The Feasibility of Cardiopulmonary Exercise Testing for Prescribing Exercise to People After Stroke

Susan Marzolini, MSc; Paul Oh, MD; William McIlroy, PhD; Dina Brooks, PhD

Background and Purpose—Despite the importance of exercise training in mitigating cardiovascular risk, the development of exercise programs for people poststroke has been limited by lack of feasibility data concerning cardiopulmonary exercise testing (CPET) to inform the exercise prescription. Therefore, we examined the feasibility of CPETs for developing an exercise prescription in people ≥3 months poststroke.

Methods—CPET results from 98 consecutively enrolled patients poststroke with motor impairments and 98 age- and sex-matched patients with coronary artery disease were examined at baseline and after 6 months of exercise training.

Results—The proportion of patients with stroke and coronary artery disease attaining an intensity sufficient for prescribing exercise at baseline was 68.4% versus 82.7%, respectively (P=0.02) and 84.7% versus 83.8% (P=0.9) at 6 months. Women were less likely than men poststroke to achieve a sufficient intensity at baseline (40% versus 80.9%, P<0.001) but not at 6 months (78.3% versus 87.1, P=0.3). A clinically relevant abnormality occurred in 11.2% of stroke and 12.2% of patients with coronary artery disease on baseline CPETs (P=0.8) and 10.6% of stroke and 5.9% of patients with coronary artery disease on the 6-month CPET (P=0.4). No serious cardiovascular events occurred during 349 CPETs.

Conclusions—Most patients after stroke achieved a level of exertion during the CPET sufficient to inform an exercise prescription. At least 1 of 10 patients poststroke developed a clinically relevant abnormality on baseline and postprogram CPETs with no serious cardiovascular events. These data support the feasibility and safety of CPETs for prescribing exercise poststroke. Strategies to improve use of baseline CPETs for women poststroke require further investigation. (Stroke. 2012;43:1075-1081.)

Key Words: electrocardiography ■ rehabilitation ■ stroke care ■ stroke delivery ■ stroke recovery

Despite exercise being an important component of stroke rehabilitation, there is a dearth of information on the clinical use and feasibility of cardiopulmonary exercise testing (CPET) for individuals with a history of stroke before engaging in exercise. This issue merits special attention in view of the growing recognition of the importance of exercise in the secondary prevention of stroke and the risk of comorbid coronary artery disease (CAD).

CPETs are not routinely administered before starting a cardiac rehabilitation (CR) program after stroke.1 Consequently, exercise is often prescribed without an objective assessment of the patients’ functional capacity, resting and exercise blood pressures, exercise-related symptoms, and/or electrocardiographic (ECG) changes including dysrhythmias.2 Despite recommendations to base exercise prescriptions on CPET results, few data are available to substantiate the feasibility and safety of graded exercise tests with ECG monitoring after stroke.3 Lacking this information has hindered the development of exercise programs tailored to the functional capacities of survivors of stroke.

A CPET involves measuring oxygen uptake, carbon dioxide output, and minute ventilation at the same time as monitoring blood pressure and 12-lead ECG. Measures derived from the CPET guide the activity attributes of the exercise prescription. From both a safety and efficacy point of view, the most important parameter of the prescription is that of intensity.4–6 Intensity of exercise is believed to be the primary factor responsible for change in peak oxygen uptake (VO2peak)6,7 and a higher VO2peak is associated with lower stroke risk in males8 as well as lower mortality in cardiac patients.5 Moreover, evidence that the intensity of physical activity (moderate to high) may be a greater determinant of stroke prevention than duration of exercise is accumulating.9,10

In view of the importance of exercise intensity, an exercise prescription based on objective measures derived from a CPET is important. The CPET determines the ventilatory

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1075
stroke or transient ischemic attack were included. Patients in both
program who had a documented history of CAD and no history of
age- and sex-matched patients consecutively enrolled in the CR
program and were not included in the analysis. Patients in the CAD
cohort had a documented history of CAD (myocardial infarction,
angiographic evidence showing ≥50% stenosis in ≥1 major coro-
nary artery, percutaneous coronary intervention, or coronary artery
bypass graft surgery, and were referred ≥6 weeks since coronary
artery bypass graft surgery or myocardial infarction or ≥3 weeks
since percutaneous coronary intervention. The study was approved
by the institution’s Research Ethics Board.

**Poststroke Baseline Assessments**

Motor recovery stage of the arm, hand, leg, and foot of the stroke-
affected side was classified on the 7-point Chedoke-McMaster Stroke
Assessment scale. A Chedoke-McMaster Stroke Assessment scale
motor impairment score of 1 indicates flaccid paralysis, 3 describes
marked spasticity and weakness, 6 indicates near normal coordination
of patterns of movement and no spasticity, and 7 describes normal
movement. Patients performed the 6-minute walk test walking as far
as possible over a 30-meter course in 6 minutes.

**Baseline Characteristics**

At entry to CR, individuals poststroke had a similar cardiovascular
risk factor profile when compared with patients with CAD (Table 1).
Fewer patients with stroke than patients with CAD were prescribed
β-blockade medications (P < 0.001). Most individuals after stroke had
a history of ischemic stroke (70.4%), used a gait aide for
ambulation (59.2%), and 93.9% had a motor impairment score between
3 (marked spasticity) and 6 (near normal coordination of
movement) of the leg on the 7-point Chedoke-McMaster Stroke
Assessment scale (Table 2). The 6-minute walk test distance at
baseline represented 52.3% ± 27% of predicted norms.

CPETs were conducted in 98 patients with stroke and 98 patients
with CAD at baseline and 85 patients with stroke and 68 patients
with CAD after 6 months of training. A greater proportion of
patients in the CAD cohort discontinued the CR program than in
the stroke cohort (30% versus 13%, P = 0.001). Most baseline
CPETs were conducted on the upright cycle for patients with CAD
(78.6%) and on the recumbent cycle for individuals after stroke
(50%; Supplemental Table I; http://stroke.ahajournals.org).

**Cardiopulmonary Exercise Test**

CPETs were conducted in all patients at baseline and 6 months
except in those who prematurely discontinued the CR program. A
resting 12-lead ECG, medical history, and anthropometric measures
were collected before each CPET. The test was conducted by 2
cardiopulmonary exercise technicians under the direct supervision of
1 physician. A CPET on either a recumbent cycle ergometer with
specialized pedals to secure feet (Ergoline Select 1000), an upright
cycle (Ergoselect 200P), or a treadmill was performed. The type of
ergometer and testing protocol was chosen by the testing staff based
on balance and control of leg/foot position on the pedal. None of the
testing modalities required exertion of the upper body. Individuals
poststroke who had excessive hemiparetic hip weakness had their leg
stabilized by an elastic band looped around the thighs. Workload
was increased by either 8.3 or 16.7 W every minute at a pedaling rate
of 60 rpm, the aim being to achieve test durations of between 8 and
12 minutes. Breath-by-breath gas samples were collected and averaged

**Methods**

This was a retrospective analysis of CPETs conducted at baseline
and after 6 months of exercise training in 98 consecutively enrolled
patients in Toronto Rehabilitation Institution’s Risk Factor Modi-
fication and Exercise Program following Stroke (TRI-REPS; Figure
1). The TRI-REPS program is a substream of the CR program
modeled after the traditional CR program. A comparison group of 98
age- and sex-matched patients consecutively enrolled in the CR
program who had a documented history of CAD and no history of
stroke or transient ischemic attack were included. Patients in both
cardiac and stroke services attended 90-minute exercise classes once
per week for 6 months and were offered baseline and follow-up
(6-month) CPETs. To test our hypothesis, we calculated the propor-
tion of patients who achieved VO₂max, VAT, or a CRA that would

an aerobic to anaerobic metabolism, and is recommended
as an appropriate target intensity level for the prescription
of exercise. Achievement of maximal oxygen uptake
(VO₂max; ie, an individual’s maximal capacity to transport
and use oxygen) is another important measure used to
prescribe exercise intensity. Therefore, VO₂max, VAT, and
the level at which a clinically relevant abnormality (CRA)
occurs are all critical measures for prescribing an exercise
intensity that is both safe and effective. However, people who
have had a stroke may be limited by a constellation of motor
and neurological impairments that may prevent them from
reaching these critical levels. These issues may discourage
the systematic application of CPETs for individuals after stroke.

Accordingly, the objective of this study was to examine the
feasibility of the CPET for developing an exercise prescrip-
tion for patients with chronic stroke (≥3 months poststroke
with no upper limit) with motor impairments. We speculated
that most patients (>50%) would reach a level of exertion
that would provide information for exercise prescription with
no serious cardiovascular events (death, myocardial infarc-
tion, or sustained ventricular tachycardia).

Figure 1. Flow diagram. AT indicates aerobic training; RT, resis-
tance training.

![Diagram](http://stroke.ahajournals.org/)

**STROKE**

98 consecutively enrolled patients

People post-stroke referred to
cardiac rehabilitation (CR) program

**CORONARY ARTERY DISEASE**

98 consecutively enrolled age and
sex matched patients

Individuals with coronary artery
disease referred to CR program

**People with motor impairments**

- 1 CR visit/week for 6 months
- AT=5 times per week
- RT=2-3 times per week

**People with coronary artery**

disease participated in CR

- 1 CR visit/week for 6 months
- AT=5 times per week
- RT=2-3 times per week

13 patients (13.3%)
discontinued CR program

30 patients (30.6%)
discontinued CR program

6 Month Cardiopulmonary Exercise Test

This was a retrospective analysis of CPETs conducted at baseline
and after 6 months of exercise training in 98 consecutively enrolled
patients in Toronto Rehabilitation Institution’s Risk Factor Modifi-
cation and Exercise Program following Stroke (TRI-REPS; Figure
1). The TRI-REPS program is a substream of the CR program
modeled after the traditional CR program. A comparison group of 98
age- and sex-matched patients consecutively enrolled in the CR
program who had a documented history of CAD and no history of
stroke or transient ischemic attack were included. Patients in both
cardiac and stroke services attended 90-minute exercise classes once
per week for 6 months and were offered baseline and follow-up
(6-month) CPETs. To test our hypothesis, we calculated the propor-
tion of patients who achieved VO₂max, VAT, or a CRA that would

prohibit an exercise prescription beyond the intensity where it
occurred on the baseline and 6-month CPETs.

**Subjects**

To be admitted to the TRI-REPS program, patients had to be ≥3
months poststroke (no upper limit) with a stroke-related motor
impairment score <7 on the Chedoke-McMaster Stroke Assessment
scale of the arm, hand, leg, or foot (described subsequently). In
addition, patients had to be able to ambulate ≥10 meters independ-
ently with or without an assistive device with no significant
limitations due to pain and no contraindications to maximal exercise
testing such as a recent significant change in the resting ECG,
symptomatic severe aortic stenosis, uncontrolled resting severe
hypertension, or uncontrolled metabolic disease such as diabetes.
Higher functioning patients were integrated into the regular CR
program and were not included in the analysis. Patients in the CAD
cohort had a documented history of CAD (myocardial infarction,
angiographic evidence showing ≥50% stenosis in ≥1 major coro-
nary artery, percutaneous coronary intervention, or coronary artery
bypass graft surgery, and were referred ≥6 weeks since coronary
artery bypass graft surgery or myocardial infarction or ≥3 weeks
since percutaneous coronary intervention. The study was approved
by the institution’s Research Ethics Board.
over a 20-second period through a calibrated metabolic cart (SensorMedics Vmax Encore) with continuous monitoring of 12-lead ECG (Marquette Case 80), and blood pressure. Indications for discontinuing CPET were peak volitional effort (ie, if the patient was unable to maintain the required pedaling rate), the appearance of adverse clinical signs or symptoms as described elsewhere,15 or if the patient achieved VO2max (described subsequently). The expected VO2peak (mL/kg/min) was calculated from established age and sex norms19 for comparison of cardiopulmonary fitness across age and sex.

**Exercise Prescription and Progression**

Participants in both stroke and cardiac streams of the CR program attended once-weekly, 90-minute supervised sessions of aerobic and resistance training with the balance of exercise conducted offsite (4 additional aerobic training and 1–2 additional resistance training sessions). The staff-to-patient ratio of the TRI-REPS program was higher than the traditional cardiac program (1:5 versus 1:12, respectively). All exercise sessions were tracked by individual exercise diary. The mode of aerobic training and type of resistance training exercises were prescribed depending on individual ability. The aerobic training goal for both cohorts was to progress patients to 20 to 60 minutes of exercise1 5 times per week1,20 For patients with CAD, the aerobic training prescription was set at an intensity equivalent to 40% to 80% of VO2peak15 and/or the level at which the VAT occurred.12 Patients were given a target distance and duration to complete. Prescriptions were progressed every 2 weeks to a maximum of 6.4 km and then to a maximum intensity of 80% of VO2peak as tolerated. Initial exercise intensity for individuals after stroke considered a combination of the following: the heart rate achieved at the VAT; 40% to 70% of heart rate reserve; and the heart rate equivalent to 40% to 80% of VO2peak.3 Exercise diary information, heart rates measured at the center as well as communication with the patient assisted the case manager in deciding when to increase the intensity and/or duration of the aerobic training exercise.20 For both cohorts, the intensity of the initial prescription and subsequent exercise was adjusted to achieve a rating of perceived exertion of 11 to 16 (“light” to “hard”)15 on the Borg 6 to 20 scale.21

The CAD cohort was prescribed an resistance training routine of 10 exercises targeting the lower body (3 exercises), upper body (5 exercises), and the trunk (2 exercises) as described elsewhere.22 For the stroke cohort, the choice and number of resistance training exercises were based on the patients’ goals, gait pattern, grip strength, joint range of motion, presence or degree of hypertonicity, and balance. The exercises were task-specific, incorporating muscle actions that are performed during daily activities, emphasizing retraining of balance, coordination, body weight support, weight shifting, and incorporating multijoint movements. Resistance was

**Table 1. Baseline Characteristics**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>CAD (n=98)</th>
<th>Stroke (n=98)</th>
<th>Stroke-Men (n=68)</th>
<th>Stroke-Women (n=30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male, no. (%)</td>
<td>68 (69.4)</td>
<td>68 (69.4)</td>
<td>. . . . . .</td>
<td>. . . . . .</td>
</tr>
<tr>
<td>Age, y (range)</td>
<td>63.3±12 (38–88)</td>
<td>63.3±12 (38–88)</td>
<td>63.6±12.3 (41–88)</td>
<td>62.7±12 (38–82)</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>28.7±5.4</td>
<td>27.7±4.9</td>
<td>28.1±4.9</td>
<td>26.9±4.7</td>
</tr>
<tr>
<td>Waist circumference, cm</td>
<td>99.8±13.2</td>
<td>98.4±12.4</td>
<td>101.9±11.8</td>
<td>90.2±9.9†</td>
</tr>
<tr>
<td>CAD diagnosis, no. (%)</td>
<td>98 (100)</td>
<td>31 (31.6)†</td>
<td>22 (32.4)</td>
<td>9 (30.0)</td>
</tr>
<tr>
<td>PCI</td>
<td>47 (48)</td>
<td>7 (7.1)</td>
<td>4 (18.2)</td>
<td>3 (33.3)</td>
</tr>
<tr>
<td>CABG</td>
<td>28 (26.6)</td>
<td>6 (6.1)</td>
<td>5 (22.7)</td>
<td>1 (11.1)</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>10 (10.2)</td>
<td>13 (13.3)</td>
<td>9 (40.9)</td>
<td>4 (44.4)</td>
</tr>
<tr>
<td>Ischemic heart disease, no Intervention</td>
<td>13 (13.3)</td>
<td>5 (5.1)</td>
<td>4 (18.2)</td>
<td>1 (11.1)</td>
</tr>
<tr>
<td>Weeks from primary diagnosis to intake (range)</td>
<td>17.1±30.7 (4–300)</td>
<td>89.7±174† (12–1460)</td>
<td>94.9±201.6 (12–1460)</td>
<td>78.0±84 (12–364)</td>
</tr>
<tr>
<td>Diabetes diagnosis, no. (%)</td>
<td>31 (31.6)</td>
<td>26 (26.5)</td>
<td>16 (23.5)</td>
<td>10 (33.3)</td>
</tr>
<tr>
<td>Medical history, no. (%)</td>
<td>. . . . . .</td>
<td>. . . . . .</td>
<td>. . . . . .</td>
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</tr>
<tr>
<td>Hypertension</td>
<td>55 (57.9)</td>
<td>76 (78.4)*</td>
<td>50 (73.5)</td>
<td>26 (86.7)</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>9 (9.2)</td>
<td>21 (21.4)*</td>
<td>14 (20.6)</td>
<td>7 (23.3)</td>
</tr>
<tr>
<td>Hyperlipidemia</td>
<td>68 (73.1)</td>
<td>56 (58.3)*</td>
<td>41 (61.2)</td>
<td>15 (50)</td>
</tr>
<tr>
<td>Past/current smoker</td>
<td>53 (55.8)/6 (6.1)</td>
<td>40 (41.7)/4 (4.1)</td>
<td>29 (43.3)/2 (6.9)</td>
<td>11 (37.9)/2 (2.9)</td>
</tr>
<tr>
<td>Chronic obstructive lung disease</td>
<td>12 (12.6)</td>
<td>13 (13.4)</td>
<td>8 (11.8)</td>
<td>5 (17.2)</td>
</tr>
<tr>
<td>Thyroid disease</td>
<td>13 (13.7)</td>
<td>5 (5.2)*</td>
<td>2 (10.3)</td>
<td>3 (10.3)</td>
</tr>
<tr>
<td>Depression requiring medication</td>
<td>9 (9.4)</td>
<td>23 (24.5)*</td>
<td>18 (27.3)</td>
<td>5 (17.9)</td>
</tr>
<tr>
<td>No significant physical activity before event (&lt;30 min, 3×/wk), no. (%)</td>
<td>64 (66.7)</td>
<td>74 (78.7)*</td>
<td>56 (86.2)</td>
<td>18 (62.1)*</td>
</tr>
<tr>
<td>Medications, no. (%)</td>
<td>. . . . . .</td>
<td>. . . . . .</td>
<td>. . . . . .</td>
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</tr>
<tr>
<td>β-blockers</td>
<td>79 (80.6)</td>
<td>42 (42.9)*</td>
<td>29 (42.6)</td>
<td>13 (43.3)</td>
</tr>
<tr>
<td>Ca²⁺ -channel antagonists</td>
<td>14 (14.3)</td>
<td>27 (27.6)*</td>
<td>20 (29.4)</td>
<td>7 (23.3)</td>
</tr>
<tr>
<td>Other antihypertensives</td>
<td>81 (82.7)</td>
<td>69 (70.4)</td>
<td>46 (67.6)</td>
<td>23 (76.7)</td>
</tr>
<tr>
<td>Lipid-lowering agents</td>
<td>91 (92.9)</td>
<td>80 (81.6)*</td>
<td>55 (80.9)</td>
<td>25 (83.3)</td>
</tr>
<tr>
<td>No 6-month CPET, no. (%)</td>
<td>30 (30.6)</td>
<td>13 (13.3)†</td>
<td>6 (8.8)</td>
<td>7 (23.3)</td>
</tr>
</tbody>
</table>

Values are mean±SD unless otherwise indicated.
CAD indicates coronary artery disease; PCI, percutaneous coronary intervention; CABG, coronary artery bypass graft; CPET, cardiopulmonary exercise testing.
*P<0.05 and †P<0.001 between CAD and stroke or between women and men poststroke.
Table 2. Additional Characteristics of Patients After Stroke

<table>
<thead>
<tr>
<th>Variable</th>
<th>All Patients (N=98) No. (%) or Mean±SD (Range)</th>
<th>Men (n=68) No. (%) or Mean±SD (Range)</th>
<th>Women (n=30) No. (%) or Mean±SD (Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I/H/U stroke type</td>
<td>69 (70.4)/27 (27.6)/2 (2)</td>
<td>48 (70.6)/19 (27.9)/1 (1.5)</td>
<td>21 (70.0)/8 (26.7)/1 (3.3)</td>
</tr>
<tr>
<td>Left/right/bilateral hemisphere affected</td>
<td>54 (55.1)/41 (41.8)/3 (3.1)</td>
<td>37 (54.4)/30 (44.1)/1 (1.5)</td>
<td>17 (56.7)/11 (36.7)/2 (6.7)</td>
</tr>
<tr>
<td>Diabetes and/or CAD</td>
<td>50 (51)</td>
<td>32 (47.1)</td>
<td>18 (60)</td>
</tr>
<tr>
<td>Gait aids, N/C/R/WC</td>
<td>40 (41)/33 (34)/22 (23)/3 (3)</td>
<td>26 (38.2)/27 (39.7)/13 (19)/2 (3)</td>
<td>14 (46.7)/6 (20)/9 (30)/1 (3.3)</td>
</tr>
<tr>
<td>CMSA score</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm/foot</td>
<td>4.2±1.6 (1–7)/4.1±1.9 (1–7)</td>
<td>4.0±1.6 (1–7)/4.2±2.0 (1–7)</td>
<td>4.7±1.6 (2–7)/4.9±1.9 (1–7)</td>
</tr>
<tr>
<td>Leg/foot</td>
<td>5.0±1.1 (3–7)/4.2±1.6 (1–7)</td>
<td>4.8±1.1 (3–7)/3.8±1.5 (1–7)</td>
<td>5.5±0.9 (4–7)/4.9±1.6 (2–7)*</td>
</tr>
<tr>
<td>Six-min walk distance, meters</td>
<td>271.6±139 (17–590)</td>
<td>256.1±139 (17–576)</td>
<td>310±137.9 (67–590)</td>
</tr>
<tr>
<td>Percent of age, height, weight, sex-predicted norm</td>
<td>52±26.8 (3–119)</td>
<td>48.7±25.8 (3–117)</td>
<td>59.9±28.2 (17–119)</td>
</tr>
<tr>
<td>Type of exercise prescribed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W+W+C</td>
<td>43 (43.8)/34 (34.7)</td>
<td>30 (44.1)/26 (38.2)</td>
<td>13 (43.3)/9 (30)</td>
</tr>
<tr>
<td>C/W+E or S</td>
<td>9 (9.2)/5 (5)</td>
<td>7 (10.3)/2 (2.9)</td>
<td>2 (6.7)/2 (6.7)</td>
</tr>
</tbody>
</table>

1 indicates ischemic; H, hemorrhagic; U, unknown; CAD, coronary artery disease; N, none; C, cane; R, rollator; WC, wheelchair; CMSA, Chedoke-McMaster Stroke Assessment; W, walk only; W+E or S, walk and either elliptical or swim combination.

*P<0.05 between women and men.

**Critical Criteria for Determination of CPET for Exercise Prescription**

To determine if the CPET provided adequate information to develop an effective exercise prescription, at least 1 of the 3 following intensity levels had to be attained on the CPET: (1) Maximal oxygen uptake, that is, VO2max; (2) VAT; and (3) a CRA that would prohibit an exercise prescription beyond the intensity where it occurred (see subsequently). VO2max and VAT were determined by 2 independent assessors experienced in threshold analysis blinded to either the objectives of the study or patient diagnoses. Disagreements were resolved by consensus.

The first criterion, VO2max, was determined based on attainment of ≥1 of the following: (1) an oxygen uptake plateau at the end of the CPET defined as an increase of <2.1 mL·kg⁻¹·min⁻¹ of oxygen for ≥60 seconds despite an increase in work rate concomitant with a respiratory exchange ratio of ≥1.15; or (2) an respiratory exchange ratio of ≥1.15 concomitant with a peak heart rate within 10 beats/min of age-predicted maximum defined by the formula 220-age (years)²⁰ or using the validated equation (HRmax = 164 – 0.7×age)²¹ for patients taking β-blockade medication. The second criterion, the VAT, was determined by a combination of the V-slope method and the ventilatory equivalents methods.²⁸²⁹ The V-slope method was defined as the point of departure from linearity of carbon dioxide output plotted against oxygen uptake. The ventilatory equivalent method was defined as the level corresponding to the rise in ventilatory equivalent of oxygen that occurs without a concurrent rise in the ventilatory equivalent of carbon dioxide. The VAT is considered a valid measure demonstrating high reproducibility and low interobserver variability when established standards are followed.³⁰³¹

Finally, CRA criteria were defined as abnormalities that would prohibit exercise beyond the intensity where it occurred, indicating increased risk of an acute cardiac event or elevated mortality risk. These included the appearance of horizontal or downsloping ST-segment depression of ≥0.10 mV (1 mm) 80 ms past the J point on the ECG, angina pectoris or chest pain developed with exertion, or complex or high-grade ventricular arrhythmia (frequent multiform ventricular premature beats (≥3 in 10 beats), runs of ventricular tachycardia (≥3 consecutive ventricular premature beats), or exercise-induced bundle branch block. Patients in both cohorts who had a CRA on the CPET underwent an ECG telemetry with blood pressure monitoring during the first exercise session (walking on a 200-meter track or stationary cycling) to establish a safe exercise intensity (ie, below the level where the CRA occurred). Modifications to the exercise program to reduce risk of a CRA during exercise such as including a longer cardiovascular warm-up, taking nitroglycerin before exercise, and exercising close to the time of peak effect of β-blockade medication was prescribed.

**Results**

The proportion of CPETs that provided information sufficient to prescribe exercise intensity (ie, VO2max, VAT, or a CRA) for the stroke and CAD groups was 68.4% versus 82.7%, respectively (P=0.02) at baseline and 84.7% versus 83.8% respectively (P=0.9) at 6 months (Table 3; Figure 2).

A CRA was observed in 11.2% and 12.2% of baseline CPETs conducted in patients with stroke and CAD, respectively (P=0.8). This included 7 of 67 patients poststroke (10.5%) with no documented history of CAD and 4 of 31 patients poststroke (12.9%) with a documented history of CAD. A CRA occurred at 6 months in 10.6% (n=9) of patients with stroke and 5.9% (n=4) of (P=0.4) patients with CAD. Of individuals poststroke with no history of CAD, 10.5% with no documented history of CAD and 4 of 31 (12.9%) with a documented history of CAD, respectively (P=0.8). This included 7 of 67 patients poststroke (10.5%) with no documented history of CAD and 4 of 31 patients poststroke (12.9%) with a documented history of CAD. A CRA occurred at 6 months in 10.6% (n=9) of patients with stroke and 5.9% (n=4) of (P=0.4) patients with CAD. Of individuals poststroke with no history of CAD, 10.5% (n=9) had a CRA at 6 months, there was no significant difference (P=0.3).
greater proportion of persons with stroke versus CAD discontinued the CPET owing to noncardiovascular reasons at baseline \( (P=0.007) \) with no significant difference at 6 months between groups \( (P=0.9; \) Supplemental Table II). No serious cardiovascular events occurred during 183 CPETs conducted in persons after stroke and in 166 persons with CAD.

**Sex Differences**

Women poststroke were significantly less likely than men poststroke \( (40\% \text{ versus } 80.9\%, \text{ respectively, } P<0.001) \) and less likely than women with CAD \( (80\%, P=0.002) \) to reach \( \geq 1 \) of the critical levels used for determining exercise prescription \( (Figure\ 3) \). There was no significant sex difference in proportion of CRAs on the baseline CPET or any further sex differences in proportion reaching \( V_{O_2}^{max}, \) VAT, or a CRA on the 6-month CPET.

Baseline sex differences for patients after stroke are presented in Tables 1 and 2. Women entered CR at a higher stage of motor recovery than men of the leg and foot \( (P=0.006) \). Women reached a significantly lower baseline peak \( V_{O_2}^{peak}, \) than men after stroke \( (52.1\% \pm 20.8\% \text{ versus } 67.9\% \pm 26.3\% \text{ of age- and sex-} \) predicted normative values, \( P=0.005 \) \) and compared with women after CAD \( (72.6\% \pm 16.7\%, P<0.001) \). Women after stroke were significantly more likely to discontinue the baseline CPET owing to noncardiovascular reasons than men \( (33\% \text{ versus } 11.8\%, P=0.01) \) including discomfort with the equipment \( (n=6), \) weakness in 1 leg \( (n=3), \) and leg pain \( (n=1). \) At 6 months, there were no significant differences in \( V_{O_2}^{peak} \) between women and men poststroke \( (68.6\% \pm 20.1\% \text{ versus } 78.3\% \pm 29.7\% \text{ of age- and sex-} \) predicted normative values, \( P=0.2) \) but differences in noncardiovascular reasons for discontinuing the CPET remained \( (16.7\% \text{ versus } 3.2\% \text{ of women and men, respectively, } P=0.047). \)

**Discussion**

We have demonstrated herein that most patients after stroke achieve exercise intensities sufficient to inform the exercise prescription on both baseline and 6-month CPETs. In addition, no serious cardiovascular events occurred during graded exercise to peak effort. However, although most women after stroke were able to reach a suitable intensity for exercise

---

**Table 3. Data Informing the Exercise Prescription**

<table>
<thead>
<tr>
<th>Data Informing Exercise Prescription</th>
<th>Baseline CAD ( (N=98) )</th>
<th>Stroke ( (N=98) )</th>
<th>6 Months CAD ( (N=68) )</th>
<th>Stroke ( (N=85) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \geq 1 ) of VAT, ( V_{O_2}^{max} ) or CRA, no. (%)</td>
<td>81 (82.7)</td>
<td>67 (68.4)*</td>
<td>57 (83.8)</td>
<td>72 (84.7)</td>
</tr>
<tr>
<td>VAT discernible, no. (%)</td>
<td>79 (80.6)</td>
<td>66 (67.3)*</td>
<td>56 (82.4)</td>
<td>71 (83.5)</td>
</tr>
<tr>
<td>( V_{O_2}^{max} ) achieved, no. (%)</td>
<td>36 (36.7)</td>
<td>18 (18.4)*</td>
<td>27 (39.7)</td>
<td>28 (32.9)</td>
</tr>
<tr>
<td>Clinically relevant abnormality, no. (%)</td>
<td>12 (12.2)</td>
<td>11 (11.2)</td>
<td>4 (5.9)</td>
<td>9 (10.6)</td>
</tr>
<tr>
<td>( \geq 1 ) mm (horizontal/downsloping ST-segment depression)</td>
<td>2 (2)</td>
<td>4 (4)</td>
<td>0 (0)</td>
<td>5 (5.9)</td>
</tr>
<tr>
<td>Complex ventricular premature beats</td>
<td>4 (4.1)</td>
<td>6 (6.1)</td>
<td>2 (2.9)</td>
<td>5 (5.9)</td>
</tr>
<tr>
<td>Frequent multiformal/ventricular tachycardia, no.</td>
<td>3/1</td>
<td>4/2</td>
<td>2/0</td>
<td>2/3</td>
</tr>
<tr>
<td>Chest discomfort</td>
<td>2 (2)</td>
<td>0 (0)</td>
<td>2 (2.9)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Chest discomfort and significant ST-segment depression</td>
<td>2 (2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Conduction abnormality or arrhythmia developing during exercise/recovery</td>
<td>2 (2)</td>
<td>1 (1)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

CAD indicates coronary artery disease; VAT, ventilatory anaerobic threshold; \( V_{O_2}^{max} \), maximal oxygen uptake; CRA, clinically relevant abnormality. *\( P<0.05 \) and †\( P<0.001 \) between CAD and stroke.

---

**Figure 2. A-B.** Proportion of cardiopulmonary exercise tests conducted at baseline (A) and 6 months (B) providing information sufficient to prescribe exercise intensity. *\( P<0.05; \) †\( P<0.001. \)
prescription on the 6-month CPET, less than half of the baseline CPETs were of adequate intensity for exercise prescription determination. Indeed, women after stroke were more disadvantaged than both men poststroke and women post-CAD regarding baseline CPET use. Age, type of stroke, time from stroke, stage of motor recovery, gait aid requirement, modality of testing, or frequency of CRAs did not explain the mitigated use when compared with men post-stroke. Rather, reduced baseline CPET use may, in part, be explained by the marked deconditioning in women after stroke at entry to CR. VO$_{2\max}$ was half of normative values and significantly lower compared with men after stroke and women with CAD. This may have accounted for women’s reduced ability to reach VO$_{2\max}$ or VAT because more highly conditioned patients are more likely to attain maximal levels on a CPET$^{32}$ and VAT is increasingly more likely to be determined in patients who attain a higher VO$_{2\max}$. Although there is a paucity of data on sex differences in functional outcomes poststroke, data from the Framingham Heart Study show that prestroke and poststroke disability and rates of institutionalization are significantly higher in women than men.$^{33}$ Although motor recovery stage was higher for women than men in the present study, there may be functional differences that were not reflected by the Chedoke-McMaster Stroke Assessment scale score and not measured in this study, which may have also accounted for the poorer baseline performance in women. The finding that there was a preponderance of noncardiovascular barriers that more frequently prevented women in reaching peak effort than men, including weakness and discomfort in 1 leg and intolerance of the exercise testing equipment, may be a reflection of greater disability.

Nevertheless, after 6 months of exercise training, use of the CPET for women poststroke was similar to men poststroke and equal to women with CAD. In view of the superior CR completion rate of stroke compared with patients with CAD, it is unlikely that this improvement can be explained by selective dropout. Rather, improved CPET use from baseline may be due, in part, to gains in cardiovascular fitness on the 6-month test that placed women at a similar cardiovascular fitness level (age and sex normative values) to both men after stroke and to women with CAD. Survivors of stroke have a physiological disadvantage compared with individuals after CAD because they exhibit muscle atrophy in the hemiparetic limb$^{34}$ contributing to quadriceps muscle weakness.$^{35}$ Although sex differences in vascular and muscle morphology poststroke have not been fully elucidated, a program of aerobic and resistance training may have mitigated these affects allowing women to reach a higher intensity on the 6-month CPET. Indeed, greater leg strength has been shown to be associated with a higher VO$_{2\max}$ in patients with CAD.$^{23}$

The improved cardiovascular fitness and ability of women to reach higher absolute intensity levels on the CPET after a program of resistance and aerobic training is of clinical significance given the disability and institutionalization rates in women poststroke.$^{33}$ Combined with greater life expectancy and later onset of stroke in women compared with men$^{35,36}$ indicates the growing importance of developing strategies to improve the feasibility of the initial CPET to inform exercise programming for women. In the interim, a CPET conducted midprogram (ie, 3 months from start) may provide valuable information for prescribing exercise.

CPETs may involve risks for patients after stroke in view of the high incidence of CAD and associated risk factors. However, no serious cardiovascular events occurred during 183 graded exercise tests to peak effort. Nevertheless, >1 in 10 patients after stroke demonstrated a significant abnormality that would prohibit exercise beyond the intensity where it occurred on both baseline and follow-up CPETs. In addition, these abnormalities occurred equally in those with and without a comorbid history of CAD. Moreover, the rate of clinically relevant abnormalities was equal to that of patients in the CAD cohort at both time points despite reaching a significantly lower CPET intensity (35% versus 73% of age- and sex-predicted maximal heart rate, respectively). Thus, it is possible that the rate of abnormality is underrepresented in the stroke cohort in this study. Other studies using coronary angiography or thallium scintigraphy suggest a higher rate of abnormality in patients after stroke.$^{37,38}$

### Limitations
CR programs offer multiple CPET modality options as well as the experience and training to assess and manage patients with multiple comorbidities that may not exist in other facilities. Therefore, findings in this study may not be generalizable to all facilities or to all individuals poststroke referred to an exercise program, including those early in stroke recovery. Although the VAT has been reported to be modality-specific, almost half of patients with stroke were prescribed a stationary cycle program either alone or in combination with a walking program. Finally, angiographic or perfusion imaging in patients with stroke who exhibited abnormalities on the CPET is lacking.

### Conclusions
The results of this study support the feasibility and use of systematically conducting CPETs for those with chronic stroke both with and without CAD comorbidity before...
engaging in exercise. Prescription methods without this information may risk an exercise intensity that does not provide adequate cardiovascular stress to induce a training response or may precipitate a cardiovascular issue. At least 1 in 10 individuals poststroke manifested a clinically relevant abnormality on stress testing that would require exercise modification; however, there were no serious cardiovascular events during CPET or CR. With appropriate adaptation of exercise test protocols, most patients can achieve adequate exercise levels and cardiac safety issues can be identified. In view of the mitigated use of the baseline CPET for prescribing exercise to women after stroke, strategies to identify and remove barriers that limit women in reaching these critical intensities require further investigation.

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We acknowledge the contribution of Dr D.J. Mertens, Rene Belliard, Walter Swardfager, and patients and staff at Toronto Rehab.

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Disclosures
None.

References
The Feasibility of Cardiopulmonary Exercise Testing for Prescribing Exercise to People After Stroke

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The Feasibility of Cardiopulmonary Exercise Testing for Prescribing Exercise to People following Stroke
### S1. Cardiopulmonary Exercise Test Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>6 Months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CAD</td>
<td>Stroke</td>
</tr>
<tr>
<td>N=98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mode of Testing, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upright/Recumbent Cycle</td>
<td>77(78.6)/3(3.1)</td>
<td>43(43.9)/49(50)</td>
</tr>
<tr>
<td>Treadmill</td>
<td>18(18.4)</td>
<td>6(6.1)</td>
</tr>
<tr>
<td>VO₂peak, mL·kg⁻¹·min⁻¹</td>
<td>19.3±6.3</td>
<td>15.1±4.6†</td>
</tr>
<tr>
<td>VO₂peak, % Age and Gender Predicted Norms</td>
<td>79.2±22.4</td>
<td>63.1±25.7†</td>
</tr>
<tr>
<td>VAT, mL·kg⁻¹·min⁻¹</td>
<td>15.9±4.6</td>
<td>13.2±3.5†</td>
</tr>
<tr>
<td>VAT, % of VO₂peak</td>
<td>77.8±9.7</td>
<td>79.1±9.6</td>
</tr>
<tr>
<td>Peak Respiratory Exchange Ratio</td>
<td>1.14±0.11</td>
<td>1.08±0.14*</td>
</tr>
<tr>
<td>% Predicted Max HR Achieved on CPET</td>
<td>94.0±16</td>
<td>79.7±15.8†</td>
</tr>
<tr>
<td>≥85% Predicted Maximal Heart Rate, n (%)</td>
<td>72(73.5)</td>
<td>36(36.7)†</td>
</tr>
<tr>
<td>Symptoms Reported During CPET</td>
<td>15(15.3)</td>
<td>6(6.1)</td>
</tr>
<tr>
<td>Dyspnea, n (%)</td>
<td>10(10.2)</td>
<td>4(4.1)</td>
</tr>
<tr>
<td>Chest Discomfort, n (%)</td>
<td>4(4.1)</td>
<td>0(0)</td>
</tr>
<tr>
<td>Dizziness, n (%)</td>
<td>1(1)</td>
<td>2(2)</td>
</tr>
<tr>
<td>Left Ventricular Hypertrophy Cornell Criteria, n (%)</td>
<td>3(3.1)</td>
<td>12(12.2)*</td>
</tr>
</tbody>
</table>

Values are mean±SD unless otherwise indicated.

CAD=coronary artery disease, VO₂peak=peak oxygen uptake, VAT=ventilatory anaerobic threshold

*p=<0.05 and †p=<0.001 between CAD and Stroke.
### S 2. Indications for Discontinuing the CPET (DATA SUPPLEMENT)

<table>
<thead>
<tr>
<th>Reasons for Discontinuing CPET</th>
<th>Baseline</th>
<th></th>
<th>6 Months</th>
<th></th>
<th>6 Months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CAD N=98</td>
<td>Stroke N=98</td>
<td>CAD N=68</td>
<td>Stroke N=85</td>
<td></td>
</tr>
<tr>
<td>Maximal oxygen uptake achieved, n (%)</td>
<td>36(36.7)</td>
<td>18(18.4)*</td>
<td>27(39.7)</td>
<td>28(32.9)</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular indications, n (%)</td>
<td>15(15.3)</td>
<td>11(11.2)</td>
<td>5(7.4)</td>
<td>8(9.0)</td>
<td></td>
</tr>
<tr>
<td>Dyspnea</td>
<td>8(8.2)</td>
<td>4(4.1)</td>
<td>2(3)</td>
<td>4(4.5)</td>
<td></td>
</tr>
<tr>
<td>Ventricular ectopy</td>
<td>1(1)</td>
<td>1(1)</td>
<td>0(0)</td>
<td>2(2.2)</td>
<td></td>
</tr>
<tr>
<td>Chest discomfort</td>
<td>2(2)</td>
<td>0(0)</td>
<td>1(1.5)</td>
<td>0(0)</td>
<td></td>
</tr>
<tr>
<td>Blood pressure</td>
<td>2(2)</td>
<td>4(4.1)</td>
<td>1(1.5)</td>
<td>1(1.1)</td>
<td></td>
</tr>
<tr>
<td>ST-segment depression</td>
<td>1(1)</td>
<td>1(1)</td>
<td>1(1.5)</td>
<td>1(1.1)</td>
<td></td>
</tr>
<tr>
<td>ST-segment depression, chest pain, dyspnea</td>
<td>1(1)</td>
<td>0(0)</td>
<td>0(0)</td>
<td>0(0)</td>
<td></td>
</tr>
<tr>
<td>Excessive increase in heart rate</td>
<td>0(0)</td>
<td>1(1)</td>
<td>0(0)</td>
<td>0(0)</td>
<td></td>
</tr>
<tr>
<td>Volitional fatigue, n (%)</td>
<td>41(41.8)</td>
<td>47(48)</td>
<td>31(44.3)</td>
<td>47(52.8)</td>
<td></td>
</tr>
<tr>
<td>Non cardiovascular reasons, n (%)</td>
<td>6(6.1)</td>
<td>18(18.4)*</td>
<td>5(7.1)</td>
<td>7(7.9)</td>
<td></td>
</tr>
<tr>
<td>Weakness in one leg</td>
<td>1(1)</td>
<td>7(7.1)</td>
<td>0(0)</td>
<td>2(2.2)</td>
<td></td>
</tr>
<tr>
<td>Leg pain</td>
<td>2(2)</td>
<td>2(2)</td>
<td>3(4.4)</td>
<td>0(0)</td>
<td></td>
</tr>
<tr>
<td>Discomfort due to equipment (seat/mouth piece)</td>
<td>3(3.1)</td>
<td>9(9.2)</td>
<td>2(2.9)</td>
<td>2(2.2)</td>
<td></td>
</tr>
<tr>
<td>Unknown, n (%)</td>
<td>0(0)</td>
<td>4(4.1)</td>
<td>0(0)</td>
<td>1(1.1)</td>
<td></td>
</tr>
</tbody>
</table>

**CAD=coronary artery disease**

**Blood pressure=SBP >250 or ≥220 mmHg for diabetes or DBP >115 or ≥110 mmHg for diabetes or failure to ↑ with an increase in work rate**

*p<0.05 between CAD and Stroke*