Relationship Between Ambulatory Capacity and Cardiorespiratory Fitness in Chronic Stroke*

Influence of Stroke-Specific Impairments

Marco Y. C. Pang, PhD; Janice J. Eng, PhD; and Andrew S. Dawson, MD

Study objectives: To identify the following in individuals with chronic stroke: (1) the relationship between the maximal oxygen consumption ($V\dot{O}_2\text{max}$) during cycle ergometry and the distance covered in the 6-min walk test (6MWT), and (2) the stroke-specific impairments that are important determinants for the 6MWT distance.

Design: Cross-sectional study using a convenience sample.

Setting: Exercise testing laboratory in a tertiary rehabilitation center.

Participants: Sixty-three older adults (mean age ± SD, 65.3 ± 8.7 years) with an average poststroke interval of 5.5 ± 4.9 years.

Intervention: Not applicable.

Main outcome measures: Each subject underwent a maximal cycle ergometer test and a 6MWT. Oxygen consumption ($V\dot{O}_2$) was measured during both tests. Subjects were also evaluated for Berg balance scale, modified Ashworth scale of spasticity, isometric knee extension strength, and percentage of body fat.

Results: The 6MWT distance had a low correlation with the $V\dot{O}_2\text{max}$ ($r = 0.402$). Balance, knee extension strength, and spasticity were all significant determinants for the 6MWT distance, with balance being the major contributor for the 6MWT distance, accounting for 66.5% of its variance.

Conclusions: Factors other than the cardiorespiratory status considerably influenced the ambulatory capacity as measured by the 6MWT. The 6MWT distance alone should not be used to indicate cardiorespiratory fitness in individuals with chronic stroke.

Key words: cerebrovascular accident; exercise test; rehabilitation

Abbreviations: AHASFC = American Heart Association Stroke Functional Classification; APHRM = age-predicted heart rate maximum; BBS = Berg balance scale; HR = heart rate; PBF = percentage of body fat; RPE = rate of perceived exertion; RPP = rate pressure product; $V\dot{O}_2$ = oxygen consumption; $V\dot{O}_2\text{max} =$ maximal oxygen consumption; 6MWT = 6-min walk test

A large proportion of individuals with stroke have residual physical impairments that may lead to a sedentary lifestyle and consequently a decline in cardiorespiratory fitness. Poor cardiorespiratory fitness has been related to a higher risk of stroke and stroke mortality. Moreover, up to 75% of persons with stroke have some form of cardiovascular disease. For these reasons, cardiorespiratory fitness should be an important domain in the assessment and treatment planning of persons with stroke.

Measurement of maximal oxygen consumption ($V\dot{O}_2\text{max}$) during the maximal exercise test is considered to be the “gold standard” for evaluating cardiorespiratory fitness. However, there are drawbacks in using the standard maximal exercise test. First, some individuals may not tolerate the maximal exercise test.

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test due to problems such as limb pain, arthritis, or muscle soreness. Second, measuring oxygen consumption \( \left( V\dot{O}_2 \right) \) requires expensive and sophisticated equipment that is not available in most stroke rehabilitation and community settings. Third, the test is time-consuming and requires personnel skilled in monitoring and knowledgeable in data interpretation.

Considering the difficulties of conducting a maximal exercise test, it would be beneficial to use an easy-to-administer submaximal exercise test that would enable clinicians to monitor cardiorespiratory fitness in persons with stroke. The 6-min walk test (6MWT) was originally developed for the cardiorespiratory population, and is an easy-to-administer submaximal measure commonly employed to determine walking endurance in individuals with decreased function. Although the 6MWT should not be considered as a replacement of formal cardiorespiratory testing, the distance covered in the 6MWT has been shown to have moderate-to-high correlation with \( V\dot{O}_2 \text{max} \) in individuals with cardiorespiratory disease and women with obesity. The 6MWT distance may serve as a useful indicator for cardiorespiratory fitness in patients with stroke.

Only one small pilot study (12 subjects) examined the relationship between the cycle ergometry \( V\dot{O}_2 \text{max} \) and the 6MWT distance in chronic stroke and found no significant correlation between the two parameters. Moreover, the degree of different stroke-specific impairments (i.e., strength, balance, spasticity) and changes in body composition affect the performance in the 6MWT has not been investigated. In this study, we assessed 63 individuals with chronic stroke to achieve the following purposes: (1) to determine whether the 6MWT distance is a good indicator for cardiorespiratory fitness, and (2) to identify the stroke-specific impairments that are important factors for influencing the 6MWT distance.

### Methods and Materials

#### Sample Size Calculation

The G Power computer program was used to calculate the sample size required for bivariate correlations and multiple regression analyses. For bivariate correlations with a medium effect size of 0.35 at an \( \alpha \) level of 0.05 and a power of 0.80, a minimum of 59 subjects are required. For multiple regression analyses, if up to six variables are modeled at an effect size of 0.25 (large) at an \( \alpha \) level of 0.05 and power of 0.80, a minimum of 62 subjects are required.

### Subjects

All potential subjects were first screened by a telephone interview and had to fulfill the following inclusion criteria: (1) had only a single stroke, (2) were \( \geq 1 \) year after stroke, (3) were independent in ambulation with or without a walking aid, and (4) were \( \geq 50 \) years old. Potential subjects were excluded if they had the following: (1) unstable cardiac disease, (2) significant musculoskeletal conditions (i.e., amputations), and (3) other neurologic conditions in addition to stroke. Eligible subjects then gave informed, written consent to participate in the study. In addition, the primary care physician provided information regarding any contraindications to participation in the study. The study was approved by the local university and hospital ethics committees.

The experiments were conducted in accordance to the Helsinki Declaration.

Potential subjects were then brought into the laboratory, and their ability to pedal the cycle ergometer was assessed. In addition, the Folstein Mini Mental Status Examination was administered to assess cognitive function. Subjects were accepted into the study if they were able to pedal at 60 revolutions per minute and obtain a Mini Mental Status Examination score \( \geq 22 \). Each subject was classified according to the functional classification score of the American Heart Association Stroke Functional Classification (AHA/SFC), which measures residual impairment and disability of stroke in the areas of basic activities of daily living and instrumental activities of daily living, where level I indicates independence and level V indicates complete dependence.

### Protocol

For both the 6MWT and cycle ergometer test, subjects wore a face mask. \( V\dot{O}_2 \) was continuously measured using a portable metabolic unit that performed breath-by-breath gas analysis (Cosmed K4 b2 system; CosMED; Rome, Italy). The level of perceived exertion was monitored by the 16-point Borg rating of perceived exertion (RPE) scale. BP was measured at rest and also at the end of the test.

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Medicine were used to determine when the test should be terminated prematurely (e.g., increasing neurologic symptoms, sustained ventricular tachycardia, angina, signs of poor perfusion, ST-segment depression > 2 mm).5

Secondary Outcome Measures

Balance: The Berg balance scale (BBS) was used to assess functional balance.30,31 It consists of 14 functional tasks done in sitting and standing positions and yields a maximum score of 56. A higher score indicates better balance skills. The BBS is a reliable and valid measure of balance for individuals with stroke.30,31

Leg Strength: A hand-held dynamometer (Nicholas MMT; Lafayette Instruments; Lafayette, IN) was used to evaluate isometric knee extension strength. Hand-held dynamometry has been shown to be a reliable method to measure leg muscle strength in stroke.32 The test was performed with the subjects sitting upright in a chair with back support. The knee was placed in 90° flexion, and subjects performed a maximal isometric contraction of knee extension. Three trials were performed on each side and force data (Newtons) were averaged and normalized to body mass (kilograms).

Spasticity: The modified Ashworth scale of spasticity was used to evaluate resistance to passive movements in the paretic leg and foot (0 = no increase in muscle tone, to 4 = affected part rigid in flexion and extension).33 The scores for the leg and foot were averaged.

Percentage of Body Fat: Each subject underwent a total body scan using dual-energy radiograph absorptionmetry (Hologic 2400; Hologic, Waltham, MA). The fat mass (kilograms) and lean mass (kilograms) were determined. The percentage of body fat (PBF) of the whole body was calculated (100% × [fat mass/lean mass]). The fat mass and lean mass of the paretic and nonparetic legs were also determined by the region of interest program.

Univariate Analysis: Pearson moment correlations were used to quantify the relationship between the 6MWT distance and the following variables, which were normally distributed (Kolmogorov-Smirnov test of normality): (1) VO₂ max, (2) rate pressure product (RPP, the product of HR and systolic BP, an indicator for myocardial exertion) at the end of the cycle ergometer test, (3) age, (4) knee extension strength of the paretic leg, (5) knee extension strength of the nonparetic leg, and (6) PBF. A point-biserial correlation coefficient was performed to quantify the relationship between the 6MWT distance and gender (a dichotomous variable). Spearman ρ correlations were done to determine whether 6MWT distance was correlated with the following: (1) RPE at the end of the cycle ergometer test, (2) years since stroke, (3) BBS, and (4) spasticity, because the data for these variables were not normally distributed. The strength of the correlation was defined by the correlation coefficient obtained: low, 0.26 to 0.49; moderate, 0.50 to 0.69; high, 0.70 to 0.89; and very high, 0.90 to 1.0.34

Regression Analysis: Those variables that were significantly correlated with the 6MWT distance in the univariate analysis were then entered into the stepwise multiple regression analysis to determine the predictors for the 6MWT distance. A predictor was entered into the model at p ≤ 0.05 and was removed at p > 0.1. Statistical analyses were performed using statistical software (SPSS version 11.5; SPSS; Chicago, IL) using a significance level of 0.05 (two-tailed).

RESULTS

Subject Characteristics

Sixty-three community-dwelling individuals with chronic stroke participated in the study (Table 1). Twenty subjects used a walking aid (wheeled walker, n = 5; crutch, n = 1; quad cane, n = 4; cane, n = 10) and 9 subjects used an ankle-foot orthosis during the 6MWT. Forty-eight subjects were receiving medications for hypertension; 7 of these subjects were receiving β-blockers.

6MWT and Maximal Cycle Ergometer Test

The results for the 6MWT and maximal cycle ergometer test are described in Table 2. There was no significant difference in 6MWT distance between male and female subjects (independent t tests,
6MWT Distance Is Not a Good Indicator for Cardiorespiratory Fitness in Chronic Stroke

The 6MWT distance has been shown to have a moderate or high correlation with \( \dot{V}O_2 \text{max} \), the criterion measure of cardiorespiratory fitness, in patients with various cardiorespiratory conditions \((r = 0.59 to 0.88)\). Moreover, \( \dot{V}O_2 \text{max} \) has been identified as an important determinant for the 6MWT distance and vice versa in these individuals. Based on previous studies, one could think that the 6MWT distance may also serve as a useful tool to indicate the cardiorespiratory fitness in chronic stroke.

In contrast to the cardiorespiratory populations, our results show that the relationship between \( \dot{V}O_2 \text{max} \) and 6MWT distance is limited \((r = 0.402)\). \( \dot{V}O_2 \text{max} \) is not a significant determinant of 6MWT distance. Therefore, while the 6MWT provides useful information about ambulatory ability in individuals with chronic stroke, the 6MWT distance alone does not serve as a good indicator for cardiorespiratory fitness in this population.

### Influence of Stroke-Specific Impairments

The low correlation between the 6MWT distance and \( \dot{V}O_2 \text{max} \) may be explained by the presence of stroke-specific impairments. These factors limited the ambulatory endurance and took precedence over the effects of the reduced cardiorespiratory fitness on ambulatory capacity in the chronic stroke population.

Multiple regression analysis revealed that balance is by far the most important predictor for 6MWT distance.

### Discussion

**Cardiorespiratory Fitness in Chronic Stroke Is Well Below Healthy Values**

Our results show that cardiovascular fitness in chronic stroke is considerably compromised. The mean \( \dot{V}O_2 \text{max} \) obtained in our study is approximately 25% (men) and 20% (women) less than the age-matched, healthy population (ie, around the tenth percentile)\(^5,35\). The results are particularly alarming in that poor cardiorespiratory fitness is prevalent despite that all of our subjects are independent ambulators and 68% of them are independent in all basic activities of daily living (level I/II according to AHASFC; Table 1)\(^24\).

### Secondary Outcome Measures

The mean knee extension strength of the paretic leg was 74.9% of the nonparetic leg. The PBF for men \((27.360 \pm 5.821\%)\) was significantly less than that for women \((38.028 \pm 5.180\%)\) [independent \(t\) tests, \(p < 0.001\)]. The lean mass of the paretic leg was significantly less than that of the nonparetic leg (paired \(t\) tests, \(p < 0.001\)), whereas the fat mass of the paretic leg was significantly greater than that of the nonparetic leg (paired \(t\) tests, \(p = 0.001\)) [Table 1].

### Determinants for 6MWT Distance

The correlations between 6MWT distance and other variables are shown in Table 3. The \( \dot{V}O_2 \text{max} \) only had a low correlation with 6MWT distance \((r = 0.402)\). In addition, it also had low correlation with HR \((r = 0.273, p < 0.05)\) and RPP \((r = 0.174, p > 0.05)\) at the end of the 6MWT. Multiple regression analysis (Table 4) revealed that BBS alone accounted for 66.5% of the variance in the 6MWT distance. Adding knee extension strength of the paretic leg and spasticity explained an additional 51.8% of the variance in the 6MWT distance. Therefore, while the 6MWT provides useful information about ambulatory ability in individuals with chronic stroke, the 6MWT distance alone does not serve as a good indicator for cardiorespiratory fitness in this population.

### Table 2—6MWT and Maximal Cycle Ergometer Test

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>6MWT</td>
<td></td>
</tr>
<tr>
<td>( \dot{V}O_2 ) during last 30s, mL/kg/min</td>
<td>14.7 ± 3.3</td>
</tr>
<tr>
<td>HR at end of test, beats/min</td>
<td>100.6 ± 14.2</td>
</tr>
<tr>
<td>APHRM at end of test, %</td>
<td>65.1 ± 8.9</td>
</tr>
<tr>
<td>RPP at end of test ((HR \times SBP \times 10^{-2}))</td>
<td>150.8 ± 35.1</td>
</tr>
<tr>
<td>Absolute distance, m</td>
<td>316.3 ± 133.7</td>
</tr>
<tr>
<td>Distance (normalized by leg length), m</td>
<td>370.2 ± 150.6</td>
</tr>
<tr>
<td>RPE, median</td>
<td>12</td>
</tr>
<tr>
<td>Maximal cycle ergometer test</td>
<td></td>
</tr>
<tr>
<td>( \dot{V}O_2 )max, mL/kg/min</td>
<td>22.0 ± 4.8</td>
</tr>
<tr>
<td>Men (n = 36)</td>
<td>23.5 ± 4.0</td>
</tr>
<tr>
<td>Women (n = 27)</td>
<td>20.1 ± 5.1</td>
</tr>
<tr>
<td>HR at end of test, beats/min</td>
<td>140.0 ± 19.3</td>
</tr>
<tr>
<td>APHRM at end of test, %</td>
<td>91.8 ± 10.7</td>
</tr>
<tr>
<td>RPP at end of test ((HR \times SBP \times 10^{-2}))</td>
<td>248.1 ± 47.8</td>
</tr>
<tr>
<td>Maximal workload achieved, W</td>
<td>103.8 ± 44.3</td>
</tr>
<tr>
<td>Respiratory exchange ratio</td>
<td>1.12 ± 0.12</td>
</tr>
<tr>
<td>RPE, median</td>
<td>17</td>
</tr>
</tbody>
</table>
distance, indicating that the 6MWT distance is highly influenced by the ability to maintain postural stability, and therefore cannot truly reflect the cardiovascular fitness of the individual. This is in agreement with a previous study in subacute stroke that showed that balance function is related to performance in the 6MWT.

Knee extension strength of the paretic leg is also a significant predictor for the 6MWT distance. The reduced lean mass in the paretic leg when compared with the nonparetic leg suggests the presence of muscle atrophy in the paretic leg, a common finding in deconditioned individuals with stroke. In addition to the decrease in central drive, the observed reduction in lean tissue mass, the decrease in the number of functioning motor units, and alterations in motor unit recruitment and discharge rate may contribute to the decreased ability to produce force and negatively affect the ambulatory performance. However, when compared to balance, knee extension strength of the paretic leg contributed only a small amount (3.9%) to the variance in the 6MWT distance. During the normal gait cycle, the activity of ankle plantarflexors, not knee extensors, generates the largest mechanical power (ie, push-off phase). While the power generated by the ankle plantarflexors has been shown to relate to gait velocity in stroke, the relationship between knee muscle power and gait velocity is not as consistent. Moreover, isometric knee extension strength was measured in this study, whereas the activity of the knee extensors is largely eccentric during normal gait. These factors may explain the modest contribution of isometric knee extension strength of the paretic leg to the 6MWT distance.

Our results also show that spasticity is a significant determinant of the 6MWT distance but contributes only a small amount. This finding is in agreement with previous studies that showed a negative correlation between spasticity and gait velocity.

Overall, our results indicate that the walking endurance in the chronic stroke population as measured by the 6MWT is influenced by the stroke-specific impairments to a much greater degree than the cardiorespiratory status. Therefore, the 6MWT distance alone is not a good indicator of the cardiorespiratory fitness of individuals with chronic stroke.

Our data indicate that the mean PBF values for male and female subjects are approximately the 75th percentile and the 85th percentile, respectively, of the age-matched, healthy population. The increase in body fat, and decrease in lean mass and VO2max probably reflect a decreased level of physical activity, although all of the recruited subjects are independent ambulators. Interestingly, PBF is not an important factor for predicting the 6MWT distance. A recent study has shown that obese women walk a significantly shorter distance than lean women in the 6MWT. The 6MWT distance is also moderately or highly correlated with various anthropometric measures such as body mass index, percentage of fat-free mass, and fat mass in these otherwise healthy women. Our results thus again point to the major impact of stroke-related impairments such as poor balance, muscle weakness, and spasticity on walking endurance, taking precedence over the effects of increased PBF.

One small pilot study examined the relationship between 6MWT distance and VO2max in chronic stroke and found no significant relationship. However, a recent study has shown a strong positive correlation between cycle ergometry VO2max (expressed as a function of the age-predicted VO2max) and 6MWT distance in a small sample of 17 individuals with subacute stroke. The difference in results can be explained by several reasons. First, the average peak HR achieved at the end of the maximal exercise test was substantially higher.

### Table 3—Correlations With 6MWT Distance

<table>
<thead>
<tr>
<th>Variables</th>
<th>6MWT Distance (Normalized to Leg Length)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal cycle ergometer test</td>
<td>0.402*</td>
</tr>
<tr>
<td>V̇O2max</td>
<td>0.490</td>
</tr>
<tr>
<td>RPP at end of test</td>
<td>0.145</td>
</tr>
<tr>
<td>RPE at end of test</td>
<td>0.094</td>
</tr>
<tr>
<td>BBS</td>
<td>0.845*</td>
</tr>
<tr>
<td>Knee extension strength</td>
<td>0.406*</td>
</tr>
<tr>
<td>Paretic leg</td>
<td>0.145</td>
</tr>
<tr>
<td>Spasticity</td>
<td>0.373*</td>
</tr>
<tr>
<td>PBF</td>
<td>0.009</td>
</tr>
</tbody>
</table>

### Table 4—Multiple Regression Analysis for Predicting 6MWT Distance

<table>
<thead>
<tr>
<th>Predictors†</th>
<th>R²</th>
<th>R² Change</th>
<th>β</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBS</td>
<td>0.665 (model a)</td>
<td>0.065</td>
<td>0.0725 &lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>Paretic knee extension strength</td>
<td>0.701 (model b)</td>
<td>0.036</td>
<td>0.175</td>
<td>0.009</td>
</tr>
<tr>
<td>Spasticity</td>
<td>0.725 (model c)</td>
<td>0.023</td>
<td>0.160</td>
<td>0.029</td>
</tr>
</tbody>
</table>

* Excluded variable: V̇O2max.
† Predictors: model a, BBS; model b, BBS, paretic knee extension strength; model c, BBS, paretic knee extension strength, spasticity.
‡ Standardized β coefficients for each predictor in model c.
less in their subjects (76.8% of APHRM) than ours (91.8%). Some of the subjects in their study, therefore, might not have attained the maximal effort. Second, inpatients with subacute stroke (≤ 7 weeks after stroke) in a rehabilitation facility were used in their study, whereas a community-dwelling chronic stroke population was used in our study. Third, their subjects had a wide range of age (24 to 84 years), whereas our subjects were all older adults with stroke (≥ 50 years old).

In healthy populations, the VO_{2\text{max}} obtained from a treadmill exercise test is slightly higher than that obtained from a cycle ergometer test. However, since balance is a major limiting factor in walking performance, measuring VO_{2\text{max}} in the chronic stroke population by using a treadmill walking test may not be the best option. As the maximal exercise test progresses, the test may need to be terminated prematurely due to gait instability. Ryan et al found a moderate correlation (r = 0.53) between over-ground gait velocity and absolute VO_{2\text{max}} (milliliters per minute) obtained from a maximal treadmill test in a small sample (n = 26) of subjects with chronic stroke. However, no external support was given to the subjects, and gait instability was one of the criteria to terminate the treadmill test. Therefore, their results could be partly explained by the fact that performance in the treadmill test and over-ground walking were both limited by poor balance.

Our finding also has clinical significance regarding the choice of training method to improve cardiorespiratory fitness in the chronic stroke population. Balance deficits may make it difficult for these individuals to increase their walking speed sufficiently to induce a cardiorespiratory training effect. In contrast, postural demand during cycle ergometry is much less when compared to walking. Therefore, cycle ergometry would be a better option for measuring and training cardiorespiratory fitness for those who have poor balance. More recently, exercise testing and training on a treadmill with a harness system has been promoted to minimize the requirement for maintaining balance and may be a useful alternative to cycle ergometry. Whether cycle ergometry is more effective than walking in improving cardiorespiratory fitness in individuals with chronic stroke will require further study.

Limitations of the Study

The results can be generalized only to individuals with chronic stroke who are independent ambulators. However, a majority (66%) of the stroke survivors eventually regain their ability to ambulate independently.  

Conclusion

We demonstrated that community-dwelling ambulatory individuals with chronic stroke have poor cardiovascular fitness. We also showed that the correlation between cardiorespiratory fitness (VO_{2\text{max}}) and ambulatory capacity (6MWT distance) is low in the chronic stroke population. The clinical implications are twofold. First, in view of the poor cardiorespiratory fitness in chronic stroke, there is an urgent need for programs to improve cardiorespiratory fitness in these community-dwelling individuals. Second, this is the first study to demonstrate that the 6MWT distance alone should not be used as an indicator for cardiorespiratory fitness in patients with chronic stroke. Deficits in the neuromuscular system caused by stroke, such as poor balance, contribute to poorer performance in the 6MWT, leading to a low correlation between VO_{2\text{max}} and 6MWT distance.

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