Exercise Testing, 6-Min Walk, and Stair Climb in the Evaluation of Patients at High Risk for Pulmonary Resection*

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To evaluate three types of exercise testing in prediction of death or prolonged mechanical ventilation after lung resection in high-risk patients, 16 patients underwent evaluation prior to resection. Eleven patients (group 1) had minor or no complications (arrhythmia, atelectasis, pneumonia) and five patients (group 2) died within 90 days of surgery. Exercise testing showed that group 1 had a shorter 6-min walk distance and a higher stair climb than group 2. The maximum oxygen uptake on a cycle ergometer was not significantly different between groups, although only ten patients completed this test. Group 1 had a significantly greater calculated oxygen uptake with stair climbing than group 2. A 6-min walk distance of greater than 1,000 feet and a stair climb of greater than 44 steps were predictive of successful surgical outcome. Preoperative exercise testing is a useful adjunct to traditional spirometric testing in evaluation of the high-risk surgical patient.

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PPO = predicted postoperative

Surgical resection offers the best hope for cure in the treatment of non-small cell lung cancer. An overall five-year survival following surgical resection of 30 to 40 percent contrasts favorably with the 5 to 10 percent five-year survival following radiotherapy. Patients with bronchogenic carcinoma often have severe chronic obstructive lung disease and surgical mortality in this high-risk subgroup approaches 15 to 20 percent. The goal of preoperative assessment is to offer potentially curative surgery to the maximum number of patients while identifying those patients at risk for mortality or significant morbidity.

Traditionally, a predicted postoperative FEV₁ (FEV₁/PPO) of 0.8 L (based on perfusion scintigraphy) is a minimal accepted FEV₁ for a patient undergoing resection. However, 0.8 L as a single value cannot be used to discriminate between patients of different ages, sizes, sexes, and levels of cardiovascular fitness. Many patients who die or require prolonged mechanical ventilation after resection have an FEV₁/PPO exceeding 0.8 L.

Exercise testing or a symptom-limited maximal oxygen uptake (VO₂ max) may better predict successful surgical outcome as they provide a broader assessment of the cardiopulmonary axis. To this date, the stair climb and 6-min walk have not been studied extensively; limited data are available on the 12-min walk. In an attempt to predict surgical morbidity and mortality we compared the relative value of the 6-min walk, stair climb, and cycle ergometry cardiopulmonary exercise test with more traditional parameters such as the FEV₁, forced vital capacity (FVC), diffusing capacity for carbon monoxide (DCO), and their predicted postoperative values.

Patients and Methods

Between January 1990 and May 1991, 33 eligible patients were entered into the study. All had biopsy-proven bronchogenic carcinoma and an FEV₁ of 1.6 L or less. All patients gave written informed consent prior to physiologic testing.

Resting spirometry and diffusing capacity values were obtained with patients in a seated position using a wedge spirometer and single-breath carbon monoxide diffusing system (Spinnaker TL pulmonary function analyzer, Cybermedic, Inc., Louisville, Colo.). The diffusing capacity was corrected for hemoglobin concentration. Arterial blood gas values were measured with the patient seated and breathing room air. (Radiometer ABC300, Radiometer America, Westlake, Ohio). If a 15 percent or greater rise in the FEV₁ was noted after administration of albuterol, the post-bronchodilator values were used. No patient had a post-bronchodilator FEV₁ of greater than 1.6 L (except patient 1 who had a value of 1.61 L). Values were expressed as a percentage of normal values derived from standard tables.

Patients were exercised on a cycle ergometer. (Monarch model 868 bicycle ergometer, Monarch-Cressent AB, Varberg, Sweden and Cybermedic Prospector cardiopulmonary stress testing unit, Cybermedic, Inc., Louisville, Colo.). The work load was increased every minute by 15 W. Continuous measurements were made of ventilation, mixed expired oxygen and carbon dioxide concentrations, and carbon dioxide output. Work load, volumes and O₂/CO₂ analyzers were calibrated prior to each study. Arterial saturation was measured by finger oximeter (Nellcor N-100 pulse oximeter, Nellcor, Inc, Hayward, Calif). A symptom-limited VO₂ max was determined; in no case was the test stopped because of ECG abnormalities. On a separate day, patients were asked to perform a timed, symptom-limited stair climb at their own pace (11 steps per flight with each step measuring 0.17 m in height). Finger oximetry was used to measure arterial oxygen saturation. Work and VO₂ max were calculated by the following formulas:

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The 6-min walk was performed twice on the same day as the stair climb. Patients were instructed to walk at a brisk pace in a hall for 6 min and were allowed to rest during the 6-min interval. Oxygen saturation was measured by finger pulse oximetry. The walk distance was measured in feet. Patients rested for 15 to 30 min between individual 6-min walk tests. The stair climb was performed after either one or both 6-min walks in a nonrandomized order at the discretion of the therapist.

Each patient underwent quantitative perfusion pulmonary scintigraphy. Patients were injected with 4 MCI of 99m technetium-macroaggregated albumin and imaging was performed by a gamma camera linked to a computer. The lung fields were divided into four zones: right upper lung, right lower lung, left upper lung, left lower lung, using standard images, including the oblique anteroposterior, and lateral images. The pulmonary function values were calculated as follows:

\[
\text{FEV}_{1}^\text{PPO} = \text{preoperative FEV} \times \left(1-\text{fractional perfusion of the lung to be resected} [F]\right)
\]

The same calculation was performed for FEV, % PPO and Dco % PPO. For patients in whom segmentectomy was planned, the number of segments in each zone was divided into the perfusion fraction for that lobe and this new fraction was used to determine (F).

The decision to perform surgery was made jointly by the thoracic surgeon and pulmonary physician who were blinded to the results of the stair climb, 6-min walk and cycle ergometer tests. Pulmonary function tests and the physician's subjective assessment of the patient's functional status were used to determine operability. Three cases were deemed inoperable based on these criteria; one patient refused surgery after being informed of the risk assessment. Other potentially eligible patients may not have been referred by their pulmonologists for surgical consideration.

A physician blinded to the results of the exercise tests followed up patients after surgery. Minor complications included arrhythmias requiring treatment; pneumonia as defined by an infiltrate on a chest radiograph; a temperature greater than 38°C for 48 h; leukocytosis (greater than 12,000 cells/μl); pleural effusion that required therapeutic bronchoscopy; myocardial infarction (elevated CPK-MB fraction); and an angiographically proven pulmonary embolism. Major complications included death within 30 days of surgery and mechanical ventilator dependency for more than 30 days.

**Statistical Analysis**

For the continuous variables, groups were compared using Student's t test unless the distribution of responses within either group was skewed; if the latter was the case, then the Wilcoxon rank sum test was used. When threshold values were obtained, producing discrete outcomes, the Fisher's exact test was utilized to examine the association between the groups and the discrete variables.

**Results**

Twenty-three patients underwent surgery for staging and possible resection (Table 1). Mediastinoscopy revealed mediastinal lymph node metastasis in four patients who did not undergo resection. Three patients were not fully evaluated. Limited data from the three patients who were not formally evaluated are listed in Table 2. One of three patients died postoperatively (day 65). This patient's immediate postoperative course was complicated by a myocardial infarction. She was readmitted to the hospital 35 days following surgery with an empyema and died 14 days later.

In all, 16 patients underwent resection and preoperative evaluation. Preoperative and postoperative data are shown in Tables 3 and 4. No complications were observed in six patients (38 percent); five patients (31 percent) had minor complications; and one patient (6 percent) died within 30 days of surgery. Five patients (31 percent) died within 90 days of surgery. Two groups were assigned; patients in group 1 had no or minor complications and patients in group 2 died within 90 days of surgery. Group 2 patients had significantly more days in the intensive care unit and hospital. Four of five patients in group 2 died in the hospital. Three of these four patients were ventilator-dependent at the time of death (patients 12, 14, and 16). One patient (patient 15) left the hospital after 21 days but returned two months later in a state of respiratory failure with metastasis to the lungs. No patient in group 1 has died with the follow-up period being as long as 18 months.

Preoperative pulmonary function tests (Table 3) revealed significant differences in the FEV₁ percent predicted between the two groups (group 1, 50 ± 13 percent vs group 2, 40 ± 4 percent). A trend toward significance was seen in the FEV₁/FVC ratio and in the FEV₁ % PPO. There was no significant difference

**Table 1—Study Patients**

<table>
<thead>
<tr>
<th>Patient</th>
<th>FEV₁</th>
<th>FEV₁ %</th>
<th>FEV₁ PPO</th>
<th>Mech vent</th>
<th>Hospital days</th>
<th>Operation</th>
</tr>
</thead>
</table>
| 1       | 1.14 | 57     | 0.84     | 1        | 16          | Pneumonec-
| 2       | 1.13 | 57     | 1.07     | 1        | 1           | tomy     |
| 3       | 1.23 | 37     | 0.55     | 1        | 8           | Lobectomy|

*Calculated in anticipation of pneumonectomy.
Table 3—Baseline and Postoperative Predicted Values

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age (yr), Sex</th>
<th>FVC, L</th>
<th>FVC, % Predicted</th>
<th>FEV₁, L</th>
<th>FEV₁, % Predicted</th>
<th>FEV₁/FVC</th>
<th>Dco, % Predicted</th>
<th>FEV₁/PPO</th>
<th>FEV₁,%PPO</th>
<th>Dco% PPO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>62, F</td>
<td>3.26</td>
<td>98</td>
<td>1.61</td>
<td>62</td>
<td>0.49</td>
<td>97</td>
<td>1.18</td>
<td>45</td>
<td>71</td>
</tr>
<tr>
<td>2</td>
<td>75, M</td>
<td>1.87</td>
<td>63</td>
<td>1.46</td>
<td>61</td>
<td>0.68</td>
<td>110</td>
<td>1.33</td>
<td>56</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>64, F</td>
<td>2.21</td>
<td>54</td>
<td>1.37</td>
<td>66</td>
<td>0.62</td>
<td>56</td>
<td>0.86</td>
<td>41</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>68, M</td>
<td>4.12</td>
<td>94</td>
<td>1.28</td>
<td>95</td>
<td>0.31</td>
<td>66</td>
<td>0.97</td>
<td>24</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>73, M</td>
<td>33.4</td>
<td>73</td>
<td>1.49</td>
<td>43</td>
<td>0.45</td>
<td>41</td>
<td>1.27</td>
<td>37</td>
<td>35</td>
</tr>
<tr>
<td>6</td>
<td>75, F</td>
<td>2.08</td>
<td>72</td>
<td>1.45</td>
<td>67</td>
<td>0.70</td>
<td>51</td>
<td>1.35</td>
<td>62</td>
<td>47</td>
</tr>
<tr>
<td>7</td>
<td>63, M</td>
<td>2.25</td>
<td>47</td>
<td>1.14</td>
<td>83</td>
<td>0.51</td>
<td>66</td>
<td>1.06</td>
<td>29</td>
<td>47</td>
</tr>
<tr>
<td>8</td>
<td>87, M</td>
<td>2.36</td>
<td>66</td>
<td>1.50</td>
<td>57</td>
<td>0.64</td>
<td>56</td>
<td>1.13</td>
<td>33</td>
<td>42</td>
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<tr>
<td>9</td>
<td>60, M</td>
<td>2.38</td>
<td>55</td>
<td>1.50</td>
<td>44</td>
<td>0.56</td>
<td>56</td>
<td>1.13</td>
<td>33</td>
<td>42</td>
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<tr>
<td>10</td>
<td>63, M</td>
<td>2.66</td>
<td>72</td>
<td>1.55</td>
<td>46</td>
<td>0.58</td>
<td>72</td>
<td>1.40</td>
<td>41</td>
<td>65</td>
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<tr>
<td>11</td>
<td>71, M</td>
<td>2.06</td>
<td>49</td>
<td>1.52</td>
<td>47</td>
<td>0.77</td>
<td>72</td>
<td>1.27</td>
<td>38</td>
<td>58</td>
</tr>
<tr>
<td>Mean</td>
<td>69</td>
<td>2.6</td>
<td>69</td>
<td>1.44</td>
<td>50</td>
<td>0.57</td>
<td>67</td>
<td>1.17</td>
<td>41</td>
<td>54</td>
</tr>
<tr>
<td>± SD</td>
<td>8.0</td>
<td>0.7</td>
<td>17</td>
<td>0.13</td>
<td>13</td>
<td>0.13</td>
<td>21</td>
<td>0.17</td>
<td>11</td>
<td>19</td>
</tr>
</tbody>
</table>

Group 2: death <90 days after surgery (n = 5)

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age (yr), Sex</th>
<th>FVC, L</th>
<th>FVC, % Predicted</th>
<th>FEV₁, L</th>
<th>FEV₁, % Predicted</th>
<th>FEV₁/FVC</th>
<th>Dco, % Predicted</th>
<th>FEV₁/PPO</th>
<th>FEV₁,%PPO</th>
<th>Dco% PPO</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>68, M</td>
<td>2.74</td>
<td>67</td>
<td>1.36</td>
<td>43</td>
<td>0.50</td>
<td>76</td>
<td>1.21</td>
<td>38</td>
<td>68</td>
</tr>
<tr>
<td>13</td>
<td>54, M</td>
<td>2.77</td>
<td>54</td>
<td>1.25</td>
<td>33</td>
<td>0.45</td>
<td>52</td>
<td>1.06</td>
<td>28</td>
<td>44</td>
</tr>
<tr>
<td>14</td>
<td>80, M</td>
<td>3.84</td>
<td>95</td>
<td>1.44</td>
<td>40</td>
<td>0.37</td>
<td>47</td>
<td>1.35</td>
<td>38</td>
<td>44</td>
</tr>
<tr>
<td>15</td>
<td>69, M</td>
<td>3.86</td>
<td>83</td>
<td>1.40</td>
<td>39</td>
<td>0.36</td>
<td>89</td>
<td>0.95</td>
<td>24</td>
<td>54</td>
</tr>
<tr>
<td>16</td>
<td>71, M</td>
<td>2.55</td>
<td>61</td>
<td>1.44</td>
<td>44</td>
<td>0.56</td>
<td>67</td>
<td>1.07</td>
<td>33</td>
<td>50</td>
</tr>
<tr>
<td>Mean</td>
<td>68</td>
<td>3.2</td>
<td>72</td>
<td>1.38</td>
<td>40</td>
<td>0.45</td>
<td>66</td>
<td>1.11</td>
<td>32</td>
<td>52</td>
</tr>
<tr>
<td>± SD</td>
<td>9.3</td>
<td>0.6</td>
<td>17</td>
<td>0.08</td>
<td>4</td>
<td>0.09</td>
<td>17</td>
<td>0.19</td>
<td>6</td>
<td>10</td>
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<tr>
<td>p value*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
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<td>&lt;0.05</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

*Group 2 vs group 1.

in FEV₁, FEV₁PPO and Dco percent predicted, and Dco%PPO.

Preoperative exercise testing revealed that group 1 had a significantly longer 6-min walk distance and a higher stair climb than group 2 (Table 4). Group 1 patients had a significantly greater calculated VO₂ with the stair climb than group 2 patients. The cycle ergometer symptom-limited VO₂ max was not significantly different between groups. However, the cycle ergometry exercise test was not completed by all patients; patient 6 could not bicycle correctly, patient 8 required an interpreter, and four patients missed their scheduled cycle ergometry appointments. The limitation to cardiopulmonary exercise testing was primarily respiratory in five patients, cardiac or de-conditioning in three patients, and both cardiac and respiratory in two patients. All patients except patients 6 and 8 exceeded 85 percent of maximally predicted values for heart rate, minute ventilation or both. Oxygen saturation fell below 85 percent in only one patient (patient 7) during exercise testing.

An attempt was made to determine sensitivity and predictive values for the 6-min walk distance, the stair climb and calculated VO₂ for survival longer than 90 days. Using a 6-min walk distance greater than 1,000 feet as predictive of long-term survival greater than 90 days, we found a sensitivity of 100 percent, a positive predictive value of 85 percent, and a negative predictive value of 100 percent. Climbing more than 44 steps had a positive predictive value of 91 percent and a negative predictive value of 80 percent. A calculated VO₂, while climbing stairs, of more than 20 ml/kg/min had a positive predictive value of 92 percent and a negative predictive value of 100 percent. A FEV₁ percent predicted of less than 45 percent had a 100 percent sensitivity, 64 percent specificity, 55 percent positive predictive value and a 100 percent negative predictive value for predicting 90-day mortality.

**DISCUSSION**

In a group of high-risk patients (FEV₁≤1.6 L) who were candidates for lung resection, we found that exercise testing was predictive of prolonged mechanical ventilation and death after surgery. Both the stair climb and 6-min walk were predictive of postoperative death within 90 days. The symptom-limited VO₂ max on the cycle ergometer was not predictive, but interpretation of test results is limited by patient number and cooperation. The calculated VO₂ in the stair climb was predictive of mortality using a threshold value of 20 ml/kg/min.

No single test has accurately predicted postoperative morbidity and mortality in the high-risk thoracotomy patient. In early studies, the preoperative FEV₁ was shown to be predictive of post-thoracotomy complications.16-18 However, the traditional use of a FEV₁PPO of more than 0.8 L does not take into account patient size, sex, age, or cardiovascular function, which may impact upon survival after surgery; major complications (ie, death or prolonged mechanical ventilation) may occur despite an FEV₁PPO greater.
than 0.8 L.7

All patients in our study had an FEV1,PPO of greater than 0.8 L and therefore met traditional resection criteria. Thirty-day postoperative mortality was 6 percent. However, a high 90-day mortality rate, 5 of 16 patients (31 percent) underscores the fragility of this test as a single predictive measurement in the high-risk patient. The 31 percent 90-day mortality rate contrasts with a 9.8 percent (21 of 215 patients; p = 0.05) 90-day mortality rate for all other patients undergoing lung resection for bronchogenic carcinoma at our institution during the same time period.

The FEV1,PPO was lower in nonsurvivors (32 ± 6 vs. 41 ± 11 percent), but the difference did not reach statistical significance. However, all patients who died had an FEV1,PPO of less than 40 percent. Markos etal also noted an increased mortality rate in patients with an FEV1,PPO of less than 40 percent with three of six patients dying as compared with five of ten patients in our study.

Several studies have investigated the role of different exercise tests in predicting postoperative complications.7;10,19,20 Whether exercise testing measures overall patient “fitness” or is an index of the patient’s ability to deliver oxygen to the tissues in the early postoperative period is not clear.

Cycle ergometry allows for accurate measurement of VO2. Prior studies suggest that patients with levels of VO2 less than 10 to 15 mL/kg/min are at high risk for complications.8,9 Bechard and Yetstein reported a 29 percent (two of seven patients) mortality in patients with VO2 less than 10 mL/kg/min. Smith et al reported complications in all six patients with a VO2 less than 15 mL/kg/min as compared with only one of ten patients with a VO2 greater than 20 mL/kg/min or more. The two patients who died in this series had a VO2 max of 18.4 and 13.5 mL/kg/min, respectively. Conversely, Markos et al did not note a significant difference in VO2 between those patients developing complications (16.8 ± 6.2 mL/kg/min) and those who did not (17.5 ± 6.3 mL/kg/min).

The VO2, as determined by cycle ergometry, has been used prospectively by Morice et al to determine operability.21 In a subset of patients whose cases were
deemed inoperable based on a FEV$_1$ of less than 40 percent predicted and a FEV$_1$PPO of less than 33 percent predicted, patients with a VO$_2$ greater than 15 ml/kg/min or more went to surgery. One of six patients developed a complication. Patients with a VO$_2$ less than 15 ml/kg/min received radiation or chemotherapy or both. Finally, Miyoshi et al$^{10}$ and Olsen et al$^{12}$ suggest that submaximal exercise testing may more reliably identify patients at risk for the development of significant morbidity or mortality, although no threshold value has been prospectively evaluated. In summary, existing data regarding the optimal use of VO$_2$ with exercise is conflicting. Most studies agree that patients with a VO$_2$ max greater than 20 ml/kg/min will tolerate surgery with an acceptable morbidity and mortality, while patients with a VO$_2$ max less than 10 to 15 ml/kg/min or more appear to be at increased risk for complications and death.

The adverse significance of a VO$_2$ less than 10 ml/kg/min is supported by our study. Both patients who completed a symptom-limited study with a VO$_2$ less than 10 ml/kg/min died postoperatively as compared with one of eight patients who exceeded 10 ml/kg/min. This particular patient who had a VO$_2$ of 13.5 ml/kg/min was discharged home and subsequently died of lung metastasis and not directly as a result of postoperative complications.

Only one other study has evaluated the predictive value of the stair climb. In a retrospective review, Olsen et al$^{12}$ found that 7 of 54 patients examined who did not complete 5 flights of stairs (75 steps) had a significantly larger number of complications, a longer period of postoperative intubation, and a longer hospital stay; nevertheless, there was no significant difference in the number of steps climbed by patients with and without complications. In a frequently referenced study, Van Nostrand et al$^{13}$ reported that of four patients unable to climb one flight of stairs without severe dyspnea, two died after lung resection. These data were obtained from chart reviews of patient histories.

The appeal of the stair climb is its simplicity and the patient's familiarity with the exercise. None of our patients had difficulty understanding the instructions for the stair climb. Each flight of stairs (11 steps) represented a unit of exercise with all patients stopping at the top of a flight of stairs. Both the number of stairs climbed and the calculated VO$_2$ max from the stair climb predicted 90-day mortality. Patients may push to reach the next landing before stopping, and this may explain the higher calculated VO$_2$ max for this test as compared with the cycle ergometer test. Conversely, however, the calculated VO$_2$ may not be accurate. Actual measurements of expired gases during stair climbing show the VO$_2$ to be lower than the values we calculated for the same number of steps.$^{22}$ We suspect that the symptom-limited VO$_2$ max is higher with stair climbing than with cycle ergometry as shown by other investigators.$^{23,24}$ But not to the extent calculated in our study.

Results from studies utilizing the 12-min walk have been variable. Although the test is a simple, familiar exercise, patients perform less work during walking tests than during a stair climb.$^{23,24}$ The 12-min walk does not correlate well with the FVC or FEV$_1$. In two studies, it was not predictive of postoperative complications.$^{6,13}$ In these two studies, Markos et al$^6$ included patients with much better lung function than the patients in the present study, and Bagge$^{25}$ reported a small group of patients who develop only minor postoperative complications. Overall, the 6-min walk needs further evaluation, but holds promise because of its simplicity and ease of performance.

In summary, patients with an FEV$_1$ less than 1.60 L may be at increased risk of surgical morbidity and mortality and require additional preoperative testing. FEV$_1$% less than 45 percent and FEV$_1$%PPPO less than 40 percent identify a subset at even higher risk. Exercise testing holds considerable promise as a means of predicting surgical morbidity and mortality in this subgroup, although appropriate threshold values have yet to be defined. The validity of a 6-min walk distance of 1,000 feet and a stair climb of more than 44 steps as threshold values to determine surgical morbidity and mortality requires further prospective evaluation.

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