ORIGINAL ARTICLE

Rowing-Ramp Protocol as A Cardiopulmonary Exercise Test for Hemiparetic Stroke Survivors

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ABSTRAK

Sebelum program rehabilitasi senaman dipreskripsikan untuk pesakit strok, kapasiti kardiopulmonari perlu dinilai dengan tepat untuk menentukan senaman intolerans dan intensiti latihan yang diperlukan. Walau bagaimanapun, belum ada ujian senaman kardiopulmonari (CPET) yang sesuai untuk pesakit strok. Ini adalah disebabkan oleh ketidakupayaan fizikal yang dialami oleh mereka. Justeru, tujuan kajian ini adalah membangunkan protokol ujian senaman kardiopulmonari yang menggunakan protokol rowing-ramp, serta menentukan kesahan serta kebolehpercayaan protokol ujian tersebut. Sebelas orang pesakit strok (6 lelaki; 5 wanita; umur, 45 $\pm$ 16.01 tahun} melakukan dua ujian senaman ansur maju menggunakan ergometer rowing (Concept II) bagi menentukan penggunaan oksigen puncak (VO$_2$ puncak). Kebolehpercayaan uji-ulang uji untuk VO$_2$ puncak, diukur berselang 1 minggu dan memberikan nilai pekali korelasi intra-kelas masing-masing 0.97 dan 0.95. Persamaan regresi linear dibangunkan untuk menentukan nilai VO$_2$ puncak berdasarkan kepada kuasa kayuhan pada tahap tertinggi. Kesahan dan kebolehpercayaan persamaan juga dihasilkan. Persamaan regresi yang diperolehi ialah VO$_2$ puncak=11.429 $\pm$ 0.232 (Kuasa Kayuhan Tahap Tertinggi) $\pm$ 12.63 (F=25.326, p<0.01; R=0.859, R2=0.738). Had persetujuan antara VO$_2$ puncak yang diukur dan anggaran boleh diterima, dengan purata bias 0.37 ml/kg/min. Pekali kesahan (R) adalah 0.83 (p<0.01) dan 0.81 (p<0.01) dalam kedua-dua percubaan. Pekali kebolehpercayaan uji-ulang uji untuk VO$_2$ puncak anggaran adalah 0.95 (p<0.01). Hubungan positif antara kuasa kayuhan tahap tertinggi dan VO$_2$ puncak mencadangkan bahawa protokol Rowing-Ramp ini boleh digunakan untuk mengukur VO$_2$ puncak pesakit strok. Kajian lanjut diperlukan demi pengesahan bersilang persamaan regresi menggunakan saiz sampel yang lebih besar, dengan mengambil kira jenis strok dan tahap keparahan.

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ABSTRACT

Cardiopulmonary capacity should be evaluated accurately to determine exercise intolerance and training intensity of stroke survivors before an exercise rehabilitation programme is prescribed. However, no cardiopulmonary exercise test (CPET) is suitable because of the stroke victims' physical impairment. The aim of this study was to develop and validate a new rowing-ramp protocol as a CPET for stroke survivors. Eleven stroke patients (6 male; 5 female; age, 45 ± 16.01 years, performed two incremental exercise tests on a Concept II rowing ergometer to determine the peak oxygen consumption (VO_2 peak). Test-retest reliability for VO_2 peak, measured 1-week apart, resulted in an intra-class correlation of 0.97 and 0.95, respectively. A linear regression equation was developed to predict the VO_2 peak from final stage stroke power. Validity and reliability of the prediction equation were established. The regression equation for predicted VO_2 peak was VO_2 peak=11.429 ± 0.232 (Final Stage Stroke Power) ± 12.63 (F=25.326, p<0.01; R=0.859, R^2=0.738). Limits of agreement between predicted and measured VO_2 peak were acceptable, with a mean bias of 0.37 ml/kg/min. The validity coefficient (R) was 0.83 (p<0.01) and 0.81 (p<0.01) in both trials. Test-Retest reliability coefficient for predicted VO_2 peak 0.95 (p<0.01). The positive relationship between Final Stage Stroke Power and VO_2 peak suggests that the Rowing-Ramp protocol could be used to measure VO_2 peak of stroke survivors. Additional studies are needed to cross-validate the regression equation using larger sample size, different type and severity of stroke.

Keywords: cardiopulmonary exercise test, oxygen consumption, rowing, CPET protocol, stroke hemiparetic

INTRODUCTION

Stroke, including hemiparetic stroke, has been recognised as a cause of physical disability leading to immobility and reduction in activities of daily living (Fujita et al. 2015; Hyndman & Ashburn 2003). Furthermore, long term and a new approach to the rehabilitation of stroke patients in Malaysia were needed (Aziz & Raymond 2008). After an extended period of inactivity, bed rest or immobility leads to a reduction of oxidative capacity of the paretic muscles (Hastings et al. 2012) and decreased motor unit recruitment, which would lead to reduced central endurance (Hamzat & Alabi 2006; Stoller et al. 2012). Studies have shown that after a stroke attack, patients have poor cardiovascular endurance (Stoller et al. 2012; Billinger et al. 2015). Therefore, determining exercise capacity and exercise intolerance

of stroke survivors are important as a safety measure, as well as for prescribing an optimal exercise rehabilitation programme.

The cardiopulmonary exercise test (CPET) is most often recommended to assess the exercise capacity (Saengsuwan et al. 2015), including diagnosis of cardiovascular problems, and to determine individualised training intensity. CPET has been used to measure a person's maximum oxygen uptake (VO_2 max), maximal oxygen uptake (VO_2 peak), ventilatory threshold, and peak heart rate (HR peak) to set an optimum target intensity for an individual (Marzolini et al. 2016). CPET was widely used as a predictor of functional status and impairments (Albouaini et al. 2007). Often, standardised protocols such as the Bruce protocol, are widely applied in both health and clinical settings (Balady et al. 2010; Ratter et al. 2014; Ratter et al. 2003). However, because there is a high workload increment required at each stage, which is not possible for people with physical impairments, a ramp protocol had been substituted because of its small workload increment and shorter duration at each stage (Sobral 2003; Myers & Froelicher 1990).

Besides the duration of the stage, exercise mode also plays an important role in predicting the VO_2 peak. Since, hemiparetic stroke patients have physical impairment especially poor posture control, poor static and dynamic balance, and even most of them having difficulties in maintaining sitting balance or standing, taking a step, walking, lifting arm, raising a

hand, hand grip, and keep heads up. With the features of a rowing machine, which include secure foot placement, rowing handles, and a mobile seat, allows a patient to stabilise and perform the rowing movement safely.

Most of the rowing CPET protocol are using HR as a marker (Huntsman et al. 2010; Martins et al. 2012). However, HR is not a reliable marker to predict VO_2 max in stroke patients because they often take medications such as beta-blockers (Albouaini et al. 2007). Even, the ventilatory threshold is also influenced by beta-blockers and also can not be used as a cardiopulmonary performance measure (Wallen et al., 2017).

Therefore, a work rate is more suitable marker in estimating the cardiopulmonary capacity of stroke patients. There are few rowing-specific tests that were developed to predict VO_2 max using the work rate. Such as stroke rate (Lakomy & Lakomy 1993), critical velocity (Kendall et al. 2012), and power output (Kendall et al. 2012; Klusiewicz et al. 2016). However, these protocols were developed for non-clinical population, using step incremental protocol with a longer working duration and big workload increment. Which is not suitable for stroke patients because of their physical impairment and limitations. Therefore, this study aimed to develop a rowing CPET protocol specifically for hemiparetic stroke patients, using a ramp protocol with a shorter duration at each stage and smaller workload increments. Which are power output per stroke (Watt) and a number of strokes per minute, stroke rate (strokes

per minute) (Soper & Hume 2004; Metcalfe et al. 2013).

MATERIALS AND METHODS

STUDY DESIGN

After initial familiarization to the testing protocol, the participants performed two rowing CPET tests to measure VO_2 peak. VO_2 peak during rowing was measured twice to check the reproducibility. Predicted VO_2 peak was calculated using the newly developed equation, requiring the use of Final Stage Stroke Power data from the rowing tests. The predicted and measured VO_2 peak were compared to assess the accuracy of the new prediction equation for Rowing-Ramp Protocol test in predicting VO_2 peak.

SUBJECTS

Eleven stroke survivors (males: n=6, age = 45±15.7 years, height = 158.9±9.09 cm, weight = 64.3±12.72 kg; females: n=5, age = 44±18.2 years, height = 162.4±12.54 cm, weight = 69.3±18.17 kg), at least 3 months post-stroke, were recruited from the Rehabilitation Clinic, Queen Elizabeth Hospital to participate in this study. There were 9 patients who suffered from hemorrhagic (5 males and 4 females), and 2 patients were with ischemic stroke (1 male and 1 female). Nine patients had strokes on the right side (5 males and 4 females) and 2 patients on the left (1 male and 1 female). Each completed a written informed consent form. This study was approved by the National Medical Research Register and Ethics Committee of Universiti Malaysia Sabah. The ethical approval of this study was obtained from the National Medical Research Register with reference no.: NMRR-16-38-28777(IIR) and Universiti Malaysia Sabah Medical Research Ethics Committee, with reference no.: UMS/FPSK6.9/100-6/1/95.

Medically stable stroke survivors were shortlisted in Queen Elizabeth Hospital. Before approaching eligible patient(s), all the case notes of potential stroke patients were scrutinized to ensure that they were fit for the study. With the consent and released by the rehabilitation specialist doctors, the patients were contacted and appointments were made with the patients to seek their approval and willingness to participate in the rehabilitation program. Besides, patients have to fulfill all the inclusion criteria listed below:
1. The patient was able to communicate (understand instructions)
2. Patient possessed unilateral hemiparesis (left or right)
3. Medically stable
4. Able to walk with or without assistance (walking aid or helper)
5. Able to stand with or without assistance (walking aid or helper)
6. Able to sit with or without assistance (walking aid or helper)
7. Able to transfer from a higher position (wheelchair or chair) to lower position (rowing seat) with or without assistance (helper)

Conversely, there were exclusion criteria to avoid health deterioration for the stroke survivors, as a precautionary

Figure 1(a): Pictures showing patients with a different physical impairment (a) one hand with a poor hand grip was performing rowing movement safely.

Figure 1(b): Patient with a hand unable to hold the rowing handle and with a stiff leg movement was performing rowing movement safely.

step, which were patients with comorbidities (such as severe heart failure, severe hypertension) and serious medical condition (such as asthma). To ensure all hemiparetic stroke patients recruited able to perform rowing, patients with elbow flexor contracture, plantar flexor contracture, unable to bend their knee because of hamstring spasticity and unable to bend their elbow because of biceps spasticity, were also excluded from this study. As shown in Figure 1(a), (b), and (c), back support, bandage and elastic band were used to ensure the correct movement of patient that suffer from

Figure 1(c): Patient with a hand unable to hold the rowing handle, with a stiff leg movement and having difficulties in maintaining sitting balance was performing rowing movement safely.

poor hand grip, stiff leg movement, and poor sitting balance.

PROCEDURES

Stretching sessions were provided before the CPET exercise test. The test began with a 5-minute warm-up at their convenience stroke rate, or when HR achieved 100 beats/minute (bpm). A 1-minute rest was given before the CPET exercise test started.

All patients completed two Rowing-Ramp protocol exercise symptom-limited tests to determine VO_2 peak. All exercise tests were performed on a Concept II Model C rowing ergometer (Morrisville, Vermont, USA), on separate days and without normal training on the same time of day to minimise variation in medication effect (Tang et al. 2016) and circadian rhythm (Winget et al. 1985). Patients were asked to eat a meal and take their medications at least 2 hours before the test and to avoid caffeine, alcohol, and smoking for at least 8 hours before the test (to minimise the peak effect of beta-blockers).

The rowing protocol and Modified Borg Dyspnoea Scale were explained to the patients and they were asked to perform at their maximal effort. Height (cm) and body mass (nearest kg) were measured using a stadiometer. Resting blood pressure was obtained using IA2 Omron Automatic Blood Pressure Monitor with IntelliSense™ (Japan). A HR monitor (COSMED K5 HR monitor, Rome, Italy) was worn by patients throughout all the tests. All patients underwent a familiarisation phase or learning day to learn the rowing technique before the test was conducted.

During the Rowing-Ramp exercise test protocol, oxygen consumption and HR were monitored and continuously analysed using a portable open-circuit spirometer (COSMED Srl-Italy K5, Rome, Italy), using the breath-by-breath method, which was calibrated before each test, according to the manufacturer's specifications. Oxygen uptake (VO_2, STPD), minute ventilation (VE, BTPS), carbon dioxide output (VCO_2, STPD), and HR were recorded every second in each stage. The data for 30 seconds intervals were averaged. The highest values of VO_2 and HR registered within 30 seconds during the Rowing-Ramp Protocol test were recorded by the metabolic cart as VO_2max, VO_2 peak, Maximal Heart Rate (HR max), and peak Heart Rate (HR peak).

There were no apparent sex-related statistical differences in our main outcome variables: VO_2 peak (Male: 20.8±11.63 ml/kg/min, Female: 17.8 ±7.65 ml/kg/min, F=0.350, p>0.05), VO_2 max (Male: 16.3±8.80 ml/kg/ min, Female: 12.0±3.34 ml/kg/min, F=1.439, p>0.05), Stroke Power (Male: 79.3±59.52 W, Female: 30.6±9.04 W, F=3.231, p>0.05) and Stroke Rate (Male: 35.3±6.89 spm, Female: 32.8±3.35 spm, F=0.558, p>0.05); thus, both male and female patients used the same exercise test protocol. Test-retest reliability data for VO_2 peak and VO_2 max measured 1 week apart.

ROWING-RAMP CPET PROTOCOL

The Rowing-Ramp protocol is using a symptom-limited exercise test. The rowing workload used was stroke rate (spm) and power output per stroke (W). Stroke Rate and Power Output were recorded at the end of every stage using a Performance Monitor 5 (PM5). The test comprised stages with a 30 seconds duration, and the rowing resistance or damper was set at five. The starting workload required in the first stage is at least 16 spm for 30 seconds, with workload increment of 4 spm every 30 seconds until volitional exhaustion.

The patients were instructed to maintain the stroke rate goal as closely as possible for the duration of the test. We monitored the Stroke Rate at every stage to ensure subjects performed at the required intensity. The test was terminated when patients were no longer able to maintain the required spm, determined by the required stroke being missed on three consecutive observations. At the end of the test, the observed mean Power Output from the PM5 was also recorded. Patients were also asked to express their level of tiredness using a visual Modified Borg

Dyspnoea Scale at the end of the test. A cool-down period was performed in seconds until HR and blood pressure returned to baseline.

STATISTICAL ANALYSIS

Eleven hemiparetic stroke patients completed two Rowing-Ramp protocol test for the derivation of the prediction equation. The Pearson-Product moment correlation coefficient (R) was calculated with a chance of 5% error, to determine the strength of the relationship between measured VO_2 peak, perceptual measures, and rowing performance (stroke power). Stepwise linear regression analysis was used to generate a prediction equation for determining the VO_2 peak from Modified Borg DS and stroke power. To compare the regression lines, the differences in slopes and intercepts were analysed.

The standard error of estimation (SEE) and total error (TE) were calculated according to the formula below:

$$SEE = s.d \sqrt{(1-r^2)}$$

s.d = standard deviation of predicted VO_2 peak
R = correlation coefficient between measured VO_2 peak and predicted VO_2 peak

TE calculated using the formula:

$$TE = \frac{\sqrt{\sum(x-X)^2}}{N}$$

where x is the predicted value of the VO_2 peak. X is the measured value of the VO_2 peak, and n is the number of subjects.

Then, the percentage value of TE (TE%) was determined using the following formula:

$$TE\% = \frac{TE}{X} \times 100$$

Relationship between measured and predicted VO_2 peak was evaluated with both Pearson correlation coefficient and the Bland-Altman statistic, in which the differences between the measured and predicted VO_2 peak from both trial 1 and trial 2 were plotted against the means of each subject. Difference between measured VO_2 peak and predicted VO_2 peak values was also analysed using a paired *t*-test.

A test-retest reliability test was performed to examine the reliability of the Rowing-Ramp protocol as a CPET for hemiparetic stroke survivors. A paired t-test was also used to determine the differences between trials (test-retest) for each observed variable of HR (HR max, HR peak), oxygen consumption (VO_2 max, VO_2 peak), perceptual measures (Modified Borg Dyspnoea Scale), and rowing performance (Mean Stroke Power Output).

All data were analysed using a standard statistical software package (SPSS Version 20). The alpha-level was set at $p<0.05$. All data are reported as the mean $\pm$ standard deviation (s.d).

RESULTS

In this study, 11 patients tolerated two sessions of the proposed symptom-limited Rowing-Ramp protocol as a CPET specific for stroke population, using breath-by-breath method by a

portable metabolic cart (COSMED Srl-Italy K5 Quark B).

To determine the reliability of the new proposed Rowing-Ramp Protocol exercise test, two trials were performed by each patient 1 week apart. Maximal Modified Borg Dyspnoea Scale scores were not significantly different between trial 1 and trial 2 (3.6±0.92 vs. 4.1±1.05; p>0.05). No significant difference was found in HR max between trial 1 and trial 2 (121.3±39.44 bpm vs. 138.6±26.11 bpm; p>0.05). However, the mean HR peak in trial 2 (141.2±28.45 bpm) was significantly higher than trial 1 (126.3±38.68 bpm; p<0.05). Additionally, HR max was significantly lower than the HR peak in both trials (p<0.05; Table 1).

In addition to stroke rate, power output was also measured in this study using the PM5. Rowing performance was monitored at every stage to ensure that the participant performed at the required intensity. There was no significant difference in mean values for all rowing performance variables including the mean stroke power output and mean stroke rate, stroke rate between trials 1 and 2. Thus, Rowing-Ramp protocol produces the same mean value of stroke power output and stroke rate (Table 1).

From Table 1, VO_2 max was significantly lower than the measured VO_2 peak in both trials (Trial 1: VO_2 max=17.7±9.85 ml/kg/min, VO_2 peak=23.82±13.63 ml/kg/min; Trial 2: VO_2 max=18.26±8.32 ml/kg/min, VO_2 peak=24.62±11.66 ml/kg/min).

Table 1: A test-retest reliability of the Rowing Ramp Protocol as a Cardiopulmonary Exercise Test (CPET) for hemiparetic stroke survivor.

Variables	Trial 1 (mean ± sd)	Trial 2 (mean ± sd)	t-test	
			T	P
HR and Perceptual Measures				
MBDS	3.6 ± 0.92	4.1 ± 1.05	- 1.838	0.10
HR peak (bpm)	126.3 ± 38.68	141.2 ± 28.45*	- 2.878	0.02
HR max (bpm)	121.3 ± 39.44	138.6 ± 26.11	- 2.188	0.05
Oxygen Consumption				
VO_2 max (ml/kg/min)	17.7 ± 9.85	18.26 ± 8.32	- 0.577	0.576
VO_2 peak (ml/kg/min)	23.82 ± 13.63	24.62 ± 11.66	- 0.730	0.482
RER	1.13 ± 0.142	1.18 ± 0.189	- 1.176	0.267
Perceptual Measures and Rowing Performance				
SR (spm)	49.0 ± 27.54	34.6 ± 15.79	- 1.650	0.130
P	25.8 ± 2.75	25.8 ± 2.89	- 0.000	1.000

* denotes significantly different at p<0.05; df=10; N=11; sd=standard deviation; HR=Heart Rate; MBDS=Modified Borg Dyspnoea Scale; HR peak=Peak Heart Rate; HR max=Maximum Heart Rate; VO_2 max=Maximum Oxygen Consumption; VO_2 peak=Peak Oxygen Consumption; RER=Respiratory Exchange Ratio; SR=Mean Stroke Rate; P=Mean Stroke Power Output.

Table 2: Correlation between Measured Maximum Oxygen Consumption, VO_2 max and Peak Oxygen Consumption, VO_2 peak of each trial

Trials	VO_2 max (ml/kg/min)	VO_2 peak (ml/kg/min)	Pearson Correlation		T-test	
			R	p	t	p
Trial 1 (mean $\pm$ sd)	17.7 9.85	23.82 13.63*	0.968	<0.01	4.228	<0.01
Trial 2 (mean $\pm$ sd)	18.26 8.32	24.62 11.66*	0.962	<0.01	4.887	<0.01

Notes: * denotes significantly different at p<0.05; df=10; N=11; R=Correlation Coefficient; sd=standard deviation; VO_2 max=Maximum Oxygen Consumption; VO_2 peak=Peak Oxygen Consumption.

Nonetheless, test-retest reliability data for VO_2 peak and VO_2 max resulted in an intra-class correlation of 0.97 (p<0.01) and 0.95 (p<0.01), respectively (Table 1). Therefore, further analysis to examine the validity and reliability of Rowing-Ramp protocol was performed using VO_2 peak, since that the CPET protocol used in this study is a ramp testing protocol.

PREDICTION EQUATION

RELATIONSHIP BETWEEN VO_2 PEAK AND ROWING PERFORMANCE DURING THE ROWING-RAMP PROTOCOL

To reduce type II error in measuring VO_2 peak in stroke patients, trial 2 was used for further analysis in the equation development, including regression analysis. There was a strong and positive correlation between relative VO_2 peak measured using Rowing-Ramp protocol and the mean stroke power (R=0.720*, p<0.01); and the Final Stage Stroke Power (R=0.859*, p<0.01) (Table 2).

Based on the significant correlation, both power output and Final Stage Stroke Power were entered into a linear regression equation (Table 3). Table 3 showed that Final Stage Stroke Power has the smallest standard error of regression (SE=5.5831). A smaller the standard error of R-square denotes a shorter distance away from the regression line. Final Stage Stroke Power also had the highest R-squared (73.8%) and adjusted R-squared (70.9%), and also has the smallest

Table 3. Linear regression analysis for Mean Stroke Power and Final Stage Stroke Power

DV	Pred	F value	P	SE R^2	R2	R2(ADJ)	Drop-off	VIF	Durbin-Watson
VO_2 peak	FSSP	25.326	0.001	5.58310	73.8%	70.9%	2.9%	1.000	3.186
VO_2 peak	P	9.708	0.012	7.56262	51.9%	46.5%	5.4%	1.000	1.761

Pred.=Predictor; SE=Standard error; VIF=variance inflation factor; R=correlation coefficient; * denotes significantly different at p<0.05; df=10; N=11; VO_2 peak=Peak Oxygen Consumption; P=Mean Stroke Power Output; FSSP=Final Stage Stroke Power

Table 4. Linear regression analysis for Final Stage Stroke Power

Model	Unstandardised Coefficients		Standardised Coefficients	T	Sig.	95%CI for B
	B	Std. Error	Beta		Lower Bound	Upper Bound
(Constant)	11.429	3.068	0.859	3.726	0.005	4.489	18.369
FSSP	0.232	0.046		5.033	0.001	0.128	0.336

* denotes significantly different at $p<0.05$; df=10; N=11; FSSP=Final Stage Stroke Power

drop-off from adjusted R-squared to the predicted R-squared (2.9%).

Table 3 displayed Final Stage Stroke Power has a significant and the highest F value (F=25.326, $p<0.01$), and has a higher correlation value with VO_2 peak (R=0.859) than power output (R=0.720). From the regression analysis with a high and significant F value, 70.9% can predict the VO_2 peak using the regression equation. Additionally, 70.9% of the total sum of squares can be explained using the estimated regression equation to predict the VO_2 peak. The remaining 29.1% is an error. From the t-distribution table, at $p<0.05$ and df=9 (df=N-2), the critical value is 2.2622. Thus, when the standard error of estimate regression is 5.5831, variance or standard deviation for VO_2 peak is as follows:

Standard deviation for VO_2 peak
= 2.2622 x SE of estimate regression
= 2.2622 x 5.58310
= 12.63

From linear regression analysis (Table 4), the significant coefficient and constant value for Final Stage Stroke Power related to VO_2 peak are 0.232 ($p<0.01$) and 11.429 ($p<0.01$), respectively. The Final Stage Stroke Power was the single best predictor of

relative VO_2 peak, explaining 70.9% of the variation. Therefore, to estimate VO_2 peak using the indirect method, we used the following regression:

VO_2 peak (ml/kg/min) = 11.429 + 0.232 (Final Stage Stroke Power) $\pm$ 12.63
Beta=0.859, $p<0.01$

This formula was established using the linear regression of the relative VO_2 peak against the Final Stage Stroke Power output, expressed in watts, attained exclusively during the Rowing-Ramp protocol test.

MEASURED AND PREDICTED VO_2 PEAK

Measured VO_2 peak was significantly correlated with predicted VO_2 peak in both trials, suggesting that measured VO_2 peak is associated with predicted VO_2 peak (R1=0.83, $p<0.01$; R2=0.81, $p<0.01$) (Figure 2). Therefore, VO_2 peak calculated using the established predicted equation is acceptable.

To ensure a more thorough assessment of the relationship between the measured and predicted VO_2 peak, Bland-Altman plots were utilized. Differences between the measured and predicted VO_2 peak are graphed against the means of the measured
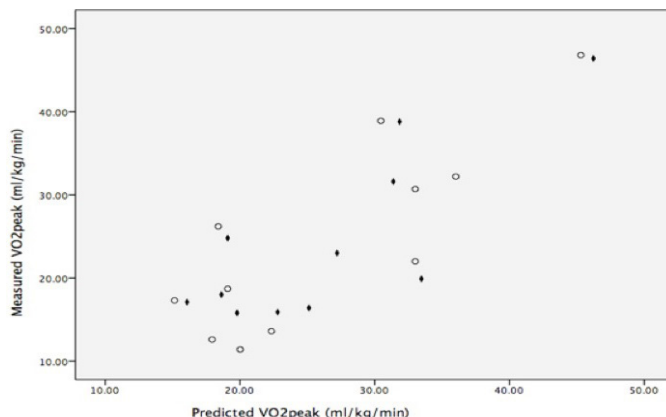
Figure 2: Correlation between peak oxygen uptake (VO$_2$ peak) measured during Rowing-Ramp protocol test and predicted peak oxygen uptake. Each data point represents an individual subject data of measured and predicted VO$_2$ peak. Circles and solid line represent Trial 1. Whereas, diamonds and dotted line represent Trial 2. N=11.

and predicted VO$_2$ peak (Figure 3). The mean difference or bias in measured and predicted VO$_2$ peak was 0.37. Two s.d. put the estimated range of mean differences as -6.6 to 7.4 ml/kg/min, with all but four subjects falling within this range or limit of agreement. As displayed in Figure 4, both predicted VO$_2$ peak (R=0.95, p<0.01) and measured VO$_2$ peak (R=0.94, p<0.01) at trial 1 correlated significantly with trial 2, indicates that predicted VO$_2$

peak is reproducible.

DISCUSSION AND CONCLUSION

CPET is an integrated and comprehensive tool to analyze cardiovascular, respiratory, metabolic and work indices for both healthy and diseased population, that can be used to understand the cause of exertion intolerance (Stevens et al. 2018). Even,
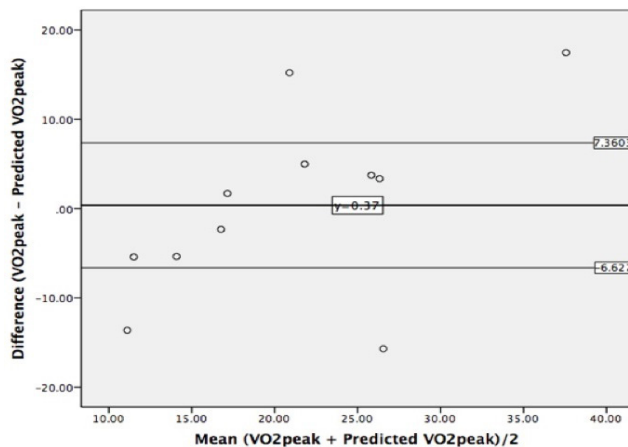

Figure 3: Bland-Altman plots of measured and predicted VO$_2$ peak data from trial 1 and trial 2.
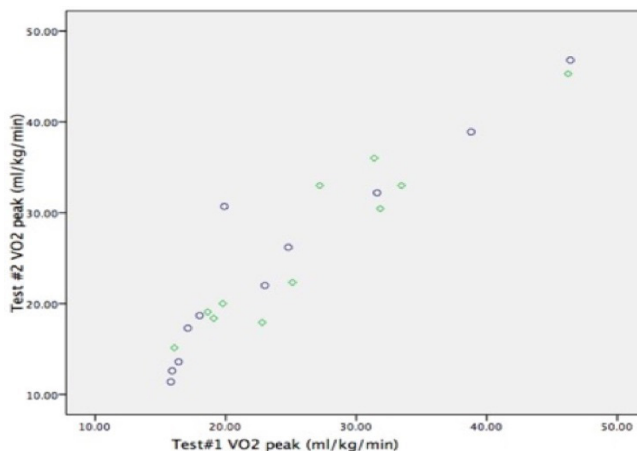
Figure 4: Test-retest reliability of measured and predicted peak oxygen uptake. Each data point represents an individual subject. Diamonds represent predicted VO_2 peak, and circles represent measured VO_2 peak. N=11.

CPET measures including VO2 peak provides a foundation to evaluate metabolic functional impairment (Stevens et al. 2018) especially among elderly with high risk for cardiovascular disease (Corra et al. 2018).

Results from this study demonstrate newly developed Rowing-Ramp protocol with a shorter and smaller work increment (4 spm every 30 seconds), and the new predictive equation is valid and reliable to estimate VO_2 peak of hemiparetic stroke patients. This observation is substantiated by the absence of a significant difference between the measured and predicted VO_2 peak, as well as by a significant and high value of test-retest correlation coefficients. Hence, there is a high reproducibility of measured and predicted VO_2 peak in hemiparetic stroke patients who were examined twice, 7 days apart.

This study also further confirms that a ramp protocol produces high reliability in oxygen uptake on different days, as mentioned by Whipp et al. (1981), even among stroke patients. Since hemiparetic stroke patients are unable to achieve maximal aerobic power, symptom-limited CPET parameters that were derived from submaximal tests used in this study is reproducible (Corra et al. 2018).

Additionally, a ramp protocol is more suitable for stroke patients because a ramp protocol produces lower electromyography amplitude, VO_2 and HR than a steps protocol in a submaximal cycle ergometer test (Zuniga et al. 2012; Zuniga et al. 2013). A ramp protocol also produces greater peak power output (Zuniga et al. 2013) and metabolic responses (Zuniga et al. 2012) than the step incremental cycle ergometer test. Therefore, a ramp protocol will facilitate achieving a VO_2 plateau (Zuniga et al. 2012; Zuniga et al. 2013). Similarly, Myers and Bellin (2000) proposed that ramp protocol should be used within clinical populations and untrained subjects.

Additionally, a previous study used a ramped Bruce protocol and found it to better record the VO_2 max than the standardised Bruce protocol (Will & Walter 1999).

The proposed equation in this study had a %SEE of 18.69%, suggesting little error associated with the regression for the measured compared with the predicted VO_2 peak. The TE from the current study was 20.75% of the mean measured VO_2 peak, demonstrating a strong relationship between the measured and predicted values.

From the regression equation proposed in this study, changes in VO_2 peak can be reflected by changes in stroke power output value. This current study is in agreement with Shimoda and Kawakami (2005), who found that maximal oxygen consumption was highly and strongly correlated with critical power among male university rowers (R=0.81), suggesting that rowing performance can be evaluated through stroke power output, without directly measuring maximal oxygen consumption as an index of aerobic capacity in stroke patients (Shimoda & Kawakami 2005).

Future studies are required on a larger independent sample of stroke patients to cross-validate the proposed equation. Even, using a different group of heart disease patients, with other metabolic and neurological diseases. This study supports the use of this new Rowing-Ramp protocol as a CPET, which is a non-invasive method to predict relative VO_2 peak in hemiparetic stroke survivors. This would easily provide accessible and relevant data that could be incorporated into a physical fitness rehabilitation programme. Because people with symptoms, chronic conditions, or disabilities may have limited exercise tolerance and are at increased risk for adverse events associated with physical activity, they require clinical exercise evaluation to screen for potentially dangerous signs or symptoms of exercise intolerance and to establish safer and more appropriate parameters for their exercise prescription (Stevens et al. 2018, Corrà et al. 2018).

This study was limited only to stroke patients that could at least walk and sit with or without assistance. This is due to the application of rowing ergometer that might need them to sit without support on the rowing machine. Without a good sitting balance, a patient might fall off the rowing ergometer. Added to this, the rowing ergometer is low in height compared to treadmill and cycling ergometer. Stroke patient might need some assistance to move to its seat as rowing's seat is movable (not static).

In this study, the safety of patients was the priority specifically while transferring or assisting them onto the rowing ergometer. Though there is a foot-placement pads on a rowing machine, patients might not be able to attach their own feet on that position as either side of their body is weak due to hemiparesis. In addition, the handles are attached quite a distance from the patient's position. For patients with stiff (spastic) distal, the affected side could be secured to the handles so that they could row easily. Equipment used in this study was the portable metabolic cart K5 (Cosmed) which might be

uncomfortable for these patients during the test. Throughout rowing training, a few of the stroke patients were having episodes of seizure thus affecting their performance in RRP test. Medications were taken to reduce and control the attack was another factor.

The results of this study show that the new Rowing-Ramp protocol is feasible as a CPET for stroke patients because it is safer for people with physical impairments. Additionally, the Rowing-Ramp protocol test offers a viable alternative exercise test for risk stratification, as well as to monitor physiological status in stroke patients who have chronic heart disease and physical disability. In which, would allow a physical therapist, a physical fitness therapist, or a clinical exercise physiologist to estimate peak oxygen consumption to be used as an exercise intensity for individualised training programmes and to track changes in cardiopulmonary fitness performance in a timely manner. This would also eliminate the need for expensive metabolic equipment or trained personnel associated with laboratory testing.

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