Stair Climbing Test as a Predictor of Cardiopulmonary Complications After Pulmonary Lobectomy in the Elderly

Alessandro Brunelli, MD, Marco Monteverde, MD, Majed Al Refai, MD, and Aroldo Fianchini, MD

Unit of Thoracic Surgery, Department of Respiratory Diseases, "Umberto I°" Regional Hospital, Ancona, Italy

Background. **The objective of this study was to assess the role of a symptom-limited stair climbing test in predicting postoperative cardiopulmonary complications in elderly candidates for lung resection.**

Methods. **A consecutive series of 109 patients more than 70 years of age who underwent pulmonary lobectomy for lung carcinoma from January 2000 through May 2003 formed the prospective database of this study. All patients in the analysis performed a preoperative symptom-limited stair climbing test. Univariate and multivariate analyses were performed to identify predictors of postoperative cardiopulmonary complications.**

Results. **At univariate analysis, the patients with complications had a lower forced expiratory capacity percentage of predicted ($p = 0.048$), predicted postoperative forced expiratory volume in 1 second percentage of predicted ($p = 0.049$), climbed a lower height at preoperative stair climbing test ($p = 0.0004$), and presented a greater proportion of cardiac comorbiditiy with respect to the patients without complications ($p = 0.02$). After logistic regression analysis, significant predictors of postoperative complications resulted in the presence of a concomitant cardiac disease ($p = 0.04$) and a low height climbed preoperatively ($p = 0.0015$).**

Conclusions. **A symptom-limited stair climbing test was a safe and simple instrument capable of predicting cardiopulmonary complications in the elderly after lung resection.**

(Ann Thorac Surg 2004;77:266–70)

Maximal exercise tests are now increasingly used before pulmonary resection as an instrument to detect severe deficits in systemic oxygen transport, which increase the risk of postoperative complications and mortality [1].

In a previous study [2], we demonstrated that a stair climbing test was effective in predicting cardiopulmonary morbidity after lung resection in a population composed mostly by patients younger than 70 years of age (66% of the total). However, it has been shown that the aerobic capacity declines approximately 10% per decade of life [3, 4], mostly because of a decreased cardiac output reserve and a less efficient redistribution of blood flow to the exercising muscles [5]. Furthermore, in elderly patients, the physiologic decline in respiratory function, the physical deconditioning, and the increased frequency of underlying comorbidities may variably reduce the exercise tolerance. Therefore, using exercise tests to uncover deficits in the oxygen transport system is a logical approach for stratifying surgical risk in these older patients. For this reason, in the present study, we focused our analysis specifically on patients older than 70 years of age. Although 38.5% of them (42 patients) were included in our previous analysis [2], we expanded that series and limited the analysis to pulmonary lobectomy only, to eliminate the confounding effect of the amount of lung parenchyma removed on the postoperative outcome.

Therefore, the objective of the present study was to prospectively assess the role of symptom-limited stair climbing test in predicting cardiopulmonary complications after pulmonary lobectomy for non–small cell lung cancer (NSCLC) in patients older than 70 years of age.

Patients and Methods

One hundred and twenty-seven patients older than 70 years of age underwent pulmonary lobectomy for NSCLC from January 2000 through May 2003 and were prospectively enrolled in the present analysis after giving their informed consent. They represented 35.7% of all the patients operated on for lung cancer at our institution during the same period of time. Eighteen patients were excluded from the study because they were unable to perform the preoperative exercise test (8 for severe musculoskeletal disease, 7 for cerebrovascular disease, 4 for peripheral vascular disease, 2 for severe debilitation, 1 for psychiatric disease). The remaining 109 patients (90 men and 19 women) formed the database of the analysis. Pulmonary lobectomy was performed through a lateral muscle-sparing thoracotomy by the same surgical team.

Resectability was assessed by means of computed tomography scan, bronchoscopy, and, when indicated, cervical mediastinoscopy.

Accepted for publication July 3, 2003.

Address reprint requests to Dr Brunelli, Via S. Margherita 23, 60129 Ancona, Italy; e-mail: alexit_2000@yahoo.com.

Published by Elsevier Inc

0003-4975/04/$30.00
doi:10.1016/S0003-4975(03)01327-4

Abbreviations and Acronyms

BMI	= body mass index
CCI	= Charlson comorbidity index
DLCO	= carbon monoxide diffusion lung capacity
ECOG	= Eastern Cooperative Oncology Group
FEV_1	= forced expiratory volume in 1 second
FVC	= forced expiratory capacity
HR	= heart rate
NSCLC	= non–small cell lung cancer
ppoDLCO	= predicted postoperative carbon monoxide diffusion lung capacity
$ppoFEV_1$	= predicted postoperative forced expiratory volume in 1 second
VO_2 max	= maximum oxygen consumption

Operability was assessed by means of pulmonary function tests, blood gas analysis, electrocardiogram, echocardiography, and more invasive cardiologic procedures if needed. Criteria of inoperability were a predicted postoperative forced expiratory volume in 1 second ($ppoFEV_1$) less than 30% of predicted, in association with a total height climbed at preoperative stair climbing test lower than 12 m and cardiac instability. Using these criteria, only 1 patient was excluded from operation during the period of the study.

For the purpose of the present study, the following spirometric variables were considered: forced expiratory volume in 1 second (FEV_1); forced vital capacity (FVC); FEV_1/FVC ratio; carbon monoxide diffusion lung capacity (DLCO); predicted postoperative FEV_1 ($ppoFEV_1$), calculated by the formula: (preoperative FEV_1/number of preoperative functioning segments) $\times$ number of postoperative functioning segments; and predicted postoperative DLCO (ppoDLCO), calculated by the formula: (preoperative DLCO/number of preoperative functioning segments) $\times$ number of postoperative functioning segments.

Pulmonary function tests were performed according to the American Thoracic Society criteria. Carbon monoxide diffusion lung capacity was measured by the single-breath method. Results of spirometry were collected after bronchodilator administration and were expressed as percentage of predicted for age, gender, and height, with the exception of the FEV_1/FVC ratio.

The number of functioning segments was estimated by means of computed tomography scan and bronchoscopy findings. In patients with a calculated $ppoFEV_1$ less than 50% of predicted, a quantitative perfusion lung scan was used, according to Markos and associates [6].

The simple calculation of $ppoFEV_1$ was previously shown to be as accurate as perfusion lung scanning [6].

The symptom-limited stair climbing test was usually performed the day before the operation. Our hospital has 16 flights of stairs, each flight having 11 steps. Each step is 0.155 m in height. The patients were asked to climb, at a pace of their own choice, the maximum number of steps and to stop only for exhaustion, limiting dyspnea, leg fatigue, or chest pain. The patients were accompanied by a physician during their exercise, who encouraged them to continue the test and assessed the patients' dyspnea and the occurrence of other symptoms. During the exercise, pulse rate and capillary oxygen saturation were monitored by means of a portable pulse oximeter. For each patient, the number of steps climbed and the time taken to complete the test was recorded. The following ergometric variables were calculated and used for the analysis: work (height of the step in meters $\times$ steps per minute $\times$ body weight in kilograms $\times$ 0.1635) [7]; maximum oxygen consumption (VO_2 max) in milliters per minute (5.8 $\times$ body weight in kilograms + 151 + 10.1 $\times$ work) [7]; maximum oxygen pulse (VO_2 max/maximum heart rate). Furthermore, a predicted postoperative VO_2 max ($ppoVO_2$ max) was calculated according to the number of functioning segments removed during operation and estimated by means of computed tomography scan, bronchoscopy, and, when used, quantitative perfusion lung scan [8, 9].

Maximum predicted heart rate (HR) was estimated by the formula: 220 $-$ age [10]. The HR reserve in percentage was calculated by the following equation: (predicted maximum HR $-$ actual maximal HR)/predicted maximal HR $\times$ 100 [10].

For the purpose of the present study, a concomitant cardiac disease (cardiac comorbidity) was defined as follows: previous cardiac surgery, previous myocardial infarction, history of coronary artery disease, current treatment for hypertension, arrhythmia, or cardiac failure. All the patients with a concomitant cardiac disease underwent an extensive cardiac evaluation before performing the stair climbing test, and they were allowed to perform the test only when deemed in a hemodynamically stable state. No patients with a concomitant cardiac disease were excluded from this study after cardiac evaluation.

The following additional factors were tested for an association with postoperative morbidity: smoking history (pack-years), nutritional status (albumin level; body mass index [BMI]), pT stage (pT1 vs pT $>$ 1), site of resection (upper or lower), side of resection (right or left), Eastern Cooperative Oncology Group (ECOG) performance status scale [11], and Charlson comorbidity index (CCI) [12]. We computed the number of pack-years of smoking as the total number of years smoked multiplied by the average number of cigarettes smoked per day, divided by 20. Pathologic T descriptors were classified according to the 1997 International System for Staging Lung Cancer [13]. For the purpose of the present study, the following lung resections were classified as upper resections: right and left upper lobectomies, culmectomy, lingulectomy, middle lobectomy, and right upper bilobectomy. The following procedures were classified as lower resections: right and left lower lobectomy and right lower bilobectomy.

Postoperative cardiopulmonary complications were considered as those occurring within 30 days from oper-

ation or during a longer period if the patient was still in the hospital. Most of the authors [2, 7, 14–16] agree that the inclusion of technical complications (ie, empyema, wound infection, bronchopleural fistula, hemothorax, chylothorax, left recurrent nerve injury, etc) as outcome variables in the analysis of the efficacy of the exercise tests to predict postoperative morbidity would inficiate the results. In fact, it appears unlikely that a reduced aerobic reserve may be the basis of a technical complication. For this reason and for the sake of comparison with other authors [2, 6, 14–16], only the following cardiopulmonary complications were included: respiratory failure requiring mechanical ventilation for more than 48 hours; pneumonia; atelectasis requiring bronchoscopy; pulmonary edema; pulmonary embolism; myocardial infarction; hemodynamically unstable arrhythmia requiring medical treatment; cardiac failure; and death. Mortality was not separately analyzed due to small numbers.

The comparison between patients with and without complications was made by means of the unpaired Student's *t* test for continuous variables and by means of the χ^2 test for categorical variables. The variables with a p value less than 0.10 at the univariate analysis were used as independent variables in a stepwise logistic regression analysis, in which the dependent variable was the presence of postoperative complications. To avoid multicollinearity, only one variable in a set of variables with a correlation coefficient greater than 0.5 was used in the regression model. All the tests were two-tailed, and p less than 0.05 was considered statistically significant. The analysis was performed by using the Statview 5.0 software (SAS Institute; Cary, NC).

Results

Twenty-nine patients had cardiopulmonary complications (26.6%), 3 of whom died (2.7%).

Complications in order of frequency were pneumonia (12 cases), arrhythmia (12 cases), respiratory failure (two cases), pulmonary edema (two cases), acute myocardial infarction (one case), and cardiac failure (one case).

The mean stair climbing time duration was 115.1 seconds (± 30.6). No patients experienced significant cardiac arrhythmia or other complications of the test. All 109 patients enrolled in the study who performed the stair climbing test underwent surgery. During the same period, 18 patients submitted to lobectomy could not perform the preoperative stair climbing test for severe limiting comorbidities. In this group of patients, morbidity rate was 38.9% (seven cases) and mortality rate was 22.2% (four cases).

Table 1 shows the characteristics of the patients enrolled in the study.

The results of the univariate comparison between patients with and without complications are shown in Tables 2 and 3.

In particular, as compared with patients without complications, those with complications had a lower FEV_1 ($p = 0.07$), FVC ($p = 0.048$), $ppoFEV_1$ ($p = 0.049$), and height climbed at preoperative exercise test ($p = 0.0004$). Patients with complications had also a significantly greater proportion of cardiac comorbidities ($p = 0.02$) and a higher ECOG score ($p = 0.07$), compared with the patients without complications.

Table 1. Characteristics of the Patients Enrolled in the Study (n = 109 Patients)

Variables	
Age (years)	75.2 (3.00)
PaO_2 (mm Hg)	79.2 (10.6)
$PaCO_2$ (mm Hg)	37.4 (4.0)
BMI (kg/m^2)	25.9 (3.4)
Preoperative Hb (g/dL)	13.9 (1.7)
FEV_1 (%)	85.2 (19.4)
FVC (%)	95.4 (16.7)
FEV_1/FVC ratio	0.67 (0.11)
DLCO (%)	74.2 (16.3)
Albumin (g/dL)	4.07 (0.6)
Pack-years smoked	43.8 (30.1)
Cardiac comorbidity (%)	61.5%
pT stage (pT > 1, %)	78.9%
Side (right, %)	44.9%
Site (upper, %)	49.5%
ECOG score	0.99 (0.7)
CCI score	2.1 (0.7)

Results are expressed as means ± SD, unless otherwise indicated.

BMI = body mass index; CCI = Charlson comorbidity index; DLCO = carbon monoxide diffusion lung capacity; ECOG = Eastern Cooperative Oncology Group performance status scale; FEV_1 = forced expiratory volume in 1 second; FVC = forced expiratory capacity.

Stepwise logistic regression analysis showed that significant independent predictors of postoperative cardiopulmonary complications were the presence of a concomitant cardiac disease (coefficient = 1.11; $p = 0.04$) and a low height climbed at preoperative stair climbing test (coefficient = −0.18; $p = 0.0015$).

Comment

Due to a rise in life expectancy, thoracic surgeons are faced with a growing number of elderly patients presenting with a potentially resectable lung cancer. However, physiologic changes in the cardiovascular and respiratory systems and the increased frequency of underlying comorbidities increase the risk of life-threatening complications in these patients. Therefore, risk stratification is of utmost importance in these surgical candidates and may assist the surgeon in choosing the most appropriate treatment and in planning the extent of the possible resection.

Maximal exercise tests are capable of uncovering severe pathophysiologic abnormalities in the oxygen transport system, which may be the basis of postoperative cardiopulmonary complications and mortality [1].

An age-associated decline in maximal oxygen consumption has been observed even in healthy subjects [3, 4] and has been associated mainly to a decreased cardiac output reserve [17–19] and to a less efficient redistribu-

Table 2. Results of the Comparison Between Patients With and Without Complications

Variables	With Complications	Without Complications	*p* Value
Age (years)	75.5 (3.0)	75.1 (3.0)	0.4[a]
Pack-years smoked	47.8 (27.5)	40.0 (29.5)	0.2[a]
PaO_2 (mm Hg)	77.8 (9.2)	79.7 (11.0)	0.4[a]
$PaCO_2$ (mm Hg)	37.5 (4.8)	37.4 (3.7)	0.9[a]
Albumin (g/dL)	3.95 (0.6)	4.1 (0.6)	0.2[a]
BMI (kg/m^2)	25.9 (4.0)	25.9 (3.1)	0.9[a]
Preoperative Hb (g/dL)	13.6 (1.9)	13.9 (1.6)	0.4[a]
FEV_1 (%)	79.6 (16.8)	87.3 (20.0)	0.07[a]
FVC (%)	90.2 (13.5)	97.3 (17.4)	0.048[a]
FEV_1/FVC ratio	0.65 (0.11)	0.68 (0.11)	0.2[a]
DLCO (%)	71.4 (14.1)	75.2 (17.0)	0.3[a]
ppoFEV_1 (%)	63.2 (14.6)	70.0 (16.4)	0.049[a]
ppoDLCO (%)	56.3 (12.5)	60.5 (15.6)	0.2[a]
ECOG score	1.2 (0.7)	0.9 (0.7)	0.07[a]
CCI score	2.5 (2.1)	2.0 (1.5)	0.2[a]
Cardiac comorbidity (%)	79.3%	55%	0.02[b]
pT stage (pT1 vs pT > 1, %)	17.4% vs. 23.2%	82.6% vs. 76.7%	0.4[b]
Side (right vs left)	28.8% vs. 25.0%	71.2% vs. 75.0%	0.6[b]
Site (upper vs lower)	22.4% vs. 32.7%	77.6% vs. 67.3%	0.2[b]

[a] Student's *t* test; [b] χ^2 test.

Results are expressed as means ± SD, unless otherwise indicated.

BMI = body mass index; CCI = Charlson comorbidity index; DLCO = carbon monoxide diffusion lung capacity; ECOG = Eastern Cooperative Oncology Group performance status scale; FEV_1 = forced expiratory volume in 1 second; FVC = forced expiratory capacity; ppo = predicted postoperative.

tion of blood flow to the exercising muscles and organs [5, 20]. However, the entity of the reduction of the aerobic capacity in the elderly varies depending on the associated comorbidities and physical deconditioning. Thus, using preoperative exercise tests is a logical approach for evaluating the cardiovascular and respiratory reserve of this particular group of patients [21].

Table 3. Results of the Comparison of the Ergometric Variables Between Patients With and Without Complications

Variables	With Complications	Without Complications	*p* Value[a]
Height climbed (m)	16.23 (3.8)	19.61 (4.4)	0.0004
VO_2max (mL/min/kg)	23.83 (3.3)	24.58 (3.4)	0.3
ppoVO_2max (mL/min/kg)	18.72 (3.3)	19.73 (3.5)	0.2
Oxygen pulse (mL/beat)	14.7 (3.6)	14.7 (3.4)	0.9
Delta $satO_2$	1.9 (3.0)	1.0 (2.8)	0.13
HRR%	18.5 (15.1)	17.6 (13.0)	0.8

[a] Student's *t* test.

Results are expressed as means ± SD.

Delta $satO_2$ = difference between rest oxygen saturation and peak exercise oxygen saturation; HRR% = heart rate reserve in percentage.

In January 2000, we started to systematically use stair climbing test on all candidates for lung resection. This test is economical, widely reproducible, and requires few personnel and equipment. Because stair climbing is a more stressful exercise than cycle ergometer and yields greater values of VO_2 max [22–24], this test appears particularly useful in detecting oxygen transport deficits. In fact, several studies have reported a good capability of this test in predicting cardiopulmonary complications after lung resection [2, 22, 25–27].

In the present analysis, the significant predictors of postoperative cardiopulmonary complications were the presence of a concomitant cardiac disease, and, most of all, the height climbed at preoperative stair climbing test, after the effect of other variables was controlled in a logistic regression analysis.

The presence of a concomitant cardiac disease has been previously shown to increase the risk of postoperative complications in series, in which, however, older patients were not separately assessed [28–31].

We expressed the number of steps climbed as height climbed in meters to provide a standardized value, according to Pate and associates [26]. This variable was the most important predictor of postoperative cardiopulmonary complications. In particular, only 17 of 82 patients (20.7%) who climbed more than 14 m had complications, whereas 4 of 7 patients (57.1%) who climbed less than 12 m had complications. Eight of 20 patients (40%) who climbed between 12 and 14 m experienced postoperative complications. The progressive increase of morbidity rate with the reduction in the height climbed indirectly demonstrated the capability of the stair climbing test to reveal severe deficits in the aerobic capacity, confirming also the cutoff values found by Olsen and associates [7] (three flights of stairs, corresponding in their setting to 13 m of height).

The difference in VO_2 max between patients with and those without complications was not statistically significant, at variance with our previous study (in which we did not separately analyze elderly patients [2]), and with other works that used a cycle ergometer [6, 14–16, 32–34]. Differences in the age of the populations analyzed and in the methodology of the exercise (constant work rate vs incremental work rate) may account for this discrepancy.

We calculated VO_2 max rather than measured it, as we wanted to adopt a technically simple, low-cost, widely applicable, noninvasive method of exercise. Although the accuracy of the calculation of VO_2 max is not widely accepted, the same equation was used for all patients. Provided a discrepancy would exist between measured and calculated VO_2 max, this discrepancy would be similar for all patients. Therefore, the method of calculation of VO_2 max unlikely affected the results of the analysis.

In a high-risk group of 8 elderly patients identified by a ppoFEV_1 or a ppoDLCO less than 40% of predicted, who would have been traditionally considered inoperable, we had four complications and, most importantly, no

mortality. We operated on these patients based only on their performance on the preoperative stair climbing test. In fact, all of them had a VO_2 max greater than 20 mL/min/kg and a ppoVO_2 max greater than 15 mL/min/kg, confirming the cutoff values proposed by other authors on similar high-risk subjects [9, 22, 33]. Moreover, 7 of our 8 high-risk patients reached a height greater than 14 m during the stair climbing test. This finding has important clinical implications. Even elderly candidates with prohibitive predicted postoperative pulmonary function should not be denied surgery if their performance during the stair climbing test indicates an adequate cardiopulmonary reserve.

In conclusion, we showed that the symptom-limited stair climbing test was a safe and simple instrument capable of predicting postoperative cardiopulmonary complications in patients older than 70 years of age undergoing pulmonary resection for lung cancer. If the stair climbing test detects a reduced aerobic reserve, then more sophisticated tests should be used, to identify and possibly correct any cause of impaired oxygen transport. Therefore, we think that our results warrant the routine use of this exercise test in the preoperative evaluation and risk stratification of elderly candidates for lung resection.

References

1. Olsen GN. The evolving role of exercise testing prior to lung resection. Chest 1989;95:218–25.
2. Brunelli A, Al Refai M, Monteverde M, Borri A, Salati M, Fianchini A. Stair climbing test predicts cardiopulmonary complications after lung resection. Chest 2002;121:1106–10.
3. Astrand I. Aerobic work capacity in men and women with special reference to age. Acta Physiol Scand 1960;49(Suppl 169):1–92.
4. Hagberg JM. Effect of training on the decline of VO2max with aging. Fed Proc 1987;46:1830–3.
5. Beere PA, Russel SD, Morey MC, Kitzman DW, Higginbotham MB. Circulation 1999;100:1085–94.
6. Markos J, Mullan BP, Hillman DR, et al. Preoperative assessment as a predictor of mortality and morbidity after lung resection. Am Rev Respir Dis 1989;139:902–10.
7. Olsen GN, Bolton JWR, Weiman DS, Hornung CA. Stair climbing as an exercise test to predict the postoperative complications of lung resection: two years experience. Chest 1991;99:587–90.
8. Corris PA, Ellis DA, Hawkins T, Gibson GJ. Use of radionuclide scanning in the preoperative estimation of pulmonary function after pneumonectomy. Thorax 1987;42:285–91.
9. Bolliger CT, Wyser C, Roser H, Soler M, Perruchoud AP. Lung scanning and exercise testing for the prediction of postoperative performance in lung resection candidates at increased risk for complications. Chest 1995;108:341–8.
10. Wasserman K, Hansen JE, Sue DY, Casaburi R, Whipp BJ. Principles of exercise testing and interpretation. Philadelphia: Lea & Febiger, 1989.
11. Minna JD, Pass H, Glatstein E, Ihde DC. Cancer of the lung. In: De Vita VT Jr, Hellman S, Rosenberg SA, eds. Cancer: principles and practice of oncology, vol 1. Philadelphia: Lippincott, 1989:628–9.
12. Birim O, Maat APWM, Kappetein AP, van Meerbeeck JP, Damhuis RAM, Bogers AJJC. Validation of the Charlson comorbidity index in patients with operated primary non-small cell lung cancer. Eur J Cardiothorac Surg 2003;23:30–4.
13. Mountain CF. Revisions in the International System for Staging Lung Cancer. Chest 1997;111:1710–7.
14. Smith TP, Kinasewitz, Tucker WY, Spillers WP, George RB. Exercise capacity as a predictor of post-thoracotomy morbidity. Am Rev Respir Dis 1984;44:730–4.
15. Bechard D, Wetstein L. Assessment of exercise oxygen consumption as preoperative criterion for lung resection. Ann Thorac Surg 1987;44:344–9.
16. Bolliger CT, Jordan P, Soler M, et al. Exercise capacity as a predictor of postoperative complications in lung resection candidates. Am J Respir Crit Care Med 1995;151:1472–80.
17. Higginbotham MB, Morris KG, Williams RS, Coleman RE, Cobb FR. Physiologic basis for the age-related decline in aerobic work capacity. Am J Cardiol 1986;57:1374–9.
18. Granath A, Jonsson B, Strandell T. Circulation in healthy old men, studied by right heart catheterization at rest and during exercise in supine and sitting position. Acta Med Scand 1964;176:425–46.
19. Ogawa T, Spina RJ, Martin WH III, et al. Effects of aging, sex and physical training on cardiovascular responses to exercise. Circulation 1992;86:494–503.
20. Wahren J, Saltin B, Jorfeldt L, Pernow B. Influence of age on the local circulatory adaptation to leg exercise. Scand J Clin Lab Invest 1974;33:79–86.
21. Wasserman K. Preoperative evaluation of cardiovascular reserve in the elderly. Chest 1993;104:663–4.
22. Holden DA, Rice TW, Stelmach K, Meeker DP. Exercise testing, 6-min walk, and stair climb in the evaluation of patients at high risk for pulmonary resection. Chest 1992;102:1774–9.
23. Swinburn CR, Wakefield JM, Jones PW. Performance, ventilation, and oxygen consumption in three different types of exercise tests in patients with chronic obstructive lung disease. Thorax 1985;40:581–6.
24. Pollock M, Roa J, Benditt J, Celli B. Estimation of ventilatory reserve by stair climbing: a study in patients with chronic airflow obstruction. Chest 1993;104:1378–83.
25. Van Norstrand D, Kjeslberg MO, Humphrey EW. Preresectional evaluation of risk from pneumonectomy. Surg Gynecol Obstet 1968;127:306–12.
26. Pate P, Tenholder MF, Griffin JP, Eastridge CE, Weiman DS. Preoperative assessment of the high-risk patient for lung resection. Ann Thorac Surg 1996;61:1494–1500.
27. Girish M, Trayner E, Damman O, Pinto-Plata V, Celli B. Symptom-limited stair climbing as a predictor of postoperative cardiopulmonary complications after high-risk surgery. Chest 2001;120:1147–51.
28. Nagasaki F, Flehinger BJ, Martini N. Complications of surgery in the treatment of carcinoma of the lung. Chest 1982;82:25–9.
29. Deslauriers J, Ginsberg RJ, Piantadosi S, Fournier B. Prospective assessment of 30-day operative morbidity for surgical resections in lung cancer. Chest 1994;106(Suppl):329–30S.
30. Romano PS, Mark DH. Patient and hospital characteristics related to in-hospital mortality after lung cancer resection. Chest 1992;101:1332–7.
31. Patel RL, Townsend ER, Fountain SW. Elective pneumonectomy: factors associated with morbidity and operative mortality. Ann Thorac Surg 1992;54:84–8.
32. Eugene J, Brown SE, Light RW, et al. maximum oxygen consumption. a physiologic guide to pulmonary resection. Surg Forum 1982;33:260–2.
33. Morice RC, Peters EJ, Ryan MB, Putnam JB, Ali MK, Roth JA. Exercise testing in the evaluation of patients at high risk for complications from lung resection. Chest 1992;101:356–61.
34. Brutsche MH, Spiliopoulos A, Bolliger CT, Licker M, Frey JG, Tschopp JM. Exercise capacity and extent of resection as predictors of surgical risk in lung cancer. Eur Respir J 2000;15:828–32.