Physical Fitness and Exercise Endurance Measured by Oxygen Uptake Kinetics in Stroke Patients

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Abstract. Hemiparetic stroke patients have both decreased oxygen consumption and low endurance to exercise. This study examined their physical fitness to quantify the initial deficit and change in oxygen uptake kinetics (VO$_2$ kinetics) during inpatients rehabilitation following stroke. Twenty-nine ambulatory hemiparetic stroke patients were treated in an 8-week program of low intensity aerobic exercise. They undertook a bicycle ergometer test with gas analysis before and after the exercise program to obtain maximum oxygen uptake (VO$_2$ peak), maximum work load (max WR), and VO$_2$ kinetics data. The time constant (ton) and O$_2$ deficit on constant load after exercise training were significantly lower than those in initial measurement by 17% and 10%, respectively. On the incremental load, VO$_2$ peak and max WR were significantly increased by 16% and 17% respectively and $\Delta$VO$_2$/$\Delta$WR was decreased by 11%. These results show that low-intensity endurance training produces energy efficiency of oxygen uptake kinetics and improves the physical fitness of ambulatory hemiparetic stroke patients.

Key words: Stroke, Physical fitness, Oxygen uptake kinetics, Exercise endurance

INTRODUCTION

Emphasis in stroke rehabilitation has been on improving self-care abilities through strength of muscle and training of coordination. Exercise is important for promoting fitness and preventing secondary disabilities due to inactivity in the physically disabled$^{1,2}$). Stroke patients, however, are known to have a low endurance to exercise, which may be compounded by the increased energy cost of movement associated with residual hemiparesis, and this may contribute to poor rehabilitation outcomes$^{3,4}$).

Recent studies have shown that aerobic exercise training is effective for the recovery of physical fitness in hemiparetic stroke patients$^{5-7}$). Therefore, measuring and assessing the cardiorespiratory endurance of hemiparetic stroke patients is important for evaluating their potentiality in daily life.

The purpose of this investigation was to examine the effects of physical fitness and exercise endurance on VO$_2$ kinetics in ambulatory hemiparetic stroke patients.

MATERIALS AND METHODS

Subjects
Twenty-nine ambulatory hemiparetic stroke patients (23 males and 6 females; 55±13 years old)
participated in this study. The time interval from stroke onset to admission was 76 ± 65 days. Subjects had mild to moderate hemiparesis, including both an upper and lower limb, which was documented on physical examination. Grades of the Brunnstrom stage of individual lower extremity were from III to V. Each patient was independent in indoor gait and/or indoor wheelchair locomotion. Cerebral vascular events and affected locations were documented by a computed tomographic scan and medical diagnosis. All patients gave their informed consent for this study.

Study design

Exercise training protocol

Each patient participated in the 8-week program of supervised exercise. They exercised on an adapted cycle ergometer for 20 min per session, five times a week, in addition to a conventional medical rehabilitation program by physical therapists at Hyogo Rehabilitation Center Hospital as inpatients.

The individual exercise training intensity consisted of a workload representing 30 to 50% of maximal effort to the highest level attainable by the individuals.

The exercise testing system

This study used a symptom-limited test by using a ramp load system including an electromagnetically controlled cycle ergometer (Lode Corival WLP-400, Groningen, Netherlands). Some patients required assistance to start pedaling of the cycle ergometer, and some had to fix an affected hand on the handle bar by using an elastic bandage.

Each test began with 3 min of resting for the baseline measurement. After constant load work exercise at 20 W for 3 min, incremental loading of 10 W/min was started. The electrocardiogram and heart rate were monitored continuously with Fukuda ML-600 (Japan). The dynamic exercise test continued until an individual’s maximal effort was achieved and exercise tests were repeated prior to the training program and immediately after the 8 weeks of training.

Kinetics measurement during exercise

Exercise metabolic parameters such as oxygen uptake (VO₂) and work rate (WR) were continuously determined during the graded exercise test by using a breath-by-breath respiration gas analysis assembly with a gas analyzer (Minato RM-300, Japan). Maximum values for the exercise parameters were the maximum of averages of every 30 sec.

On the stage of constant load, the time constant (τ on) and O₂ deficit were calculated from actual VO₂ change using a statistical program⁸, which was used to fit a single exponential data curve from the onset of exercise to the end of the steady-state exercise (Fig. 1). Peak oxygen uptake (peak VO₂) and maximum work rate (maximum WR) were measured as parameters of exercise endurance abilities, forcing to maximal effort exercise on the incremental load, and ∆VO₂/∆WR was calculated as a parameter of efficiency of energy expenditure⁹.

Statistical analysis

Data are shown as mean ± SD and paired Student’s t-test was used for statistical analyses of the data. Statistical significance was accepted for values of p less than 0.05.

RESULTS

The results of this study are summarized in Table 1. The τ on and O₂ deficit on the constant load after exercise training were significantly lower than those in initial measurements by 17% and 10%, respectively (τ on; p<0.005, O₂ deficit; p<0.05). On the incremental load, VO₂ peak and max WR were significantly increased by 16% and 17%, respectively (VO₂ peak; p<0.005, max WR; p<0.001) and ∆VO₂/∆WR was significantly decreased by 11% (p<0.05).
DISCUSSION

The evaluation of physical fitness and physical activities is important for patients with physical disabilities\(^1,2\). In clinical practice, the assessment of physical fitness is useful for advising patients about their life style and designing a rehabilitation program to maintain physical activities. It has been commonly reported that the physically disabled such as hemiplegic patients, could improve their physical fitness after aerobic exercise training\(^5–7\). Oxygen uptake is the classic measure of overall cardiorespiratory fitness and peak VO\(_2\) describes the highest oxygen uptake obtained by an individual for a given form of exercise, despite increased effort and work. In contrast, VO\(_2\) kinetics shows the efficiency of the cardiorespiratory response to an imposed work demand. Specifically, VO\(_2\) kinetics describes the rate at which the cardiorespiratory system is able to deliver oxygen to skeletal muscles and the rate at which oxygen is consumed by skeletal muscles at the beginning of exercise\(^10,11\).

We have little information concerning whether the effect of endurance training on VO\(_2\) kinetics is influenced by the onset of submaximal exercise\(^12\). In the present study, it was first demonstrated that the exercise endurance in ambulatory hemiparetic stroke patients was recovered for VO\(_2\) kinetics such as \(\tau\) on and O\(_2\) deficit at the onset of exercise. The rise to steady state is described by a time constant \(\tau\), which is determined by fitting an exponential curve to VO\(_2\) kinetics data. A slow \(\tau\) on is a marker of impaired oxygen delivery and/or extraction. It takes longer for the individual with a slow \(\tau\) on to reach steady state. VO\(_2\) kinetics is influenced by a combination of cardiovascular and peripheral factors. Recent studies have been carried out to determine whether cardiac output, arteriovenous oxygen difference, aspects of skeletal muscle metabolism, or a combination of factors play a role in exercise\(^13,14\).

The exercise training programs produced improvements in the physical fitness as represented by improvements of 16% in VO\(_2\) peak, 17% in max WR and 11% in ΔVO\(_2\)/ΔWR, respectively. The recovery of exercise endurance resulted in the prolongation of the gait distance for 6 min in ambulatory stroke hemiparetic patients (data not shown). These findings were in agreement with other studies published on exercise training programs for individuals with a physical disabilities\(^15–17\).

In conclusion, this study demonstrates that low-intensity endurance training produces energy efficiency in VO\(_2\) kinetics and improves physical fitness among ambulatory hemiparetic stroke patients.

**REFERENCES**


**Table 1. Effects of physical fitness and exercise endurance on oxygen uptake kinetics of physical fitness training for stroke patients**

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After 8 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time constant (sec)</td>
<td>38.3 ± 11.9</td>
<td>32.1 ± 3.6**</td>
</tr>
<tr>
<td>O(_2) deficit (ml)</td>
<td>244.9 ± 84.4</td>
<td>203.2 ± 98.0*</td>
</tr>
<tr>
<td>Peak oxygen uptake (ml/min/kg)</td>
<td>16.3 ± 4.4</td>
<td>18.1 ± 5.5**</td>
</tr>
<tr>
<td>Maximum work rate (watt)</td>
<td>71.6 ± 32.3</td>
<td>85.8 ± 37.4***</td>
</tr>
<tr>
<td>ΔVO(_2)/ΔW (ml/w)</td>
<td>14.6 ± 4.3</td>
<td>13.0 ± 3.2*</td>
</tr>
</tbody>
</table>

* p<0.05, ** p<0.005, *** p<0.001


