6-Minute Walk Work for Assessment of Functional Capacity in Patients With COPD*

Rick Carter, PhD, MBA, FCCP; David B. Holiday, PhD; Chiagozie Nwasuruba, MD; James Stocks, MD; Carol Grothues, PhD; and Brian Tiep, MD

The 6-min walk (6MW) test is commonly used to assess exercise capacity in patients with COPD and to track functional change resulting from disease progression or therapeutic intervention. Not surprisingly, distance covered has been the preferred outcome for this test. However, distance walked does not account for differences in body weight that are known to influence exercise capacity.

Objective: The aim of this study was to evaluate the 6-min distance x body weight product (6MWORK) as an improved outcome measure with a solid physiologic foundation.

Patients and methods: One hundred twenty-four men and women with moderate-to-severe COPD volunteered and completed the testing sequence, which included pulmonary function, a peak effort ramp cardiopulmonary exercise study with gas exchange, and the 6MW. Means and SD were generated for the variables of interest. Differences were analyzed using analysis of variance techniques. Correlation coefficients and receiver operating characteristic (ROC) curves were calculated for the 6-min walk distance (6MWD) and 6MWORK with indexes of pulmonary function, work performance, and Borg scores for dyspnea and effort.

Results: Men and women presented with a significant smoking history that also differed by gender (48 vs 66 pack-years, respectively; p < 0.01). The mean (± SD) FEV1 values were 45 ± 12.6% and 48 ± 12.1%, respectively (not significant), while the diffusing capacity of the lung for carbon monoxide (DLCO) was 14.7 ± 6.1 vs 10.3 ± 3.9 mL/min/mm Hg, respectively (p < 0.001), for men and women. The 6MWD averaged 416.8 ± 79.0 m for men and 367.8 ± 78.6 m for women, and these differences were significant (p < 0.002). When 6MWD was compared as the percent predicted of normal values, each gender presented with a similar reduction of 78.6 ± 14.5% vs 79.9 ± 17.5% (p > 0.05), respectively. 6MWORK averaged 35,370 ± 9,482 kg/m and 25,643 ± 9,080 kg/m (p < 0.0001) for men and women, respectively. 6MWORK yielded higher correlation coefficients than did 6MWD when correlated with DLCO, lung diffusion for alveolar ventilation, FEV1, FEV1/FVC ratio, watts, peak oxygen uptake, peak minute ventilation, and peak tidal volume. The ROC curve demonstrated that 6MWORK had a significantly larger calculated area under the curve (p < 0.05) [plot of 100-sensitivity to specificity for each variable of interest for all subjects] than 6MWD when differentiating an objectively selected definition of low work capacity vs high work capacity (bicycle ergometry work, < 55 vs > 55 W, respectively).

Conclusions: We conclude that work calculated as the product of distance x body weight is an improved outcome measure for the 6MW. 6MWORK can be used whenever the 6MW is required to estimate a patient's functional capacity. This measure is also a common measure, which can be converted to indexes of caloric expenditure for direct cross-modality comparisons.

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Key words: COPD; functional capacity; quality of life; 6-min walk; work capacity

Abbreviations: θ = angle of incline for the treadmill; DLCO = diffusing capacity of the lung for carbon monoxide; K = work coefficient; ROC = receiver operating characteristic; 6MW = 6-min walk; 6MWD = 6-min walk distance; 6MWORK = 6-min distance x body weight product; SpO2 = pulse oximetric saturation; T = walking period; V = walking velocity; V̇E = minute ventilation; VO2 = oxygen uptake; VT = tidal volume; WHO = horizontal work

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Assessment of functional capacity has gained importance in understanding the impact of disease and development of disease management methodologies for the COPD patient. The development of standardized laboratory measures of exercise capacity and quality-of-life in COPD patients reflects the growing perception of the importance of these outcomes in patients. However, laboratory tests of exercise performance are often time-consuming and costly. Second, these tests are often not well-accepted by the patient especially when multiple tests are required over the course of the study. Therefore, over the past 2 decades, alternative walking tests have been developed and applied to evaluate functional ability with varying degrees of success.

In 1976, McGavin et al. introduced the 12-min walk test to evaluate disability in patients with COPD. Shortly thereafter, this was modified by Guyatt et al. to the 6-min walk distance (6MWD). The outcome measure commonly reported is the distance traveled in the allotted 6 min. The 6MWD has demonstrated good reliability and validity as a measure of functional capacity,3 and its utility has been enhanced by the availability of published normative tables.6,7 However, the 6MWD, when compared to other measures of function, and morbidity and mortality has been inconsistent.

Several factors may explain these inconsistencies. The height of the subject affects stride length. This can potentially influence the distance covered and the efficiency of ambulation. The body weight of the patient directly affects the work/energy required to perform the walk. In the measurement of the 6MWD, we are interested in the physiologic alteration imposed by the disease, amplified by exacerbations and benefited by therapeutic interventions including exercise training. The 6MWD is intended to account for work (energy expenditure), which is determined as force × distance traveled, therefore, it would seem logical to include force (body weight) as well as walk distance when assessing an individual’s ability to ambulate.

Chuang et al.8 investigated the use of the body weight-walking distance (ie, body weight × walking distance) product as an alternative method for assessing functional capacity for walking. This calculation accounts for body weight differences and thereby estimates both work and energy expenditure expressed as force × distance. The approach assumes that walking on a level treadmill is equivalent to walking on a level hallway. Cavagna and Margaria9 determined that horizontal work (WHO) on a treadmill can be approximated by the formula WHO ≈ K × m × V × T × cosθ, where K is the work coefficient in kilocalories/kilograms/kilometer, m is the distance in meters, V is the walking velocity, T is the walking period, and θ is the angle of incline for the treadmill. Because θ is zero when walking at the level and K is nearly constant for walking at 50 to 100 m per minute (ie, this relates to stride length, muscle contractile efficiency, and the elastic properties of connective tissues), and T is a constant of 6 min, the equation reduces to the following simpler form: WHO ≈ m × V. This equation can be expressed as the product of distance traveled × body weight. Therefore, the reduced equation is simply the equation for work, which is W = F × D, where W is work, F is force, and D is distance. Another advantage of the proposed work calculation is its ease of conversion to standard indexes of caloric expenditure. Based on these observations we hypothesize that expressing the 6-min walk (6MW) in work units will improve its accuracy and extend the utility of the 6MWD test. Therefore, the aim of this investigation was to determine the utility of the body weight × walking distance product (ie, calculated work) for the 6MW. Furthermore, because men are known to possess greater height, body weight, and functional ability than women, we elected to analyze and present some gender-specific data as well as combined data for the group.

**Materials and Methods**

**Study Population**

One hundred twenty-four patients (90 men and 34 women) between 45 and 81 years of age with moderate-to-very severe COPD participated in this clinical trial. This trial was approved by the local institutional review board. All patients were initially screened for study eligibility by a pulmonary physician. All participants met the following entry criteria: (1) FEV1 35 to 70% of predicted, FEV1/FVC ratio 30 to 60%, and a total lung capacity (TLC) > 90% of predicted; (2) capable of undergoing exercise testing to peak effort; (3) resting PaO2, 35 to 60 mm Hg; (4) a prebronnchodilator to postbronchodilator response of < 20%; (5) greater than an eighth-grade education and able to read; (6) hypoxemia that is correctable with low flow oxygen administration (ie, oxygen was administered using a nasal cannula at an oxygen delivery to maintain pulse oximetric saturation (SpO2) > 90%); and (7) all participants were in a nonacute phase of their disease and were receiving a stable drug regimen. Participants had no coexisting medical conditions that would interfere with physiologic testing or the ability to complete written questionnaires. Exclusionary criteria included the presence of cardiac, renal, or endocrine disease, claudication limiting exercise capacity, musculoskeletal pain, syncope, significant ST-T depression or cardiac arrhythmia on exercise testing, or a pattern for a restrictive lung disease. The mean (± SD) group demographic characteristics can be found in Table 1.

**Pulmonary Function**

Spirometry was performed using a rolling-seal spirometer (Vmax 20C; SensorMedics, Yorba Linda, CA). Lung volumes were measured with a body plethysmograph (Vmax 22; AutoBox;
SensorMedics). The diffusing capacity of the lung for carbon monoxide (DLco) was measured by the single-breath technique of Jones and Mead13 using the above-mentioned system (Vmax 22, AutoBox; SensorMedics). The normal values of Crapo et al11 were used for spirometric measurements. Normal predicted lung volumes were derived from the equations of Goldman and Becklake12 (for women) and from those of Boren et al13 (for men). The prediction of DLco was performed according to the data of Make et al.14 All values reported for pulmonary function testing were obtained after the patient received albuterol via a metered-dose inhaler. All patients had prior instruction in the use of metered-dose inhalers and were observed for the effective administration of the bronchodilator. The dosing protocol was as follows: administer 1 puff; wait 10 min; administer 1 additional puff; wait another 10 min, prior to performing the postbronchodilator spirometry. Pulmonary function testing was performed following the standards outlined by the American Thoracic Society16.

### Table 1—Demographic Characteristics for the COPD Patients Studied

<table>
<thead>
<tr>
<th>Variable</th>
<th>Combined</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>66.8 ± 7.3</td>
<td>66.9 ± 6.9</td>
<td>66.5 ± 7.1</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>81.0 ± 17.2</td>
<td>55.2 ± 14.7</td>
<td>69.3 ± 18.2</td>
</tr>
<tr>
<td>Height, cm</td>
<td>171.8 ± 9.3</td>
<td>175.5 ± 7.4</td>
<td>161.7 ± 5.9</td>
</tr>
<tr>
<td>BMI</td>
<td>27.1 ± 5.2</td>
<td>27.3 ± 4.6</td>
<td>26.4 ± 6.7</td>
</tr>
<tr>
<td>Smoking history, pack-yr</td>
<td>61.9 ± 33.6</td>
<td>66.4 ± 30.9</td>
<td>47.9 ± 37.7</td>
</tr>
</tbody>
</table>

†Values given as mean ± SD. BMI = body mass index.  
§Not significant.  
‡p < 0.001.  
§p < 0.01.

### 6MWD

We conducted the 6MWD test as described by Guyatt and colleagues,17 which was a modification of the 12-min walk test originally described by McGavin et al. A 100-foot (30.5-m) hospital corridor course was used and was marked by colored tape at each end. Patients were instructed to walk from end to end at their own pace, while attempting to cover as much distance as possible in the allotted 6 min. A research assistant timed the walk and recorded the distance traveled, the Borg scores for dyspnea and leg fatigue, as well as heart rate for each minute of walking completed. We continuously monitored the SpO2 of each patient. For patients requiring supplemental oxygen (nine patients), the research assistant carried a portable oxygen cylinder during the walk. Supplemental oxygen was prescribed at a flow that was sufficient to maintain SpO2 at > 90%. The research assistant offered verbal encouragement to each patient. Patients were allowed to stop and rest as necessary but were encouraged to proceed with the walk on recovery. At the end of the 6MW, the total distance covered was recorded to the nearest meter.

### Exercise Gas Exchange

Exercise gas exchange measurements were obtained using an electronically braked cycle ergometry 30 min after the administration of bronchodilator therapy. Each patient was prepared for testing after a detailed explanation of the procedure was delivered and discussed. ECG electrodes were positioned on the thorax using a standard 12-lead configuration. The patient then sat on the ergometer, where the seat height was adjusted to full knee extension. The mouthpiece was placed in the patient’s mouth, and the nose clip was secured in order to prevent air leaks. The technician observed the end-tidal CO2 values, and when they stabilized a 3-min resting baseline gas value was measured. Each subject was instructed to use specific hand signals during the test. Gas exchange data were analyzed (CPX-D gas exchange system; Medical Graphics; St. Paul, MN). The system was recalibrated prior to each test using known gas concentrations, and a volume syringe was used to ensure the accuracy of the pneumotach. Following testing, the data were analyzed, a printed copy of the data was obtained, and the data were stored for future reference. Normal predicted values were computed according to the method of Wasserman et al.10

### Ramp Cycle Ergometry

A ramp cycle ergometry protocol was used for each patient. Ramp workload increments were determined using the patient’s age, reported home activities, and measured pulmonary function data.18 Peak ventilatory capacity was estimated according to the method of Carter et al.20 These criteria were selected to attain a balance between maximizing data collection and work performance, while minimizing the fatigue. Once the workload was selected (typically, between 10 to 30 W), the computer was programmed to deliver a patient-specific ramp workload after 3 min of resting data collection and 1 min of zero-load cycle ergometry. Each patient pedalled to his or her limit of effort. If a patient was stopped by the technician, he/she was either retested at a later time or was excluded from the study. The criteria for terminating testing included the following: an arrhythmia contra-indicating further testing; ST-T wave changes suggesting ischemia; a significant increase in BP (ie, > 20 mm Hg); patient confusion; or equipment problems. Gas exchange data were obtained as outlined above.

### Statistical Analysis

All statistics, except for receiver operating characteristic (ROC) curve analyses, were generated using a personal computer (PC-SAS, version 8e; SAS Institute; Cary, NC). Demographic statistics were generated for the variables of interest and were expressed as the mean ± SD. Correlation techniques were used to explore relationships among the variables under study. To discern statistically significant differences, t tests or analysis of variance techniques were used. A computer program (MedCalc, version 6.15; MecCalc; Mariakerke, Belgium) was used to generate a comparison of ROC curves for assessing the optimal combinations of sensitivity and specificity of various case definitions through area-under-the-curve analyses.21–23 The level of significance was set at 0.05.

### RESULTS

All 90 men and 34 women completed the 6MW test and cycle ergometry with gas exchange. Men were slightly taller and heavier than women (Table 1). Both men and women had extensive smoking histories, with men reporting a significantly greater number of pack-years of smoking (66 pack-years) than women (48 pack-years; p < .01). As presented in Table 2, disease...
severity ranged from moderate to severe airway obstruction, as determined by their pulmonary function indexes. Women presented with a significantly lower mean DLCO than did men (10.34 ± 3.9 vs 14.7 ± 6.1 mL/min/mm Hg, respectively; p < 0.001). This finding suggested greater emphysematous changes in the women who were studied.

All patients presented with a significantly reduced work capacity. Overall, the mean peak oxygen uptake (VO₂) during cycle ergometry was 1,095.6 ± 323.5 mL/min at a mean workload of 63.4 ± 25.3 W. This represented 60.5 ± 13.3% of the predicted VO₂. Similar reductions in other peak gas exchange indexes were noted (Table 3).

Each patient completed the 6MW test in the hospital corridor. The mean distance covered for all patients tested was 403.0 ± 81.6 m. Only two patients required supplemental oxygen to maintain a SpO₂ of > 90%. When compared as a percentage of the predicted normal age-specific and gender-specific walk distance values, each gender presented with an equivalent reduction in total walk distance (78.6 ± 14.6% vs 79.9 ± 17.5% predicted; p > 0.05). Dyspnea and leg fatigue ratings for all patients increased during the course of the walk, peaking by the end of the walk. Perceived dyspnea and leg fatigue scores were equivalent for each gender at the end of the 6MW test (p > 0.05) [Table 3]. Work for the 6MW test was calculated as the product of the walk distance (in meters) × body weight (in kilograms), with the resultant work expressed in kilogram-meters per meter of work accomplished for the 6MW. The mean total work for the entire group was 32,637.0 ± 10,314.8 kg/m.

Correlational techniques were used to investigate the relationships among pulmonary function, gas exchange, and walk indexes. Table 4 presents the correlation coefficients for 6MWD and the 6-min distance × body weight product (6MWORK) to those for selected pulmonary function indexes. Table 5 presents the correlation coefficients for comparisons of 6MWD and 6MWORK to peak cycle ergom-

Table 2—Indices of Pulmonary Function for the COPD Patients Evaluated*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Combined</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV₁, L</td>
<td>1.33 ± 0.43</td>
<td>1.43 ± 0.44</td>
<td>1.08 ± 0.26</td>
</tr>
<tr>
<td>% predicted</td>
<td>45.9 ± 12.5</td>
<td>44.9 ± 12.6</td>
<td>48.4 ± 12.1</td>
</tr>
<tr>
<td>FVC, L</td>
<td>3.25 ± 0.91</td>
<td>3.59 ± 0.81</td>
<td>2.35 ± 0.44</td>
</tr>
<tr>
<td>% predicted</td>
<td>82.9 ± 15.5</td>
<td>83.9 ± 16.3</td>
<td>80.1 ± 12.7</td>
</tr>
<tr>
<td>FEV₁/FVC</td>
<td>41.9 ± 10.2</td>
<td>40.2 ± 9.3</td>
<td>46.5 ± 11.0</td>
</tr>
<tr>
<td>% predicted</td>
<td>56.2 ± 13.9</td>
<td>54.3 ± 13.1</td>
<td>61.1 ± 15.2</td>
</tr>
<tr>
<td>VC, L</td>
<td>3.44 ± 0.93</td>
<td>3.8 ± 0.81</td>
<td>2.49 ± 0.44</td>
</tr>
<tr>
<td>IC, L</td>
<td>2.58 ± 0.77</td>
<td>2.83 ± 0.70</td>
<td>1.89 ± 0.51</td>
</tr>
<tr>
<td>RV, L</td>
<td>3.77 ± 0.92</td>
<td>3.91 ± 0.94</td>
<td>3.39 ± 0.73</td>
</tr>
<tr>
<td>TLC, L</td>
<td>7.21 ± 1.40</td>
<td>7.70 ± 1.22</td>
<td>5.88 ± 0.99</td>
</tr>
<tr>
<td>% predicted</td>
<td>129.4 ± 4.0</td>
<td>131.4 ± 20.5</td>
<td>123.0 ± 16.1</td>
</tr>
</tbody>
</table>
| DLCO, mL/min/mm Hg | 13.6 ± 5.9 | 14.7 ± 6.1 | 10.34 ± 3.9%
| DLVA, L/min/mm Hg | 2.03 ± 1.25 | 1.87 ± 1.19 | 2.49 ± 1.36 |

*Values given as mean ± SD. VC = vital capacity; IC = inspiratory capacity; RV = residual volume; TLC = total lung capacity; DLVA = lung diffusion corrected for alveolar ventilation.

†Not significant.
‡p < 0.001.
§p < 0.01.
¶p < 0.05.

Table 3—Peak Cycle Ergometry Gas Exchange Indices*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Combined</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work, W</td>
<td>63.4 ± 25.4</td>
<td>69.0 ± 25.3</td>
<td>48.7 ± 18.9</td>
</tr>
<tr>
<td>VO₂, mL/min</td>
<td>1,095.6 ± 323.5</td>
<td>1,184.0 ± 302.1</td>
<td>860.3 ± 256.5</td>
</tr>
<tr>
<td>% predicted</td>
<td>60.5 ± 13.3</td>
<td>57.5 ± 11.4</td>
<td>68.2 ± 14.8</td>
</tr>
<tr>
<td>VCO₂, mL/min</td>
<td>1,065.3 ± 361.4</td>
<td>1,153.0 ± 349.8</td>
<td>830.5 ± 281.2</td>
</tr>
<tr>
<td>VE, L/min</td>
<td>39.5 ± 12.1</td>
<td>42.6 ± 11.9</td>
<td>31.1 ± 8.1</td>
</tr>
<tr>
<td>% predicted</td>
<td>79.9 ± 19.1</td>
<td>80.8 ± 19.6</td>
<td>77.4 ± 17.4</td>
</tr>
<tr>
<td>RR, breaths/min</td>
<td>31.4 ± 6.2</td>
<td>30.7 ± 5.8</td>
<td>33.4 ± 7.0</td>
</tr>
<tr>
<td>Vt, mL/breath</td>
<td>1,294.3 ± 398.8</td>
<td>1,425.0 ± 370.3</td>
<td>946.9 ± 229.1</td>
</tr>
<tr>
<td>SpO₂, %</td>
<td>95.6 ± 3.5</td>
<td>95.5 ± 3.6</td>
<td>95.3 ± 3.3</td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>117.0 ± 18.1</td>
<td>118.3 ± 19.4</td>
<td>113.5 ± 14.4</td>
</tr>
<tr>
<td>Borg score</td>
<td>5.5 ± 2.9</td>
<td>5.5 ± 2.9</td>
<td>5.6 ± 2.6</td>
</tr>
<tr>
<td>Dyspnea</td>
<td>4.5 ± 2.8</td>
<td>4.3 ± 2.8</td>
<td>5.1 ± 2.9</td>
</tr>
</tbody>
</table>

*Values given as mean ± SD. VCO₂ = carbon dioxide production; RR = respiratory rate; HR = heart rate.

†p < 0.0001.
‡Not significant.
§p < 0.05.
there exists a cut point for 6MWORK that achieves areas of 0.073 (p = 0.60) and 0.708 for 6MWD, a difference in ses. The area under the curve was 0.782 for relevant to the aims of these cross-sectional analy-
determined at the start of the trial and also was used to move that body through space. Since all individ-
us vary with respect to body weight, the expected work of walking/ambulation will vary. By including the work calculation for the 6MW, a major source of variation is accounted for (ie, less scatter). Thus, the resultant measurement is considered to be more precise (Fig 1, 2).

In 1955, Passmore and Durnin demonstrated the effects of increasing body weight on energy expenditure during level walking at different speeds. They documented that changes in weight can significantly affect the energy requirement, and thus the amount of work accomplished. Since work is closely related to the energy requirements for task participation, it should yield an improved outcome index for the 6MW when compared to the distance ambulated. The calculation of 6MWORK also may assist in accounting for differences in walk distance resulting from changes in body weight alone. Another advantage of using work units as the reported measure focuses on the utility of the measure across different tasks. The work measure can be easily converted to caloric equivalents or power, which is defined as work per unit of time. Caloric equivalents are commonly used in nutritional and performance calculations. Thus, the utility of this conversion is substantial. Last, if the time of the performance is changing, the power calculation may offer some advantage.

As in prior trials, work capacity decreased for each gender. The physiologic gas exchange data suggest ventilatory limitation to exercise in this group. This is supported by the highly significant correlations between 6MWORK and the FEV1, FVC, DLCO, and DLVA, with less significant relationships noted for 6MWD. Each of these indexes is related to the patient’s ability to ventilate and to perform exercise or the activities of daily living.

An additional and important finding is that leg fatigue scores were greater than those for the sensation of dyspnea, suggesting that leg fatigue is contributing to the achieved limits of exercise. This finding is consistent with that of Leblanc et al., but is counter to the findings of others. The lack of

### Table 4—Correlation Coefficients for 6MWD and 6MWORK to Selected Pulmonary Function Indices for the Entire Group*

<table>
<thead>
<tr>
<th>Variable</th>
<th>6MWD r Value</th>
<th>6MWD p Value</th>
<th>6MWORK r Value</th>
<th>6MWORK p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLCO, mL/min/mm Hg</td>
<td>0.46</td>
<td>0.0001</td>
<td>0.60</td>
<td>0.0001</td>
</tr>
<tr>
<td>FEV1, L</td>
<td>0.38</td>
<td>0.0001</td>
<td>0.52</td>
<td>0.0001</td>
</tr>
<tr>
<td>FVC, L</td>
<td>0.38</td>
<td>0.0001</td>
<td>0.48</td>
<td>0.0001</td>
</tr>
<tr>
<td>VC, L</td>
<td>0.40</td>
<td>0.0001</td>
<td>0.48</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

*See Table 2 for abbreviation not used in the text.

### Table 5—Correlation Coefficients for 6MWD and 6MWORK to Selected Cycle Ergometry Gas Exchange Indices

<table>
<thead>
<tr>
<th>Variable</th>
<th>6MWD r Value</th>
<th>6MWD p Value</th>
<th>6MWORK r Value</th>
<th>6MWORK p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work, W</td>
<td>0.59</td>
<td>0.0001</td>
<td>0.79</td>
<td>0.0001</td>
</tr>
<tr>
<td>VO2, mL/min</td>
<td>0.54</td>
<td>0.0001</td>
<td>0.81</td>
<td>0.0001</td>
</tr>
<tr>
<td>VCO2, mL/min</td>
<td>0.56</td>
<td>0.0001</td>
<td>0.77</td>
<td>0.0001</td>
</tr>
<tr>
<td>Vt, L</td>
<td>0.46</td>
<td>0.0001</td>
<td>0.59</td>
<td>0.0001</td>
</tr>
<tr>
<td>Vt, mL</td>
<td>0.43</td>
<td>0.0001</td>
<td>0.57</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Discussion

Our findings indicate an advantage for using the calculation of work over simple distance covered in 6-min of level walking for patients with COPD (correlational analysis with less scatter observed and ROC analysis). The work calculation takes into account the mass of the body and the energy required to move that body through space. Since all individuals vary with respect to body weight, the expected work of walking/ambulation will vary. By including the work calculation for the 6MW, a major source of variation is accounted for (ie, less scatter). Thus, the resultant measurement is considered to be more precise (Fig 1, 2).

In 1955, Passmore and Durnin demonstrated the effects of increasing body weight on energy expenditure during level walking at different speeds. They documented that changes in weight can significantly affect the energy requirement, and thus the amount of work accomplished. Since work is closely related to the energy requirements for task participation, it should yield an improved outcome index for the 6MW when compared to the distance ambulated. The calculation of 6MWORK also may assist in accounting for differences in walk distance resulting from changes in body weight alone. Another advantage of using work units as the reported measure focuses on the utility of the measure across different tasks. The work measure can be easily converted to caloric equivalents or power, which is defined as work per unit of time. Caloric equivalents are commonly used in nutritional and performance calculations. Thus, the utility of this conversion is substantial. Last, if the time of the performance is changing, the power calculation may offer some advantage.

As in prior trials, work capacity decreased for each gender. The physiologic gas exchange data suggest ventilatory limitation to exercise in this group. This is supported by the highly significant correlations between 6MWORK and the FEV1, FVC, DLCO, and DLVA, with less significant relationships noted for 6MWD. Each of these indexes is related to the patient’s ability to ventilate and to perform exercise or the activities of daily living.

An additional and important finding is that leg fatigue scores were greater than those for the sensation of dyspnea, suggesting that leg fatigue is contributing to the achieved limits of exercise. This finding is consistent with that of Leblanc et al., but is counter to the findings of others. The lack of
agreement may be explained partially by differences in study populations, sample sizes, previous exercise programs, or testing methods.

The 6MW test has been used extensively throughout the world to evaluate functional capacity and dyspnea sensation in many patient groups, and has withstood the test of time.\textsuperscript{3,32–34} The 6MW test is simple to administer, requires no expensive or sophisticated equipment, and has been standardized. The 6MW test has demonstrated good reliability and validity, and is considered to be a submaximal performance test by design.\textsuperscript{8} The main measurement end point, to date, has been the total distance covered in the allotted 6-min period. Yet, only modest correlations to other indexes of work capacity have been reported.\textsuperscript{35} Chuang et al\textsuperscript{8} drew on their understanding of physics and work physiology by concluding that a better unit of measure for the 6MW is the product of body weight (in kilograms) $\times$ distance walked (in meters) as an index of work.

We have confirmed and extended their findings in
a number of ways. First, we have confirmed that there is less scatter in the data when plotting or correlating peak \( \dot{V}O_2 \) to 6MWORK, and this is in agreement with the data obtained for the 33 men who were studied previously. Second, we have demonstrated less scatter between 6MWORK and the indexes of pulmonary function and peak gas exchange for women compared to men. Last, and most importantly, using ROC analysis (Fig 3), we demonstrated that the area under the curve is significantly greater for 6MWORK compared to 6MWD for the same individuals. This analysis compares the performance of the 6MWD to that of the 6MWORK calculation. The left-sided shift for the 6MWORK curve on the figure demonstrated improved sensitivity and specificity for the 6MWORK measure compared to that for the 6MWD. Thus, the calculation and reporting of 6MWORK appears to be a valuable option for researchers and clinicians. Furthermore, by using this convention for expressing the results of the 6MW, researchers and clinicians will be in a better position to relate the results to other standardized indexes in physiology and medicine.

If we use distance covered (in meters) and weight (in kilograms), the product would be expressed in units of kilogram/meters. This unit of measure is easily converted to such classic physiologic indexes as foot/pound, kilogram/meters, kilocalories, or kilojoules. To go a step further, power is defined as work/unit of time and is commonly represented by such indexes as horsepower, kilogram/meter/minute, foot/pounds/minute, watt, kilocalories/minute, and kilojoules/minute. As a result, energy and work are inseparable, and, by using 6MWORK for reporting the results of the 6MW test, cross-comparisons with existing data become easier and more direct.

**Summary**

We have demonstrated that the product of body weight \( \times \) distance or work is a good measure for reporting exercise capacity for the 6MW test for patients with COPD. This work calculation yields improved correlation coefficients with lung function and gas exchange indexes in the patients studied. Through ROC analysis, the area under the curve was significantly greater for 6MWORK compared to 6MWD. This suggests greater sensitivity and specificity for 6MWORK. Thus, the work calculation appears to be an accurate measure of level walking ability and extends the utility of the 6MW test. Since work is better correlated to metabolic expenditure, and since metabolic expenditure is closely coupled to changes in ventilation, cardiac performance, and other metabolic pathways, the calculation of work as an outcome for the 6MW test is advantageous. We
recommend that the 6MWORK calculation be used in conjunction with 6MWD in future studies to better characterize the functional capacity of patients with COPD.

REFERENCES