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Application of stepper in cardiopulmonary exercise test for patients with hemiplegia

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Abstract

A method to perform exercise testing for patients with hemiplegia is unavailable though over half of them have cardio-pulmonary disorders. We aimed to assess the reliability and validity of using a stepper in cardiopulmonary exercise testing (CPET) in this population.

14 stroke patients with hemiplegia who failed to ride the stationary bike were included. Exclusion criteria included manual muscle strength $\leqq 1$ in the lower extremity, and conventional contraindications of CPET. They underwent CPET twice by using a stepper to evaluate test–retest reliability and validity. Additionally, 10 healthy participants underwent CPET twice on the cycle ergometer and stepper respectively.

In the test–retest, the ratio of two-time difference to mean was 5.0, 3, 11.3 and 12.0% on average for peak oxygen consumption, peak heart rate (HR), anaerobic threshold and minute ventilation - carbonic dioxide production slope respectively. Cronbach's alpha coefficient of peak oxygen consumption and anaerobic threshold were 0.992 and 0.919. In the stepper exercise testing of the hemiplegic participants, the ratio of peak HR to age-predicted maximal HR was 75% on average. Peak respiratory exchange ratio (mean $\pm$ standard deviation $= 1.17 \pm 0.08$) was not different from that of healthy controls (1.21 ± 0.09). Notably, VO_2 trajectory in relation to work rate is nonlinear and different in the rest-retest.

This is the first research to study CPET variables in detail using stepper in patients with hemiplegia. CPET variables associated with peak are valid and reliable; nonetheless, those with sub-maximum are not. The study provides a method to do exercise testing for the patients with hemiplegia and its notice in application.

Abbreviations: APMHR = age-predicted maximal heart rate, CPET = cardiopulmonary exercise testing, Dif = the absolute value of the test-retest difference = |1st – 2nd|, $EqCO_2$ = ventilatory equivalent for CO_2, HR = heart rate, MMT = manual muscle strength testing, OUES = oxygen uptake efficiency slope, peak VO_2 = peak oxygen consumption, RER = respiratory exchange ratio, VAT = ventilatory anaerobic threshold, VCO_2 = carbonic dioxide production, VCP = ventilatory compensatory point, V_E = minute ventilation, WR = work rate.

Keywords: anaerobic threshold, oxygen consumption, reliability, stroke, validity

1. Introduction

Since decades ago, treadmill and cycle ergometry have been the standard modality used in stress exercise testing. However, both are not feasible for patients with hemiplegia due to unilateral weakness, balance deficits, and incoordination. These deficits in motor function affect exercise performance and compromise maximal-effort testing. Essentially, no well-recognized modality

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is available for the hemiplegic patients who are incapable of riding the cycle ergometer.[1–3]

Aerobic fitness is known to be low in stroke survivors. Even among ambulatory patients with hemiparetic stroke, the peak oxygen consumption (peak VO_2) is approximately only half of age-matched individuals.[4] Moreover, as many as 65% of stroke patients had coronary artery disease.[5] Accordingly, there is a substantial need to develop a method to evaluate the cardiopulmonary fitness and guide exercise prescription for patients with hemiplegia.

Semi-recumbent stepper combines upper/lower-extremity and bilateral reciprocal movement of the arm coupled with the opposite leg, which allows for a push-and-pull motion. A seat back and a safety belt improve trunk support. A foot strap secures the hemiparetic lower limb to the pedal. It may be feasible in patients with hemiplegia because it bypasses neurologic deficits so that metabolic maximum can be nearly approached. The stepping-like movement can even be an apparatus of rehabilitation and locomotion if some modification is made to the stepper (patent: No. US9,371,107 B2). Since about 10 years ago, a few recumbent steppers with a design of cadence-independent external energy output have been on the market, such as SCIFit StepOne™ Recumbent Stepper (SCIFIT Corporate Headquarters, Tulsa, OK) and NuStep T5XR (Ann Arbor, MI). This made its application in stress exercise testing for patients with hemiplegia possible. However, in the meantime, we speculated that there are pitfalls in the interpretation of the cardiopulmonary exercise testing (CPET) derived from the stepper, which requires clarification. Although a few studies employed recumbent stepper or combined upper- and lower-limb ergometer to do exercise testing for patients with hemiplegia,[1–3] no published literature delineated clearly the cardiopulmonary parameters and its notice in application using these unconventional modalities.

The current study hypothesized that

(1) in selected patients with hemiplegia who failed to ride the stationary bike, stepper can be performed well – feasibility;
(2) a high respiratory exchange ratio (RER), peak heart rate (HR), and the ratio of the peak HR to age-predicted maximal HR (APMHR) can be achieved, indicating near-maximal effort – validity;
(3) the physical parameters at peak are highly reproducible, but not at submaximum – reliability.

Meanwhile, healthy subjects were also recruited to compare the CPET results derived from stepper against cycle ergometer.

2. Materials and methods

2.1. Participants and protocol

Fourteen stroke patients with hemiplegia who failed to ride the stationary bike well were included. Those with manual muscle strength ≦1 (Medical Research Council scale) in the proximal lower extremity and a passive range of motion <15° in ankle dorsiflexion were excluded. In addition, those who had orthopedic problems, insufficient cognition and communication to understand the process and risks of the study or conventional contraindications of exercise testing were excluded.[6] The subjects underwent symptom-limited incremental CPET on a stepper twice within one week and at least 2 days apart to establish the test–retest reliability. Additionally, 10 healthy volunteers were recruited. They underwent incremental CPET twice by using the stepper and cycle ergometer within 1 week and at least 2 days apart to compare the results between these two modalities. The experiment protocol was approved by the Chang Gung Memorial Hospital Institutional Review Board. All the subjects provided written informed consent after explanation of the experimental procedures.

2.2. Cardiopulmonary exercise test

SCIFit StepOne™ Recumbent Stepper (SCIFIT Corporate Headquarters, Tulsa, OK) was used to perform the stepper exercise testing (Fig. 1). The subjects were instructed to keep a comfortable cadence (mostly between 80 and 90 strides per minute) and maintain it within ±5 during the testing. They were also required to keep the largest stride length on the stepper. The protocol comprised 1 minute of unloaded pedalling, followed by a step increase in work rate (WR) of 10 (hemiplegic subjects) or 15 W/min (healthy subjects). Each subject was instructed to refrain from exercise for 24 h before the test. Before the initial test, the subjects were asked to step for 5 minute to familiarize the process. If necessary, adaptive equipment (ankle-foot stabilizer) was used for the stroke-affected side. The exercise test was terminated using the following criteria:

(1) the subject could not keep up with the cadence or stride length,
(2) the participant reached volitional fatigue and requested to end the test,

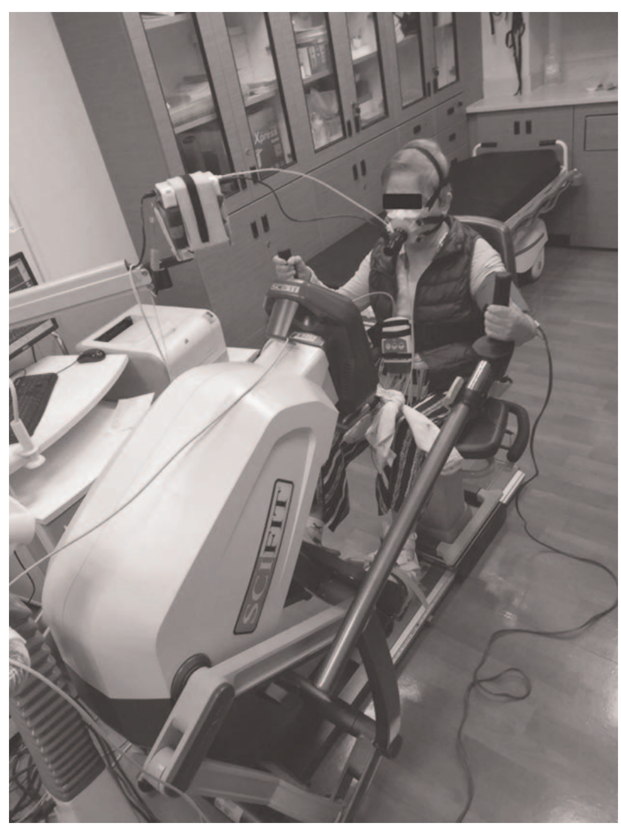

Figure 1. A patient with hemiplegia performing a symptom-limited cardiopulmonary exercise test by using the recumbent stepper.

(3) the participant's peak VO_2 plateaued or decreased despite continuation of exercise, or
(4) an adverse cardiovascular event was observed.

Furthermore, a calibrated upright bicycle ergometer (Ergoselect 150P, Germany) was used in healthy subjects. Identical to the stepper protocol, a step increase of 15 W/min was also adopted. A computer-based system (MasterScreen CPX, Cardinal-health, Germany) was used to measure peak oxygen consumption (VO_{2peak}), minute ventilation (V_E), carbonic dioxide production (VCO_2), and so on, breath by breath. Before each test, the gas analysers and the turbine flow meter of the system were calibrated following the manufacturer's instructions and by using a gas mixture of known concentration (FO_2: 0.16; FCO_2: 0.05; N_2 as balance) and an automatically-pumping high and low flow system. HR was determined from the R-R interval on a 12-lead electrocardiogram. Arterial blood pressure was measured using an automatic blood pressure system (Tango, SunTech Medical, UK). In subjects with hemiplegia, the pressure cuff was wrapped on the paretic arm. The affected upper limb did not participate in the push-pull movement if he failed to do hand grasp well. If the subject was capable of grasping the handrail, the affected upper limb may be involved in the exercise. As the blood pressure was taken, this arm was temporarily hanging on side naturally. Arterial O_2 saturation was monitored using finger pulse-oximetry (model 9500, Nonin Onyx, Plymouth, Minnesota).

2.3. Data processing

Breath-by-breath data were averaged into 30 seconds and plotted in a standard "9-panel" CPET report format for estimation of ventilatory anaerobic threshold (VAT) and ventilatory compensatory point (VCP) by standard gas exchange and ventilatory criteria.[6] Peak VO_2 and other variables were reported as the 30-s average during exercise. Norm Prediction of peak VO_2 was referred to Itoh et al equation.[7] VAT was determined primarily by V-slope method and verified based on ventilatory criteria as follows:

(1) departure from linearity for VCO_2 against VO_2,
(2) the V_E/VO_2 ratio increased without a corresponding increase in the V_E/VCO_2 ratio and
(3) end-tidal tensions of oxygen ($P_{ET}O_2$) increased without a corresponding decrease in end-tidal tensions of carbon dioxide ($P_{ET}CO_2$). VCP was identified by departure from linearity for V_E against VCO_2 and verified by an accompanying increase in the V_E-VCO_2 ratio and a decrease in the $P_{ET}CO_2$.[8] VAT and VCP were recognized by 2 experienced and independent reviewers.

ventilatory equivalent for O_{2nadir} and ventilatory equivalent for CO_2 $_{(}EqCO_{2)nadir}$ were the lowest values of V_E/VO_2 ratio and V_E/VCO_2 ratio during exercise.[9] V_E–VCO_2 slope was obtained as the slope of the regression line between V_E and VCO_2 during the exercise test.[10] Oxygen uptake efficiency slope (OUES) represents the rate of increase in VO_2 in response to a change in V_E and was computed as the slope of the regression line derived from VO_2 and the logarithm of V_E based on the equation: $VO_2 = OUES \times \ln V_E + b$. OUES is an estimation of the oxygen uptake efficiency, with steeper slopes indicating better oxygen uptake efficiency.[11,12] In contrast, a flatter V_E–VCO_2 slope indicated better ventilation efficiency. In addition, age-predicted maximal HR (APMHR, bpm) = 220 − age.

2.4. Statistics

Validation was assessed by the extent the metabolic load approached to the maximum when the stepper was utilized in patients with hemiplegia. The test–retest reliability (or agreement) was evaluated by

(1) absolute value of the difference between the test and retest (Dif),
(2) the ratio of Dif to the mean of test-retest,
(3) 2-way mixed intra-class correlation, and
(4) Bland–Altman plot and scatter plot. Wilcoxon signed-rank test was used to compare the CPET results between the stepper and cycle ergometry in the healthy subjects. Data were expressed as mean ± standard deviation and analyzed using SPSS 19.0 software. The criterion for significance was $P < .05$.

3. Result

In the pilot study, we found that at least three stroke-related neuromuscular deficits precluded stroke patients with hemiplegia from performing stress exercise testing using a stepper (SCIFit StepOne™). First, the affected lower limb has manual muscle strength testing (MMT) grade ≦ 1 in which hip abducts as sitting, which precludes stepping. Second, the affected lower limb has a strong ankle plantar flexion spasticity because ankle dorsiflexion is necessary for the stepping motion. Strong ankle plantar flexion spasticity would make the foot slip from the pedal. Third, aphasia causes trouble in comprehending the whole testing procedure and expression of the subject's rate of perceived exertion or any discomfort during the testing. Excluding the above-mentioned three neurologic deficits, we recruited 14 stroke patients with unilateral weakness (Table 1). All completed the test-retest. Accordingly, apart from the above-mentioned stroke-related deficits, the stepper is feasible in stress exercise testing for patients with hemiplegia.

The demographics of patients with hemiplegia are shown in Table 1. The mean age was 62 ± 11 years. Of 14 patients, three were able to walk independently but limped (Modified Rankin scale was 3). The others (n = 11) could not walk independently (modified rankin scale = 4). None of them could ride the stationary bike well. There were five men and five women in the healthy control. The mean age of the healthy control group was 32 ± 10 years. Height and weight were 167 ± 9 cm and 65 ± 13 kg.

Compared with cycle ergometry, maintaining the cadence of the stepper in a narrow range is relatively difficult. In the testing

Table 1

Demographic data of the stroke patients.

	Unit	Number
Case number	–	14
Age	Year	62 ± 11
Gender	M/F	11/3
Body height	Cm	165 ± 8
Body weight	Kg	68 ± 9
Weak side	R/L	6/8
Infarction/hemorrhage	–	9/5
MRS	Grade 3/4	3/11
β-blocker		4

MRS: modified rankin scale.
Values are presented as mean ± standard deviation.

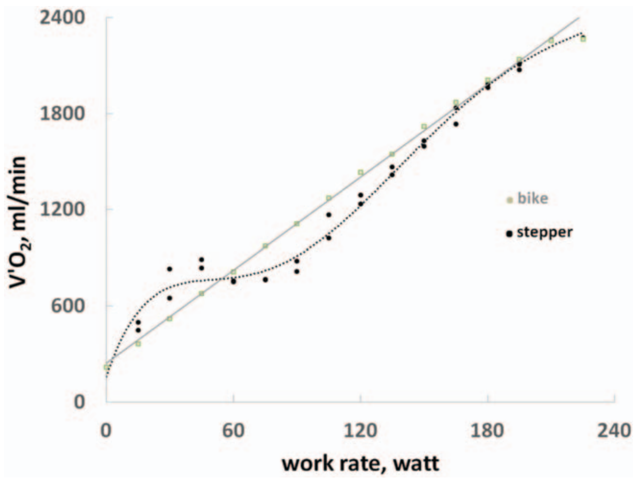

Figure 2. One healthy participant performed incremental cardiopulmonary exercise test on a cycle ergometer and a stepper respectively using step increase of 15W per min. In the exercise testing by using a stepper, VO_2 increases nonlinearly, in which VO_2 rises more rapidly than cycling in the initial portion. The initial high oxygen consumption is possibly because the joysticks (or handle) of the stepper are relatively heavy to push and pull at the start. This ascending–flat–ascending pattern is observed in most of the tests by using a stepper, regardless of healthy or hemiplegic subjects.

using cycle ergometer, the subjects were instructed to pedal at 60±2 RPM and most patients had no trouble in compliance. However, in terms of the stepper, no patient was able to maintain the cadence in such a narrow range. Instead, the range was approximately±5–10 steps per minute.

Peak VO_2 was 15.6 ml/min/kg on average, which is 61.9% of predicted value. Notably, we observed that the trajectory of oxygen consumption during exercise testing using stepper is a non-linear increase and has a flat part in between, rather than linear pattern when cycling. This phenomenon was observed in most of the participants, no matter healthy or hemiplegic. Figure 2 is one example of a healthy subject.

The test–retest reliability of the patients with hemiplegia using a stepper was demonstrated in Table 2. Peak values had good reliability, including VO_2, WR, HR, and V_E. It is noteworthy that these four variables had relatively small Dif and Dif / test-retest mean that are good enough to be utilized as an outcome measurement in interventional studies. In contrast, the values derived from the sub-maximum showed poorer reliability or were frequently unattainable. VCP had the best reliability in terms of Dif / mean and Cronbach's α value among the sub-maximal variables. However, it cannot be identified in 13 out of 28 tests. OUES, $EqCO_{2nadir}$, and VAT may seem to have a good Cronbach's α value (>0.9), but they all have a big Dif. The Bland–Altman and scatter plot of peak VO_2 and VAT are shown in Figure 3 as a comparative example.

Regarding validation, data showed that the stepper exercise nearly approaches the metabolic maximum in the hemiplegic subjects. Peak HR/APMHR (75% on average) is large enough considering that the excise pattern is recumbent stepping (rather than treadmill) and 4 of 14 patients were on β-blocker use. The Peak RER was 1.17±0.08 (n=28 person-time), which showed no statistical difference from that of healthy young control (1.21 ±0.09; n=10) (P=0.206). Both parameters indicate maximal exertion was nearly achieved (Table 4).

Stepping elicited a different pattern of cardiopulmonary adaptation from the cycling. Their results of CPET from healthy subjects are compared in Table 3. Peak VO_2 tended to be higher in the stepper, although not significantly different. Stepping exercise test had lower peak RER and peak V_E. The OUES was also higher in stepper testing.

4. Discussion

Although this is not the first attempt to evaluate exercise cardiopulmonary function in hemiplegic stroke patients, it is the first research to study the cardiopulmonary function index in detail using stepper in exercise testing. The result showed that the stepper was feasible in a subset of hemiplegic stroke population (excluding MMT ≦ 1 in the lower extremity). Variables of symptom-limited incremental CPET associated with peak state was valid and reliable. This is an effective method to bypass the neurologic deficit to approach the metabolic maximal effort. Nonetheless, submaximal variables were not sufficiently reliable. We speculate that this is related to a remarkable deviation of test-retest trajectory of VO_2 in the stepper exercise testing in the hemiplegic subjects. Moreover, the VO_2 rises in a non-linear pattern, a newly-discovered phenomenon, found in most of the

Table 2

Test–retest reliability of stress exercise testing by using a stepper in subjects with hemiplegia.

	unit	1st	2nd	Dif	Dif/mean of 1st and 2nd	Cronbach's α value
Peak VO2	mL/min/kg	15.7±5.8	15.5±5.1	0.7±0.6	5.0±4.9	0.992
Peak WR	Watt	74±28	73±25	4±5	5±6	0.986
Peak HR	/min	130±23	131±23	4±3	3±2	0.989
Peak VE	L/min	45±18	44±16	3±2	6±4	0.988
Peak RER		1.16±0.08	1.18±0.08	0.04±0.03	3.58±2.30	0.905
VAT	mL/min/kg	10.7±3.7	10.4±2.8	1.3±1.3	11.3±10.2	0.919
EqO2nadir		28.3±2.5	28.6±3.7	2.6±1.7	9.0±5.5	0.652
VCP&	mL/min/kg	13.9±5.2	13.3±4.6	0.6±0.4	5.6±4.9	0.995
EqCO2nadir		31.3±2.8	30.9±3.6	1.2±1.0	4.0±3.3	0.937
VE-VCO2 slope		30.6±3.7	31.4±4.4	3.7±3.2	12.0±10.8	0.437
OUES		565±215	593±219	73±44	13±7	0.962

values are mean±standard deviation; Dif is the absolute value of the test-retest difference=|1st − 2nd|.
& cannot be identified in 13 of 28 tests; only those with identifiable VCP in the first and second tests were calculated (n=5).
$EqCO_2$ = ventilatory equivalent for CO_2, EqO_2 = ventilatory equivalent for O_2, HR = heart rate; OUES = oxygen uptake efficiency slope, V_E = minute ventilation; RER = respiratory exchange ratio; VAT = ventilatory anaerobic threshold; VCP = ventilatory compensatory point. WR = work rate. Values are presented as mean±standard deviation.

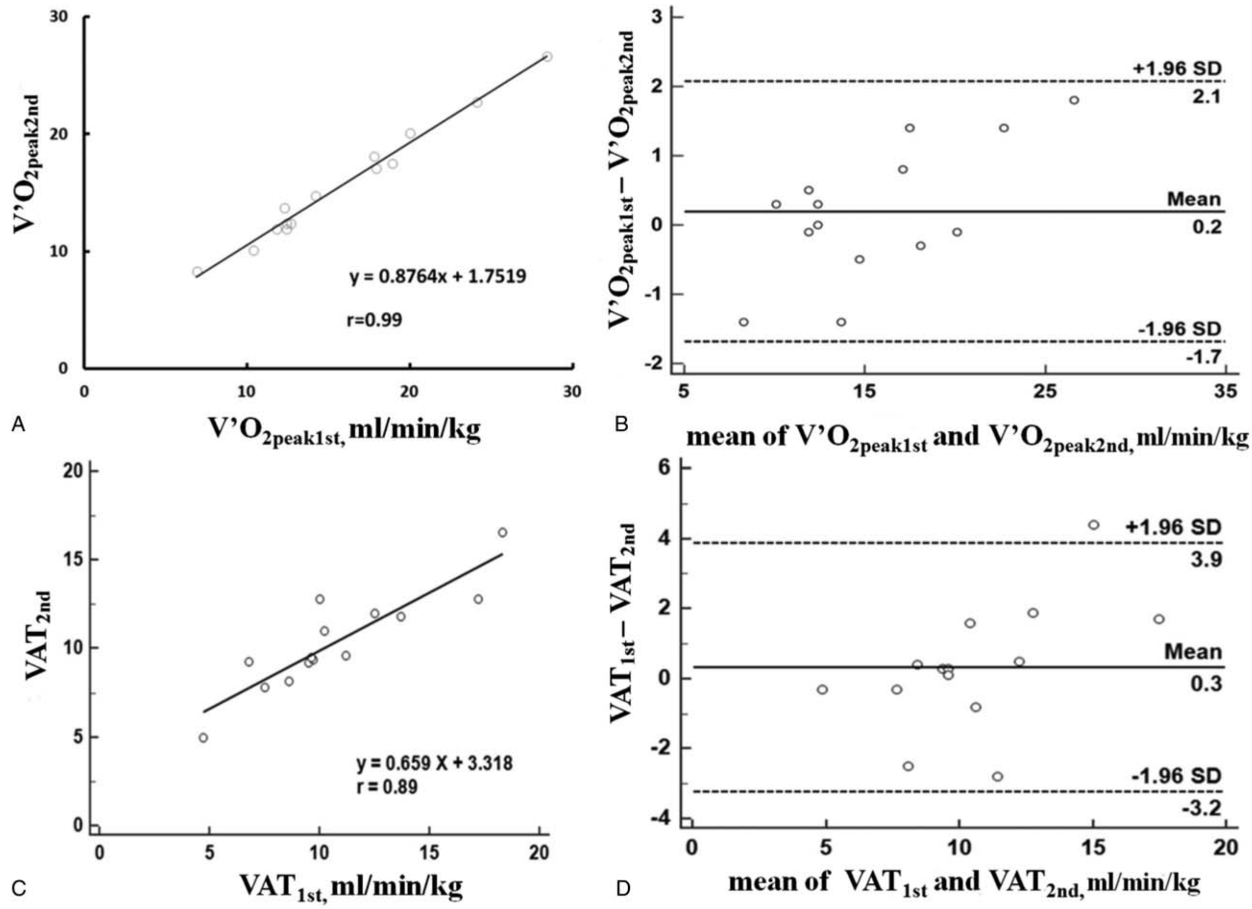

Figure 3. Scatter plots of VO_{2peak} and VAT in test and retest were demonstrated in A and C, respectively. Agreement using Bland–Altman plots of VO_{2peak} and VAT were shown in B and D. Graphs B and D plot the respective differences between the two tests against the means of these 2 tests. The dark solid horizontal lines in each Bland–Altman plot represents the average bias, whereas the dotted lines represent average bias ± 1.96 standard deviation (95% upper and lower limit).

Table 3

Comparison of the result of cardiopulmonary exercise testing using recumbent stepper and cycle ergometry in the healthy subjects (n = 10).

	Unit	Stepper	Cycle ergometry
Peak VO_2	mL/min	1890 ± 580	1825 ± 587
Peak VO_2	mL/min/kg	29.0 ± 5.4	27.9 ± 4.9
Peak WR	watt	169 ± 45	169 ± 51
Peak HR	/min	170 ± 16	176 ± 12
Peak V_E	L/min	68 ± 23*	73 ± 26
Peak RER		1.21 ± 0.09*	1.29 ± 0.09
VAT	mL/min	1195 ± 420	1109 ± 375
VAT	mL/min/kg	18.4 ± 5.0	17.0 ± 3.4
VCP&	mL/min	1539 ± 461	1513 ± 388
VCP&	mL/min/kg	23.5 ± 4.5	22.0 ± 3.7
EqO_{2nadir}		22.7 ± 1.9	22.1 ± 2.6
$EqCO_{2nadir}$		24.4 ± 2.0	23.8 ± 2.0
V_E-VCO_2 slope		26.7 ± 2.7	27.6 ± 3.0
OUES		883 ± 224*	831 ± 194

& cannot be identified in 2 of 10 tests in stepper; and 2 of 10 tests in cycle.

$EqCO_2$ = ventilatory equivalent for CO_2, EqO_2 = ventilatory equivalent for O_2, HR = heart rate; OUES = oxygen uptake efficiency slope, V_E = minute ventilation; RER = respiratory exchange ratio; VAT = ventilatory anaerobic threshold; VCP = ventilatory compensatory point. WR = work rate. Values are presented as mean ± standard deviation.

* Wilcoxon signed-rank test, $P < .05$.

hemiparetic and healthy participants (Figs. 2 and 4). In addition, with normal people as a control group, the result confirmed that the examination can measure the general cardiopulmonary function.

Non-linear increase of oxygen consumption in stepper testing indicates that the internal energy expenditure (oxygen consumption) is not in parallel to the external energy output, which was set to be a linear step increase of WR (Fig. 2). The ladder-like trajectory can be divided into 3 phases: ascending–flat–ascending. In the flat phase, increase of external energy output does not elicit increase of internal energy expenditure. In the initial ascending part, VO_2 in the stepper testing increases steeper than cycling (shown in Fig. 2) and then goes flat. The high initial

Table 4

Validity of stepper in the subjects with hemiplegia.

	Unit	Number
Peak HR	beat/min	135 ± 23
Peak HR / APMHR	%	75 ± 22
Peak RER	–	1.17 ± 0.08

APMHR = age-predicted maximal heart rate, HR = heart rate, RER = respiratory exchange ratio. Values are presented mean ± standard deviation.

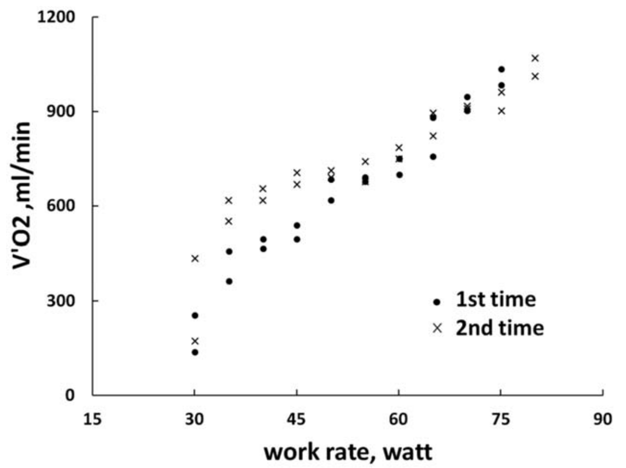

Figure 4. Oxygen consumption during the two cardiopulmonary exercise tests by a single hemiplegic patient using stepper was plotted as a comparison. Although the peak values were very close, the trajectories were different between the test and retest in the initial ascending and the flat part.

oxygen consumption is possibly because the joysticks (or handle) of the stepper are relatively heavy to push and pull at the start

Why the submaximal variables are insufficiently reliable? VAT, $EqCO_{2nadir}$ and OUES have a big Dif and ratio of Dif-to-mean that precludes them from being used in interventional studies, such as exercise training, in which the change often falls within the 95% confidence interval of Dif (Table 2, Fig. 3). VCP, based on the present result, is also reliable, but unattainable in half of the cases. The reason could be explained by Figure 4. We found that trajectories of VO_2 increase was different between the test and retest. The difference occurred obviously in the initial ascending and flat part. The final ascending limb is relatively close between the two tests. Consequently, this caused different values of VAT and ventilatory equivalent for O_{2nadir}, but the Dif was not obvious in VCP. Deviation of VO_2 trajectories is because it is difficult for the patients with hemiplegia to keep the cadence in a narrow range on the stepper (described in the Results section) and to have every stride step down to the largest stride length as requested. Variation in cadence and stride length results in a deviation of internal energy expenditure. In addition, technical deviation of constant load of SCIFit StepOne^{TM} (-9.87~0.37% deviation between 25 and 175 Watts based on the specification) is relatively large compared with cycle ergometry (Ergoselect 1200EL+/- 5% between 25 and 400 Watts but +/- 3 Watts between 25 and 100 Watts).

As to validation, based on peak RER (1.17±0.08) and the ratio of peak HR to APMHR (75±22%) in the stepper testing (Table 4), exertional level was approached to near-peak in the hemiplegic subjects. Clinically, 85% target threshold of APMHR achieved is currently used to quantify exertional level during treadmill exercise testing.[13,14] The stepping exercising pattern may have a lower peak HR since less muscle is involved. Additionally. 4 subjects were under β-blocker use in the present study. Thus, lower average peak HR is expectable. Stepping seems to induce less spasticity and the reciprocal exercising pattern is more feasible compared to cycling. Stepping with a backrest is an effective way to bypass the hemiplegic neurologic deficit and get closer to maximal exertion.

Compared with the result of CPET by using cycle ergometry, the stepper has comparable peak VO_2 and WR, lower peak RER and peak V_E, and higher OUES. Therefore, the stepper caused less respiratory and metabolic load to obtain a comparable task. This better working economy is likely related to increased venous return and hence, higher cardiac output and lower ventilation-perfusion mismatch, on the recumbent stepper. Bilateral reciprocal movement of the four extremities and the backrest that supports the trunk might also enhance working economy.

Three previous studies used similar modalities in exercise testing for post-stroke patients, but they all have shortcomings compared to the present study. Hill et al. used a combined upper- and lower-limb ergometer. The gas analysis data were not obtained. The ratio of peak HR to APMHR was 75% on average, which is very close to our result.[1] In another study, 11 post-stroke patients underwent CPET twice on a cycle and a total-body recumbent stepper.[2] Peak VO_2 and HR showed strong correlation between the two modalities. This study has three major differences from ours. First, submaximal parameters were not investigated. Second, test–retest reliability testing of recumbent stepper was not performed. Third, the study included stroke patients who could perform cycling. On the contrary, the aim of our study is to develop exercise testing for those who have trouble cycling. Thus, no subject was capable of cycling in our study. We think cycle ergometry remains a better modality than stepper for those who can do both. In the third study, test–retest reliability of the recumbent stepper was performed in stroke patients (n=20). Like the previous two studies, submaximal values from gas analysis were not investigated. Peak VO_2 was obtained by an equation from the submaximal exercise test. 95% CI of the difference between the two visits was larger than±1MET based on the Bland–Altman plots.[3] In our study, 95% CI of the difference between the two peak VO_2 was smaller than 0.5 MET. Accordingly, the present study is the first research to study the CPET variables in detail using stepper in exercise testing.

5. Limitation

The stepper is not feasible in those patients with hemiplegia with MMT grade ≦1 in the affected lower extremity.

6. Conclusion

This is the first research to study the CPET variables in detail using stepper in patients with hemiplegia. The stepper is applicable in a selected hemiplegic stroke population (excluding MMT ≦ 1 in the lower extremity). Variables of CPET associated with the peak state are valid and reliable; nonetheless, those in the submaximal state are not. The research provides a method to evaluate cardiopulmonary fitness for the patients with hemiplegia and its notice in application.

Author contributions

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Writing – original draft: Shu-Chun Huang.
Writing – review & editing: Tieh-Cheng Fu, Carl PC Chen, Jong-Shyan Wang.

References

[1] Hill DC, Ethans KD, MacLeod DA, et al. Exercise stress testing in subacute stroke patients using a combined upper- and lower-limb ergometer. Arch Phys Med Rehabil 2005;86:1860–6.
[2] Billinger SA, Tseng BY, Kluding PM. Modified total-body recumbent stepper exercise test for assessing peak oxygen consumption in people with chronic stroke. Phys Ther 2008;88:1188–95.
[3] Wilson DR, Mattlage AE, Seier NM, et al. Recumbent Stepper Submaximal Test response is reliable in adults with and without stroke. PLoS One 2017;12:e0172294.
[4] Ivey FM, Hafer-Macko CE, Macko RF. Exercise rehabilitation after stroke. NeuroRx 2006;3:439–50.
[5] Hertzer NR, Young JR, Beven EG, et al. Coronary angiography in 506 patients with extracranial cerebrovascular disease. Arch Intern Med 1985;145:849–52.
[6] Deborah R. ACSM's guidelines for exercise testing and prescription. tenth editionPhiladelphia: Wolters Kluwer; 2018. Chapt 5, page 111.
[7] Itoh H, Taniguchi K, Koike A, et al. Evaluation of severity of heart failure using ventilatory gas analysis. Circulation 1990;81(1 Suppl): II31–7.
[8] Whipp BJ, Ward SA, Wasserman K. Respiratory markers of the anaerobic threshold. Adv Cardiol 1986;35:47–64.
[9] Tan C, Rossiter HB, Porszasz J, et al. Reliability and physiological interpretation of pulmonary gas exchange by "Circulatory Equivalents" in chronic heart failure. J Am Heart Assoc 2018;7:e008072DOI: 10.1161.
[10] Antoine-Jonville S, Pichon A, Vazir A, et al. Oxygen uptake efficiency slope, aerobic fitness, and V(E)-VCO2 slope in heart failure. Med Sci Sports Exerc 2012;44:428–34.
[11] Van Laethem C, Van De Veire N, De Backer G, et al. Response of the oxygen uptake efficiency slope to exercise training in patients with chronic heart failure. Eur J Heart Fail 2007;9:625–9.
[12] Huang SC, Wong MK, Lin PJ, et al. Modified high-intensity interval training increases peak cardiac power output in patients with heart failure. Eur J Appl Physiol 2014;114:1853–62.
[13] Pinkstaff S, Peberdy MA, Kontos MC, et al. Quantifying exertion level during exercise stress testing using percentage of age-predicted maximal heart rate, rate pressure product, and perceived exertion. Mayo Clin Proc 2010;85:1095–100.
[14] Fletcher GF, Ades PA, Kligfield P, et al. Exercise standards for testing and training: a scientific statement from the American Heart Association. Circulation 2013;128:873–934.