

Original
Article

The Predictive Value of Stair Climbing Test on Postoperative Complications in Lung Cancer Patients with Limited Pulmonary Function

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Purpose: To evaluate the predictive value of stair climbing test (SCT) on postoperative complications in lung cancer patients with limited pulmonary function.

Methods: A total of 727 hospitalized lung cancer patients with limited pulmonary function were retrospectively reviewed. Included in the cohort were 424 patients who underwent SCT preoperatively. Patients were grouped according to general condition, past medical history, surgical approach, pulmonary function test, and SCT results. Comparison of the postoperative cardiopulmonary complication rates was made and independent risk factors were identified.

Results: A total of 89 cardiopulmonary-related complications occurred in 69 cases, accounting for 16.3% of the entire cohort. The postoperative cardiopulmonary complication rates were significantly different between groups stratified by smoking index, percentage of forced expiratory volume in one second, percentage of diffusion capacity for carbon monoxide, SCT results, excision extension, and anesthetic duration ($p < 0.05$). Multivariate analysis showed that only height achieved ($p < 0.001$), changes in heart rate (ΔHR ; $p < 0.001$), and excision extension ($p = 0.006$) were independent risk factors for postoperative cardiopulmonary complications.

Conclusions: The SCT could be used as a preoperative screening method for lung cancer patients with limited pulmonary function. For those patients who could only climb less than 6 floors or had $\Delta HR > 30$ bpm in the test, sublobar resection should be selected to reduce the postoperative cardiopulmonary complication rate.

Keywords: stair climbing test, pulmonary resection, postoperative complication

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Introduction

Pulmonary resection procedure is considered to be high risk in suspected lung cancer patients with underlying cardiopulmonary disease, who make up a large proportion of patients in large general hospitals. Previous researches validated several tests that could predict postoperative complications or unacceptable decrease in quality of life after surgery, including spirometry, diffusion capacity for carbon monoxide (DLCO) and cycle ergometer or treadmill cardiopulmonary exercise testing (CPET) measuring maximum oxygen uptake (VO_{2max}).¹⁾ It is generally accepted that a minimum reserve

of l/kg/min of VO_{2max} is acceptable for pneumonectomy and lobectomy in patients with less pulmonary function reserve.²⁾ However, measuring VO_{2max} and split function is relatively long in duration, requiring specialized equipment and expertise; simpler methods of measuring minimal aerobic exercise ability required for lung resection are needed in large volume centers and those with limited access to abovementioned facilities.

It has been nearly 20 years since our center applied stair climbing test (SCT) combined with arterial blood gas analysis before and after the test as an important supplementary method to evaluate the surgical risk of patients with limited pulmonary function and manage to prevent cardiopulmonary complications. In this pilot study, we aimed to clarify the predictive value of general condition of the patients, pulmonary function test results, and quantitative indicators of the SCT on postoperative morbidity and mortality rate after lung resection. A long-term plan is to validate and standardize SCT as a potential alternative to formal exercise testing.

Materials and Methods

Study design

From August 2017 to October 2021, adult candidates for pulmonary resection at the Thoracic Surgery Department of China-Japan Friendship Hospital were clinically evaluated and reviewed. Lung cancer patients with “limited pulmonary function” were screened and selected. The inclusion criteria included at least one of the following situations: 1) Clinically diagnosed with chronic obstructive pulmonary disease (COPD), with risk factors such as tobacco exposure and recurrent lower respiratory tract infection, with symptoms such as dyspnea and chronic cough, and forced expiratory volume in one second (FEV_1)/forced vital capacity (FVC) <0.7 in spirometry; almost all these patients received standard treatment of respiratory medicine, including inhaled medications such as long-acting beta-receptor agonist (LABA)/long-acting M-receptor antagonist (LAMA); 2) interstitial lung disease (ILD) diagnosed by chest high-resolution CT, with irregular linear or reticulated shadows on peripheral lung field or subpleural space, many accompanied by changes in lung parenchyma, forming tractional bronchiectasis or honeycomb-like fibrosis at the bases of both lungs; 3) imaging diagnosed as emphysema, with decreased lung field density and bronchovascular shadows; and 4) preoperative spirometry indicating FEV_1 less than 80% of predicted ($FEV_1\% <80\%$) (in line with Grade 2 and above according

to the GOLD criteria for the diagnosis of COPD) or DLCO less than 80% of predicted ($DLCO\% <80\%$) (consistent with mild or above degree diffusion dysfunction). Patients were excluded with poorly controlled medical conditions. Those with lower limb pathology unable to cooperate fully were also excluded. The institutional review board approved the protocol and all patients gave written informed consent.

Stair climbing

Besides spirometry, SCT was routinely performed to preoperative patients with “limited pulmonary function.” Before the test, we recorded resting blood pressure, and respiratory and pulse rate, and arterial blood gas analysis was performed to obtain arterial partial pressure of oxygen (PaO_2), arterial partial pressure of carbon dioxide ($PaCO_2$), and arterial oxygen saturation (SaO_2) of the arterial blood. Patients were asked to climb “as fast and high” as they could without stopping to a maximum elevation of 20 m. They were allowed to touch the handrail in order to maintain balance, but using the handrail for upper body effort was not permitted. An assistant followed the subjects in case of basic life support and gave vocal encouragement but provided no other help throughout the ascent. We chose to carry out the SCT at the stairwell of the ward building, from the 6th to the 12th floor. Between floors, there were two flights of stairs and one landing between the flights; each flight of stairs had 10 steps and the height of each step was 16.5 cm. When climbing up to the 12th floor, the cumulative climbing height was 19.8 m. The test was considered completed when a patient stopped for more than 3 s or reached the target elevation of 19.8 m. After the test, the patient was brought back to the thoracic surgery ward on the 6th floor via the elevator immediately. The arterial blood sample collection was completed by the nurse waiting at the bedside. The assistant recorded the maximum number of floors that the patient could board, the time cost, and again the blood pressure, respiratory and pulse rate, and the results of arterial blood gas analysis upon termination of the test.

Statistical analysis

The following clinical data were collected and included in the retrospective study: patient’s age, gender, smoking history, smoking index, history of COPD and ILD, $FEV_1\%$, $DLCO\%$, and the quantitative indicators of the SCT including floors climbed, speed of ascent, changes in heart rate (ΔHR), ΔSaO_2 before and after the test, American Society of Anesthesiologists (ASA)

Table 1 The baseline characteristics of the surgery and the perioperative conditions of the enrolled 424 lung cancer patients

Surgery and the perioperative conditions	Statistics (n, %)	
Surgical approach [#]	VATS	389 (91.7%)
	Open	35 (8.3%)
Excision extension	Lobectomy/bilobectomy/ lobectomy + sublobectomy	326 (76.9%)
	Sublobectomy ^{&}	98 (23.1%)
Anesthetic duration* (min)		210 (150, 270)
Intraoperative blood loss* (ml)		100 (50, 200)
Blood transfusion		12 (2.8%)
Postoperative admission to ICU		25 (5.9%)
Duration of the chest drainage* (day)		6 (4, 8)
Postoperative cardiopulmonary complications	Continuous air leakage	36 (8.5%)
	Pulmonary infection	13 (3.1%)
	Arrhythmia	20 (4.7%)
	Acute myocardial infarction	6 (1.4%)
	Pulmonary embolism	5 (1.2%)
	Re-tracheal intubation	9 (2.1%)

[#]VATS stands for minimally invasive surgery, that is generally uniport or double-ports thoracoscopic surgery. The length of the main incision is about 3 cm. OPEN stands for open surgery, which may be converted from VATS or direct open surgery. The muscle-sparing principle is generally adopted in open surgery, and the incision length is about 15–20 cm.

[&]Wedge resection for 42 cases, partial lobectomy for 33 cases, segmentectomy for 23 cases.

*The non-normal distribution data were presented as M (Q1, Q3).

VATS: video-assisted thoracoscopic surgery; ICU: intensive care unit

score, surgical approach (video-assisted thoracoscopic surgery or open), excision extension (lobectomy or sublobectomy), anesthetic duration, intraoperative blood loss, blood transfusion, postoperative admission to intensive care unit, duration of the chest drainage, and postoperative cardiopulmonary complications (continuous air leakage, pulmonary infection, arrhythmia, acute myocardial infarction, pulmonary embolism, re-tracheal intubation, etc.). Postoperative death was recorded, and the mortality rate was calculated.

Statistical calculations were performed with SPSS 19.0 software. Categorical data or counting data were grouped and compared between the groups, under the χ^2 test or Fisher's exact test. Binary logistic regression model was applied for multivariate analysis to identify the independent risk factors of postoperative cardiopulmonary complications. A p value of <0.05 was accepted as significant.

Results

A total of 727 hospitalized lung cancer patients with limited pulmonary function were retrospectively reviewed during the study period. Included in the cohort were 424 patients who underwent SCT preoperatively

and completed data collection. Stair climbing was well tolerated by all subjects and no individual complained of angina, dizziness, or palpitations, nor did any patient fall during stair climbing. No patient required oxygen therapy or any kind of medical intervention during or immediately after the test. A total of 89 postoperative cardiopulmonary-related complications occurred in 69 cases, accounting for 16.3% of the entire cohort. Perioperative mortality rate was 0.9% (4/424). Among all 4 patients who died postoperatively, 2 patients died of acute exacerbation of ILD and respiratory failure, 1 patient died of severe pulmonary infection and respiratory failure secondary to persistent and severe air leakage, and 1 patient died of acute myocardial infarction (possibly induced by postoperative hypoxemia). The baseline characteristics of the surgery and their perioperative conditions are summarized in **Table 1**.

Based on the current diagnostic criteria or the mean and median values of the baseline characteristics, the potential risk factors of postoperative cardiopulmonary complications were stratified and compared between groups. The results of univariate analysis are shown in **Table 2**.

The rate of postoperative cardiopulmonary complications was quite different (p <0.1) between the groups

Table 2 The univariate analysis results of the differences in the incidence of postoperative cardiopulmonary complications between stratified groups

Statistics	With complications	Without complications	p value
Gender			
Male (n = 268)	50	218	0.081
Female (n = 156)	19	137	
Age (year)			
≥65 (n = 195)	33	162	0.738
<65 (n = 229)	36	193	
Smoking history			
Yes (n = 187)	37	150	0.082
No (n = 237)	32	205	
Smoking index			
≥400 (n = 154)	33	121	0.030
<400 (n = 270)	36	234	
COPD			
Yes (n = 161)	29	132	0.448
No (n = 263)	40	223	
ILD			
Yes (n = 43)	9	34	0.383
No (n = 381)	60	321	
FEV ₁ %			
≥80% (n = 62)	6	56	0.027
≥50%, <80% (n = 339)	55	284	
≥30%, <50% (n = 23)	8	15	
DLCO%			
≥80% (n = 349)	48	301	0.003
≥60%, <80% (n = 56)	13	43	
<60% (n = 19)	8	11	
Height achieved			
Reach 6 floors (n = 366)	38	328	<0.001
At least 4, less than 6 floors (n = 47)	21	26	
Less than 4 floors (n = 11)	10	1	
Speed of ascent			
Over 15 s per floor (n = 115)	39	76	<0.001
Less than 15 s per floor (n = 309)	30	279	
ΔHR			
≥30 bpm (n = 42)	20	22	<0.001
<30 bpm (n = 382)	49	333	

(Continued)

Table 2 (Continued)

Statistics	With complications	Without complications	p value
ΔSaO ₂			
≥4% (n = 26)	10	16	0.004
<4% (n = 398)	59	339	
ASA score			
I/II (n = 356)	54	302	0.158
III/IV (n = 68)	15	53	
Surgical approach			
VATS (n = 389)	60	329	0.114
Open (n = 35)	9	26	
Excision extension			
Lobectomy/ bilobectomy/ lobectomy + sublobectomy (n = 326)	60	266	0.030
Sublobectomy (n = 98)	9	89	
Anesthetic duration (min)			
>210 (n = 193)	39	154	0.045
≤210 (n = 231)	30	201	
Intraoperative blood loss (ml)			
>100 (n = 185)	34	151	0.302
≤100 (n = 239)	35	204	

COPD: chronic obstructive pulmonary disease; ILD: interstitial lung disease; FEV₁%: percentage of forced expiratory volume in one second; DLCO%: percentage of diffusion capacity for carbon monoxide; ΔHR: changes in heart rate; ΔSaO₂: arterial oxygen saturation; ASA: American Society of Anesthesiologists

stratified by gender, smoking history and smoking index, FEV₁%, DLCO%, SCT results (height achieved, speed of ascent, changes in heart rate, and SaO₂ before and after the test), excision extension, anesthetic duration, etc. These preliminarily screened risk factors were put into the binary logistic regression model for multivariate analysis; the results are shown in **Table 3**.

Binary logistic regression analysis showed that for lung cancer patients with limited pulmonary function, only height achieved (p <0.001), ΔHR (p <0.001), and excision extension (p = 0.006) were independent risk factors for postoperative cardiopulmonary complications, while gender (p = 0.313), smoking history (p = 0.481), smoking index (p = 0.547), FEV₁% (p = 0.096), DLCO% (p = 0.217), speed of ascent (p = 0.055), ΔSaO₂ (p = 0.084), and anesthetic duration (p = 0.110) could not significantly affect the rate of complications.

Table 3 The multivariate analysis results of the independent risk factors of postoperative cardiopulmonary complications

Statistics	OR (95% CI)	p value
Height achieved		
Reach 6 floors	1.00	<0.001
At least 4, less than 6 floors	5.72 (2.77–11.82)	
Less than 4 floors	84.91 (10.02–719.65)	
Δ HR (bpm)		
<30	1.00	<0.001
\geq 30	4.78 (2.17–10.53)	
Excision extension		
Sublobectomy	1.00	0.006
Lobectomy/ bilobectomy/ lobectomy + sublobectomy	3.54 (1.43–8.75)	

OR: odds ratio; CI: confidence interval

Discussion

Patients with limited pulmonary function, usually combined with COPD or ILD, are also high-risk candidates for lung cancer.^{3–5} For these lung cancer patients with surgical indications, surgical contraindications should be strictly mastered. Alternative palliative treatment methods should be selected appropriately in order to avoid serious postoperative cardiopulmonary complications and even death. On the other hand, simply deciding whether or not to operate according to the pulmonary function test or spirometry result alone would deprive the potentially curative surgical opportunity for these cancer patients. Therefore, reasonable screening and hierarchical management of lung cancer patients with limited pulmonary function would be of great clinical importance.

In terms of lung function evaluation, CPET and the corresponding VO_{2max} remain the gold standard for evaluating patients with impaired lung function prepared for lung resection, which is better than FEV_1 , FEV_1/FVC , and other indicators. CPET and VO_{2max} are significantly related to postoperative complications and even the mortality rate.¹ As one of the simplified alternatives to CPET, stair climbing performance has long been used to identify patients at risk for complications and mortality after lung resection. For lung resection candidates with mild pulmonary dysfunction or more serious conditions, it is simple, practical, low cost, and widely used.^{6,7} However, testing technical details, measured variables, and

suggested cutoff values of SCT vary significantly across studies.^{8,9} The evaluation of diagnostic value and predictive performance of the SCT were based on some observational studies with limited sample size, and these results have not as yet altered current clinical practice.

Height achieved and speed of ascent during SCT have all been confirmed to be related to VO_{2max} according to published literatures and previous experience. Studies have demonstrated that a climbing altitude of 16.6–22 m (about 6 floors) seemed to be a minimum requirement of cardiorespiratory system for lung resection candidates.^{8,10} Bernasconi et al.¹¹ performed a research on 54 lung resection candidates who completed both CPET and SCT (up to 20 m), and a strong correlation existed between speed of ascent and VO_{2max} measured using cycle ergometry. Nineteen patients enrolled were able to complete the SCT at a height of 20 m within 1 min and 20 s, that is, if the climbing speed exceeded 15 m/min, the corresponding VO_{2max} was no less than 20 ml/min/kg, suggesting that the patients' pulmonary function was sufficient to undergo lung resection up to pneumonectomy. In addition, the height achieved was also confirmed to be significantly correlated with changes in $FEV_1\%$ ($r = 0.46$, $p < 0.05$) and $DLCO\%$ ($r = 0.54$, $p < 0.05$) before and after the surgery.¹²

This study focuses on the predictive value of relevant indicators of SCT on the occurrence rate of the postoperative cardiopulmonary complications. The results of our multivariate analysis suggested that the height achieved had a significant predictive value ($p < 0.001$). The largest prospective study ($n = 160$) on evaluating the capability of SCT to predict cardiopulmonary complications after lung resection in lung cancer patients was published by Brunelli et al.⁷ Multivariate analysis results showed that only the height of stair climbing is an independent risk factor for postoperative complications. Patients who had no postoperative complications mastered to a height of 20.6 m on average, whereas those who experienced complications could only climb a mean height of 14.96 m ($p < 0.001$). The height achieved is also instructive for the long-term prognosis after surgery. A study on stage I non-small cell lung cancer (NSCLC) found that the 5-year survival rate of patients who could climb more than 18 m in height was significantly higher than that of the control group (77% vs 54%, $p = 0.001$). Climbing height ($p = 0.003$) is one of the independent risk factors affecting the prognosis.¹³

In the 2013 edition of the American College of Chest Physicians (ACCP) Preoperative Evaluation Guidelines

for Pneumonectomy,¹⁴⁾ it is recommended that patients undergoing lung resection should complete the static pulmonary function test before surgery and calculate the predicted postoperative (PPO) FEV₁% and PPO DLCO% based on the resection range. If both indexes are between 30% and 60%, simple functional test screening is recommended. If the screening results are satisfactory (the climbing height is greater than 22 m), patients are still classified into the low-risk group. If either PPO FEV₁% or PPO DLCO% is less than 30%, or the screening test result is not satisfactory, CPET evaluation is recommended. In a meta-analysis published in 2020,¹⁵⁾ a total of 13 studies were included and the number of enrolled cases was as high as 2038. Among many indicators including the time cost, height achieved, changes in arterial blood oxygen saturation, and heart rate changes, climbing height was proved to be a first-line screening indicator for the cardiopulmonary function (relative risk = 2.34, 95% confidence interval: 1.59–3.43) and may have a predictive value for the risk of postoperative complications. If the height of continuous climbing is less than 10 m, CPET should be completed before surgery for functional evaluation.

In this study, the rate of postoperative complications in the faster climbing speed group was lower, but speed of ascent was not an independent risk factor ($p = 0.055$). This could be due to the high proportion of elderly patients (195 cases over 65 years, accounting for 46.0%) and the presence of confounding factors such as dyskinesia due to other reasons. The accompanying doctor's repeated emphasis on safety during the testing process may also limit the full display of the patient's true ability. The study also confirmed that the heart rate changes greater than or equal to 30 beats/min before and after the test was an independent risk factor for postoperative cardiopulmonary complications ($p < 0.001$). Although the risk of complications was significantly increased in patients with SaO₂ changes greater than or equal to 4%, the change in SaO₂ was not an independent risk factor ($p = 0.084$). Nakamura et al.¹⁶⁾ retrospectively analyzed 162 lung resection candidates who can climb up to 6 floors (22.2 m). The patients with SaO₂ changes greater than or equal to 4% before and after the SCT had significantly higher postoperative complication rate (17.2%, 5/29) compared with the rate (0.75%, 1/133) of other patients ($p = 0.0002$). Another prospective study¹⁷⁾ from Turkey included 150 lung cancer patients who received surgical treatment; multivariate analysis confirmed that the SaO₂ changes before and after the SCT could

independently predict the rates of postoperative cardiopulmonary complications. Dong et al.¹⁸⁾ retrospectively reviewed 143 NSCLC patients; 41 cases (28.7%) suffered from postoperative cardiopulmonary complications. Among them, those who climbed up 5 floors (18.36 m) in more than 92 s, exercise oxygen desaturation (EOD) more than or equal to 5%, or heart rates changes less than 55 bpm had a much higher incidence of postoperative cardiopulmonary complications. The results of multivariate analysis showed that EOD and failure to meet conventional pulmonary function standards were independent risk factors for postoperative cardiopulmonary complications. A larger sample size study again verified the above results and established a predictive model for the probability of complications.¹⁹⁾

Considering that in addition to the loss of lung function, the occurrence of complications and even death are also affected by the general condition of the patient, past medical history, surgical quality control, and other factors, potential risk factors were preliminarily screened in univariate analysis. There existed significant differences in the incidence rates of postoperative cardiopulmonary complications between the groups grouped by gender, smoking history and smoking index, excision extension, and anesthetic duration. However, in the multivariate analysis, only excision extension was proved to be an independent risk factor ($p = 0.006$). This result confirmed that for lung cancer patients with limited cardiopulmonary function, choosing sublobectomy with limited excision extension might effectively reduce the occurrence of postoperative complications. Similar in method but slightly different in the result, a large sample and multi-center study based on the General Thoracic Surgery Database of the American Association of Thoracic Surgeons confirmed that age, gender, ASA score, surgical approach, and excision extension are all independent risk factors of postoperative cardiopulmonary complications and even mortality rate for lung resection candidates.²⁰⁾ In general, for those elderly patients, heavy smokers, or patients with poor general conditions who were not appropriate candidates for surgery under the traditional criteria, sublobectomy could be selected and might break the limits of absolute contraindications.²¹⁾ Excessively pursuing “minimally invasive” or “bloodless” surgery and reducing the anesthetic duration could not significantly improve the rate of postoperative cardiopulmonary complications.

Our pilot study has certain limitations. In addition to the inherent limitations of the retrospective study,

unrepeatability, safety guarantee, and difficulty in standardization in the implementation of SCT should be taken into full consideration.²²⁾

Conclusion

The SCT could be used as a preoperative screening method for lung cancer patients with limited pulmonary function, and the height achieved and changes in heart rate had a predictive value for postoperative cardiopulmonary complications. For those patients who could only climb less than 6 floors (climbing altitude less than 20 m) or have changes in heart rate more than 30 bpm in the stair-climbing test, sublobar resection should be selected in order to reduce the postoperative cardiopulmonary complication rate. Our research findings lay the foundation for further research directed at simplifying preoperative assessments of lung resection candidates. Future studies with prospective design and a larger study population are needed to solve these related issues.

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