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Relationship between ambulatory capacity and cardiorespiratory fitness in chronic stroke: Influence of stroke-specific impairments

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Abstract

Study Objectives—To identify in individuals with chronic stroke (1) the relationship between the maximal oxygen uptake (VO_2max) during cycle ergometry and the distance covered in the Six Minute Walk Test (6MWT), and (2) the stroke-specific impairments which 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 ± standard deviation, 65.3 ± 8.7) with an average post-stroke 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 (VO_2) was measured during both tests. Subjects were also evaluated for Berg Balance Scale, Modified Ashworth Scale of Spasticity, isometric knee extension strength and percent body fat.

Results—The 6MW distance had a low correlation with the VO_2max (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.

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Keywords

Cerebrovascular accident; Exercise test; Rehabilitation

INTRODUCTION

A large proportion of individuals with stroke have residual physical impairments[1], which 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.[2–3] Moreover, up to 75 % of persons with stroke have some form of cardiovascular disease.[4] 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 (VO_2max) during the maximal exercise test is considered to be a gold standard for evaluating cardiorespiratory fitness.[5] However, there are drawbacks in using the standard maximal exercise test. First, some individuals may not tolerate the maximal exercise test due to problems such as limb pain, arthritis or muscle soreness.[6] Second, measuring VO_2 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.[5]

Considering the difficulties of conducting a maximal exercise test, it would be beneficial to use an easy-to-administer submaximal exercise test which would enable clinicians to monitor cardiorespiratory fitness in persons with stroke. The Six Minute Walk Test (6MWT) is originally developed for the cardiorespiratory population [7–8] and is an easy-to-administer submaximal measure commonly employed to determine walking endurance in individuals with decreased function.[9–18] Although the 6MWT should not be considered as a replacement of formal cardiorespiratory testing,[13] the distance covered in the 6MWT has been shown to have moderate to high correlation with VO_2max in individuals with cardiorespiratory disease[9–11,13–17] and women with obesity.[12] The 6MWT distance may serve as a useful indicator for cardiorespiratory fitness in stroke.

Only one small pilot study (12 subjects) has examined the relationship between the cycle ergometry VO_2max and the 6MWT distance in chronic stroke and found no significant correlation between the two parameters.[19] Moreover, the degree 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 computer program G Power was used to calculate the sample size required for bivariate correlations and multiple regression analyses.[20] For bivariate correlations with a medium effect size=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 6 variables are modeled at an effect size=0.25 (large) at an alpha level of 0.05 and power of 0.80, a minimum of 62 subjects are required.[20–21]

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 ≥1 year post-stroke, (3) were independent in ambulation with or without a walking aid, and (4) were 50 years of age or older. Potential subjects were excluded if they had (1) unstable cardiac disease, (2) significant musculoskeletal conditions (i.e. amputations), (3) other neurological 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.[22]

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 (MMSE) was administered to assess cognitive function.[23] Subjects were accepted into the study if they were able to (1) pedal at 60 rpm and (2) obtain a MMSE score ≥22.

Each subject was classified according to the Functional Classification score of the American Heart Association Stroke Outcome Classification (AHASFC), which measures residual impairment and disability of stroke in the areas of basic and instrumental activities of daily living (BADL and IADL) where level I indicates independence and level V indicates complete dependence.[24]

Protocol

For both the 6MWT and cycle ergometer test, subjects wore a face mask. VO_2 was continuously measured using a portable metabolic unit, which performed breath by breath gas analysis (Cosmed K4 b^2 system; COSMED Srl; Rome, Italy). The level of perceived exertion was monitored by the 16-point Borg Rating of Perceived Exertion (RPE) scale.[25] Blood pressure (BP) was measured at rest and also at the end of the test.

6MWT—Subjects were instructed to “cover as much distance as they can around a 42-m rectangular path within 6 minutes and not to stop unless they needed to”.[26] Subjects wore a heart rate (HR) monitor (Polar A3; Polar electro Inc; Woodbury, NY, USA) for continuous HR measurement. The total distance walked was recorded.

Maximal Cycle Ergometer Test—Approximately 1- 2 weeks after the 6MWT, each subject underwent a maximal cycle ergometer test. A 12-lead electrocardiography system was used to monitor cardiac activity by a physician (Quark C12; COSMED Srl; Rome, Italy). The test was performed on the cycle ergometer (Excaliber; Lode B.V. Medical Technology; Groningen, Netherlands). Because a test time between 8 and 10 minutes was ideal, the testing protocol varied according to the capabilities of different individuals.[5,27] For 29 subjects, the workload started at 20W and increased by 20W/min. For the other 34 subjects who were more impaired, the workload started at 10W with increments of 10W/min.[5] Subjects were required to pedal at approximately 60 rpm. Peak HR achieved at the end of the test was expressed as a percentage of the age-predicted HR maximum (APHRM) [(220-age)/100)].[5] For those who were taking beta-blockers, the APHRM was adjusted [85%(220-age)/100].[28–29]

VO_2max was used as the criterion measure for cardiorespiratory fitness.[5] VO_2max was considered to have been reached if at least two out of three criteria for maximal effort were fulfilled: (1) a respiratory exchange ratio of ≥1.0, (2) a plateau in VO_2 (<150 ml/min) with increase in exercise intensity, or (3) volitional fatigue (i.e. decline in cycling rate <30 rpm).[5,27] Guidelines provided by American College of Sports Medicine (ACSM) were used to determine when the test should be terminated prematurely (e.g. increasing neurological symptoms, sustained ventricular tachycardia, angina, signs of poor perfusion, ST-segment depression of more than 2mm).[5]

Secondary outcome measures

Balance—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. 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, USA) 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 (N) were averaged and normalized to body mass (kg).

Spasticity—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, 4: affected part rigid in flexion and extension).[33] The scores for the leg and foot were averaged.

Percent body fat—Each subject underwent a total body scan using dual-energy X-ray absorptiometry (Hologic 2400; Hologic Inc; Waltham, MA, USA). The fat mass (kg) and lean mass (kg) were determined. The percent body fat of the whole body was calculated [100%×(fat mass)/(fat mass + lean mass)]. The fat mass and lean mass of the paretic and non-paretic leg were also determined by the region of interest (ROI) program.

Data Analysis

The 6MWT distance was normalized to leg length (meters). The last 30 seconds (s) of the VO_2 data during the 6MWT were averaged. Since the metabolic unit performed breath by breath gas analysis, the VO_2 data from the cycle ergometer test were averaged at a rate of every 15s to obtain a more accurate measure of the VO_2max. The maximal value (in ml/kg/min) obtained was considered to be the VO_2max.

Univariate analysis—Pearson's 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) VO_2max, (2) rate pressure product [RPP; the product of HR and systolic BP (SBP), an indicator for myocardial exertion] at the end of the cycle ergometer test, (3) age, (4) knee extension strength of the paretic leg and (5) the non-paretic leg, (6) PBF. A point-biserial correlation coefficient was performed to quantify the relationship between the 6MWT distance and gender (a dichotomous variable). Spearman's rho correlations were done to determine whether 6MWT distance was correlated with: (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: 0.26–0.49, low; 0.50–0.69, moderate; 0.70–0.89, high; 0.90–1.0, very high.[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 $p \leq 0.05$ and was removed at $p > 0.1$. Statistical analyses were performed using SPSS11.5 software (SPSS Inc.) using a significance level of 0.05 (2-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 taking medications for hypertension. Seven of these subjects were taking beta-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, p= 0.133). All subjects fulfilled our criteria for VO_2max. The mean VO_2max for males was significantly greater than that for females (independent t-tests, p=0.004). The mean VO_2 during the last 30s of the 6MWT reached 67.7±15.1% of the VO_2max obtained from the cycle ergometer test.

Secondary outcome measures

The mean knee extension strength of the paretic leg was 74.5% of the non-paretic leg. The percent body fat for males (27.360±5.821) was significantly less than that for females (38.028±5.180) (independent t-tests, $p<0.001$). The lean mass of the paretic leg was significantly less than that of the non-paretic leg (paired t-tests, $p<0.001$) whereas the fat mass of the paretic leg was significantly greater than that of the non-paretic leg (paired t-tests, $p=0.001$) (Table 1).

Determinants for 6MW distance

The correlations between 6MWT distance and other variables are shown in Table 3. The VO_2max only had a low correlation with the 6MWT distance (r=0.402). In addition, it also had low correlation with the 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 3.6% and 2.3% of the variance in the 6MWT distance, respectively, to a total of 72.5% (F=51.814, $p<0.001$). The VO_2max variable was removed from the stepwise regression model ($p>0.1$) and was therefore not a significant determinant for the 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 VO_2max obtained in our study is approximately 25% (male) and 20% (female) less than the age-matched, healthy population (i.e. around the 10^{th} 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 BADL (Level I/II according to AHASFC; Table 1).[24]

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 VO_2max, the criterion measure of cardiorespiratory fitness, in patients with various cardiorespiratory conditions (r=0.59–0.88).[9–15,17] Moreover, VO_2max 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 VO_2max and the 6MWT distance is limited (r=0.402). VO_2max is not a significant determinant of the 6MWT distance. Therefore, while the 6MWT provides useful information about the 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 VO_2max 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, 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, which showed that balance function is related to performance in the 6MWT.[37]

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 non-paretic leg suggests the presence of muscle atrophy in the paretic leg, a common finding in deconditioned individuals with stroke.[38] In addition to the decrease in central drive, the observed reduction in lean tissue mass, decrease in the number of functioning motor units,[39] and alterations in motor unit recruitment and discharge rate[40] 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 (i.e. push-off phase).[41] 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.[42] Moreover, isometric knee extension strength was measured in this study whereas the activity of the knee extensors is largely eccentric during normal gait.[42] 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, which showed a negative correlation between spasticity and gait velocity.[26,43]

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 percent body fat for male and female subjects is around 75th and 85th percentile, respectively, of the age-matched, healthy population.[5] The increase in body fat, decrease in lean mass and VO_2max probably reflect a decreased level of physical activity, although all of the recruited subjects are independent ambulators. Interestingly, percent body fat 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.[12] The 6MWT distance is also moderately or highly correlated with various anthropometric measures such as body mass index (BMI) ($r=-0.77$), percent fat free mass (r=0.80) and fat mass (r=−0.74) in these otherwise healthy women.[12] 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 percent body fat.

One small pilot study (n=12) has examined the relationship between the 6MWT distance and VO_2max in chronic stroke and found no significant relationship.[19] However, a recent study has shown a strong positive correlation (r=0.84) between the cycle ergometry VO_2max (expressed as a function of the age-predicted VO_2max) and the 6MWT distance in a small sample of 17 individuals with subacute stroke.[44] 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 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 post-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 (24–84 years) whereas our subjects were all older adults with stroke (≥50 years).

In healthy populations, the VO_2max obtained from a treadmill exercise test is slightly higher than that obtained from a cycle ergometer test.[5] However, since balance is a major limiting factor in walking performance, measuring VO_2max 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. (2000) found a moderate correlation (r=0.53) between overground gait velocity and absolute VO_2max (ml/min) obtained from a maximal treadmill test in a small sample (n=26) of subjects with chronic stroke.[45] 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 overground 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.[29,46] 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.[1]

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_2max) 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 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_2max and 6MWT distance.

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Abbreviations

6MWT	Six Minute Walk Test
ACSM	American College of Sports Medicine
AHASFC	American Heart and Stroke Functional Classification
APHRM	Age-predicted heart rate maximum
BADL	Basic activities of daily living
BBS	Berg Balance Scale
BMI	Body mass index
BP	Blood pressure
HR	Heart rate
IADL	Instrumental activities of daily living
MMSE	Mini Mental Status Examination
RER	Respiratory exchange ratio
RPE	Rate of perceived exertion
RPP	Rate pressure product
SBP	Systolic blood pressure
VO_2	oxygen consumption

VO_2max	maximal oxygen consumption

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Table 1

Subject Characteristics

Variable	Mean	SD	Range
Gender (male/female), n	36/27		
Type of stroke (ischemic/hemorrhagic/unknown), n	24/36/3		
Hemiparetic side (left/right), n	41/22		
AHASFC (I/II/III/IV/V), n	7/36/17/3/0		
Time since stroke, years	5.5	4.9	1–28
Age, years	65.3	8.7	50–87
Mass, kg	76.8	15.9	42.2–129.0
Height, cm	169.1	10.7	145.6–192.5
BBS	47.4	6.4	25–56
Knee extension strength, N/kg			
Paretic leg	1.13	0.42	0.21–2.61
Non-paretic leg	1.53	0.43	0.66–2.73
Spasticity (median and range)	0.5		0.0–2.0
Percent body fat	31.932	7.661	15.123–46.015
Fat mass, kg			
Paretic leg	3.601	1.530	1.378–9.057
Non-paretic leg	3.506	1.549	1.148–9.293
Lean mass, kg			
Paretic leg	7.732	2.055	3.816–13.421
Non-paretic leg	8.119	2.057	3.971–12.321

Table 2

Six Minute Walk Test and Maximal Cycle Ergometer Test (n=63)

Variable	Mean ±SD
Six Minute Walk Test	
VO_2 during last 30s (ml/kg/min)	14.7±3.3
HR at end of test (beats/min)	100.6±14.2
%APHRM at end of test	65.1±8.9
RPP at end of test (HR×SBP×10^{-2})	150.8±35.1
Absolute distance (m)	316.3±133.7
Distance (normalized by leg length)	370.2±159.6
RPE (median)	12
Maximal Cycle Ergometer Test	
VO_2max (ml/kg/min)	22.0±4.8
Male (n=36)	23.5±4.0
Female (n=27)	20.1±5.1
HR at end of test (beats/min)	140.0±19.3
%APHRM at end of test	91.8±10.7
RPP at end of test (HR×SBP×10^{-2})	248.1±47.8
Maximal workload achieved (W)	103.8±44.3
Respiratory exchange ratio (RER)	1.12±0.12
RPE (median)	17

Table 3

Correlations with 6MWT distance

	6MWT distance (normalized to leg length)
Outcome measures	
Maximal cycle ergometer test	
VO_2max	0.402†
RPP at end of test	0.196
RPE at end of test	0.094
BBS	0.845†
Knee extension strength	
Paretic leg	0.406†
Non-paretic leg	0.145
Spasticity	−0.373†
Percent body fat	−0.009
Subject demographics	
Age	0.154
Time since stroke	0.153
Gender (Male=0, Female=1)	0.191

*p<0.05;

†p<0.005

Table 4

Multiple regression analysis for predicting 6MWT distance

Predictors	R^2	R^2 change	β	p
BBS	0.665[a]	0.665	0.726	<0.001
Paretic knee extension strength	0.701[b]	0.036	0.175	0.009
Spasticity	0.725[c]	0.023	−0.160	0.029

Predictors:
Model a: BBS
Model b: BBS, paretic knee extension strength
Model c: BBS, paretic knee extension strength, spasticity

β: Standardized Beta Coefficients for each predictor in model c.

Excluded variable: VO_2max