{34} Task-related circuit training focusing on lower extremity muscle strength and functional tasks improves performance of locomotor tasks in chronic stroke.\textsuperscript{35} A health promotion program consisting of aerobic exercise, muscle strengthening and flexibility exercise improves general fitness.\textsuperscript{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\textsuperscript{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 V\textsubscript{O2} 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 examina-
tion \((0.214 \pm 0.069 \text{ vs. } 0.257 \pm 0.091 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{beats}^{-1})\) for the HR-O2-coeff and \(22.47 \pm 7.49 \text{ vs. } 26.93 \pm 10.02 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}\) for predicted \(\dot{V}O_2\max\); \(P < 0.05, \text{paired t-test}\).

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.\(^1\) The absolute HR was significantly lower at each RPM level and the HR-O2-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.\(^2\) 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-

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

References