Aerobic Capacity in Patients Entering Cardiac Rehabilitation

Philip A. Ades, MD; Patrick D. Savage, MS; Clinton A. Brawner, BS; Caroline E. Lyon, MD; Jonathan K. Ehrman, PhD; Janice Y. Bunn, PhD; Steven J. Keteyian, PhD

Background—Symptom-limited treadmill testing is commonly performed on entry to cardiac rehabilitation (CR) for its prognostic value and to design a safe and effective exercise program. Normative values for this evaluation are not available. The primary goals of this study were to establish normative values for peak aerobic capacity (peak VO₂) for patients entering CR and to create nomograms for conversion of peak VO₂ to a percentage of predicted exercise capacity, stratified by age, gender, and diagnosis.

Methods and Results—Peak VO₂ was measured in 2896 patients entering CR from 1996 to 2004. Peak VO₂ was higher in men than in women: 19.3±6.1 mL·kg⁻¹·min⁻¹ (range, 5.2 to 49.7 mL·kg⁻¹·min⁻¹) versus 14.5±3.9 mL·kg⁻¹·min⁻¹ (range, 3.8 to 29.8 mL·kg⁻¹·min⁻¹) (P<0.0001). Peak VO₂ decreased steadily with age with a greater rate of decline in men than women (−0.242 versus −0.116 mL·kg⁻¹·min⁻¹ per year) (P<0.01). Factors associated with lower peak VO₂ include coronary artery bypass grafting (CABG), angina at stress testing, hypertension, and, in women, β-blocking medications. Nomograms are presented for individual values to be compared with mean values by age, gender, and cardiac diagnosis. These include a nomogram to convert estimated maximal metabolic equivalents to actual peak VO₂ for patients who do not undergo direct measurement of peak VO₂.

Conclusions—Values of peak VO₂ on entry to CR are extremely low, particularly in women, approaching values seen with severe chronic heart failure. This underscores the importance of CR after a major cardiac event to improve physical function and long-term prognosis. (Circulation. 2006;113:2706-2712.)

Key Words: aerobic capacity ■ cardiac rehabilitation ■ exercise ■ exercise test

Symptom-limited exercise testing commonly is performed on entry into cardiac rehabilitation (CR) after a major cardiac event. During this evaluation, maximal exercise aerobic capacity (peak VO₂) is frequently measured indirectly from the maximal treadmill workload. Peak VO₂ carries important prognostic information for patients with coronary heart disease and chronic heart failure.1 It also is used to help formulate a safe, effective, and individualized exercise prescription in CR and to guide return to work and daily activity recommendations. However, despite the almost universal performance of a stress test preceding CR, normative values for peak VO₂ on the treadmill in patients with newly diagnosed coronary heart disease have not been established. The determination of normative values for this group of patients is of value beyond the prediction of prognosis; it allows assessment of clinical status of the individual patient compared with peers, leads to the formulation of realistic clinical goals, may provide motivation for patients to participate in CR exercise training, and allows benchmarking of the fitness of patients entering CR compared with established norms. Thus, the primary goals of this study are 2-fold: to establish normative values of peak VO₂ for patients entering CR stratified by age, gender, and diagnosis and to create nomograms to allow conversion of measured or estimated peak VO₂ data for an individual patient to a percentage of predicted exercise capacity. We also provide data on the exercise training response in a subset of these patients.

Clinical Perspective p 2712

Methods

Study Population

A total of 2896 patients with a recent acute cardiac event requiring hospitalization were evaluated with symptom-limited treadmill testing and expired gas analysis on entry into CR in Burlington, VT (n=1502), and Detroit, Mich (n=1394), from January 1996 to December 2004. Patient diagnosis was determined from the recent hospital admission that resulted in referral to CR. If >1 cardiac diagnosis was recorded during that admission, we defined the index diagnosis as follows: CABG (n=1166) superceded other reasons for hospitalization such as unstable angina or myocardial infarction (MI). If the admitting diagnosis was MI (n=1064) and a subsequent percutaneous coronary intervention (PCI) was or was not performed, it was coded as an MI. If a PCI was performed in the absence of MI, it was coded as PCI without MI (n=471). Medical therapy for unstable angina was coded as Med Rx (n=190). Other (n=42; 1%)
Aerobic Capacity in Cardiac Rehabilitation

Results

The combined sample of patients (n=2896) had a mean age of 61±11 years and was 28% female (Table 1). The racial distribution was 71% white, 26% black, and 3% Hispanic or other (Table 2).

Peak VO₂ was significantly higher in men than in women: 19.3±6.1 mL·kg⁻¹·min⁻¹ (lowest to highest, 5.2 to 49.7 mL·kg⁻¹·min⁻¹) versus 14.5±3.9 mL·kg⁻¹·min⁻¹ (lowest to highest, 3.8 to 29.8 mL·kg⁻¹·min⁻¹) (P<0.0001). This difference remained after adjustment for age because men were only slightly younger (60.6±11.2 years; range, 21 to 88 years) than the women (62.3±11.4 years; range, 23 to 87 years; P<0.0001). Peak respiratory exchange ratio (VCO₂/VO₂) was slightly higher in men than in women: 1.11±0.12 versus 1.06±0.03 (P<0.05).

Peak VO₂ diminished progressively with age in both men and women from the third through the eighth decade (Figure 2).

Statistical Analysis

Comparisons between groups were based on analysis of variance or analysis of covariance techniques when adjusting for covariates such as age. Categorical variables were compared by use of a χ² test of independence. A value of P<0.05 was considered statistically significant. Regression models were created separately for men and women, as well as for men and women falling into specific diagnostic categories. Solutions to the regression analyses provided the equations used to generate all nomograms. Dependent variables included peak VO₂ and percentage of predicted peak VO₂, whereas independent variables included age, gender, cardiac diagnosis, and estimated METS. Statistical analyses were performed with Statview and SAS for Windows, version 8.2 (SAS Inc, Cary, NC), whereas nomograms were produced by use of Stata, version 9 (Stata Corp, College Station, Tex). The authors had full access to the data and take responsibility for their integrity. All authors have read and agree to the manuscript as written.
The rate of decline in men with age (−0.242 mL·kg⁻¹·min⁻¹ per year) was greater than the rate of decline in women (−0.116 mL·kg⁻¹·min⁻¹ per year; P<0.01).

Angina occurred in 5% of tests (150 of 2896) and was associated with a lower peak VO₂ in both men (17.6±4.8 versus 19.5±6.2 mL·kg⁻¹·min⁻¹; P<0.005) and women (13.3±3.3 versus 14.5±4.0 mL·kg⁻¹·min⁻¹; P<0.05). The presence of ≥1-mm ST-segment depression in the setting of a normal baseline ECG occurred in 9% of tests and had no overall association with peak VO₂. Fatigue was the limiting symptom for 86% of stress tests, whereas another 10% of tests were stopped for other symptoms of a cardiovascular nature such as shortness of breath, >2-mm ST-segment depression on the ECG, angina, arrhythmia, hypertension, or hypotension associated with dizziness.

Cardiac diagnostic categories had a significant association with peak VO₂ values, even when adjusted for age (Table 3). In men, patients with PCI without MI had the highest values of peak VO₂, whereas patients who underwent CABG surgery had the lowest values, with no differences between categories of MI or Med Rx (Table 3). In women, patients with CABG had the lowest values of peak VO₂, with no differences between diagnostic categories of MI, Med Rx, or PCI without MI (Table 3). Thus, overall, patients after CABG had significantly lower values of peak VO₂ than patients with other cardiac diagnoses.

The time elapsed between the day of hospitalization and the day of the exercise test had an association with peak VO₂ in that a longer duration before the stress test was associated with a lower peak VO₂. This was due in part to an age effect because longer duration before the stress test correlated with older age (r=0.16, P<0.001). The time since hospitalization differed by diagnosis and gender, with patients after CABG and medically treated angina entering later than patients with MI or PCI without MI (P<0.001). Women in each diagnostic category delayed entry compared with men (Table 4) (P<0.0001).

The prevalence of cardiac risk factors was 62% for hypertension, 78% for overweight (BMI >25 kg/m²), and 40% for obesity (BMI >30 kg/m²) (Table 2). Smoking within the previous 2 years occurred in 19.4% of patients, whereas 80.6% were smokers in the remote past or never smoked. A recent or past history of smoking had no effect on peak VO₂ measured in mL·kg⁻¹·min⁻¹, although absolute peak VO₂ (in L/min) in those who had smoked was lower compared with those who never smoked. The presence of hypertension was associated with a lower age-adjusted peak VO₂ in both genders. Peak VO₂ also decreased with increasing BMI. Finally, patients with diabetes had lower age-adjusted values of peak VO₂ than patients without diabetes (men, 16.7±4.7 versus 20.0±6.3 mL·kg⁻¹·min⁻¹; P<0.0001; women, 12.9±3.5 versus 15.2±3.6 mL·kg⁻¹·min⁻¹; P<0.05).

The use of β-adrenergic blocking medications, taken by 75% of the study sample, was associated in women with a lower peak VO₂ (−4%; P=0.03). In men, peak VO₂ tended to be lower with β-blockade (−3%; P=0.056). Race had no effect on peak VO₂ regardless of gender.

Nomograms are presented to allow determination of the percentage of predicted peak VO₂ for an individual undergoing exercise testing at entry to CR, with gender, age, diagnosis, and measure of peak VO₂ known (Figures 2 through 4). Separate nomograms are presented for the overall male and female samples (Figure 2A), for individuals who have undergone CABG (Figure 3), and for the combined nonsurgical groups of MI, Med Rx of angina, and PCI without MI (Figure 4). Drawing a straight line between age and measured peak VO₂ value allows determination of the percentage of predicted peak VO₂. For example, in Figure 2A, a value of 120% would result for a patient who is female and 50 years of age who has a peak VO₂ of 19 mL·kg⁻¹·min⁻¹.

A nomogram (Figure 5) also is presented to allow conversion of estimated peak METS to peak VO₂ so that, in a setting where expired gas analysis is not performed, peak VO₂ can be estimated, allowing use of the previously described nomograms (Figures 2 through 4) to compare a given patient with normative values. It is noted that estimated peak METS, calculated from the speed and height of the treadmill using the American College of Sports Medicine Equation 9, systematically overestimated peak METS (peak METS=peak VO₂/3.5). In men, the mean

### Table 3. Peak VO₂ by Cardiac Diagnosis

<table>
<thead>
<tr>
<th>Cardiac Diagnosis</th>
<th>Women*</th>
<th>Men†</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCI, no MI</td>
<td>15.1±4.1</td>
<td>21.2±7.2</td>
</tr>
<tr>
<td>MI</td>
<td>14.7±4.2</td>
<td>20.4±6.6</td>
</tr>
<tr>
<td>Med Rx (unstable angina)</td>
<td>14.7±3.8</td>
<td>18.3±5.8</td>
</tr>
<tr>
<td>CABG</td>
<td>13.5±3.4</td>
<td>17.8±4.8</td>
</tr>
</tbody>
</table>

*CABG significantly lower than PCI without MI.
†CABG lower than MI. PCI without MI higher than MI.

### Table 4. Entry Diagnoses

<table>
<thead>
<tr>
<th>Entry Diagnosis</th>
<th>No.</th>
<th>Mean Time Since Event (Median), d</th>
<th>Mean Time Since Event (Median), d</th>
</tr>
</thead>
<tbody>
<tr>
<td>CABG</td>
<td>272</td>
<td>66±49* (53)</td>
<td>55±43* (43)</td>
</tr>
<tr>
<td>MI</td>
<td>325</td>
<td>52±49 (35)</td>
<td>42±37 (32)</td>
</tr>
<tr>
<td>PCI</td>
<td>130</td>
<td>56±56 (39)</td>
<td>42±37 (30)</td>
</tr>
<tr>
<td>Chronic stable angina</td>
<td>88</td>
<td>79±87* (42)</td>
<td>65±64* (38)</td>
</tr>
</tbody>
</table>

*Duration (days) differed vs diagnoses of MI or PCI, P<0.001.
overestimation was by a ratio of 1.30±0.56 (30%); in women, the overestimation was by a ratio of 1.23±0.40 (23%), with the nomogram correcting for these overestimations. The correlation coefficient between estimated peak METS and measured peak METS (measured METS=peak V\(\dot{O}\)\(_2\)/3.5) was \(R=0.48\) overall \((P<0.0001)\). This correlation was higher in women \((R=0.66)\) than in men \((R=0.39; \text{both } P<0.001; \text{Figure 5B})\).

Peak V\(\dot{O}\)\(_2\) was remeasured in 504 patients after they completed 36 sessions of aerobic training over 3 months at the Vermont study site. Peak V\(\dot{O}\)\(_2\) increased overall by 17.0% compared with baseline values (18.3±5.9 mL·kg\(^{-1}\)·min\(^{-1}\); \(P<0.0001)\). The training-induced increase in peak V\(\dot{O}\)\(_2\) in men (18%) \((n=386)\) was greater than that seen in women (12%) \((n=118)\) \((3.5±4.2 \text{ versus } 1.8±2.9 \text{ mL·kg}^{-1}· \text{min}^{-1}; \text{both } P<0.0001 \text{ within groups})\). Patients not completing the training program had a slightly higher peak V\(\dot{O}\)\(_2\) at baseline than those who completed the program (19.4±6.9 versus 18.3±5.9; \(P<0.01)\). This was explained primarily by the lower age of noncompleters (60±10 versus 65±10 years; \(P<0.001)\).

**Discussion**

Symptom-limited exercise testing with measurement of peak V\(\dot{O}\)\(_2\) is commonly performed on entry into CR for several reasons: It provides important prognostic information; it documents the safety of exercise; it assists with return to work guidelines; and it is used to formulate a safe, effective, and individualized exercise prescription for exercise training. Peak V\(\dot{O}\)\(_2\) is either directly measured during the exercise test or estimated from the maximal exercise capacity in METS. Despite the routine measure of exercise capacity before METS,
normative values are not available for peak \( \dot{V}O_2 \) measured on the treadmill. Values cannot be predicted from existing nomograms of exercise tolerance in patients with chronic coronary heart disease\(^{10,11} \) because of the potentially disabling effects of the acute coronary event such as MI or CABG, along with the deconditioning effects of the recovery period, which can last many weeks. Thus, the value of this investigation is that we provide normative values and predictive nomograms for peak \( \dot{V}O_2 \) soon after the acute coronary event in patients entering CR. Because many CR programs do not directly measure peak \( \dot{V}O_2 \) at the entry stress test but rather estimate peak exercise capacity in METS, we also provide a nomogram for conversion of peak estimated METS to measured peak \( \dot{V}O_2 \). Using these data, the clinician can now assess the fitness status of an individual patient in relation to age-, gender-, and diagnoses-matched peers. This will assist not only in estimating prognosis but also in setting realistic clinical goals, in encouraging participation in CR training programs, and in benchmarking fitness levels of patients in a given CR program compared with established norms.

We note that estimating peak workload in METS from the treadmill speed and elevation results in a systematic overestimation of peak METS of 30% in men and 23% in women compared with the direct measurement of peak \( \dot{V}O_2 \) and calculation of peak METS. This is clinically relevant because many health insurance companies base the number of approved CR sessions on the baseline functional status of the patient measured in METS, with more sessions covered for less fit patients. Use of our conversion nomogram to peak \( \dot{V}O_2 \) and therefore peak METS corrects the overestimation of METS using the American College of Sports Medicine Equation 9, which was not developed or validated in patients with coronary heart disease entering CR and may result in more appropriate insurance coverage for these patients.

Values of peak \( \dot{V}O_2 \), particularly for women, were extremely low (overall mean for women, mL \( \cdot \) kg\(^{-1} \) \( \cdot \) min\(^{-1} \)) and approach values seen when patients are considered for cardiac transplantation in the setting of chronic heart failure. Values measured in men, with a mean of 19.3 \( \pm \) 6.1 mL \( \cdot \) kg\(^{-1} \) \( \cdot \) min\(^{-1} \), also were low at roughly 60% of age-matched norms for healthy individuals without heart disease.\(^{12} \) Several other clinical factors, particularly cardiac diagnosis and the presence of certain cardiac risk factors, also had an influence on peak \( \dot{V}O_2 \).

The effect of age on peak \( \dot{V}O_2 \) was powerful. In men, peak \( \dot{V}O_2 \) decreased 39% from men in their 40s to men in their 80s. Sequentially, by decade, from 40 to 50 years of age, 50 to 60 years of age, and so on through the 80s, peak \( \dot{V}O_2 \) dropped steadily by 11%, 11%, 14%, and 11%, respectively, or \(-0.242 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \) per year. The relative drop with age in women was less steep, decreasing by 22% from 40 years of age through the 80s (\( P<0.01 \) versus men). From age 40 to 50 years of age, 50 to 60 years of age, and on through the 80s, the decreases were \(-1\% \), 7%, 10%, and 8% per decade (\( P<0.01 \)) or \(-0.166 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \) per year (\( P<0.01 \) versus men). These age effects are different from the longitudinal data of Fleg et al\(^{12} \) in healthy individuals, which showed an accelerating rate of decline of peak \( \dot{V}O_2 \) in the sixth and seventh decades (>20% per decade) compared with the third and fourth decades (3% to 6% per decade). This may be due in part to selective participation in CR where more disabled patients may be less likely to participate. Fleg et al also noted, as did we, that the decline of peak \( \dot{V}O_2 \) in women was less steep than in men and that younger women started at a lower level of fitness than younger men.

In our cohort, the impact of cardiac diagnosis on peak \( \dot{V}O_2 \) was significant. At all ages and in both men and women, patients who underwent CABG surgery had lower age-adjusted values of peak \( \dot{V}O_2 \) than patients treated medically or with a PCI. This is not surprising in that patients undergoing CABG are generally hospitalized longer and require a longer convalescence than patients treated medically. Patients who did not suffer an MI and who underwent PCI had the best exercise tolerance, probably because they had the shortest hospitalizations and had no myocardial damage. Other factors associated with a lower peak \( \dot{V}O_2 \) include angina at the stress test, hypertension, diabetes, use of \( \beta \)-blocking medications, higher BMI, and current or past smoking (absolute \( \dot{V}O_2 \) in L/min only for smoking).

Peak \( \dot{V}O_2 \) measures in our sample were lower than those seen in other studies of patients entering CR. The studies of Kavanagh et al.\(^{2,3} \) with a younger cohort of patients entering CR between 1968 and 1994 tested on the cycle ergometer showed slightly higher mean values of peak \( \dot{V}O_2 \): 20.5 mL \( \cdot \) kg\(^{-1} \) \( \cdot \) min\(^{-1} \).
in men and 15.1 mL · kg\(^{-1}\) · min\(^{-1}\) in women. This was observed despite the fact that peak VO\(_2\) measured on the cycle ergometer is lower than that measured on the treadmill.\(^{13}\) Their patients were studied at a time when the mean time until CR entry was approximately 100 days after the cardiac event (ie, a longer recovery period intervened), and the mean age of participants was 53 years in men and 60 years in women compared with our mean ages of 61 years in men and 62 years in women. Although both Kavanagh et al\(^{2,3}\) and Vanhee et al\(^{4}\) documented the prognostic value of the CR entry stress test, neither presented their data in a nomogram, which is a useful format when the results of individual patients are interpreted in the clinical setting. It is notable that despite a mean recovery period of 52 days (median, 38 days) since the cardiac event in the present study, fitness levels were far lower than those measured for age-matched individuals carefully screened to be free of coronary heart disease.\(^{12}\)

The extremely low aerobic functional capacities of postcardiac event patients described in this report require that most activities of daily living are performed at a high percentage of an individual’s functional reserve. Thus, many lower-intensity daily activities require a significant level of exertion, likely leading to a reduction of these activities. For example, food shopping while pushing a grocery cart requires a 3.5-MET level of exercise intensity, which, when converted to oxygen consumption, converts to 12.25 mL · kg\(^{-1}\) · min\(^{-1}\), putting the average women in this study at 85% of her maximal aerobic capacity just to go shopping.\(^{14}\) This does not include getting the groceries into the car, to the house, up the stairs, and in cupboards, which can require up to 8 METS, beyond the capacity of most individuals we studied. Avoiding such activities will contribute to a vicious cycle of reduced physical activity and a reduction in functional capacity. This has been confirmed by others who have found extremely high rates of disability in older patients with coronary heart disease.\(^{15}\) CR exercise training and activity counseling are critically important interventions to interrupt this cycle of decline.

Indeed, for the subset of our patients who had peak VO\(_2\) measured after 3 months of exercise conditioning, a 17% increase in peak aerobic capacity was measured. This training response is consistent with the relative increases seen in previous studies despite the lower aerobic capacity of the present patients at baseline.\(^{16}\) Thus, despite lower baseline levels of aerobic fitness, the training response to exercise training persists, effectively distancing patients from functional disability. A new finding, however, is the relatively greater increase in peak VO\(_2\), seen in male versus female participants (18% versus 12%; \(P<0.01\)). Although the women in this study were older than the men, studies have not shown a different relative improvement in peak VO\(_2\) response to training by age or gender.\(^{17-19}\)

Thus, a strong case is made for the widespread application of CR training protocols, particularly in older coronary patients. In addition to mortality benefits described in both meta-analyses and single-center studies,\(^{20-22}\) the most predictable benefit of CR is an increase in exercise tolerance,\(^{16}\) along with benefits related to physical functioning.\(^{23}\) Selective use of resistance training also has been shown effective in reducing measures of disability in this patient population\(^{26,27}\) and may be associated with increases in peak VO\(_2\), although this is controversial.\(^{28}\) Finally, it should be noted that the magnitude of training-induced increases in peak VO\(_2\) has been shown to independently predict a decrease in cardiovascular mortality.\(^{29}\)

From a clinical point of view, the data collected in this study are useful for the care of individual patients. Patients with lower-than-average fitness for their age, gender, and diagnosis may require longer-term exercise training programs that often are facility based. Displaying data of the individual against age-, gender-, and diagnosis-matched data also may provide increased motivation for patients to pursue exercise training and an active lifestyle.

Limitations of this study include the fact that data were collected only from 2 large CR centers serving communities in semirural New England and the urban Midwest, respectively. Although the combined sample was characterized by both racial and urban-rural diversity, the data may not reflect data from smaller centers in other parts of the country. In addition, although we presented data on the effect of cardiac risk factors on peak VO\(_2\), we did not have data on comorbidities such as arthritis, peripheral vascular disease, or obstructive lung disease, each of which could negatively affect exercise capacity. Optimal, a comorbidity score could be added as a dependent variable. We also note that the nomogram presented in Figure 5 that converts estimated METS to peak VO\(_2\) has not been validated in an independent sample of patients. Finally, the exercise training data that we have presented are limited by the high percentage of patients who did not complete the entire training program for various reasons.

In summary, we performed 2896 treadmill stress tests on entry into CR with expired gas analysis. Our results document that peak VO\(_2\) values were far lower than age-matched norms for healthy individuals and lower than previously published values in CR patients.\(^{1-3}\) These findings imply very high levels of physical disability in contemporary populations of cardiac patients who should benefit significantly from participation in CR exercise training protocols. Nomograms are provided to place the results of an individual patient in the context of age-, gender-, and diagnosis-specific norms in an easily accessible format.

**Acknowledgments**

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**Disclosures**

None.

**References**


CLINICAL PERSPECTIVE

In this study of peak VO2 in patients entering cardiac rehabilitation (CR) after a coronary event, we analyzed results in 2896 patients. Peak VO2 in women was particularly low, with values approximating those seen in patients with severe chronic heart failure. Our results affirm the importance of CR exercise training programs for these patients. Along with gender, other factors that predicted low fitness were older age, CABG surgery, the occurrence of angina at the stress test, hypertension, obesity, and type 2 diabetes mellitus. Nomograms are presented to determine for the individual patient the percentage of predicted peak VO2 given the patient’s age, gender, and diagnosis. Results from this study will assist clinicians in estimating prognosis, setting realistic clinical goals, encouraging patient participation in CR exercise, and benchmarking fitness levels against established norms. A nomogram also is presented to convert estimated fitness level in maximal metabolic equivalents to actual peak VO2 for patients who do not undergo direct measurement of peak VO2. This conversion shows that the commonly used conversion equation from the American College of Sports Medicine overestimates fitness levels by 30%. Because baseline exercise capacity is often used by third-party health insurers to determine the number of rehabilitation sessions required, a more accurate determination of exercise capacity may afford a greater number of sessions to the typical patient.
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