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An Indirect Method of Estimating $\dot{V}O_2$ from Work Load Using Arm-Cranking in Adult Hemiplegic Patients

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ABSTRACT

The purpose of this study was to develop an oxygen consumption ($\dot{V}O_2$) measurement for adult hemiplegic patients during an incremental exercise arm-cranking test. Fifty-five adult hemiplegic patients performed a three-stage arm-cranking exercise test while $\dot{V}O_2$ was measured. The control group consisted of thirteen healthy elderly persons who performed a similar arm-cranking test until exhaustion. The results indicated that there was a significant difference in $\dot{V}O_2$ during rest periods between the adult hemiplegic and control groups. Based on data analysis, we developed an equation to estimate the $\dot{V}O_2$ for adult hemiplegic patients: $\dot{V}O_2$(ml/min)=(kgm/min×4.2ml/kgm)+((4.2ml/kg/min×kg body weight)+105.6ml/min) (r=0.847), while the equation for the controls was $\dot{V}O_2$(ml/min)=(kgm/min×4.3ml/kgm)+((2.9ml/kg/min×kg body weight)+105.5ml/min) (r=0.932). There was no significant difference between the estimated $\dot{V}O_2$ for the new equations (n$\dot{V}O_2$) and the measured $\dot{V}O_2$ (m$\dot{V}O_2$) in the two groups at any stage. In our data analysis, based on an estimated $\dot{V}O_2$ from the American College of Sports Medicine (ACSM) equation (a$\dot{V}O_2$), the n$\dot{V}O_2$ and m$\dot{V}O_2$ at each stage showed lower a$\dot{V}O_2$ than either n$\dot{V}O_2$ or m$\dot{V}O_2$ in each subject ($p<0.05$). These findings suggest that the ACSM equation is unlikely to be applicable for estimating $\dot{V}O_2$ for one hand arm-cranking exercise. In conclusion, the new equations established in this study, when used with a specific prescribed exercise testing protocol, would allow us to estimate $\dot{V}O_2$ more accurately for both adult hemiplegic patients and healthy elderly persons.

Key words: *A regression equation of $\dot{V}O_2$-work load, Adult hemiplegia, Oxygen consumption, Arm-cranking*

In physical therapy for the adult hemiplegic patient, setting a proper work intensity for each patient is very important.

In order to determine work intensity for hemiplegic patients, oxygen consumption ($\dot{V}O_2$) has been widely used when making an appropriate therapeutic exercise program. For subjects without any physical disability, many researchers have developed accurate $\dot{V}O_2$ measurement methods[1,3,5,7,12,14–16].

For example, the American College of Sports Medicine (ACSM) has established a metabolic equation in estimating $\dot{V}O_2$ for exercise prescriptions and fitness evaluation[1]. The ACSM's $\dot{V}O_2$ measurement protocol requires either a cycle ergometer or an arm-cranking ergometer. However, it is difficult for hemiplegic patients to perform an exercise test using a bicycle ergometer because of disability in the lower extremities. An arm-cranking ergometer also challenges hemiplegic patients to crank an ergometer with only one arm. Therefore, the development of a new testing protocol and equation for estimating $\dot{V}O_2$ is necessary for hemiplegic patients, since the work load of the ACSM protocol is too high for hemiplegic patients.

The purpose of this study is to develop a $\dot{V}O_2$ measurement for adult hemiplegic patients during an incremental exercise arm-cranking test.

MATERIALS AND METHODS

Subjects

55 adult hemiplegic patients (42 males and 13 females; mean age 62.4 yrs, mean height 158.7 cm, and mean weight 56.1 kg) volunteered for this study as subjects. They had all had a hemispheric stroke at least 2 months before this study. All patients had completed a formal rehabilitation program after the stroke and were diagnosed as medically stable. They were all outpatients and could walk with a cane except for one patient who suffered amputation of the lower extremity of the affected side. None of these subjects were taking medication which could alter their heart rate dur-

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Table 1. Physical characteristics of adult hemiplegia and healthy controls

	Adult hemiplegia (n=55)	Healthy controls (n=13)
age (yrs)	62.4±11.0	57.6±2.9
height (cm)	158.7± 7.4	159.8±8.7
weight (kg)	56.1±10.2	60.6±9.2

(mean±SD)

ing this study.

A control group of 13 healthy elderly persons (5 males and 8 females; mean age 57.6 yrs, mean height 159.8 cm, and mean weight 60.6 kg) were randomly selected for this study. There were no statistically significant differences in mean age, height and weight between the adult hemiplegic patients and the healthy elderly persons (Table 1).

Finally, the nature, purpose, and possible risks involved in this study were thoroughly explained to all subjects before obtaining their voluntary consent to participate.

Ergometer adjustment and power

A Monark portable ergometer (Model 881E) was used in this experiment. The ergometer was calibrated once weekly by using known a reference weight. Minimal or no adjustment was needed at each calibration, suggesting that a relatively constant and stable resistance was maintained during all testing procedures. An electronic revolution counter was attached to the ergometer to count the revolutions per minute (rpm) of the subject's cranking.

After a subject took a sitting position, the axis of the crank was adjusted to the level of the subject's acromion process on the cranking side. The distance between subject and ergometer was set so that his/her elbow could flex slightly when grasping the handle (Fig. 1).

Metabolic measurements

The subjects were attached to an Aeromonitor AE-280S (Minato Medical Science Co. Ltd.) by the breath by breath method. The AE-280S was calibrated before each test according to the Aeromonitor AE-280S Operating Manual[19] by using a reference gas of known concentration, volume and temperature. The subjects wore the mask and breathed through a low resistance breathing valve. The AE-280S was interfaced with an ECG telemeter DS-3140 (Fukuda Denshi Co. Ltd.), and heart rate (HR) was monitored by chest electrodes (Modified CM5 Placement).

The incremental exercise arm-cranking test

After obtaining resting data (i.e. HR, $\dot{V}O_2$) for 10 min in a sitting position, all subjects began an incremental exercise test. The test protocol consisted of three stages: Stage I, 3 min of unloaded (0 watt) cranking; Stage II, 5 min of 5 watts cranking; and Stage III, 5 min of 10 watts cranking for all adult hemiplegic patients. The adult hemiplegic patients were asked to crank the handle at a constant rate of 50 rpm throughout all stages as dictated by an audible tempo produced by a metronome. For the healthy elderly persons, the arm-cranking ergometer was operated at 50 rpm, beginning at 0 watt, with increasing power output by 5 watts for every 3 min until their exhaustion. The healthy elderly persons were also asked to crank at a constant rate of 50 rpm throughout all stages along with an audible tempo produced by a metronome. During an exercise test, all adult hemiplegic patients cranked the handle only with the sound side arm while the healthy elderly persons used their dominant side arm only. All subjects completed several practice sessions on the arm-cranking ergometer before the measurement so that they could be accustomed to the testing procedure. $\dot{V}O_2$ was then measured and analyzed for the last one min of the rest period and for the last one min in each stage.

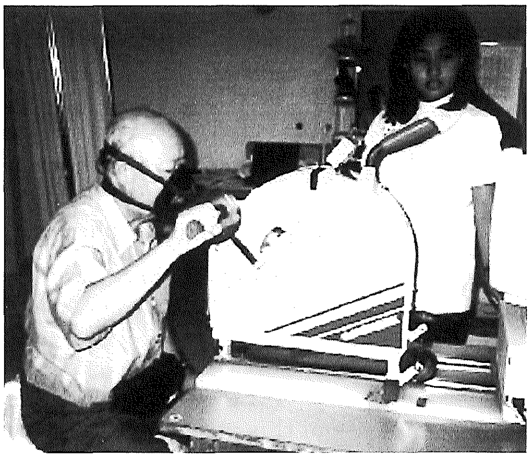

Fig. 1. Arm-cranking exercise test
Subject took sitting position and cranked the Monark Portable Ergometer 881E using only sound side upper extremity.
The axis of the crank was fixed at the level of his/her sound side acromion and sound side elbow joint when slightly flexed graspning the handle.

Equation development and statistical analysis

Work load, HR and an average of $\dot{V}O_2$ at each stage were entered into Stat View 5.0J (HULINKS INC.) to determine a linear regression equation. A dependent t-test was used in comparing $\dot{V}O_2$ during the rest period (r$\dot{V}O_2$) between the adult hemiplegic patients and healthy controls. We used one-way ANOVA with repeated measures to compare the estimated $\dot{V}O_2$ using the ACSM equation (a$\dot{V}O_2$), the estimated $\dot{V}O_2$ using the new equation (n$\dot{V}O_2$), and the measured $\dot{V}O_2$ (m$\dot{V}O_2$) at each stage. Tukey's post-hoc test was also used in data analysis. The ACSM arm-cranking ergometer equation includes cranking frequency, distance of the flywheel, applied resistance to the ergometer, and an estimate of resting metabolism in order to predict $\dot{V}O_2$ in a sitting position. The simplified version of this equation was as follows:

$\dot{V}O_2$(ml/min)=(kgm/min×3.0ml/kgm)+
(3.5ml/kg/min×kg body weight)
(work load: 150~750kgm/min).

An equation for $\dot{V}O_2$ estimation from the work load was obtained for each group (i.e. adult hemiplegic patients and healthy elderly persons). The two equations were then compared by analysis of covariance according to the statistical method listed in IGAKUHENO TOUKEIGAKU[27] with Excel Ver.5 (Microsoft Co.).

RESULTS

Linear regression equation between $\dot{V}O_2$ and HR

A linear regression equation was established based on the relationship between $\dot{V}O_2$ and HR for each subject. The correlation coefficients were 0.804~0.998 for the hemiplegic patients and 0.981~1.000 for the healthy controls, respectively.

$\dot{V}O_2$ during the rest period (r$\dot{V}O_2$)

According to the data analysis, threr was a r$\dot{V}O_2$ of 4.2±0.7ml/kg/min for the hemiplegic patients, and a r$\dot{V}O_2$ of 2.9±0.4ml/kg/min for the healthy controls, respectively. There was a significant difference in r$\dot{V}O_2$ ($p<0.0001$) between the hemiplegic patients and healthy controls.

Linear regression equation between $\dot{V}O_2$ and work load

The following equations were formulated for both the hemiplegic patients and healthy controls in order to estimate their $\dot{V}O_2$. Six kgm/watt was used as a conversion factor for the work intensity. A regression analysis was performed using all of the m$\dot{V}O_2$ and all of the work load for each subject.

The first equation was made in order to estimate $\dot{V}O_2$ for the hemiplegic patients:

$\dot{V}O_2$ (ml/min)=(kgm/min×4.2ml/kgm)+
335.6ml/min (r=0.809).

The second equation was made by adding an estimation of resting metabolism per kg of body weight to the first equation. The additional $\dot{V}O_2$ of 105.6ml/min was used for this equation:

$\dot{V}O_2$ (ml/min)=(kgm/min×4.2ml/kgm)+
((4.2ml/kg/min×kg body weight)
+105.6ml/min) (r=0.847) (Fig. 2).

The third equation represented an estimate of $\dot{V}O_2$ for the healthy controls:

$\dot{V}O_2$ (ml/min)=(kgm/min×4.4ml/kgm)+
277.2ml/min (r=0.917).

Finally, the fourth equation was formed after adding an estimation of resting metabolism per kg of body weight. The additional $\dot{V}O_2$ of 105.5ml/min was also used for this equation:

$\dot{V}O_2$ (ml/min)=(kgm/min×4.3ml/kgm)+
((2.9ml/kg/min×kg body weight)
+105.5ml/min) (r=0.932) (Fig. 3).

Comparison among a$\dot{V}O_2$, n$\dot{V}O_2$ and m$\dot{V}O_2$ at each stage

According to the ANOVA, there was a significant difference ($p<0.0001$) at each stage for both the hemiplegic patients and healthy controls. Tukey's post-hoc analysis indicated that a$\dot{V}O_2$ was significantly lower than n$\dot{V}O_2$ and m$\dot{V}O_2$ at each stage for both groups ($p<0.05$). There was no significant difference between n$\dot{V}O_2$ and m$\dot{V}O_2$ in either group (Table 2).

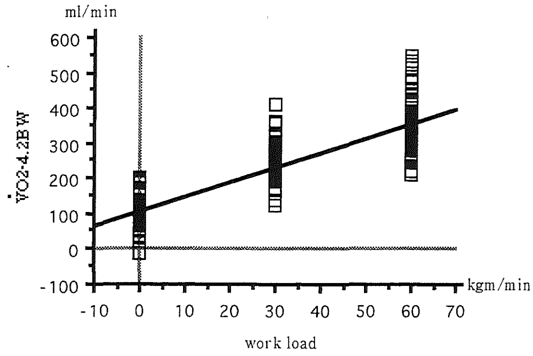

Fig. 2. Liner regression equation between $\dot{V}O_2$ and work load for adult hemiplegia
$\dot{V}O_2$ (ml/min)=(kgm/min×4.2ml/kgm)+((4.2ml/kg/min× kg body weight)+105.6ml/min)(r=0.847)

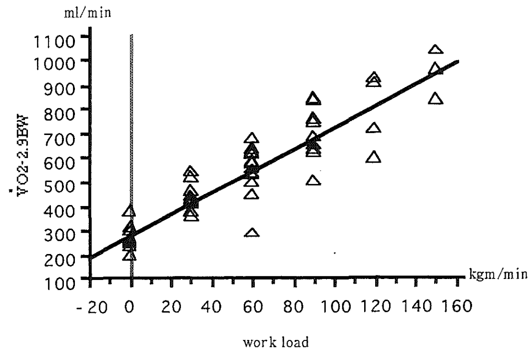

Fig. 3. Livear regression equation between $\dot{V}O_2$ and wor for healthy controls
$\dot{V}O_2$ (ml/min)=(kgm/min×4.3ml/kgm)+((2.9ml/kg/min× kg body weight)+105.5ml/min)(r=0.932)

Comparison of the equation of $\dot{V}O_2$ estimation from work load between adult hemiplegic patients and healthy elderly persons

The analysis of covariance showed no significant difference in the coefficient of slope. However, a significant difference was found in the *y* intercept between the hemiplegic patients and healthy controls ($p<0.001$) (Fig. 4).

DISCUSSION

Many investigators report both an endurance capacity and incremental exercise tests for hemiplegic patients[4,6,8,9,11,13,20-24,26]. In addition, since the ACSM equation is commonly used for estimating $\dot{V}O_2$, many researchers have attempted to determine the accuracy of the ACSM equation[1,3,5,7,12,14-16]. However, certain studies[4,6,11,20-24] made clear only an incremental exercise test using a bicycle ergometer without mentioning the testing proce-

Table 2. Comparation among $m\dot{V}O_2$, $n\dot{V}O_2$ and $a\dot{V}O_2$ in adult hemiplegia and healthy controls

		$m\dot{V}O_2$ (ml/min)	$n\dot{V}O_2$ (ml/min)	$a\dot{V}O_2$ (ml/min)
Adult hemiplegia (n=55)	stage I*	326.8±55.1	339.5±41.8	196.3±35.7**
	stage II*	478.1±66.8	465.5±41.8	286.3±35.7**
	stage III*	575.9±95.3	591.5±41.8	376.3±35.7**
Healthy controls (n=13)	stage I*	263.9±47.7	281.3±26.6	212.1±32.2**
	stage II*	423.9±54.2	410.3±26.6	302.1±32.2**
	stageIII*	545.0±101.0	539.3±26.6	392.1±32.2**

(mean±SD)
* ANOVA; $p<0.0001$
**$p<0.05$ compared with $m\dot{V}O_2$ and $n\dot{V}O_2$

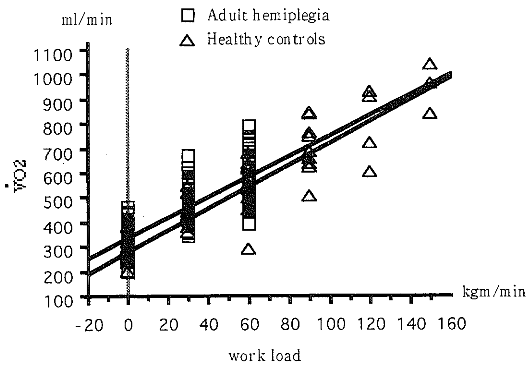

Fig. 4. Comparision of $\dot{V}O_2$ estimation equations from work load between adult hemiplegia and healthy controls
estimation equation for adult hemiplegia:
$\dot{V}O_2$ (ml/min)=(kgm/min×4.2ml/kgm)+335.6ml/min ($r=0.809$)
estimation equation for healthy controls:
$\dot{V}O_2$ (ml/min)=(kgm/min×4.4ml/kgm)+277.2ml/min ($r=0.917$)
Result of analysis of covariance:
coefficient of slope: no significant difference
y intercept: significant difference ($p<0.001$)

dures for an arm-cranking ergometer[8,9,21,26].

Because of the easiness for hemiplegic patients of performing an arm-cranking exercise, it has been widely used to improve their endurance capacity in a clinical setting. However, no studies have ever determined the equation for $\dot{V}O_2$ of hemiplegic patients using the arm-cranking exercise. Thus, it is important to develop an indirect method of estimating $\dot{V}O_2$ from the work load in adult hemiplegic patients during an incremental exercise arm-cranking test.

Relationship between $\dot{V}O_2$ and HR

Generally, a correlation between $\dot{V}O_2$ and HR is not shown in a low intensity exercise test because of the influence of natural fluctuation[28]. In this study, however, the relationship between $\dot{V}O_2$ and HR exhibited a high correlation even in a very low work intensity for each subject (adult hemiplegic patients: 0.804~0.998; healthy elderly persons: 0.981~1.000). This finding suggested that a one hand arm-cranking exercise test using a very low work intensity is useful for estimating $\dot{V}O_2$.

An equation of $\dot{V}O_2$ estimation from work load using an arm-cranking exercise

In our study, the $r\dot{V}O_2$ of adult hemiplegic patients and healthy controls was found to be 4.2 ml/kg/min and 2.9 ml/kg/min respectively, in comparison with a $r\dot{V}O_2$ of 3.5 ml/kg/min which was obtained using the ACSM equation and other studies[1,3,7,14-16]. A significant difference was found between adult hemiplegic patients and healthy controls ($p<0.0001$). This result suggests that each hemiplegic patient might consume more $\dot{V}O_2$ in order to keep themselves in a sitting position. We presumed that the hemiplegic patients contracted more anti-gravity muscles to brace themselves in a sitting position with the synergies of both upper and lower extremities of the affected side, because of sitting on a chair with no backrest during this test. Recently, new analysis of tissue oxygenation was developed using near-infrared spectroscopy (NIRS)[10,17,25]. We would like to examine the tissue oxygenation of both the upper and lower extremities of the affected side using NIRS in the future. Furthermore, we would like to examine compensatory muscle contractions during exercise using electrical myography.

Our data analysis also provided an equation for each group in order to estimate $\dot{V}O_2$ from the work load using the arm-cranking exercise. For adult hemiplegic patients, $\dot{V}O_2$ is predicted by the following equation:

$\dot{V}O_2$ (ml/min)=(kgm/min×4.2 ml/kgm)+((4.2 ml/kg/min×kg body weight)+105.6 ml/min) ($r=0.847$).

For healthy controls, $\dot{V}O_2$ is calculated by the following equation:

$\dot{V}O_2$ (ml/min)=(kgm/min×4.3 ml/kgm)+((2.9 ml/kg/min×kg body weight)+105.5 ml/min) ($r=0.932$)

The relationship between $\dot{V}O_2$ and work load exhibited a high correlation (adult hemiplegic patients: $r=0.847$; healthy elderly persons: $r=0.932$) even for a very low work intensity.

In these equations, we decided $\dot{V}O_2$ per work load to be 4.2 and 4.3 ml/kgm. We also determined $\dot{V}O_2$ during unloaded arm-cranking to be 105.6

and 105.5 ml/min. In our equations, the $\dot{V}O_2$ per work load was larger than in the ACSM equation. This increase in the $\dot{V}O_2$/work load constant would likely be explained by the fact that adult hemiplegic patients had to contract more muscles not only to stabilize the upper trunk, but also to accomplish a stable arm-cranking motion. We also found a similar phenomenon among healthy elderly persons when we asked them to arm-crank the ergometer with one arm. In fact, our data analysis indicated that there was no statistically significant difference in the $\dot{V}O_2$ per work load (i.e. a coefficient of slope) between the two groups. Therefore, we concluded that $\dot{V}O_2$ per work load is between 4.2 and 4.3 ml/kgm during one hand arm-cranking for all elderly persons.

However, we found a significant difference in the *y* intercept between hemiplegic patients and healthy controls ($p<0.001$). This is due to the fact that the $r\dot{V}O_2$ of adult hemiplegic patients was larger than that of healthy elderly persons. Thus, the equation for adult hemiplegic patients runs parallel to the equation for healthy elderly persons (Fig. 4).

The ACSM equation is unlikely to be applicable for estimating $\dot{V}O_2$ for adult hemiplegic patients and healthy elderly persons during the one hand arm-cranking exercise. Although there was no significant difference between the $n\dot{V}O_2$ and $m\dot{V}O_2$ in adult hemiplegic patients and healthy controls at each stage, our data analysis on $a\dot{V}O_2$, $n\dot{V}O_2$ and $m\dot{V}O_2$ at each stage showed lower $a\dot{V}O_2$ than both $n\dot{V}O_2$ and $m\dot{V}O_2$ in adult hemiplegic patients and healthy controls ($p<0.05$). Finally, the new equations established in this study, when used with a prescribed exercise testing protocol, allow us to estimate $\dot{V}O_2$ more accurately for both adult hemiplegic patients and healthy elderly persons.

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