Symptom-Limited Stair Climbing as a Predictor of Postoperative Cardiopulmonary Complications After High-Risk Surgery*

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Study objective: Thoracotomy, sternotomy, and upper abdominal laparotomy are associated with high rate of postoperative cardiopulmonary complications (POCs). We hypothesized that symptom-limited stair climbing predicts POCs after high-risk surgery.

Design: A prospective evaluation of 83 patients undergoing thoracotomy, sternotomy, and upper abdominal laparotomy surgery.

Methods: The 52 men and 31 women completed symptom-limited stair climbing. A separate investigator, blinded to the number of flights of stairs climbed, assessed 30-day actual outcomes for POCs, including pneumonia, atelectasis, mechanical ventilation for > 48 h, reintubation, myocardial infarction, congestive heart failure, arrhythmia, pulmonary embolus, and death within 30 days of surgery. The operations performed included 31 lobectomies, 6 wedge resections, 3 pneumonectomies, 3 subternal thymectomies, 1 subternal thyroidectomy, 23 colectomies, 3 laparotomies, 7 abdominal aortic aneurysm repairs, 5 esophagogastrectomies, and 1 nephrectomy.

Results: POCs occurred in 21 of 83 patients (25%) overall, in 9 of 44 patients undergoing thoracotomy/sternotomy (20%), and in 12 of 39 patients undergoing upper abdominal laparotomy (31%). Of those unable to climb one flight of stairs, 89% developed a POC. No patient able to climb the maximum of seven flights of stairs had a POC. The inability to climb two flights of stairs was associated with a positive predictive value of 82% for the development of a POC. The number of days in the hospital postoperatively decreased with a patient’s increased ability to climb stairs.

Conclusions: Symptom-limited stair climbing offers a simple, inexpensive means to predict POCs after high-risk surgery.

Key words: postoperative cardiopulmonary complications; risk stratification; stair climbing

Abbreviations: POC = postoperative cardiopulmonary complication; \( \dot{V}_O_2 \) = oxygen uptake

The incidence of postoperative cardiopulmonary complications (POCs) is highest in patients undergoing upper abdominal and thoracic surgery.1,2

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POCs prolong hospital stays and costs. Risk stratification may help to select patients for appropriate counseling and prophylactic treatment. Cycle ergometry has been used to assess operative risk after thoracotomy.3–7 Previous studies8–10 assessing the ability of stair climbing to predict POCs were limited by small size or retrospective nature and were applied exclusively to patients undergoing lung resections. Stair climbing, like cardiopulmonary exercise testing, allows one to estimate oxygen uptake and cardiopulmonary reserve in patients with COPD.11 In the current study, we sought to prospectively test the predictive value of stair climbing in an expanded patient population that was at risk for the development of POCs after thoracic or upper abdominal surgery.

MATERIALS AND METHODS

Patient Selection

Randomly selected patients undergoing surgery between March 1994 and April 1998 were identified in an outpatient
testing center or on the inpatient service. The surgery types included thoracotomy, sternotomy, and upper abdominal laparotomy. Surgery was performed by seven surgeons who were aware of our prospective study. No patient was denied surgery on the basis of our preoperative testing. No patient underwent lung resection in whom the postoperative predicted FEV1 was < 800 mL or 40%. All patients gave informed consent as approved by the institutional review board of St. Elizabeth’s Medical Center.

**Patient Evaluation**

All patients underwent a complete history and physical examination on initial screening. They also underwent spirometry testing and an ECG. Pulmonary function tests were performed according to the recommendations of the American Thoracic Society.12 Arterial blood gas sampling was performed on all subjects in the seated position while breathing room air.

**Stair Climbing**

Patients were brought to a staircase, which consisted of seven flights of stairs. Each flight of stairs was 18 steps. In our hospital, each step measured 6.5 inches high and 12 inches wide. A landing occurred after every nine steps. These values are very similar across hospitals.11 Subjects were instructed as follows: “climb as far as possible at your pace using the railing only for balance.” They were told to stop once they could climb no more. On stopping, the number of flights of stairs climbed was noted. Half landings were rounded down. None of our patients developed any complications during the test. After surgery was completed and the patient was discharged home, an investigator who was physically unable to climb a flight of stairs due to severe constraints were excluded from the study. Patients who were unable to climb a flight of stairs due to severe cardiopulmonary, neurologic, rheumatologic, or vascular disease were counted as 0 flights climbed.

**Postoperative Outcomes**

Postoperative care was directed by the surgical ICU team and the floor team without input from the research team. POCs were counted as 0 flights climbed. Surgery was performed by seven surgeons who were aware of our prospective study. No patient was denied surgery on the basis of our preoperative testing. No patient underwent lung resection in whom the postoperative predicted FEV1 was < 800 mL or 40%. All patients gave informed consent as approved by the institutional review board of St. Elizabeth’s Medical Center.

**Statistical Analysis**

Statistical analysis was performed using independent Student’s *t* tests for continuous variables. A two-tailed Fisher’s Exact Test was used for categoric variables. Sensitivity, specificity, positive predictive value, and negative predictive value were calculated for multiple stair-climbing thresholds. Data were expressed as the mean ± SEM. A p value of < 0.05 was considered to be significant.

**Results**

Thirty-one women and 52 men between the ages of 39 and 84 years were included in the study. Twenty-one of 83 patients (25%) experienced at least one POC (Table 1). Five patients experienced both cardiac and pulmonary complications. There were 25 pulmonary complications, 9 cardiac complications, and 3 deaths. One death was a sudden cardiopulmonary arrest in a 70-year-old woman (climbed four flights of stairs) 13 days after undergoing a lobectomy complicated by staphylococcal pneumonia. Another death occurred in a 79-year-old woman (climbed 0 flights of stairs) who experienced congestive heart failure 11 days after undergoing a colectomy, and the final death was in a 59-year-old man (climbed three flights of stairs) 10 days after undergoing a lobectomy complicated by pneumonia, respiratory failure, and ARDS.

Forty patients underwent thoracotomies, 4 patients underwent sternotomies, and 39 patients underwent upper abdominal laparotomies. A breakdown of the type of surgery performed is shown in Table 2. Of the 44 patients who underwent sternotomies or thoracotomies, 9 (20%) developed a complication. Of the 39 patients undergoing an upper abdominal surgical procedure, 12 (31%) developed a complication. The mean FEV1 in the thoracic surgery group with a complication was 1.98 L, and among those without a complication the mean FEV1 was 2.25 L (p = 0.52). The mean FEV1 in the abdominal surgery group with complications was 1.61 L; among those in the group without complications, the mean FEV1 was 2.35 L (p = 0.04)

<table>
<thead>
<tr>
<th>Type of Complication</th>
<th>Patients, No. (%)</th>
</tr>
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<tbody>
<tr>
<td>Pulmonary</td>
<td>25 (30)</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>14 (17)</td>
</tr>
<tr>
<td>Reintubation</td>
<td>4 (5)</td>
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<tr>
<td>Prolonged mechanical ventilation</td>
<td>5 (6)</td>
</tr>
<tr>
<td>Lobar atelectasis</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Hypercapnia</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Cardiac</td>
<td>9 (11)</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>6 (7)</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>3 (4)</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Death</td>
<td>3 (4)</td>
</tr>
</tbody>
</table>

Table 1—Type and Number of Complications
Table 3 illustrates the clinical characteristics of those patients from all surgical groups enrolled in the study who did and did not have a complication. The group with complications climbed fewer stairs, had lower FVC and FEV\textsubscript{1} values, had longer surgery times, longer ICU stays, and longer hospital stays. There were no differences between the groups in terms of gender, the number of patients with pulmonary disease, the results of arterial blood gas testing, and FEV\textsubscript{1}/FVC ratio. Of those patients not able to climb one flight of stairs, 8 (89\%) developed a POC. No patient able to climb the maximum of seven flights of stairs developed a POC. Figure 1 demonstrates the rising incidence of POCs with a decreased ability to climb stairs.

To assess the predictive ability of stair climbing to identify the risk of POC, the positive predictive values for the inability to climb two, three, four, or five flights of stairs were calculated. The inability to climb two flights of stairs was associated with a positive predictive value of 80\% and a sensitivity of 38\%. Conversely, the ability to climb five or more flights of stairs was associated with a negative predictive value of 95\% and a specificity of 32\%.

In a subgroup analysis of 44 patients undergoing thoracotomy or sternotomy, the positive predictive value of climbing two or fewer flights of stairs was 75\% and the negative predictive value was 85\%. The sensitivity and specificity were 97\% and 33\%, respectively.

The overall trend was for the number of days in the hospital to decrease with a patient’s increased ability to climb stairs. Figure 2 is a plot of the flights of stairs climbed against the postoperative length of hospital stay, including the time spent in subacute hospital settings. Patients with and without complications are distinguished in this figure. In general, the group with POCs climbed fewer flights of stairs and had a longer length of stay compared with the group without POCs.

**Discussion**

In a diverse group of patients undergoing high-risk surgery, we found that symptom-limited stair climb-
The determination of exercise capacity as part of the assessment of preoperative risk has been done using the 6-min walk distance test, cycle ergometry with assessment of oxygen uptake, and stair climbing. These tests of exercise capacity are usually employed in those cases in which the standard means of risk assessment has placed marginal candidates at high risk.

Maximal oxygen uptake (\(\text{VO}_2\)), a key finding measured during cardiopulmonary exercise testing, also can be estimated during symptom-limited stair climbing. Thus, the number of flights climbed can serve as an indicator of cardiopulmonary reserve and of a patient’s ability to tolerate cardiopulmonary stress. The association between maximal \(\text{VO}_2\) measured during cardiopulmonary exercise testing and POC is variable. However, many investigators have demonstrated an increased incidence of POC as \(\text{VO}_2\) falls to < 20 mL/kg/min.

The POCs unifying abnormality is that of oxygen deficit, which may lead to organ dysfunction, failure, and death. Cellular respiration depends on the adequate delivery of oxygen and metabolic substances to the cell and the removal of carbon dioxide and metabolic byproducts from the cell. The completion of this task requires interactions of the heart, lungs, blood vessels, and peripheral muscle components. The dysfunction of any of these components may affect the degree to which oxygen may be used for respiration. The assessment of the maximal \(\text{VO}_2\) is therefore an assessment of aerobic capacity and of the reserve a patient may have when dealing with the multiple physiologic abnormalities that normally accompany surgery.

Pollock et al had 31 patients with varying degrees of COPD climb stairs. Using a Douglas bag for the sampling of expired gases, these authors confirmed a linear relationship between maximal \(\text{VO}_2\) and the number of flights of stairs climbed. These authors concluded that, like cardiopulmonary exercise testing, stair climbing offered a means of assessing \(\text{VO}_2\) and maximal minute ventilation.

In 1968, Van Nostrand et al published a retrospective review of pneumonectomy patients who had performed a preoperative stair climb. These authors noted a mortality rate of 11% among patients who able to climb more than two flights of stairs. However, among patients unable to climb two flights of stairs, two of four patients (50%) died.

Olsen et al performed a retrospective chart review of 84 patients who underwent stair climbing to a maximum of five flights. These authors noted that patients unable to climb three flights of stairs had a high number of POCs, longer intubations, and longer postoperative lengths of stay in the hospital compared with those patients able to climb three flights of stairs.

Stair climbing also has been used in a prospective study by Holden et al, who assessed 16 high-risk patients (ie, \(\text{FEV}_1, < 1.6 \text{ L}\)) who were undergoing lung resection. A 6-min walking distance test and stair climbing were predictive of postoperative mortality and prolonged mechanical ventilation. The inability to climb 45 steps (about two flights of stairs) indicated a 91% positive predictive value for a POC.

Our study comprises a larger group of patients and includes procedures other than thoracotomy. We found that the positive predictive value for the
development of a POC for climbing less than two flights of stairs was 82%, and that for climbing less than three flights of stairs was 63%. We believe that a cutoff of two or fewer flights climbed may be the most useful for large-scale screening for the development of POCs in patients undergoing high-risk surgery.

Stair climbing did not accurately predict mortality. The 30-day mortality rate in our population was 4%, and two of three deaths occurred in patients climbing three or more flights of stairs. One of the nine patients (11%) who was unable to climb a flight of stairs died.

One interesting finding was of the very high complication rate (89%) of those patients unable to climb any flights of stairs. The reasons for not climbing stairs included two patients with severe obesity (ie, >120 kg), four patients with COPD, one patient with cardiac disease, and two patients with vascular disease. All patients refused to climb due to physical limitation. Epstein et al17 reported a higher incidence of mortality and POCs in patients who were unable to perform cycle ergometry preoperatively compared with those patients who could partake in exercise. Using multiple logistic regression analysis, the authors attributed the increased mortality to identifiable cardiopulmonary factors as well as to an independent effect of the inability to exercise. A similar finding was noted by Gerson et al,18 who assessed 177 patients with supine cycle ergometry. Each patient was required to cycle for 2 min with a pulse >99 beats/min. Among the 69 patients who were unable to achieve this level of exercise, there was a 42% incidence of complication with a 7% incidence of mortality.

There has been an interest in combining risk indexes with measurements of aerobic capacity as a means of predicting POC. Gerson et al15 combined the ability to perform cycle ergometry over a threshold level with the presence or absence of the Goldman criteria as a means for predicting POC and mortality. Epstein et al17 combined a cardiopulmonary risk index score of 4 with the inability to exercise. In both studies, the ability or inability to complete an exercise test added to the predictive value of the selected risk index for POC. We believe that there may be a role for the use of stair climbing as an adjunct to a defined risk index for the prediction of POCs.

In conclusion, our prospective study demonstrates the predictive ability of stair climbing as a measurement of cardiopulmonary reserve and as an assessment of a patient’s ability to undergo high-risk surgery. Stair climbing is a low-tech exercise that is safe, inexpensive, familiar to patients, and available to most physicians. Future studies are needed to determine whether the predictive ability of stair climbing will add further predictive power to previously defined risk indexes.

REFERENCES