Clinical Investigations

Respiration

Respiration 2012;84:117–122
DOI: 10.1159/000337258

Received: December 5, 2011
Accepted after revision: February 11, 2012
Published online: May 4, 2012

Speed of Ascent During Stair Climbing Identifies Operable Lung Resection Candidates

Maurizio Bernasconi[a] Coenraad F.N. Koegelenberg[a] Florian von Groote-Bidlingmaier[a] David Maree[a] Barend J. Barnard[b] Andreas H. Diacon[a, c] Chris T. Bolliger[a]

[a]Division of Pulmonology, Department of Medicine, [b]Division of Cardiothoracic Surgery, Department of Surgery, and [c]Division of Medical Physiology, Department of Biomedical Sciences, Tygerberg Academic Hospital, Stellenbosch University, Cape Town, South Africa

Key Words

Stair climbing test · Oxygen consumption · Lung resection · Operability

Abstract

Background: Preoperative evaluation of lung resection candidates with impaired pulmonary reserves includes measurement of aerobic capacity. Stair climbing is an attractive low-cost alternative to treadmill exercise testing but it lacks standardisation. ***Objectives:*** To directly compare stair climbing and treadmill exercise testing with respect to an established cut-off value for lung resection. ***Methods:*** We subjected 56 lung resection candidates to both symptom-limited treadmill exercise testing and stair climbing to a maximum of 20 m. Both exercise tests were monitored with the same portable spiroergometer. Subjects were on average 46.6 years old, 61% were male and 54% had $FEV_1/FVC < 70\%$. Mean FEV_1 and $DLCO_c$ were 51.6 and 57.1%, respectively. ***Results:*** Mean altitude reached, exercise time, speed of ascent and peak VO_2 were 16.9 m, 74 s, 14.7 m/min and 22.4 ml/min/kg, respectively, in 54 subjects completing stair climbing. Thirty-one subjects (58%) reached 20 m without stopping. Treadmill tests were completed by 51 subjects and lasted longer (432 s; $p < 0.001$), but VO_{2max} was not different compared to stair climbing (22.7 ml/min/kg; $p = 0.673$). Speed of ascent was significantly correlated to both stair climbing peak VO_2 ($r = 0.63$) and treadmill VO_{2max} ($r = 0.67$). All 19 subjects (34%) who reached 20 m in 80 s or less (≥15 m/min) had a VO_{2max} of ≥20 ml/min/kg. ***Conclusions:*** We found a clinically useful correlation between speed of ascent during stair climbing and VO_{2max} during treadmill exercise testing. Climbing to 20 m with an average speed of ascent of ≥15 m/min accurately identified subjects qualifying for pneumonectomy according to established criteria.

Introduction

Pulmonary resection remains a high-risk procedure in patients with impaired cardiopulmonary reserve [1]. Validated algorithms that identify candidates at risk of complications or with an unacceptable decrease in quality of life after lung resection include cardiac history, spirometry, diffusion capacity for carbon monoxide (DLCO), formal cardiopulmonary exercise testing on a cycle ergometer or treadmill with measurement of the aerobic capacity (VO_{2max}) and the calculation of predicted postoperative reserves, sometimes necessitating split function studies

KARGER

Fax +41 61 306 12 34
E-Mail karger@karger.ch
www.karger.com

0025–7931/12/0842–0117$38.00/0

Accessible online at:
www.karger.com/res

Dr. Maurizio Bernasconi
Division of Pulmonology, Department of Medicine
Stellenbosch University, PO Box 19063
7505 Tygerberg, Cape Town (South Africa)
Tel. +27 21 938 9243, E-Mail mauribernasconi@gmail.com

[2, 3]. It is generally accepted that low aerobic capacity correlates with the risk of postoperative complications [4]. A VO_{2max} of ≥20 ml/kg/min is considered the minimum reserve for pneumonectomy and lobectomy and has been associated with a very low postoperative morbidity (11%) and mortality (1.5%) [2]. However, measurement of DLCO, VO_{2max} and split function requires specialised equipment and expertise, which is expensive and not always accessible.

Considerable effort has gone into sophisticated technology to exclude patients with critical impairment from lung resection. It is also clear that patients with normal or near-normal reserves are at low risk, but simple criteria allowing the admission of patients with only mild or moderate impairment to lung resection without the indiscriminate use of costly technology are lacking. Symptom-limited stair climbing with no or minimal instrumentation is simple, low cost and widely available. Stair climbing performance identifies patients at risk for morbidity and mortality after lung resection, but technical aspects and suggested cut-off values vary significantly across studies [5–9]. An altitude climbed of 16.6–22 m (about 6 floors) seems necessary to adequately stress the cardiorespiratory system of lung resection candidates [4, 10, 11]. In one study, inability to climb 12 m was associated with a 13-fold higher mortality than in patients who climbed more than 22 m [12]. A recent pilot study performed at our institution demonstrated a good correlation between speed of ascent and VO_{2max} measured during cycle ergometry [11].

We aimed to directly compare speed of ascent to a height of 20 m with aerobic capacity measured during stair climbing and during formal treadmill exercise testing. Our ultimate aim was to validate a standardised stair climbing test to 20 m in a cohort of lung resection candidates with various degrees of pulmonary impairment, and to investigate its ability to identify subjects at low risk.

Materials and Methods

Study Design and Population

Tygerberg Academic Hospital is a 1,200-bed academic hospital in Cape Town, South Africa. It is one of two referral centres and renders a tertiary service to a population of approximately 1.5 million people. Candidates for elective pulmonary resection are routinely referred to the Pulmonology Division for preoperative evaluation. Adult candidates for pulmonary resection were clinically evaluated and considered eligible for the study if they had FEV_1 and/or $DLCO_c$ of less than 80% of predicted (Jaeger MasterLab, Erich Jaeger GmbH and CoKG, Würzburg, Germany). Patients were excluded with poorly controlled medical conditions or contraindications for exercise testing such as chronic obstructive pulmonary disease exacerbation, unstable angina pectoris, recent myocardial infarction, aortic outflow obstruction, uncontrolled arterial hypertension, recent thromboembolic disease and current haemoptysis. Patients with lower limb pathology unable to cooperate fully were also excluded. The local institutional review board approved the protocol and all patients gave written informed consent.

Exercise Testing

Stair climbing and treadmill tests were performed on the same day and in that sequence. On both the stairs and treadmill the aerobic capacity was measured by breathing room air with direct breath-by-breath measurement of expired gases through a validated, light, portable telemetric gas analyser (MetaMax® Spiroergometer, CORTEX Biophysik GmbH, Leipzig, Germany) which was carried by the subjects on a comfortable belt system that allowed constant and simultaneous data transmission to a central computer station (MetaSoft® software, CORTEX Biophysik GmbH) [13]. Symptom-limited stair climbing took place on a central staircase with steps 17.4 cm high. Between floors there were 20 steps and one intermediate landing. Subjects were asked to climb 'as fast and as high without stopping' as they possibly could to a maximum elevation of precisely 20 m, corresponding to approximately 6 floors. An assistant followed the subjects and gave vocal encouragement but provided no other help throughout the ascent. The test was considered completed when a patient stopped for more than 3 s or reached the target elevation of 20 m. The assistant recorded the exercise time and height reached. A compulsory rest period of at least 2 h was respected before the treadmill test, which was done with a Balke ramp protocol according to current published guidelines [14]. All subjects were once again equally encouraged to give their best effort. Capillary blood samples for lactate and pH measurements were collected upon exercise test termination. For stair climbing we reported as peak VO_2 the highest VO_2 maintained for at least 5 s. On the treadmill VO_{2max} was defined as the VO_2 measured when standard criteria for adequate exercise were met [14].

Statistical Analysis

The sample was chosen to obtain a representative study population across all degrees of exercise impairment. We aimed to include subjects over at least a year but also to include at least five subjects in each of the following categories of VO_{2max} impairment: >82% (normal), 61–81% (mild), 51–60% (moderate), <50% (severe) [15]. Discrete variables are expressed as counts (percentages) and continuous variables as means ± standard deviation (SD). Continuous variables with normal distribution were compared by the paired Student t test. Correlation analyses were performed using a Spearman rank test (r = Spearman's correlation coefficient). A p value of <0.05 was accepted as significant.

Results

Patient Characteristics

Between May 2010 and April 2011 we included the 56 lung resection candidates whose demographics, medical history and lung function measurements are reported in table 1. According to VO_{2max} reached on the treadmill, 13, 21, 11 and 7 subjects had no, mild, moderate and severe cardiopulmonary impairment, respectively [15]. Tuberculosis-related conditions such as bronchiectasis, fibrocavitatory changes and aspergilloma were the most common indication for lung resection. Five out of 56 subjects could only partly complete the study: 2 subjects had ECG findings requiring further evaluation and 3 subjects did not complete the treadmill test because of severe dyspnoea, haemoptysis and lower limb weakness. All other exercise tests were terminated because of subjective inability to continue climbing the stairs or walking on the treadmill due to either fatigue or dyspnoea and remained free of complications.

Exercise Testing

Of 54 subjects who completed the stair climbing exercise 22 (41%) did not reach the target altitude of 20 m. As expected, the speed of ascent and VO_2 peak increased progressively with the altitude reached and was higher in those reaching the target of 20 m than those that did not (table 2). Table 3 summarises cardiopulmonary and metabolic parameters measured during the stair climbing and treadmill exercise tests. Not surprisingly, the treadmill ramp protocol took longer to complete than stair climbing by an average of about 6 min ($p < 0.001$, t test), which was also reflected in a slightly higher maximum heart rate ($p = 0.004$, t test). However, the proportion of subjects reaching at least 80% of their theoretical maximum heart rate did not differ significantly, which was also the case with all other cardiopulmonary parameters measured.

Correlation between Stair Climbing and Treadmill Exercise Testing

Despite its short duration, speed of ascent was well correlated with peak VO_2/kg during stair climbing ($r = 0.63$, fig. 1a) and with VO_{2max}/kg reached on the treadmill ($r = 0.67$, fig. 1b), as calculated for all patients. In patients unable to reach 20 m, neither speed of ascent nor altitude reached were statistically correlated with VO_2 ($r = 0.211$, $p = 0.347$ and $r = 0.216$, $p = 0.334$, respectively). Altitude alone correlated less well with peak VO_2/kg ($r = 0.43$). Moreover, speed of ascent was the best predictor of a peak VO_2/kg greater than 20 ml/min/kg, followed by age and altitude in the univariate logistic regression analysis ($p = 0.004$, 0.023 and 0.05, respectively). The diagnostic performance of speed of ascent to predict a minimum VO_{2max}/kg of 20 ml/min/kg is shown in table 4. Eighteen

Table 1. Patient characteristics

Demographics (n = 56)		
Male, n	34	60.7%
Race, n		
Caucasian	7	12.5%
Black African	18	32.1%
Mixed race	31	55.4%
Age (mean, range), years	46.6	20–72.4
Body mass index (mean, SD)	22.3	6.1
Medical history and comorbidities		
Previous pulmonary tuberculosis, n	44	78.6%
Previous haemoptysis, n	38	67.8%
HIV infection, n	10	17.8%
Current or former smoker, n	35	62.5%
Pack years in smokers (mean, SD)	25.2	14.9
COPD (defined as FEV_1/FVC <0.7), n	30	53.5%
Revised cardiac risk index		
1, n	51	91.1%
2, n	5	8.9%
Pulmonary function test		
TLC % predicted (mean, SD)	90.0	23.7
FVC % predicted (mean, SD)	64.6	16.1
FEV_1 % predicted (mean, SD)	51.6	16.2
FEV_1/FVC (mean, SD)	0.67	0.16
$DLCO_c$ % predicted (mean, SD)	57.1	18.6
Indication for pulmonary resection		
Fibrocavitatory disease, bronchiectasis, n	26	46.4%
Aspergilloma, n	17	30.3%
Non-small cell lung cancer, n	10	17.9%
Hydatid cyst, n	3	5.4%
Planned extent of resection		
Lobectomy, n	29	51.8%
Bi-lobectomy, n	2	3.6%
Pneumonectomy, n	25	44.6%

COPD = Chronic obstructive pulmonary disease; TLC = total lung capacity; FVC = forced vital capacity; FEV_1 = forced expiratory volume in 1 s; $DLCO_c$ = diffusion capacity for CO corrected for haemoglobin.

Table 2. Stair climbing (mean ± SD)

	Subjects, n (%)	Altitude reached m	Speed of ascent m/min	VO_{2max} ml/min/kg
All subjects	54 (100)	16.9 ± 4.3	14.7 ± 5.7	22.4 ± 6.2
Reached 20 m	32 (59)	20	17.3 ± 5.9	24.7 ± 6.2
Did not reach 20 m	22 (41)	12.4 ± 3.6	10.6 ± 2.2	19.1 ± 4.3
Reached ≤10 m	5 (9)	7.4 ± 2.0	9.8 ± 3.0	18.0 ± 5.8
Reached 10–15 m	11 (20)	12.4 ± 0.8	11.1 ± 1.9	19.5 ± 3.6
Reached 15–20 m	6 (11)	16.8 ± 0.9	10.5 ± 2.1	20.5 ± 3.8

Table 3. Cardiopulmonary and metabolic parameters during exercise testing

Parameter	Stairs			Treadmill		
	n	mean	SD	mean	SD	<p
VO_{2max}, l/min	51	1.36	0.45	1.36	0.47	0.859
VO_{2max}, ml/min/kg	51	22.9	6.0	22.7	6.2	0.673
Exercise duration, s	51	74.3	24.3	432.2	185.3	<0.001
HR, beat/min	45	152.9	17.0	159.0	17.8	0.004
HRR <20%, %	45	79.6	40.8	86.4	34.7	0.183
VE, l/min	51	43.5	13.2	42.9	12.2	0.486
BR, %	49	22.2	16.7	23.2	16.2	0.510
pH	24	7.32	0.06	7.32	0.09	1
Lactate, mmol/l	24	5.6	2.3	6.4	2.7	0.432

n = Number of values available; HR = heart rate; HRR = heart rate reserve (HR max/[220-Age] × 100); VE = ventilation; BR = breath reserve (VE/[FEV_1 × 37.5]). p = Paired t tests for means (two-tailed).

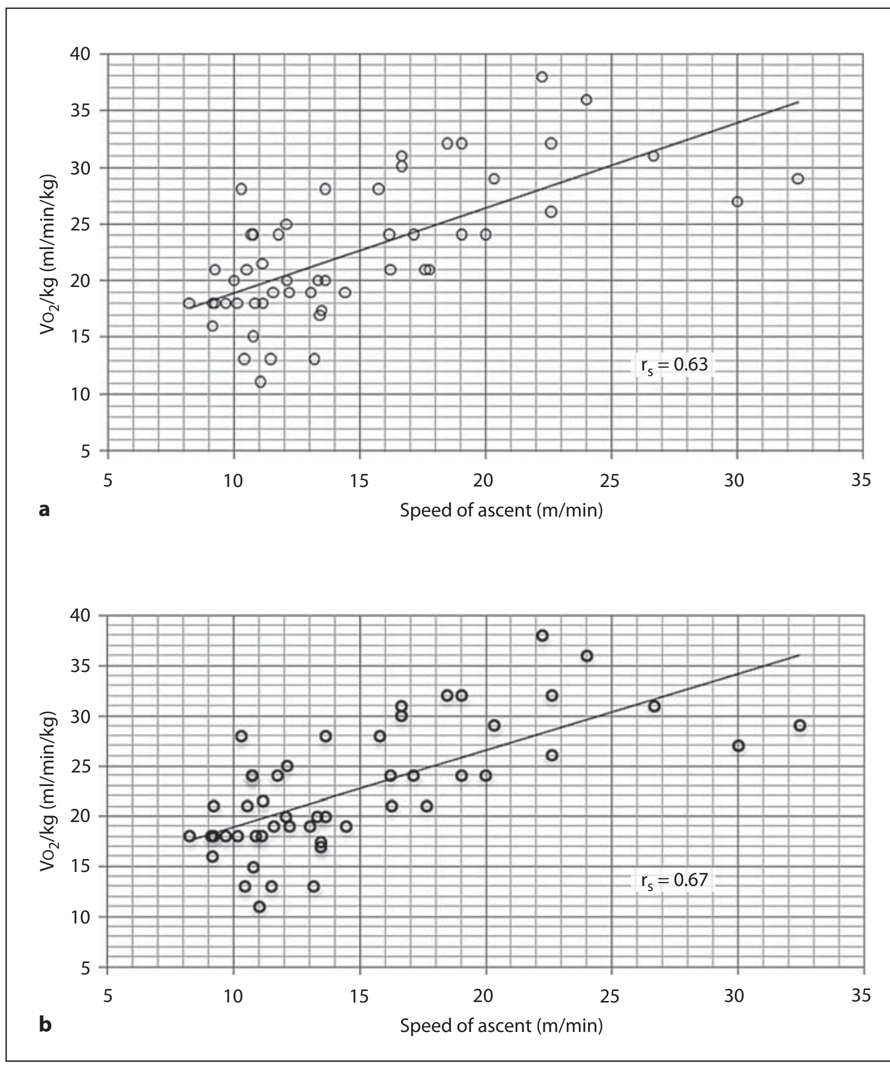

Fig. 1. a Speed of ascent and peak VO_2, stair climbing (n = 54). **b** Speed of ascent and VO_{2max}, treadmill (n = 51).

Table 4. Speed of ascent as a predictor of VO_{2max} on the treadmill in subjects reaching 20 m (n = 31)

Speed of ascent	Subjects	%	VO_2/kg >20 ml/min/kg							
			TP, n	FP, n	TN, n	FN, n	Sens, %	Spec, %	NPV, %	PPV, %
>10 m/min	28	90.3	23	5	2	1	95.8	28.6	66.7	82.1
>11 m/min	27	87.1	23	4	3	1	95.8	42.9	75.0	85.2
>12 m/min	26	83.9	22	4	3	2	91.7	42.9	60.0	84.6
>13 m/min	25	80.6	21	4	3	3	87.5	42.9	50.0	84.0
>14 m/min	19	61.3	18	1	6	6	75.0	85.7	50.0	94.7
>15 m/min	18	58.1	18	0	7	6	75.0	100.0	53.8	100.0

TP = True-positive; FP = false-positive; TN = true-negative; FN = false-negative; Sens = sensitivity; Spec = specificity; NPV = negative predictive value; PPV = positive predictive value.

(58%) out of the 31 subjects who reached the target altitude of 20 m climbed it in less than 80 s (speed of ascent ≥15 m/min) and also had a VO_{2max} of greater than 20 ml/min/kg on the treadmill. This means that in 18 out of 56 subjects (32%) a decision regarding operability could be made based on symptom-limited stair climbing alone.

Discussion

Our study validates timed stair climbing to 20 m as a simple, practical and low-cost exercise test for lung resection candidates with at least mild pulmonary impairment. Despite its short duration, 79% of the 56 subjects reached at least 80% of their theoretical maximum heart rate. Speed of ascent to 20 m correlated equally well with peak VO_2 during stair climbing itself and VO_{2max} during formal treadmill exercise testing. All subjects who reached 20 m within 80 s (speed of ascent ≥15 m/min) had a VO_{2max} greater than 20 ml/min/kg. This implies that in this cohort of subjects with pulmonary impairment, every third lung resection candidate could potentially have been considered fit for lung resection up to the extent of pneumonectomy without formal exercise testing.

It is interesting that a short but intensive climb to a relatively low altitude (average duration 1.25 min) is of high enough intensity to predict the outcome of a standard maximal exercise test to exhaustion of much longer duration (7.25 min in this study). This confirms the results of an earlier pilot study at our institution [11] and those of Cataneo and Cataneo [16] to an even lower altitude of 12.16 m. Timed 'racing' up the stairs to a target height at maximum speed is indeed highly motivating and easy to standardise, which is in contrast with the alternative challenge of climbing steadily at one's own pace to a maximum altitude gained [17–19]. Current guidelines for surgical treatment of lung cancer suggest an ability to climb higher than 22 m at any pace is sufficient to undergo resection up to pneumonectomy [3]. However, Brunelli et al. [19] showed that 37% of subjects reaching 22 m did not generate a VO_{2max} greater than 20 ml/min/kg. The present study supports this concern: 19% of the subjects who reached 20 m also did not achieve that level of VO_2. Speed of ascent (r = 0.63) was better correlated with peak VO_2 than altitude (r = 0.43) even when 20 m were not reached. Adding a time variable seems, therefore, crucial in order to increase the accuracy of the test in predicting a VO_{2max} above previously validated cut-off values in subjects with mild exercise impairment. In patients who did not reach 20 m, neither speed of ascent nor altitude climbed were correlated with peak VO_2 suggesting that such patients should undergo complete cardiopulmonary exercise testing.

This study has some limitations. Firstly, the patient population studied presented at a relatively young age and with mostly nonmalignant pathology. Whether our results can be extrapolated to an older population with mostly smoking-related indications for lung resection is not clear. Older subjects are less likely to reach 20 m in 80 s and this trend would reduce the risk of false-positive results. Both tests were safe in the population tested but more data are needed in older, less mobile subjects. Secondly, too few subjects reached VO_{2max} between 15 and 20 ml/min/kg to enable a useful analysis of this commonly accepted cut-off for lung resection up to the extent of lobectomy. Thirdly, we did not collect data on postoperative complications and mortality.

Based on our findings a next step would be to prospectively test the suggested cut-offs and to compare perioperative morbidity and mortality with historical data. As the best available figures for morbidity and mortality are around 1.5 and 11%, respectively [2], such a study will have to include several hundreds of patients in order to prove the noninferiority of timed stair climbing to formal exercise testing.

In conclusion, we have shown that a short, timed stair climbing exercise to 20 m is of a similar intensity to formal treadmill exercise testing. The critical VO_{2max} of >20 ml/min/kg was reached by all subjects climbing to 20 m in less than 80 s. These observations add to the growing body of evidence that stair climbing is a clinically useful test for the evaluation of lung resection candidates with impaired lung function.

Acknowledgements

M. Bernasconi was supported by the Swiss National Science Foundation (www.snf.ch), Freiwillige Akademische Gesellschaft (Basel, Switzerland) and E. Balli Foundation (Bellinzona, Switzerland). We would like to thank all members of the pulmonary function laboratory team of Tygerberg Academic Hospital for their assistance and Justin Harvey for support with the statistical analysis.

Financial Disclosure and Conflicts of Interest

None of the authors have a financial interest to declare.

References

1 Bolliger CT, Koegelenberg CF, Kendal R: Preoperative assessment for lung cancer surgery. Curr Opin Pulm Med 2005;11:301–306.
2 Wyser C, Stulz P, Soler M, Tamm M, Muller-Brand J, Habicht J, Perruchoud AP, Bolliger CT: Prospective evaluation of an algorithm for the functional assessment of lung resection candidates. Am J Respir Crit Care Med 1999;159:1450–1456.
3 Brunelli A, Charloux A, Bolliger CT, Rocco G, Sculier JP, Varela G, Licker M, Ferguson MK, Faivre-Finn C, Huber RM, Clini EM, Win T, De Ruysscher D, Goldman L: ERS/ESTS clinical guidelines on fitness for radical therapy in lung cancer patients (surgery and chemo-radiotherapy). Eur Respir J 2009;34:17–41.
4 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;15:828–832.
5 Olsen GN, Bolton JW, Weiman DS, Hornung CA: Stair climbing as an exercise test to predict the postoperative complications of lung resection: two years' experience. Chest 1991;99:587–590.
6 Brunelli A, Monteverde M, Al Refai M, Fianchini A: Stair climbing test as a predictor of cardiopulmonary complications after pulmonary lobectomy in the elderly. Ann Thorac Surg 2004;77:266–270.
7 Girish M, Trayner E Jr, Dammann O, Pinto-Plata V, Celli B: Symptom-limited stair climbing as a predictor of postoperative cardiopulmonary complications after high-risk surgery. Chest 2001;120:1147–1151.
8 Brunelli A, Sabbatini A, Xiume F, Borri A, Salati M, Marasco RD, Fianchini A: Inability to perform maximal stair climbing test before lung resection: a propensity score analysis on early outcome. Eur J Cardiothorac Surg 2005;27:367–372.
9 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;102:1774–1179.
10 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;104:1378–1383.
11 Koegelenberg CF, Diacon AH, Irani S, Bolliger CT: Stair climbing in the functional assessment of lung resection candidates. Respiration 2008;75:374–379.
12 Brunelli A, Refai M, Xiume F, Salati M, Sciarra V, Socci L, Sabbatini A: Performance at symptom-limited stair-climbing test is associated with increased cardiopulmonary complications, mortality, and costs after major lung resection. Ann Thorac Surg 2008;86:240–247.
13 Larsson PU, Wadell KM, Jakobsson EJ, Burlin LU, Henriksson-Larsen KB: Validation of the MetaMax II portable metabolic measurement system. Int J Sports Med 2004;25:115–123.
14 Ross RM: ATS/ACCP statement on cardiopulmonary exercise testing. Am J Respir Crit Care Med 2003;167:1451.
15 Schmid A, Schilter D, Fengels I, Chhajed PN, Strobel W, Tamm M, Brutsche MH: Design and validation of an interpretative strategy for cardiopulmonary exercise tests. Respirology 2007;12:916–923.
16 Cataneo DC, Cataneo AJ: Accuracy of the stair climbing test using maximal oxygen uptake as the gold standard. J Bras Pneumol 2007;33:128–133.
17 Brunelli A, Al Refai M, Monteverde M, Borri A, Salati M, Fianchini A: Stair climbing test predicts cardiopulmonary complications after lung resection. Chest 2002;121:1106–1110.
18 Brunelli A, Fianchini A: Stair climbing test in lung resection candidates with low predicted postoperative FEV_1. Chest 2003;124:1179.
19 Brunelli A, Xiume F, Refai M, Salati M, Di Nunzio L, Pompili C, Sabbatini A: Peak oxygen consumption measured during the stair-climbing test in lung resection candidates. Respiration 2010;80:207–211.
20 Bolliger CT, Guckel C, Engel H, Stohr S, Wyser CP, Schoetzau A, Habicht J, Solèr M, Tamm M, Perruchoud AP: Prediction of functional reserves after lung resection: comparison between quantitative computed tomography, scintigraphy, and anatomy. Respiration 2002;69:482–489.
21 Koegelenberg CF, Bolliger CT: Assessing regional lung function. Thoracic Surgery Clinics 2008;18:19–29.