Value of the Bruce protocol to determine peak exercise oxygen consumption in patients evaluated for cardiac transplantation

Theresa A. Strzelczyk, MS, RN, FAACVPR, David A. Cusick, MD, Pamela B. Pfeifer, MS, RN, Mary D. Bondmass, MS, RN, and Rebecca J. Quigg, MD Chicago, Ill

Background Peak exercise oxygen consumption (peak VO₂) is an important discriminator of survival in patients with systolic heart failure and is used to select ambulatory patients for transplantation. The major trials assessing the relationship between peak VO₂ and survival have used a variety of low-level exercise protocols. It is unknown how peak VO₂ measured in this patient population by the more vigorous Bruce treadmill protocol compares with that obtained on less intense protocols.

Methods We studied 15 patients (50 ± 12 years old) with severe heart failure (left ventricular ejection fraction 23.5% ± 8.6%). Patients randomly performed 3 exercise tests with the Bruce treadmill, modified Naughton treadmill, and modified bicycle protocols within 14 days. To determine the ability of this patient population to perform the Bruce protocol, we also retrospectively analyzed the ability of 84 patients to perform this test on their initial evaluations at our center.

Results All patients reached the anaerobic threshold (AT) on all 3 protocols. The Bruce and modified Naughton treadmill protocols resulted in similar peak VO₂, percent predicted peak VO₂, and VO₂ at AT values (17.7 ± 3.8 mL/kg/min, 57.2% ± 21.1% and 15.4 ± 4.1 mL/kg/min vs 18.0 ± 4.7 mL/kg/min, 58.1% ± 22.5% and 15.6 ± 4.4 mL/kg/min, respectively). Peak VO₂ and VO₂ at AT on both treadmill protocols were higher than those obtained with bicycle testing (15.3 ± 3.1 and 11.8 ± 3.0 mL/kg/min, P < .05). Exercise duration was shorter with the Bruce and bicycle protocols (6.2 ± 2.2 and 6.7 ± 2.4 minutes, respectively) compared with the modified Naughton protocol (9.7 ± 4.3 minutes, both P < .005). In addition, 79 of the 84 patients (94%) evaluated were able to complete the Bruce protocol and reach AT.

Conclusions The Bruce protocol was more time efficient than the modified Naughton protocol and yielded similar peak VO₂, percent predicted peak VO₂, and VO₂ at AT values. Exercise protocol should be considered when assessing peak VO₂ criteria for transplant listing. [Am Heart J 2001;142:466-75.]
failure by demonstrating significantly higher peak VO2 values on the more challenging Bruce treadmill protocol compared with 3 other lower intensity treadmill protocols. Whether patients with more severe heart failure also demonstrate this protocol-dependent variability in peak VO2 has not been studied. If present, a disparity in the method of obtaining peak VO2 measurements could have major clinical implications by affecting the uniformity of exercise criteria used to determine listing for cardiac transplantation.

Patients with severe systolic heart failure have traditionally undergone exercise stress testing on low-intensity protocols because they are perceived to be too ill to perform the standard Bruce treadmill protocol, which is used in most cardiac patients. At our center, the Bruce protocol has been used exclusively in our heart failure population because of the assumed time efficiency of using this protocol compared with time-consuming low-intensity protocols.

This study was designed to compare the results obtained on the Bruce treadmill protocol with those obtained from low-intensity modified exercise protocols to determine (1) whether peak exercise VO2 values in patients with severe systolic heart failure vary significantly depending on the intensity and type of exercise protocol and (2) whether the Bruce treadmill protocol is widely applicable to patients with severe systolic heart failure.

**Methods**

**Patient population**

The study was approved by the Institutional Review Board at Northwestern University and Northwestern Memorial Hospital. Sixteen patients with New York Heart Association class III-IV systolic heart failure, referred as potential cardiac transplant candidates, were prospectively studied. There were 14 men and 2 women (aged 50 ± 12 years, range 29-68 years). The etiology of systolic heart failure was coronary artery disease in 6 patients (38%), dilated cardiomyopathy in 9 patients (56%), and valvular heart disease in 1 patient (6%). Left ventricular ejection fraction before enrollment in the study was 23.5% ± 8.6%. Before the study, 16 patients were on loop diuretics, 15 were on stable doses of digoxin, 15 were on angiotensin-converting enzyme inhibitors (10 patients, enalapril; 3 patients, captopril; and 2 patients, fosinopril) and 1 patient was on hydralazine because of an angiotensin-converting enzyme inhibitor intolerance. Three patients were also receiving hydralazine in addition to angiotensin-converting enzyme inhibitors. No patient studied in the protocol compared with time-consuming low-intensity protocols.

This study was designed to compare the results obtained on the Bruce treadmill protocol with those obtained from low-intensity modified exercise protocols to determine (1) whether peak exercise VO2 values in patients with severe systolic heart failure vary significantly depending on the intensity and type of exercise protocol and (2) whether the Bruce treadmill protocol is widely applicable to patients with severe systolic heart failure.

The peak exercise VO2 value was defined as the highest VO2 value achieved at end-exercise after the anaerobic threshold was reached. Age- and sex-adjusted percent (%) predicted peak VO2 values were calculated by the standard equations described by Wasserman et al,21 which correct for the use of the bicycle or treadmill but not for exercise intensity. The VO2 at anaerobic threshold values were determined as the point at which expired carbon dioxide increased in a nonlinear fashion relative to the rate of oxygen consumption by the V-slope method.22 The VO2 at the anaerobic threshold value for each patient was visually noted and agreed on by 3 independent cardiopulmonary exercise-testing specialists.

**Review of previous exercise test results to support the utility of the Bruce protocol**

There have been no reports in the literature of patients with severe heart failure undergoing exercise testing on the Bruce protocol. If fact, it is widely felt that the Bruce protocol is too vigorous for patients with severe heart failure to reach the anaerobic threshold. In our previous experience with >500 initial and follow-up cardiopulmonary exercise tests in similar patients performing the Bruce protocol at 2 institutions, we observed a high success rate and a low adverse event or failure rate. Therefore, to document the widespread utility of this protocol, we sought to evaluate whether patients at our current institution who had previously performed their initial exercise test on the Bruce protocol had had an adequate level of success in reaching the anaerobic threshold without adverse events.

We retrospectively reviewed the results of the initial cardiopulmonary exercise tests in 84 consecutive ambulatory patients with left ventricular ejection fraction <35% and New York Heart Association class III-IV referred to our program over a 56-month period. Mean patient age was 54.7 ± 13.3 years and mean left ventricular ejection fraction was 24% ± 7.4%. The ability of patients to perform an exercise test on the Bruce protocol and to reach the anaerobic threshold, along with peak VO2, percent predicted peak VO2, and peak RER val-
ues, were recorded. If any patient was tested on a low-intensity protocol, the reason was documented and the patient’s ability to perform on the Bruce protocol at a later date was recorded. All cardiopulmonary exercise tests in both the prospective randomized study and the retrospective Bruce protocol analysis were performed with trained heart failure/exercise testing personnel and a heart failure physician on site throughout the testing.

**Statistical analysis**

All data are expressed as mean ± SD. Resting and peak exercise heart rate and blood pressure, peak RPE, peak RER, exercise duration, peak exercise VO₂, age and sex percent predicted VO₂, and VO₂ at anaerobic threshold values were compared among the 3 methods of exercise testing by multivariate analysis (analysis of variance). Pairwise comparisons were made with the Bonferroni method. A P value of <.05 was considered statistically significant.

**Results**

**Comparison of the Bruce treadmill, modified Naughton treadmill, and bicycle ergometer protocols**

All 16 patients completed the exercise tests without difficulty and with no adverse events. One patient failed to reach the anaerobic threshold on all 3 protocols because of severe deconditioning after a previous stroke and was excluded from the analysis. The remaining 15 patients reached the anaerobic threshold and exercised to an RPE of >17 on all 3 exercise protocols. Mean RPE values were similar on all 3 protocols (Table III). The peak RER was >1.1 on all 3 protocols and was significantly higher on the bicycle protocol compared with the modified Naughton treadmill protocol. The resting and peak exercise heart rates, resting systolic...
blood pressure, and rest and peak exercise diastolic blood pressures were similar on all 3 exercise protocols. However, the peak exercise systolic blood pressure was significantly higher on the bicycle ergometer protocol compared with that reached on the modified Naughton treadmill protocol.

The mean peak VO₂ values obtained on the Bruce and modified Naughton protocols were significantly higher than those obtained with the bicycle protocol (17.7 ± 3.8 mL/kg/min and 18.0 ± 4.7 vs 15.3 ± 3.1 mL/kg/min, respectively; \( P < .05 \)) (Figure 1, A). Peak VO₂ values obtained on the 2 treadmill protocols were similar. The calculated percent age- and sex-predicted peak VO₂ values on the modified Naughton protocol were higher than those obtained on the bicycle protocol (58.1% ± 22.5% vs 52.4% ± 14.9%, \( P < .05 \)) (Figure 1, B). The percent predicted peak VO₂ obtained on the Bruce protocol tended to be higher than that obtained on the bicycle ergometer protocol (57.2% ± 21.1% vs 52.4% ± 14.9%) but did not reach statistical significance. The percent of predicted peak VO₂ values was similar on the 2 treadmill protocols. The VO₂ at anaerobic threshold values were also significantly higher on the Bruce and modified Naughton treadmill protocols compared with the bicycle protocol (15.4 ± 4.1 and 15.6 ± 4.4 mL/kg/min vs 11.8 ± 3.0 mL/kg/min, respectively; \( P < .05 \) (Figure 1, C)). Of note, VO₂ at the anaerobic threshold was similar on both treadmill protocols. This was consistent with the similarity in peak VO₂ values also seen on the 2 treadmill protocols. All 15 patients had a higher peak VO₂ value on the Bruce protocol than on the bicycle protocol. On average, the Bruce protocol resulted in a peak VO₂ value of 2.4 ± 1.7 mL/kg/min higher (range 0.7-5.3 mL/kg/min) than on
The percent predicted peak VO₂ was also higher on the Bruce protocol than on the bicycle ergometer protocol in all 15 patients, by an average of 6.8% ± 5.1% (range 0.6%-15.2%).

Peak VO₂ values obtained on the modified Naughton protocol were higher than those reached on the bicycle ergometer protocol in 14 of the 15 patients. In these 14 patients the average peak VO₂ value was 2.7 ± 2.1 mL/kg/min higher (range 0.2-6.6 mL/kg/min) on the modified Naughton than on the bicycle ergometer protocol. The calculated percent predicted peak VO₂ values were higher on the modified Naughton protocol in 13 of the 15 patients by an average of 7.3 ± 5.7 percentage points (range 2.2-15.2 percentage points).

Exercise duration was significantly shorter on the Bruce treadmill and bicycle protocols (6.2 ± 2.2 and 6.7 ± 2.4 minutes, respectively) compared with the modified Naughton protocol (9.7 ± 4.3 minutes, \( P < .05 \)), resulting in a reduction in the time needed to perform a maximal exercise test on these 2 protocols (Figure 2). The length of time required to perform the exercise test was as much as 3.5 ± 2.7 minutes (range 0.16-8.5 minutes) higher on the modified Naughton than on the Bruce protocol. The patients’ subjective preference for the type of testing protocol was not designated as a predefined end point. However, after the 3 studies were completed, all 15 patients preferred the Bruce protocol to the other 2 more time-consuming protocols. Several patients who were elderly had difficulty learning how to bicycle on a stationary bicycle ergometer.

Use of the Bruce protocol

Of 84 sequential ambulatory patients referred to our program, 83 (99%) were scheduled for a test on the Bruce treadmill protocol. Only 1 patient (1%) was alternatively scheduled for bicycle ergometer testing because of known lower extremity problems. Of the 83 patients initially scheduled to perform the Bruce protocol, only 1 patient (1%) was changed to the modified Bruce protocol at the time of the test because of inability to perform stage 1 of the Bruce protocol. The remaining 82 patients (99%) were able to perform the Bruce protocol without difficulty. No adverse patient events occurred.

Of the 82 patients who performed the Bruce protocol, 77 (94%) reached the anaerobic threshold. Mean values for VO₂ at the anaerobic threshold were 13.8 ± 5.0 mL/kg/min, peak VO₂ was 17.5 ± 5.6 mL/kg/min, and peak RER was 1.16 ± 0.10, indicating the ability to perform a good exercise effort on this protocol. Of the 5 patients who were unable to reach the anaerobic threshold on their initial exercise tests on the Bruce protocol, 3 patients were later able to reach it on the Bruce protocol after optimization of heart failure therapy and cardiac rehabilitation; 2 patients died before repeat testing.
The results of this study indicate that peak VO2 and VO2 at the anaerobic threshold obtained with the Bruce and modified Naughton treadmill protocols are consistently higher than peak VO2 values achieved with the bicycle ergometer protocol. Despite the more intense Bruce exercise protocol, all 15 patients who were able to reach the anaerobic threshold on the low-intensity protocols were able to reach the anaerobic threshold on the Bruce protocol. Although the Bruce treadmill protocol gave results similar to those of the modified Naughton treadmill protocol, it was more time efficient because the time required to perform a maximal exercise test was nearly 30% less. Retrospective analysis of consecutive ambulatory patients who underwent exercise testing at our center demonstrated that the majority were able to safely complete the more intense but time-efficient Bruce exercise testing protocol and reach the anaerobic threshold.

The use of a treadmill or bicycle ergometer as the mode of exercise when determining functional capacity in cardiac patients continues to be a subject of debate. \(^2^3\) Advantages of using a bicycle ergometer include an accurate means to quantify workload at less

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Bruce treadmill</th>
<th>Modified Naughton treadmill</th>
<th>Bicycle ergometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak RPE</td>
<td>18.1 ± 1.3</td>
<td>18.3 ± 1.6</td>
<td>17.9 ± 1.4</td>
</tr>
<tr>
<td>Peak RER</td>
<td>1.20 ± 0.1</td>
<td>1.1 ± 0.1</td>
<td>1.22 ± 0.1*</td>
</tr>
<tr>
<td>Resting heart rate [beats/min]</td>
<td>77 ± 19</td>
<td>80 ± 24</td>
<td>79 ± 18</td>
</tr>
<tr>
<td>Peak heart rate [beats/min]</td>
<td>140 ± 24</td>
<td>137 ± 22</td>
<td>135 ± 21</td>
</tr>
<tr>
<td>Resting systolic blood pressure [mm Hg]</td>
<td>106 ± 17</td>
<td>110 ± 12</td>
<td>110 ± 18</td>
</tr>
<tr>
<td>Resting diastolic blood pressure [mm Hg]</td>
<td>65 ± 7</td>
<td>70 ± 6</td>
<td>67 ± 10</td>
</tr>
<tr>
<td>Peak systolic blood pressure [mm Hg]</td>
<td>141 ± 37</td>
<td>132 ± 34</td>
<td>148 ± 33*</td>
</tr>
<tr>
<td>Peak diastolic blood pressure [mm Hg]</td>
<td>71 ± 12</td>
<td>70 ± 14</td>
<td>74 ± 13</td>
</tr>
</tbody>
</table>

\(^*P < .05\) versus modified Naughton protocol.

### Table III. Exercise testing results on the Bruce treadmill, modified Naughton treadmill, and bicycle ergometer protocols

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Bruce treadmill</th>
<th>Modified Naughton treadmill</th>
<th>Bicycle ergometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak RPE</td>
<td>18.1 ± 1.3</td>
<td>18.3 ± 1.6</td>
<td>17.9 ± 1.4</td>
</tr>
<tr>
<td>Peak RER</td>
<td>1.20 ± 0.1</td>
<td>1.1 ± 0.1</td>
<td>1.22 ± 0.1*</td>
</tr>
<tr>
<td>Resting heart rate [beats/min]</td>
<td>77 ± 19</td>
<td>80 ± 24</td>
<td>79 ± 18</td>
</tr>
<tr>
<td>Peak heart rate [beats/min]</td>
<td>140 ± 24</td>
<td>137 ± 22</td>
<td>135 ± 21</td>
</tr>
<tr>
<td>Resting systolic blood pressure [mm Hg]</td>
<td>106 ± 17</td>
<td>110 ± 12</td>
<td>110 ± 18</td>
</tr>
<tr>
<td>Resting diastolic blood pressure [mm Hg]</td>
<td>65 ± 7</td>
<td>70 ± 6</td>
<td>67 ± 10</td>
</tr>
<tr>
<td>Peak systolic blood pressure [mm Hg]</td>
<td>141 ± 37</td>
<td>132 ± 34</td>
<td>148 ± 33*</td>
</tr>
<tr>
<td>Peak diastolic blood pressure [mm Hg]</td>
<td>71 ± 12</td>
<td>70 ± 14</td>
<td>74 ± 13</td>
</tr>
</tbody>
</table>

\(^*P < .05\) versus modified Naughton protocol.
expense, smaller space requirements, and less noise than with use of a treadmill. However, several investigators have reported lower peak VO\(_2\) values in cardiac patients when using a bicycle ergometer\(^{17,18}\) possibly explained by the lack of familiarity with bicycle exercise in the United States. In contrast, walking on a treadmill is more similar to activities of daily living, which may make treadmill testing more acceptable to the patient. We have also demonstrated that use of a bicycle ergometer to obtain peak VO\(_2\) measurements

---

**Figure 1**

A, Peak VO\(_2\) values. B, Percent predicted peak VO\(_2\) values. C, Oxygen consumption at anaerobic threshold (AT) values on the Bruce and modified Naughton treadmill and bicycle ergometer exercise protocols. Asterisk, P < .05 versus bicycle ergometer protocol.
results in significantly lower peak VO₂ values than use of a treadmill protocol. When individual peak VO₂ values were compared, they were as much as 5.3 mL/kg/min higher on the Bruce treadmill protocol and 6.6 mL/kg/min higher on the modified Naughton treadmill protocol compared with values obtained on the bicycle protocol.

The most recently published criteria for transplant listing recommend that patients with peak VO₂ values of <15 mL/kg/min be listed for heart transplantation. However, the mode of exercise testing is not distinguished in either of these recipient criteria guidelines. Previous data evaluating the association of peak VO₂ and survival, which were used to create these guidelines, included approximately 74% of patients who performed exercise on a bicycle ergometer protocol and 26% of patients who performed exercise on a modified treadmill protocol (Table I). Additionally, these studies chose an arbitrary cut off peak VO₂ value from either the mean or median value of their study group or based on previous data, which had also done so arbitrarily. However, both Veterans Heart Failure Trials demonstrated that peak VO₂ is a continuous variable with mortality progressively increasing with progressively lower peak VO₂ values. This concept was further supported in a preliminary report by Aaronson et al. Also, Kao et al. showed that survival was not different in patients listed for transplant with peak VO₂ values between 14.0 and 17.0 mL/kg/min. Data demonstrating the relationship of percent predicted peak VO₂ values and survival have used a bicycle ergometer protocol in 33% of patients or a modified treadmill protocol in 67% of patients (Table II). To date, there have been no reports demonstrating the relationship of peak VO₂ or percent predicted peak VO₂ values obtained on the Bruce protocol and survival.

Most cardiac transplant centers use peak VO₂ criteria of either <15 mL/kg/min and/or <50% to 60% of predicted peak VO₂ values to make decisions regarding transplant listing irrespective of the mode of exercise testing (Tables I and II). On the basis of our results, we believe that cardiac transplant centers should take into consideration the type of exercise protocol used, which could significantly affect the resulting peak VO₂ values, when determining medical need for transplant listing. With use of peak VO₂ criteria of <15.0 mL/kg/min in our cohort of 15 patients, 2 patients met criteria for transplant listing by the bicycle protocol but exceeded peak VO₂ criteria when tested on either the Bruce or modified Naughton treadmill protocols. Five patients met peak VO₂ criteria for transplant listing on all 3 protocols; 8 patients exceeded criteria on all protocols. Thus, with use of peak VO₂ criteria of <15.0 mL/kg/min in this patient cohort, bicycle testing alone could have resulted in 2 patients being inappropriately listed for transplant. If the criteria of <60% of age- and sex-predicted peak VO₂ for transplant listing was used for our cohort of 15 patients, 5 patients met criteria for transplant listing when tested on the bicycle protocol but exceeded peak VO₂ criteria when tested on either the Bruce or modified Naughton treadmill protocols. Nine patients met percent predicted VO₂ criteria on all 3 protocols and 1 patient did not meet criteria on any protocol.

This study demonstrates that peak VO₂, percent predicted VO₂, and VO₂ at anaerobic threshold values on
the Bruce treadmill protocol are comparable to those obtained on the modified Naughton treadmill protocol, with the Bruce protocol being more time efficient. Use of the bicycle ergometer protocol may significantly underestimate peak \( \text{VO}_2 \) (by up to 6.6 mL/kg/min) and the percent predicted peak \( \text{VO}_2 \) (by up to 15.2 percentage points) compared with either the modified Naughton or Bruce treadmill protocols. The Bruce treadmill protocol is safe and widely applicable to the population of ambulatory patients with severe systolic heart failure who would be considered for cardiac transplantation, with only 1% of our patients unable to perform the Bruce treadmill protocol. Use of the Bruce treadmill protocol may decrease testing time as much as 8.5 minutes (mean 3.5 ± 2.7 minutes, range 0.2-8.5 minutes) compared with the time required to perform the modified Naughton treadmill protocol. On the basis of the results of this study, it would be appropriate to consider the initiation of standardized exercise testing protocols nationwide in patients whose peak \( \text{VO}_2 \) values will be used to make the very monumental decision whether they will be listed for cardiac transplantation. This would allow the fairest allocation of donor hearts to ambulatory patients with heart failure. At the very least, the implications of these results would suggest that all transplant centers should always take into consideration the intensity of the type of protocol that has been used to evaluate their patient in making the decision whether to list a patient for transplantation. On the basis of our data, it could be reason-ably assumed that a patient who underwent testing on the bicycle ergometer would have a peak \( \text{VO}_2 \) approximately 85% of that that might have been obtained with upright treadmill exercise. Conversely, peak \( \text{VO}_2 \) values obtained on either the modified Naughton or Bruce treadmill protocols may be approximately 15% higher than those that might be obtained with the bicycle ergometer.

Conclusions

The Bruce treadmill protocol can be used to assess ambulatory patients with severe systolic heart failure for cardiac transplant listing. Although peak \( \text{VO}_2 \) and percent predicted peak \( \text{VO}_2 \) values on the Bruce treadmill protocol are similar to those obtained on the modified Naughton treadmill protocol, time to perform the test is significantly less. Last, the type of exercise protocol used to assess peak \( \text{VO}_2 \) values should be carefully considered to ensure uniformity of the listing of patients across transplant centers. Long-term data evaluating the relationship between peak \( \text{VO}_2 \) values measured on the Bruce treadmill protocol and survival are needed.

We thank Michele A. Parker, MS, RN, for the statistical analysis and Joseph W. Clauser, BS, for technical assistance during exercise testing.

References


AVAILABILITY OF JOURNAL BACK ISSUES

As a service to our subscribers, copies of back issues of the American Heart Journal for the preceding 5 years are maintained and are available for purchase from Mosby until inventory is depleted. Please write to Mosby Subscription Customer Service, 6277 Sea Harbor Dr, Orlando, FL 32887, or call 800-654-2452 or 407-345-4000 for information on availability and prices of particular issues. If unavailable from the publisher, photocopies of complete issues may be purchased from Bell & Howell Information and Learning, 300 N. Zeeb Rd., Ann Arbor, MI 48106, (734)761-4100 or (800) 521-0600.