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Original Article

General endurance in hemiplegic patients: comparison between healthy subjects and hemiplegics using the incremental stand-up exercise-load method

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Objectives: To evaluate the utility of our newly devised method (incremental stand-up exercise-load) to determine features of general endurance in hemiplegic patients. Subjects/Patients: Participants were 15 healthy adults and 15 hemiplegics, with 13 men and 2 women in each group.Methods: To evaluate endurance, the subjects were required to assume a sitting position on a bed for 3 minutes and thereafter repeat standing-sitting (SS) movements. Successively increasing loads were imposed by increasing the frequency of repetition of the SS movements. An expired gas analyzer measured the magnitude of general endurance. Results were compared between the two groups using the anaerobic threshold (AT) as an indicator. Results: The AT value was determinable in 80% of subjects in both groups. The AT values in hemiplegics (10.4±2.0 ml/min/kg) were significantly ($p<0.01$) less than those (17.3±3.0 ml/min/kg) in controls. Time of imposition of the load in hemiplegics (11 min 7 s±13 min 45 s) were significantly ($p<0.01$) less than those (27 min 0 s± 7 min 36 s) in controls.

Conclusion: This newly devised method that does not require special equipment is suitable to examine general endurance in hemiplegic patients.

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Introduction

When designing a rehabilitation program for hemiplegics, appropriate assessment of their general endurance under varying motor loads is essential. Although a variety of different treadmills and ergometers have been developed for testing exercise stress for the diagnosis and treatment-efficacy evaluation of ischemic heart disease and arrhythmia, the advantages and disadvantages of such devices are subject to debate in the field of circulatory medicine[1]. These devices were developed to impose a motor load on healthy humans without motor impairment. Reviews of motor load imposed on hemiplegic patients, including the significance and influence of heart disease on rehabilitation in such patients, have been published in the early 1990s[2,3]. However, it is often difficult to impose an appropriate motor load on hemiplegic patients according to established protocols because of their motor dysfunction. In addition, special and complementary measures such as reducing the velocity of operation of the device or inventing a special contrivance are very often required[4,5,6,7]. Therefore, we adopted an approach using a novel incremental stand-up exercise-loading (ISEL) method with AT evaluation to appropriately monitor general endurance in hemiplegic patients without a complementary installation. The ISEL method consists of a protocol in which increasing loads are successively imposed on the participant accompanied by an increasing frequency of repeating standing-sitting (SS) movements. We measured the magnitude of general endurance in both healthy participants and hemiplegics, and compared the results between the two groups while taking AT as an indicator[8].

Materials and Methods

Participants

This study included 15 healthy adults (controls) and 15 hemiplegics, with each group comprising 13 men and 2 women. The mean age, height and weight of the hemiplegic group were 50.6±5.6 years, 164±6.7 cm, and 64.5±11.6 kg, while those of the control group were 43.1±9.2 years, 165±7.0 cm and 62.1±11.0 kg, respectively. There were no significant differences in any of these parameters between the two groups. The controls were healthy adults without hypertension or other heart disease, and consisted of physical therapists, occupational therapists, speech therapists and physicians at the Tokyo Metropolitan Otsuka Hospital. The inclusion criteria for the hemiplegic group were hemiplegics (1) with unilateral paralysis but mobile (with or without support) and able to stand unaided; (2) receiving care by the authors at the above hospital; and (3) willing to collaborate according to the study protocol. Patients excluded from the study included those with congestive heart failure, unstable angina, or overt signs of dementia. All patients were allowed to continue oral administration of prescribed medication. The causes of hemiplegia included cerebral hemorrhage in 10 patients and cerebral infarction in 5. The hemiplegics had undergone conventional physical therapy during therapeutically scheduled periods and were living at home before and during the study. The mean interval between their cerebrovascular incidents immediately before this study was 39±28 months, indicating that the events were chronic in nature. Paralysis was observed on the right (n=9) and left (n=6) side. As for mobility, 14 patients could walk independently outdoors and 1 required support (e.g. by a handrail) under surveillance. All could stand up unaided. A short-leg orthosis (14 of 15 participants) or a walking stick (12 of 14 participants who required an orthosis) was used as support for walking. In the hemiplegics, the mean Barthel index was 88.2±10.6; 8, 5, 1 and 1 patient were of Brunnstrom (Br.) stage III, IV, V and VI, respectively. This study was approved by the local ethics committee of Tokyo Metropolitan Otsuka Hospital and informed consent was obtained from the patients participating in this study.

Apparatus

The ISEL method with a rest-stand-sit protocol was used to evaluate endurance, and the oxygen uptake volume ($\dot{V}O_2$) of expired gas through exercise was analyzed in all participants.

Endurance test. The participant sat on an electrically adjustable bed so that his/her soles were in contact with the horizontal upper surface of a 15-cm-high wooden box, and the lower surface of the buttocks were level with the fibular heads. A metal horizontal bar (diameter: 5 cm x length: 0.8 m) was fixed in front of the participant at shoulder level to serve as a pivotal support for holding onto with the non-paralyzed hand while standing.

Expired gas analysis. $\dot{V}O_2$ values in expired gas were analyzed with an automatic oxygen consumption analysis system (Anima, R1500S, Tokyo, Japan). An electrocardiogram was recorded from the chest with an ECG recorder (Nihon-Kohden, KD-602P, Tokyo, Japan) during exercise. Blood pressure was recorded from the upper arm with a sphygmomanometer (Nihon-Kohrin, BP-203NP, Aichi, Japan).

Procedures

In evaluating endurance by the present ISEL method, analysis of expired gas by measuring $\dot{V}O_2$ values (ml/min/kg) and derivation of the AT values of participants were conducted as follows:

Endurance test. In the endurance test, although we did not select the initial frequency of 5 times/min after testing the ability of patients to perform the SS movement at various frequencies, we experienced a patient who could not repeat the movement at a frequency of 10 times/min. The natural behavior of hemiplegic patients was then studied before designating 5 times/min as the initial frequency. Hemiplegic patients showed a natural behavioral pattern by first slowly grasping the horizontal bar in front of them before gradually standing up at the initial stage of the protocol. The SS movements took 12 sec (6 sec each for standing and for sitting), and the study was therefore initiated at a frequency of 5 times/min.

Each cycle of the SS protocolof the ISEL method lasted 3 minutes. The study was initiated with one 3-minute rest followed by successively increasing the frequency of the SS protocol to 5, 10, and 15 SS repeats/minute etc. without resting; the rate was increased by 5 SS repeats/min after each cycle. The study was completed when the participant could not maintain the pace of repeating the SS paradigm any further. Electrically generated acoustic output by an electric metronome (Yamaha Co. Ltd., Tokyo) facilitated synchronization of the cyclic SS movements by the participants. The author (AK) further complemented the paradigm by synchronizing with the repeated SS movements with vocal hints of “stand” and “sit”, as and when appropriate. The paradigm was repeated twice on a daily basis for each participant, and data were polled to evaluate reproducibility.

Expired gas analysis. The criteria for discontinuation of exercise in this study were adopted according to those described in modified Bruce protocol9, where the load was reduced without any gradient designated in the initial stage. Moreover, each participant was asked to discontinue exercise if the indicated pace could not be maintained. Measured in the study were $\dot{V}O_2$ (ml/min/kg) at rest and at peak, blood pressure (mmHg), heart rate (b/min), and the total time (min) during which the motor load was imposed. The value of $\dot{V}O_2$ immediately before motor loading was taken as $\dot{V}O_2$-rest, and the mean $\dot{V}O_2$ value in the last minute before the discontinuation of exercise was taken as $\dot{V}O_2$-peak. The AT value (ml/min/kg) was calculated from the correlation between $\dot{V}O_2$ and the expiratory minute volume (VE) using software developed exclusively for this analysis system.

Statistical analysis

The results are expressed as the mean ±SD. The differences in clinical characteristics between the hemiplegics and controls were determined by the Mann-Whitney test and the χ^2 test for independent variables. The relationships between the AT value and the other various parameters (period after cerebrovascular event, Brunnstrom stage, $\dot{V}O_2$-peak, time of load imposition, time of continuous locomotion, distance of continuous locomotion, systolic blood pressure (SBP), diastolic blood pressure (DBP), resting heart rate (HR-rest) and peak heart rate (HR-peak)) were verified with the Pearson’s correlation coefficient test. Differences where $p<0.05$ were considered statistically significant.

Results

$\dot{V}O_2$ in endurance test. From the results of endurance testing (Table 1) with our ISEL method, both $\dot{V}O_2$-rest and $\dot{V}O_2$-peak were higher ($p<0.01$) in controls than in hemiplegics. $\dot{V}O_2$-rest in controls was 7.2± 1.1 ml/min/kg, which was approximately twice that in the hemiplegic group. Systolic blood pressure on discontinuation of exercise was higher ($p<0.05$) in the hemiplegic group (156±17 mmHg) than in controls (147±15 mmHg). HR on termination of exercise was 20% lower ($p<0.01$) in the hemiplegic group (133±19 beats/min) than in controls (167±17 beats/min).

AT, total time of load imposition and $\dot{V}O_2$. Cases with determinable AT accounted for 80% of participants in both groups. AT in hemiplegics (10.4±2.0 ml/min/kg) wassignificantly ($p<0.01$) lower than that in controls (17.3±3.0 ml/min/kg), while the total time of load imposition in hemiplegics (11 min 7 s±13 min 45 s) was significantly ($p<0.01$) shorter than that in controls (27 min 0 s±7 min 36 s) (Table 2). AT in hemiplegics (ca. 60% of that in controls) was strongly correlated ($p<0.01$) with the total time of motor load imposition. Correlations between $\dot{V}O_2$ and VE in AT-determinable participant (Fig. 1) and AT-indeterminable case (Fig. 2) were established based on quantitative reproducibility of two trials involving 4 healthy and 4 hemiplegic participants.

The correlation coefficients between the first and second values were significant for $\dot{V}O_2$-rest, $\dot{V}O_2$-peak, HR-rest, HR-peak and AT in both groups (Table 3). As such, reproducibility in both the control and hemiplegic

Table 1. $\dot{V}O_2$, systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR) in endurance test using incremental stand-up exercise-load (ISEL) method.

Group	$\dot{V}O_2$ (ml/min/kg)		SBP (mm Hg)		DBP (mm Hg)		HR (beats/min)	
	rest	peak	rest	peak	rest	peak	rest	peak
Control	7.2±1.1	27.6±7.2	127±13	147±15	76.6±8.6	79.9±11	77.9±6.1	167±17
Hemiplegic	3.7±0.6**	17.6±3.3**	144±14**	156±17*	86.6±7.7**	91.6±7.9	74.0±9.3	133±19**

**p < 0.01; * p < 0.05: Comparison between controls and hemiplegics.

Table 2. Determinability rate (%) of AT, AT (ml/min/kg) and load imposition time.

Group	Determinability rate of AT (%)	AT (ml/min/kg)	Load imposition time
Control	80	17.3±3.0	27 min 0 s±7 min 36 s
Hemiplegic	80	10.4±2.0**	11 min 7 s±13 min 45 s**

**$p < 0.01$: Comparison between controls and hemiplegics.

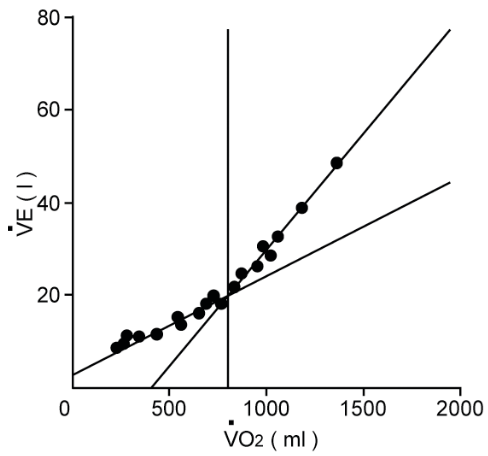

Fig. 1. Correlation of expiratory minute volume (VE) and oxygen uptake ($\dot{V}O_2$) in hemiplegic participant with determinable anaerobic threshold (AT).

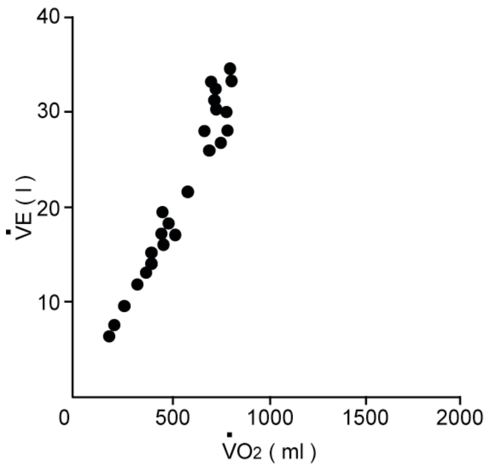

Fig. 2. Correlation of expiratory minute volume (VE) with oxygen uptake ($\dot{V}O_2$) in hemiplegic patient with indeterminable AT.

groups was establsihed. AT can therefore be reliably determined.

Causes for discontinuation of exercise. The primary cause for discontinuation of exercise was muscle fatigue in both the control (7 participants) and hemiplegic (9 patients) participants. In the control group, achieving the predetermined HR ranked second (6 participants) among reasons for discontinuing exercise, followed by dyspnea (4 participants) and inability to cope with the pace of movement (2 participants). In the hemiplegic group, both spasticity and inability to cope with the pace of movement accounted for the second-ranking reason, affecting 5 patients in all. Dyspnea ranked third, affecting 4 patients. Two hemiplegic patients discontinued the exercise for other reasons.

Correlations of AT with other items. Based on the results, correlations of AT with other items were examined separately for the control and hemiplegic groups (Table 4). AT in the control group was strongly correlated with the total time of motor load imposition and $\dot{V}O_2$-peak value in that order. In the hemiplegic group, AT was correlated with the following in the order of $\dot{V}O_2$-peak, time of continuous locomotion (L-t), total time of motor load imposition, distance of continuous locomotion (L-d) and HR-peak, whereas no significant correlation was noted with either time (months) after the cerebrovascular incident or the Br. stage.

Discussion

AT was defined by Wasserman et al.[8] as "the oxygen uptake level at the moment when the anaerobic energy production mechanism commences to function as a supplement to the aerobic energy production mechanism during exercise, successively increasing in intensity." AT is well known to be the most practical indicator to assess the maximum motor capacity of subjects even when they are performing submaximal exercise. However, AT has been associated with some problems. Its physiological meaning with regard to lactic acid has not been fully elucidated[11,12,13], and determination of the transition point by means of the V-slope method[10] is made subjectively and is impossible to determine at times[14]. Although practical and reliable

Table 3. Correlation coefficients between first and second values of oxygen uptake volume ($\dot{V}O_2$), heart rate (HR) and AT.

Group	$\dot{V}O_2$ (ml/min/kg)		HR (beats/min)		AT (ml/min/kg)
	rest	peak	rest	peak	
Control	0.99*	0.97**	0.98**	0.92*	0.96*
Hemiplegic	0.98**	0.92*	0.98**	0.89*	0.91*

**p < 0.01; *p < 0.05.

Table 4. Correlation coefficients between AT and other parameters.

Group	CVP	Br-stage	$\dot{V}O_2$-peak	T-load	L-t	L-d	SBP	DBP	HR-rest	HR-peak
Control	-	-	0.77**	0.78**	-	-	0.32	0.13	0.085	0.49
Hemiplegic	0.08	0.23	0.81**	0.58**	0.69**	0.44*	0.12	0.39	0.1	0.48**

**p < 0.01; * p < 0.05: CVP: Time since cerebrovascular event; Br-stage: Brunnstrom stage; $\dot{V}O_2$-peak: Peak oxygen uptake volume, T-load: Time of load imposition; L-t: Time of continuous locomotion; L-d: Distance of continuous locomotion; SBP: Systolic blood pressure DBP: Diastolic blood pressure; HR-rest: Resting heart rate; HR-peak: Peak heart rate.

new methods have recently been developed[15,16], we decided on AT as the indicator for our ISEL method, as it is so widely used.

The significant differences in systolic and diastolic blood pressure between the control and hemiplegic groups were most likely attributable to the high prevalence (80%) of hypertension (as an underlying disease) in the latter. The total time of the motor load imposition was significantly shorter, and a lower HR-peak was observed in the hemiplegic group. These findings suggest that the load imposed on the whole body was not sufficient to affect the heart load in the hemiplegic group. This deficiency is further supported by the fact that HR did not increase to the pre-determined level in any hemiplegic participant.

AT was determinable in 12 of 15 cases in both the control and hemiplegic groups. AT might have been indeterminable for the following four reasons[17]: (i) insufficient load imposed on the body to activate the anaerobic energy production mechanism; (ii) low motor capacity of participants; (iii) unstableventilation; and (iv) incompatibility between motor capacity and the load protocol. In the 3 healthy subjects in whom AT was indeterminable, the poor capacity of one was not suitable for the load protocol, and in the remaining 2 the load imposed was not sufficiently large. In 3 hemiplegics with similarly indeterminable AT values, while one showed poor motor capacity, the remaining 2 encountered an incompatible protocol. Fatigue prevented these 2 patients from increasing their pace, thereby terminating the test. On comparing various motor loads to find the most appropriate load for determining AT, Majima et al.[18] concluded determinable AT rates of 92, 77 and 47% with a bicycle ergometer, treadmill, and movements without affecting the lower extremities (repetitive extension and flexion of the unaffected hip and knee joints while the patient remained seated), respectively. In our ISEL method, the determinable AT was 80% in hemiplegic patients, a rate that is not low compared with those of other motor loads. According to Majima et al., a gradient of ergometer loads devised for controls has been employed in appropriate participants such as hemiplegics according to their ability to walk up a slope with increasing speed. However, 8 participants (>50% of patients) in our study were categorized as Br. Stage of category 3 and were spastic with severe paralysis. As such, we can not properly draw a conclusion based on the findings in the present study that the determinable AT rate was low. In fact, a determinable AT rate of 47% in cases with sound leg load models using a bicycle ergometer is markedly low compared with our results. Although 20% of the patients in our study were non-determinable, establishing further improvements in the determinable rate is an important future issue that warrants the challenge.

Our ISEL method has the advantage of being economically feasible and clinically practical; testing can be done without the space required for procedures using expensive equipment such as a treadmill or an ergometer.

The AT value obtained in healthy participants using the present ISEL method was 17.3±3.0 ml/min/kg, a value that approximates well to the standard 16.1±2.9 ml/min/kg[19] determined as the respiratory-circulatory index during exercise in Japanese participants in their fifties. The mean AT value in hemiplegics in the present study was 10.4±2.0 ml/min/kg, albeit that their standard AT value has not been determined to date. Using a bicycle ergometer, Majima et al. provided general endurance training to 9 ambulatory patients (mean age: 52 years) with a prior history of apoplectic events, and mean AT values of 8.8±1.5 and 9.6±0.8 ml/min/kg before and after training were obtained respectively[20]. In addition, Okuma et al.[21] measured a mean AT value of 13.2±2.0 ml/min/kg during repetitive SS movements in 28 hemiplegics. Thus, the AT value of 10.4±2.0 ml/min/kg obtained in our study coincides well with those reported previously.

The finding that the AT value correlated well with the total time of motor load imposition and $\dot{V}O_2$-peak (Table 2) indicates that AT may serve as a reliable index for testing general endurance in hemiplegics. In addition to the use of the reliable AT index, monitoring the AT value appropriately with a reliable method is complementary. As the present study yielded an excellent determinable AT rate of 80% using a novel AT-monitoring method, the present ISEL method and the AT index are therefore reliable and appropriate for evaluating the general endurance of hemiplegic patients.

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