The Evolving Role of Exercise Testing Prior to Lung Resection*

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Exercise testing prior to lung resection has long and honored tradition. It began as a test of tolerance using simple techniques such as stair climbing. This was followed by aggressive and invasive protocols using right cardiac catheterization in the search for pulmonary hypertension. More recently, measurement of VO2 with exercise has been reported to predict both postoperative mortality and survivable morbidity. Exercise testing holds promise as a noninvasive test to predict the physiologic outcome from lung resection. Significant questions remain concerning the pathophysiologic mechanisms responsible for an abnormal result and who should be denied thoracotomy based on these results. (Chest 1989; 95:218-25)

AT = anaerobic threshold; R = respiratory exchange ratio; TUPAO = temporary unilateral pulmonary arterial occlusion

Testing patients before surgery in an attempt to predict complications after thoracotomy has been popular since the days of surgery for tuberculosis.1 Some 30 years later, we are still searching for the ideal test which, when performed before surgery, will identify those who will suffer complications after surgery. This search is important because lung cancer, a disease with virtually 100 percent mortality when untreated, is most commonly treated surgically. Philosophically, one can debate the relative merits of a surgical attempt at cure vs high morbidity and mortality after thoracotomy, in turn, balanced against the poor prognosis using nonsurgical therapy.2,3 Assuming this debate resolves in favor of an attempt at lung resection, which test should be done to select those patients with the best chance of cure and the lowest chance of postoperative morbidity, cardiorespiratory crippling, or death?

Three avenues of thought have evolved. The first premise, based on early studies of spirometry and "split-function" spirometry, suggests that eliminating the patient with too severe ventilatory compromise should permit a higher rate of survival.4 The second concept proposes that postoperative pulmonary hypertension and cor pulmonale must be predicted even if invasive studies are required. The third and newest precept is that survivable noncrippling postoperative morbidity, as well as mortality, may be predicted before surgery by measuring VO2 on exercise.

**Physiologic Principles**

This review attempts to explore the basic physiology of exercise, primarily as it relates to the preoperative evaluation of a patient for lung resection. The reader is directed to other sources for an in-depth discussion of the physiology of exercise.5-8 Exercise is attractive before surgery because it increases utilization of oxygen peripherally and requires the entire interlocking lung/heart/vascular oxygen transport system to react. In the lung, exercise requires increases in ventilation, VO2, carbon dioxide excretion, and blood flow similar to those experienced following pneumonectomy. Thus, the potential exists to evaluate much of the cardiopulmonary system with just one test.

**Oxygen Consumption or Uptake**

Oxygen consumption by the muscles and uptake in the lung are basic to the physiology of exercise, and the terms are frequently used interchangeably in the literature. For this discussion, we will use VO2 in reference to measured oxygen uptake.

In early studies of exercise testing, VO2 is used to describe the level of work performed in fit subjects. The higher the maximal VO2 achieved, the more "fit" the subject.9 As work load is progressively increased, VO2 increases until a plateau is reached where further work produces no further increase in VO2. This point is called VO2max.10 In these earlier studies, another parameter (eg, minute ventilation, pulse rate, etc) is used as the measured physiologic response to the work level (VO2) performed; however, more recently, VO2 is itself measured as an indicator of oxygen transport. In this instance, some other benchmark is needed to document the level of work performed. This benchmark may be time, the work load quantified in watts, kilogram-meters (or kilopond-meters) per minute, treadmill grade and speed, meters walked, or steps climbed. If VO2 is thus used as the major indicator of oxygen transport, then comparison to a predicted VO2 for the condition of the subject and test is necessary; for example, an obese subject has a higher VO2 with

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exercise, secondary to the energy requirement of moving his larger mass.\(^7\)\(^13\) Similarly, exercise on a treadmill is associated with a 5 to 12 percent higher \(\dot{V}O_2\)max than with cycle ergometry, presumably because of the larger number of muscle groups involved in walking, compared to seated pedalling.

If \(\dot{V}O_2\) is used as the major measured parameter of oxygen transport, one has to interpret a reduction in measured \(\dot{V}O_2\) for the subject's mass, as well as for the type and level of work performed. Physiologic abnormalities capable of limiting \(\dot{V}O_2\) at maximal exercise are anaemia/carboxyhaemoglobinemia, heart disease, metabolic disease, muscular disease, peripheral vascular disease, pulmonary disease, and reduced effort.\(^7\) A reduction of \(\dot{V}O_2\) found on less than maximal (submaximal) exercise could reasonably be due to technical error or some very significant limitation of oxygen transport. Much of the work under these conditions is assumed to be performed anaerobically. The limitations in oxygen transport responsible for a reduced submaximal \(\dot{V}O_2\) could be similar to those listed earlier as being capable of limiting \(\dot{V}O_2\)max, but to be measurable below maximal would imply greater severity.

\textbf{Anaerobiosis}

An incremental increase in work load is accompanied by an increase in \(\dot{V}O_2\) and carbon dioxide excretion. At some point the utilization of oxygen by the muscles may exceed the oxygen availability provided by the transport axis. At this point, anaerobic mechanisms are used by the muscles, and lactate is produced. Information concerning this point may be obtained by direct measurement of the level of lactate in the blood. Some investigators, rather than analyzing blood for lactate itself, simply measure a reflection of lactate accumulation, eg, pH and bicarbonate decrement.\(^12\) Others extrapolate by seeking the point at which the slope of carbon dioxide production from lactate metabolism exceeds oxygen uptake. This point is seen as an increase in the respiratory exchange ratio of more than 1.0. This point has been called the “AT” or “anaerobic threshold,” and its location and significance have been debated.\(^7\)\(^13\)

\textbf{Types of Exercise}

If one agrees that preoperative exercise testing may test the entire lung/heart/vascular/muscle axis, then the decision required is what kind of exercise test? For the sake of this discussion, I will divide preoperative exercise testing into two major types: incremental and constant (steady-state) work rate. These two types are further defined based on their end points, ie, submaximal and maximal end points. These four combinations are illustrated graphically in Figure 1. This simplified classification is designed to assist the reader in comparing the multiple exercise protocols performed in the studies subsequently reviewed (Table 1).\(^14\)\(^34\)

Incremental testing is performed by starting with a minimal load and sequentially increasing the work rate to a submaximal or maximal end point. Steady-state protocols produce a sustained (2-minute to 10-minute) level of work (usually submaximal), during which multiple components of the oxygen transport system may be assessed.\(^35\) Maximal end point can be defined as an exercise (usually incremental) which is performed to a plateau (\(\dot{V}O_2\)max) at which further work will not produce an increase in \(\dot{V}O_2\). In patients with lung cancer who have other smoking-related diseases, a lesser intensity of work may be better tolerated. The term, “symptom-limited” maximum \(\dot{V}O_2\), is then used as a substitute for \(\dot{V}O_2\)max.

\textbf{Premise}

The remainder of this discussion will attempt to put the relevant English literature into perspective. In this way, those studies which I believe have contributed to our knowledge of the preoperative prediction of postoperative complications will be discussed critically, but the entire bibliography is outlined in Table 1.\(^1\)\(^16\)\(^34\) The discussion will be organized into three main types of exercise studies published to date. Type
Table 1 – Preoperative Studies Using Exercise

<table>
<thead>
<tr>
<th>Type of Exercise Test and Reference</th>
<th>No. of Patients</th>
<th>Spirometry Abnormal, Percent</th>
<th>Exercise Type (see Fig 1)</th>
<th>Surgery, %P/#L†</th>
<th>Complications, Mort/Morb</th>
<th>Complications Predicted?§</th>
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<td>213</td>
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<td>...</td>
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<td>D</td>
<td>.../44</td>
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<td>97</td>
<td>C</td>
<td>8/13</td>
<td>24/25</td>
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</table>

*Percentage of patients who had either FEV1<2 L or MVV<50 percent of predicted.
†Number of pneumonectomies/No. of lobectomies.
‡Complication mortality in percent/morbidity rate in percent.
§Were reported complications predicted by data from exercise test?

1 reports include those studies of “tolerance” in which the simple accomplishment of an exercise challenge is used to predict postoperative results. Type 2 studies are those in which the prediction of pulmonary hypertension after resection is the paramount goal. Type 3 studies include those recent investigations in which exercise VO2 is used to predict both postoperative morbidity and mortality. Not all of the reports outlined in Table 1 will be discussed, but similarities will be sought to facilitate interpretation of underlying principles. Since the studies reviewed use various pulmonary function tests and parameters, liberties are taken in comparing the severity of dysfunction of the patients studied. To aid in the comparisons of the multiple exercise protocols reported in these studies, the work rates and predicted/estimated VO2 will be calculated and “standardized” using conversion factors available from reference sources.58 To obtain an estimate of VO2, the following formula incorporating weight and work load is used:5

Predicted VO2 = 5.8 × weight (kg) + 151 + (10.1 × watts)

Table 1 and the discussion are organized to explore the following questions: (1) How many patients were studied? (2) Did the patients exhibit abnormal resting pulmonary function? (3) What type of exercise challenge was used? (4) How extensive were the resections performed? (5) What was the morbidity and mortality of the resections? (6) Were the results of the exercise study predictive of the postoperative outcome?

Type 1: Exercise Tolerance Tests

It is not clear who the first surgeon was who took his patient for a walk to determine their status prior to thoracotomy.6 This subjective assessment has, in many institutions, been “handed down” from senior attending surgeon to junior surgical resident. It is entirely possible, but unproven, that the results of this simple assessment may contribute more to the surgeon's final decision than all of the sophisticated physiologic tests yet devised.

It appears that walking the patient was not beneficial to Gaensler and co-workers in 1955. They found no significant difference between those with and without postoperative disability in the ventilation measured during a walk of 180 ft in one minute. This was also true if the data were modified using the MVV, yielding the “walking dyspnea index.” Assuming 180 ft/min equals 2 mph at zero grade, this exercise equates to a work rate for a 70-kg man of 150 kpm/min or about 25 W. This rate also translate roughly to a VO2 of 800 ml/min or 12 ml/kg/min.

Van Nostrand and colleagues in 1968 reported a series of 213 patients undergoing pneumonectomy.
The mortality in this group was 28 of 213, and 40 percent of the deaths were attributed to cardiorespiratory insufficiency. Patients were rejected for pneumonectomy before surgery if (a) they were unable to climb one flight (19 steps) without severe dyspnea, (b) their estimated postoperative FEV\textsubscript{1} was less than 700 ml, or (c) the pulmonary arterial pressure rose to more than 40 mm Hg on clamping the pulmonary artery during surgery. Of this total group of 213 patients, 92 had an FEV\textsubscript{1} of less than 2 L, and only 119 were actually exercised. Few details are provided on the exercise itself, but two of four patients unable to perform a level walk or climb the one flight of stairs without severe dyspnea died after surgery. Only seven (11 percent) of 63 of those able to climb two flights with minimal dyspnea failed to survive the pneumonectomy. This two-flight stair climb, assuming a standard 9-in (23-cm) step and a stepping rate of 20/min, would yield a work rate of about 320 kp·m/min (52 W) for a 70-kg man.\textsuperscript{35} This work rate equates to an estimated VO\textsubscript{2} of 1.1 L/min or 16 ml/kg/min. No statistical analysis was performed on these data, but the authors\textsuperscript{36} concluded that none of the tests, either alone or in combination, was better than the method (a, b, and c discussed previously) that they had used.

In 1972, Reichel\textsuperscript{37} reported a retrospective series based on the review of 75 of 80 hospital records of patients who had undergone pneumonectomy. There were 18 postoperative deaths (24 percent), with an additional 13 patients (17 percent) having major complications. The patients studied, where data are provided, appeared to suffer some degree of airflow obstruction in that the mean MMF was 0.98 L/s and the FEV\textsubscript{1}/FVC was 58 to 63 percent. Thirty-one of the 75 patients performed incremental treadmill exercise. The exercise performed was in six stages of increasing grade, speed, and cumulative time, culminating at 3 mph at a 10 percent grade. This highest work rate, for a 70-kg man is equivalent to approximately 600 kp·m/min (100 W) and would require a VO\textsubscript{2} of 1,750 ml/min (25 ml/kg/min).\textsuperscript{38} Of the four patients unable to walk at 2 mph on a level slope for four minutes (stage 1), two died, and one survived severe complications. Of the 11 completing the 14 minutes of exercise, all had successful surgery. It appears that the results of exercise were more accurate in predicting the group who sustained complications than the resting ECG, blood gas levels, Dco, lung volumes, spirometric data, or helium mixing time. No physiologic data were reported from the exercise study itself to assess those factors limiting the patients who failed to complete the protocol.

In 1984, Bagg\textsuperscript{39} reported the findings in 30 patients with bronchogenic carcinoma who were subjected to a 12-minute walk before surgery. Preoperative pulmonary function studies were obtained, but the results were not reported. Exercise was performed by measuring the distance in meters that the patients could walk indoors on a level surface in 12 minutes. The distance walked in meters and the level of dyspnea experienced failed to discriminate the seven patients who suffered postoperative ventilatory complications from the 15 who did not. This finding was of interest, considering that a correlation between the 12-minute walk and exercise VO\textsubscript{2} had previously been reported.\textsuperscript{36}

Positive results were reported in 1984 by Berggren and co-investigators.\textsuperscript{40} This group studied 82 patients with lung cancer, all over 70 years old. The patients were evaluated with spirometry and cycle ergometer exercise. The exercise was performed at 50 W for six minutes and then increased by 10-W increments to a maximal cardiac frequency of less than 170 beats per minute. Those patients who could perform at 50 W for six minutes were accepted for surgery. There was a 15.9 percent in-hospital mortality but an impressive 32 percent five-year survival rate. The findings in 47 patients who underwent lobectomy were reported in detail, half of whom demonstrated an FEV\textsubscript{1} of less than 2.4 L before surgery. In this group undergoing lobectomy, postoperative mortality was 7.7 percent in those who completed more than 83 W for six minutes and was 22 percent in those completing less than 83 W (p<0.05). The mortality was also higher if the FVC was less than 3.7 L, the FEV\textsubscript{1} was less than 2.4 L, and the FEV\textsubscript{1}/FVC was less than 68 percent. No physiologic measurements were reported during the exercise test. The completion of 83 W of power output equates to an estimated VO\textsubscript{2} of 1.4 L/min or 20 ml/kg/min for a 70-kg man.

It appears, therefore, that completion of a specific challenge to near maximal level bodes a good prognostic omen in most of these studies. Other than assuming that this means a good general level of "fitness," few data are provided to assist in determining why this might be true.

**Type 2: Prediction of Pulmonary Hypertension**

In the era of surgical therapy for tuberculosis, clinicians and investigators were concerned with the appearance of pulmonary hypertension after surgery. Studies in animals and clinical experience both demonstrated the impact of cor pulmonale on the outcome from surgery.\textsuperscript{36,40} The postoperative pulmonary hypertension was linked to the resection of functioning tissue and vascular bed in those patients with underlying parenchymal disease in the remaining lung. These physicians elected to test the compliance of the pulmonary vasculature by increasing pulmonary blood flow with exercise and used cardiac catheterization. Right cardiac catheterization could evaluate vascular compliance even further by occluding with a balloon the pulmonary artery of the lung to be resected.\textsuperscript{41}
This occlusion forces all of cardiac output through the lung destined to remain similar to what occurs after a pneumonectomy. This technique became known as TUPAO for temporary unilateral pulmonary arterial occlusion.

At least four investigators have reported the use of TUPAO with exercise. In 1956, Uggla used steady-state submaximal (150-kg-m, 25-W) exercise with TUPAO in 109 patients with pulmonary tuberculosis. The equivalent VO2 for this work rate would be approximately 810 ml/min or 12 ml/kg/min for a 70-kg man. Uggla divided the patients after surgery into 48 who were "fit for work," 36 "cardiorespiratory cripples," and 24 who died (22 with cor pulmonale). Spirometry and pulmonary function tests did not adequately separate the three groups. The mean maximum breathing capacity (MBC; now MVV) of all three groups was only 40 to 49 percent of predicted.

The conclusions reached were that pulmonary hypertension at rest (mean PA > 25 mm Hg) was "highly unfavorable" and that the PaO2 during occlusion was the best prognosticator. Neither a table of nor statistical comparison of mean data was provided. Other studies using TUPAO have failed to establish clear-cut criteria for inoperability.

More recently, Fee and co-workers reported their findings using flow-directed catheterization and treadmill exercise. This study investigated 45 patients divided into two groups based on pulmonary function tests and blood gas levels. Group A (27 patients) demonstrated a PaO2 of more than 50 mm Hg and a FVC and FEV1 of more than 50 percent of predicted. Group B (18 patients) had a PaO2 of less than 50 mm Hg or an FEV1 (or FVC) of less than 50 percent of predicted. All patients were then catheterized with flow-directed thermal-dilution catheter and exercised at two treadmill work loads. These work loads were submaximal and in a steady state, consisting of 2 mph at a 4 percent grade and then, after a 45-min resting period, 4 mph at a 4 percent grade. These treadmill work rates equate roughly to cycle ergometer power outputs of 164 kp-m/min (27 W) and 328 kp-m/min (54 W), respectively. Estimates of VO2 for these work loads are, for a 70-kg man, 830 ml/min (12 ml/kg/min) and 1.1 L/min (16 ml/kg/min). Cardiac outputs and pulmonary arterial pressures during the exercise were measured every minute, and values for pulmonary vascular resistance (PVR) were calculated. Based on the findings with exercise, the patients were again divided into two groups. Group 1 (n=18) demonstrated a PVR of less than 190 dynes·s·cm⁻², and group 2 (n=12) had a PVR greater than 190 dynes·s·cm⁻². Thirty of the 45 patients underwent surgery which included open biopsy (ten), segmentectomy (two), lobectomy (11), and pneumonectomy (seven). Five patients failed to survive surgery, two had only an open biopsy, and only one had a pneumonectomy. All five of the deaths occurred in patients whose exercise PVR was more than 190 dynes·s·cm⁻². Four of the five were in the group with "better" pulmonary function (group A). These findings led the investigators to conclude that surgery in patients with PVR over 190 dynes·s·cm⁻² is hazardous; however, seven of the 25 surviving patients also had a PVR greater than 190 dynes·s·cm⁻² and would have been denied resection by strictly using this criterion.

From a review of these studies, pulmonary hypertension after surgery appears to be a grave concern; however, the current frequency of cor pulmonale as a cause of postoperative morbidity and mortality is unknown.

Type 3: Measurement of VO2

It is in this area that the most intriguing results are being reported. The first report was that of Eugene and co-workers in 1982. These workers reported the findings in 19 patients studied with spirometry and incremental ergometric exercise. Spirometric revealed the FEV1 to be less than 1.5 L in five of the 19 patients. The exercise work rate was not specified but was increased every four minutes to fatigue. Expired air was collected during the last two minutes of each increment to calculate the VO2. The VO2 at the highest work load was considered the VO2max. Surgical procedures performed were a pneumonectomy in six patients, and a lobectomy in 12. There were three postoperative cardiorespiratory deaths. Spirometric values failed to predict the deaths, but all three demonstrated levels of VO2max less than 1 L (0.821 ± 0.034 L/min), whereas all 15 patients with a VO2max less than 1 L survived resection. No correlation was found between the spirometric and exercise results, but nonfatal morbidity was not sought. No hypothesis was proposed as to how the VO2max predicted the nonsurvivors.

Contrasting results were reported by Coleman and co-investigators also in 1982. These workers reported a prospective study of 59 patients studied with spirometry, lung volumes, DCO, and exercise. The mean FEV1 of the 59 patients was 80 ± 25 percent of predicted. The exercise was performed using two flights of stair climbing in 15 seconds and categorizing the dyspnea expressed into four grades. The stair climb was then followed by a progressive multistage ergometer study which began at 150 kp-m (25 W) and increased each minute. Data were obtained for the last 20 seconds of the highest work rate that could be tolerated for a full minute. The VO2max was evaluated as a predictor of complications during the first 28 postoperative days. The complications sought included the following: death (two), ventilatory failure (three), pneumonia (11), atelectasis (six); myocardial infarction.

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of 22 patients. The peak exercise ventilation (VE/VO2) was measured as the highest VO2 obtained and was corrected for body weight (m/kg/min). The surgical procedures performed were four pneumonectomies and 12 lobectomies. Complications were reported as those occurring after surgery were those reported by Coleman and colleagues60 but excluded those believed to be "technical" in nature. The complications reported included the following: death (two); respiratory failure (three); pneumonia (four); myocardial infarction (two); atelectasis (one); and cardiac arrhythmias (one). The routine pulmonary function studies and quantitative lung scan prediction of postoperative FEV1 failed to identify those patients suffering complications; however, VO2max was significantly lower in the group with complications (p<0.001). The group with complications was significantly older, and a significant, but unreported, correlation was present between the VO2max and age. These investigators60 noted that when the VO2max was less than 15 ml/kg/min, six of six patients sustained complications, but when VO2max exceeded 20 ml/kg/min, only one of ten suffered a nonfatal complication. No hypothesis was proposed to explain how VO2max predicts mortality or morbidity.

These findings were supported by the report of Bechard and Wetstein31 in 1987. These investigators studied 50 consecutive patients undergoing thoracotomy who had a mean age of 63.8 years; the FEV1 was less than 2 L in 38 percent (19) of the 50. Exercise was performed using cycle ergometry with one-minute increments of 12.5 W to exhaustion or dyspnea. Maximum VO2 and anaerobic threshold were measured. Patients were accepted for pneumonectomy (n = 10) if the FEV1 was more than 1.7 L, for lobectomy (n = 28) if the FEV1 was more than 1.2 L, and for wedge resection (n = 12) if the FEV1 was more than 0.9 L. Postoperative mortality was 4 percent, and morbidity was defined virtually identically to the report of Smith et al.60 Complications were present in 12 percent (six) of the 50 patients. Both fatalities and five patients suffering survivable complications had VO2max levels less than 10 ml/kg/min (p<0.001). Neither the static pulmonary function studies nor the maximal inspiratory and expiratory force measurements of respiratory muscle strength identified the patients with complications. Anaerobic threshold was significantly lower in the group with complications but was only obtained in three of these patients. These workers31 believe that a VO2max less than 10 ml/kg/min may preclude surgery even if spirometric results are acceptable. They also did not propose a hypothesis of how exercise VO2 predicts mortality and survivable morbidity.

Contrasting the previous results is the report of Miyoshi and co-workers62 published in 1987. These investigators studied 33 patients whose routine pulmonary function studies included spirometry and Dco. The exercise study was performed using a cycle ergometer at 50 rpm with three-minute increments of 25 W each. Exercise was stopped when the heart rate reached 140 beats per minute or the respiratory quotient exceeded 1.0. Arterial blood concentrations of lactate were obtained during the last 30 seconds of each work rate. Complications occurred in 45 percent (15) of the 33 patients, but only eight were pulmonary complications. The FEV1/FVC was 77 percent in the 25 patients not having complications and 56 percent in those eight patients suffering complications (p<0.05). The complications reported included atelectasis (four), respiratory failure (four), pneumonia (five), and pulmonary edema (two). Four deaths resulting from complications occurred as in-hospital mortality. The exercise VO2 failed to separate the eight patients suffering complications from the 25 free of complications; however, the VO2 per meter of BSA at a submaximal lactate level of 20 mg/dl (2.2 mM/L or mEq/L),49 called the "VO2/BSA at La-20," discriminated between the four who survived (471 ± 53 ml/min/m2) and the four who died (296 ± 72 ml/min/m2). The resting pulmonary function studies failed to separate survivors from nonsurvivors. The results of this study suggest that in-hospital mortality can be predicted by submaximal exercise VO2 when the work level achieved is corrected for a fixed level of lactate production. Again, no hypothesis was proposed as to how VO2/BSA at La-20 predicted mortality.

Also in 1987, Corris and co-workers63 reported a study using exercise VO2 and quantitative scintillation scanning. The study included 28 patients with lung cancer evaluated before and after pneumonectomy. Routine pulmonary function studies revealed that the
mean FEV1 was 75 percent of predicted. Quantitative ventilation and perfusion scans were performed and the results used in a standard equation to predict postoperative function. Exercise was performed in only 14 patients to a symptom-limited maximum using a cycle ergometer at 25-W increments. No information is provided on complications of the surgery, but all 14 patients were re-exercised four months after pneumonectomy. These investigators found good correlations between predicted and observed postoperative FEV1, Dco, and DVA (Kco). Of interest, they also found a strong correlation (r = 0.98) between the measured perfusion of the lung to be resected and the reduction in VO2max after surgery. This association was accompanied by agreement (correlation coefficient and p value not provided) between the exercise VEmax and VO2max predicted before surgery and observed after surgery. The lung scan prediction of postoperative VO2max has not been reported previously and will require confirmation in other studies.

**Conclusions**

Exercise studies prior to lung resection seem to have evolved somewhat from a simple unmonitored test of "endurance" which correlated roughly with surgical survival to using preoperative measurements of exercise VO2 to predict postoperative survivable morbidity. It appears from this review that those studies which have exercised their subjects to the highest work rate (measured or estimated VO2) have demonstrated the strongest predictability of postoperative results. This finding would suggest that pushing these patients to hear VO2max uncovers deficits in oxygen transport which may affect postoperative outcome and survival. How VO2max can predict postoperative morbidity such as atelectasis, pneumonia, or pulmonary embolism is not clear. A tenuous conclusion might also suggest that survivable morbidity is only predicted at VO2max, but mortality may be predicted using data obtained at submaximal exercise levels. It is also possible that the "elevation" suggested by the title of this review may be no more than a sophisticated way (using VO2 on exercise) to obtain a yardstick of "fitness" much the same as has been done in normal subjects for decades.

There are unanswered questions which remain in this clinical area, and they are listed in the following tabulation:

1. Does exercise testing predict mortality and morbidity better than other forms of preoperative testing? Putative answer — yes.
2. Which patients should be exercised?
   a. Those at increased risk by routine pulmonary function tests?
   b. Everyone before surgery for lung resection?
3. How should the exercise be standardized?
   a. Submaximal?
   b. Maximal/maximum?
   (1) To maximal heart rate?
   (2) To maximal symptoms?
   (3) To lactate, pH, bicarbonates, or "AT"?
4. How does VO2max predict mortality? morbidity?
   a. As an overall assessment of "fitness"?
   b. As a manifestation of abnormal oxygen transport?
5. Who should be rejected for lung cancer resection?
   a. Those with a reduced VO2max suggesting increased mortality rate?
   b. Those with a reduced VO2max suggesting survivable morbidity?
   c. A patient with a high VO2max and a previous lung resection with resulting in low FEV1?

The quest for answers to these questions should include a testable hypothesis of how preoperative exercise testing can predict postoperative mortality and especially survivable morbidity.

**References**

28 Brundler H, Chen S, Perruchoud AP. Right heart catheterization in the preoperative evaluation of patients with lung cancer. Respiration 1985; 48:261-68