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Exercise oxygen desaturation is a predictor of cardiopulmonary complications after lung resection

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ABSTRACT

Background To investigate whether oxygen desaturation during low technology tests was associated with complications after lung resection.

Methods A retrospective cohort study was conducted on 1097 candidates for pulmonary resection; seven metabolic equivalents in the Master's double two-step test were loaded. The predicted postoperative (PPO) forced expiratory volume in 1 s and PPO diffusing capacity of the lung for carbon monoxide were estimated. The patients were divided into three groups: those with both values ≥60% (≥60% group (n=298)), either value <30% (<30% group (n=112)) and others (30%–60% group (n=687)). The relationships between postoperative cardiopulmonary complications and exercise stress test based on availability, symptoms and percutaneous oxygen saturation values were investigated in each group.

Results The cardiopulmonary morbidity rates in the ≥60%, 30%–60%, and <30% groups were 7.7%, 14.6%, and 47.3%, respectively. Multivariate analyses revealed that predictors of complications were age (OR 0.96; p<0.001), male sex (OR 1.74; p=0.016) and exercise oxygen desaturation (EOD) >4% (OR 2.39; p=0.001) in the 30%–60% group, and male sex (OR 3.76; p=0.042) and EOD >4% (OR 2.28; p=0.030) in the <30% group. The two-flight test (TFT) was performed in 181 patients (22.8%); desaturation >4% in the TFT was also a predictor of complications.

Conclusions A low technology test is also valuable for high-risk patients. EOD >4% is a predictor of postoperative complications.

Clinical registration This study is a non-interventional observational study and has not been registered in a public database. The study followed the Strengthening the Reporting of Observational Studies in Epidemiology reporting guidelines.
This study was approved by the Ethics Committee of the Juntendo University School of Medicine (no. 2016085).

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Cardiopulmonary exercise test (CPET) is recommended for preoperative evaluation of patients undergoing lung resection. However, if CPET cannot be performed, can patients with poor predicted forced expiratory volume in 1 s or diffusing capacity of the lung for carbon monoxide be evaluated using a low technology test?

WHAT THIS STUDY ADDS

⇒ Desaturation >4% in a low technology test is a predictor of postoperative complications even in such patients.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ A low technology test is valuable for preoperative patients, including high-risk patients. Oxygen saturation should be measured during exercise tests. In centres where CPET cannot be performed, a low technology test may be a useful tool in predicting postoperative complications following lung resection.

INTRODUCTION

Surgical resection is the most effective treatment for early-stage non-small cell lung cancer. However, as complications after lung resection worsen the prognosis and quality of life of patients,[1] it is important to accurately predict the complications and select the most appropriate treatment and surgical methods.

The American College of Chest Physicians (ACCP) guideline classifies patients into three groups based on the predicted postoperative (PPO) forced expiratory volume in 1 s (FEV_1) and diffusing capacity of the lung for carbon monoxide (D_{LCO}). A low technology test is recommended for patients whose PPO FEV_1 or PPO D_{LCO} is <60% and both are >30%. The cardiopulmonary exercise test (CPET) is recommended for patients whose PPO FEV_1 or PPO D_{LCO} is <30%, as per the ACCP guideline[1] and for those whose PPO FEV_1 or PPO D_{LCO} is <80%, as per the European Respiratory Society/European Society of Thoracic Surgery guidelines.[2] CPET is a very good evaluation method, but only a few facilities can perform the CPET.[3] The use of low technology tests, such as the shuttle walk test (SWT), 6-minute walk test (6MWT) and stair climbing test (SCT), has been reported, but the methods and evaluations of these tests are not standardised[4] and recommendations vary depending on the guidelines.[1 2]

In this study, a uniform load test was conducted, and the relationship between the evaluation items of the simple stress test and postoperative cardiopulmonary complications was established.

METHODS

Study design and setting

In this single-centre, retrospective cohort study, patients who were candidates for pulmonary resection in Juntendo University Hospital were enrolled. The seven-metabolic equivalent (MET) load test was performed for all surgical candidates except patients not indicated for the Master's double two-step test (MDT).

The study followed the Strengthening the Reporting of Observational Studies in Epidemiology reporting guidelines.

Data source

We used data from the de-identified longitudinal medical record-derived database of our institute. This study included 1401 patients who underwent pulmonary resection in our institute between April 2017 and December 2019. Among them, 304 patients were excluded from this study because the exercise load was inappropriate owing to several factors, such as arrhythmia, severe hypertension and possibility of myocardial infarction.[5] The remaining 1097 patients were given a uniform seven-MET load in the MDT. Follow-up data were collected from medical records in February 2022.

Preoperative evaluations

Preoperative evaluations included family and medical history, physical examinations, complete blood count, biochemical analysis, coagulation studies, arterial blood gas analysis under room temperature conditions, chest radiography, pulmonary function tests, exercise ECG and echocardiogram in patients with an abnormal ECG or history of heart disease. PPO D_{LCO} and PPO FEV_1 were estimated by using the following formula in ACCP guidelines: preoperative D_{LCO} and preoperative $FEV_1 \times (1-$ number of lung segments removed/total number of segments).[5] The patients were classified into three groups based on their values: the <30% group, PPO D_{LCO} or PPO FEV_1 <30%; the ≥60% group, both PPO D_{LCO} and PPO FEV_1 ≥60%; and the 30%–60% group, PPO FEV_1 or PPO D_{LCO}<60% and both >30%.[1]

The seven METs in the MDT were loaded in the exercise ECGs.[6] Patients climbed two steps for 3 min and were monitored by an ECG and a pulse oximeter. The number of steps and speed were calculated by sex, age and weight so that the exercise load was seven METs. Normally, this test confirms changes in the ECG, but we also evaluated exercise tolerance. The following items were recorded in the medical record: whether they were able to complete the 3-minute exercise load test, whether they needed assistance, whether they had symptoms and changes in the percutaneous oxygen saturation (SpO_2).

The two-flight test (TFT) was performed by thoracic surgeons on patients with impaired respiratory function, two or more lung resections, and cardiopulmonary complications based on the American College of Cardiology/American Heart Association guideline to evaluate the load of four METs and the surgical tolerance as well as the risk of cardiovascular complications.[7 8] The patients climbed two flights of stairs (42 steps) at their own pace while the pulse rate and oxygen saturation were continuously recorded.

Definition of surgical outcomes

Operative mortality was defined as death within 90 days of resection. Postoperative complications were evaluated based on the Clavien-Dindo classification, and complications of grade II or higher were recorded. Cardiopulmonary complications were evaluated according to previous reports.[9 10] Acute respiratory distress syndrome, acute lung injury, pneumonia, hypoxia that needed home oxygen therapy, acute heart failure and arrhythmia were defined as cardiopulmonary complications in this study.

Statistical analysis

Comparisons among the three groups, categorised based on PPO FEV_1 and PPO D_{LCO} values, were performed using the X^2 test and Fisher's t-test for categorical variables and Student's t-test, Welch's t-test and the Mann-Whitney U test for continuous variables.

To identify predictors of cardiopulmonary complications, a comparison among patients with and without complications in the 30%–60% and <30% groups was performed. Significant factors in that analysis and clinically important factors (age, sex, inability to finish seven-MET load test due to dyspnoea, desaturation and minimum SpO_2 values in exercise test) were included in the multivariate analysis. The cut-off values of minimum SpO_2 and decrease in SpO_2 were set at 90% and 4%, with reference to the receiver operating characteristic curve and previous reports that used the SCT.[9 11]

The correlation of SpO_2 values depending on the type of exercise load was evaluated using Pearson's correlation coefficient. The p value for statistical significance was set at 0.05. All statistical analyses were performed using IBM SPSS for Windows, V.25.0 (IBM Corp).

Data availability

The data are available from the corresponding author on reasonable request. The data are not publicly available due to privacy reasons.

Patient and public involvement

No patient or public participation is involved in this paper, only the publication of the study on the web. We

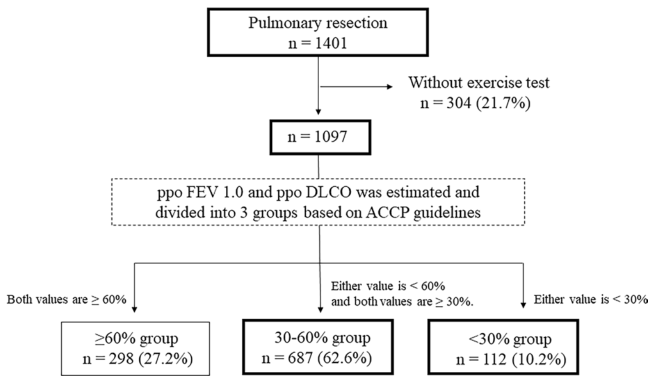

Figure 1 Flow diagram of participant selection. Patients who did not perform a uniform exercise stress test (seven metabolic equivalents) were excluded. Patients are classified into three groups based on the predicted postoperative (PPO) forced expiratory volume in 1 s (FEV_1) and diffusing capacity of the lung for carbon monoxide (D_{LCO}). ACCP, American College of Chest Physicians.

would like to share this research presentation with the public in the future.

RESULTS

Figure 1 summarises the demographic characteristics of the study population. The ≥60%, 30%–60% and <30% groups included 298 (27.2%), 687 (62.6%) and 112 patients (10.2%), respectively. The clinicopathological characteristics of patients in the three groups are shown in table 1. The smoking history and degree of progression to lung cancer tended to be higher in the higher-risk groups. Moreover, in the low-risk group, segmentectomy and wedge resection were significantly more frequently performed than in other groups, while systematic lymphadenectomy was performed in fewer cases. Our facility basically performs thoracotomy or robotic surgery, and 79% of all surgeries were performed with thoracotomy. Especially in patients with poor respiratory function, thoracotomy was often performed.

Table 2 shows the result of performing MDT. Two cases in the ≥60% group, 60 cases in the 30%–60% group and 35 cases in the <30% group could not complete the load test of seven METs for 3 min. The main reasons for failure to complete were dyspnoea and lower limb fatigue, both of which were higher in the <30% group. Among the patients who could complete, there were patients who required assistance in exertion and patients in whom the pace was disturbed.

Surgical outcomes are shown in table 3. In the ≥60%, 30%–60% and <30% groups, the 90-day mortality rates were 0% (n=0), 1.3% (n=9) and 4.5% (n=5), respectively, and cardiopulmonary complications were observed in 23 (7.7%), 100 (14.6%) and 53 (47.3%) patients, respectively. The mean hospitalisation duration was 8.2±21.7, 9.5±15.3, and 12.9±5.9 days in the >60%, 30%–60%, and <30% groups, respectively. There was no significant difference in the number of early postoperative deaths; however, complications were significantly higher in the lower respiratory function group.

Table 1 Clinicopathological characteristics of three groups classified by PPO FEV_1 and PPO D_{LCO}

Variables	≥60% group	30%–60% group	<30% group	P value	
Number of patients	298 (27.2%)	687 (62.6%)	112 (10.2%)	L vs S	S vs C
Age	62.4±11.6	69.3±10.5	72.6±7.5	<0.001	<0.001
Sex (male)	152 (51.0%)	389 (56.6%)	92 (82.1%)	0.104	<0.001
Smoking history pack-years	13.4±22.1	25.9±30.1	49.9±31.5	<0.001	<0.001
CEA (ng/mL)	3.2±3.9	6.2±19.7	8.8±11.7	<0.001	0.200
Preoperative PO_2 (mm Hg)	88.9±17.1	85.8±13.0	82.0±9.4	0.009	0.009
FVC (L)	3.39±0.83	2.97±0.76	2.86±0.71	<0.001	0.166
FEV_1 (L)	2.92±6.6	2.14±0.60	1.95±0.56	0.041	0.002
FEV_1/FVC (%)	75.2±7.1	72.2±9.7	68.7±13.8	<0.001	0.013
$\%D_{LCO}$ (%)	77.9±9.3	55.5±10.9	32.2±10.1	<0.001	<0.001
Clinical stage I	254 (85.2%)	553 (80.5%)	77 (68.8%)	0.001	0.003
Surgical approach (thoracotomy)	202 (67.8%)	564 (82.1%)	97 (86.6%)	0.001	0.300
Wedge resection/segmentectomy	187 (62.8%)	231 (33.7%)	26 (33.2%)	<0.001	0.030
Lobectomy	118 (39.6%)	456 (66.4%)	74 (66.1%)	<0.001	0.949
Systematic nodal dissection	163 (56.4%)	509 (74.1%)	88 (78.6%)	0.494	0.371
Operative time	121.9±59.6	141.9±58.5	166.4±68.8	<0.001	<0.001

Groups were classified by the PPO FEV_1 and PPO D_{LCO}.
CEA, carcinoembryonic antigen; $\%D_{LCO}$, percentage of diffusing capacity of the lung for carbon monoxide; FEV_1, forced expiratory volume in 1 s; FVC, forced vital capacity; PO_2, partial pressure of oxygen; PPO, predicted postoperative.

Table 2 Tolerance of seven-MET exercise load

Variables	≥60% group	30%–60% group	<30% group	P value	
Number of patients	298 (27.2%)	687 (62.6%)	112 (10.2%)	L vs S	S vs C
Complete without assistance	279 (93.6%)	546 (79.5%)	52 (46.3%)	<0.001	<0.001
Assistance required	18 (6.0%)	102 (14.8%)	37 (33.0%)	<0.001	<0.001
Disturbed pace	8 (2.7%)	56 (8.2%)	20 (17.8%)	0.001	0.001
Unable to finish	2 (0.7%)	60 (8.7%)	35 (31.3%)	<0.001	<0.001
Dyspnoea	0	19 (2.8%)	23 (20.5%)	0.004	<0.001
Fatigue	2 (0.7%)	46 (6.7%)	16 (14.3%)	<0.001	0.005
SpO_2 before load (%)	97.6±1.0	97.5±1.0	97.2±1.3	0.253	0.008
Exercise SpO_2 (%)	96.8±1.8	96.0±3.0	91.5±6.1	<0.001	<0.001
Exercise SpO_2 (%) <90%	2 (0.7%)	24 (3.5%)	32 (28.6%)	0.011	<0.001
Decreased value of SpO_2 (%)	0.9±1.8	1.6±2.7	5.6±5.6	<0.001	<0.001
EOD >4%	9 (3.0%)	67 (9.7%)	54 (48.2%)	<0.001	<0.001

Groups were classified by the predicted postoperative (PPO) FEV_1 and PPO D_{LCO}.
D_{LCO}, diffusing capacity of the lung for carbon monoxide; EOD, exercise oxygen desaturation; FEV_1, forced expiratory volume in 1 s; MET, metabolic equivalent; SpO_2, percutaneous oxygen saturation.

Table 4 shows the univariate analysis of cardiopulmonary morbidity in the 30%–60% group and the <30% group. Exercise oxygen desaturation (EOD) and minimum SpO_2 during exercise were significantly different between the 30%–60% group and the <30% group.

In the 30%–60% group, multivariate analyses revealed that the male sex (OR 1.74; p=0.016), older age (OR 0.96; p<0.001) and EOD >4% (OR 2.39; p=0.001) were predictors of cardiopulmonary complications (table 5). In total, 627 patients (91.3%) were able to complete the seven-MET load test. The cardiopulmonary morbidity rate was 32.8% in patients whose desaturation was >4% and 12.1% in those whose desaturation was ≤4%.

In the <30% group, multivariate analysis revealed that the male sex (OR 3.76; p=0.030) and EOD >4% (OR 2.28; p=0.042) were predictors of cardiopulmonary complications (table 5). Seventy-seven patients (68.7%) were able to complete the seven-MET load test. The cardiopulmonary morbidity rate was 59.3% in patients whose desaturation was >4% and 25.6% in those whose desaturation was ≤4%.

We conducted TFT for non-low-risk patients in clinical practice and the records of 181 cases (22.7%) were investigated. The average desaturation during exercise in these 181 cases was 4.5±5.1 in the seven-MET load test and 6.4±4.5 in the TFT (equivalent to four METs). A correlation was observed between the two variables (R=0.598,

Table 3 Morbidity and mortality

Variables	≥60% group	30%–60% group	<30% group	P value	
Number of patients	298 (27.2%)	687 (62.6%)	112 (10.2%)	L vs S	S vs C
30-day mortality	0	5 (0.7%)	2 (1.8%)	0.140	0.265
90-day mortality	0	9 (1.3%)	5 (4.5%)	0.047	0.501
2-year mortality	4 (1.3%)	30 (4.4%)	25 (22.3%)	0.017	<0.001
Cardiopulmonary complication	23 (7.7%)	100 (14.6%)	53 (47.3%)	0.002	<0.001
Respiratory morbidity	7 (2.3%)	51 (7.4%)	44 (38.4%)	0.002	<0.001
Pneumonia	0	15 (2.2%)	8 (6.3%)	0.010	0.015
Hypoxia	0	19 (2.8%)	20 (17.9%)	0.004	<0.001
AE-IP	0	4 (0.6%)	5 (4.5%)	0.187	<0.001
Prolonged air leakage	19 (6.4%)	70 (10.2%)	16 (14.3%)	0.055	0.195
Arrhythmia	16 (5.4%)	56 (8.2%)	19 (17.0%)	0.123	0.003
Length of hospital days	8.2±21.7	9.5±15.3	12.9±5.9	0.286	0.005

Groups were classified by the predicted postoperative (PPO) FEV_1 and PPO D_{LCO}.
AE-IP, acute exacerbation of interstitial pneumonia; D_{LCO}, diffusing capacity of the lung for carbon monoxide; FEV_1, forced expiratory volume in 1 s.

Table 4 Univariate analysis between patients with and without complications (≥grade II) in the non-low-risk group

	30%–60% group (n=687)			<30% group (n=112)		
	Without complication (n=587)	With complication (n=100)	P value	Without complication (n=58)	With complication (n=53)	P value
Age	68.8±10.7	72.4±8.4	<0.001	71.9±8.6	73.5±6.1	0.265
Sex (male)	314 (53.5%)	75 (75.0%)	<0.001	43 (72.9%)	49 (92.5%)	0.007
Smoking status (pack-year)	24.0±28.2	37.0±37.9	0.001	48.3±33.7	52.0±28.9	0.539
%VC <80%	362 (62.0%)	53 (53.0%)	0.111	33 (63.5%)	25 (51.0%)	0.206
$FEV_{1.0}$/FVC <70%	193 (33.9%)	49 (49.0%)	0.002	25 (44.6%)	27 (51.9%)	0.449
%D_{LCO} <40%	29 (4.9%)	6 (6.0%)	0.645	47 (83.9%)	44 (84.6%)	0.922
PO_2 <70 mm Hg	24 (4.1%)	8 (8.0%)	0.318	3 (5.0%)	6 (11.5%)	0.611
Lobectomy and more	378 (66.1%)	78 (78.0%)	0.019	43 (74.1%)	43 (82.7%)	0.278
Tolerance of seven-MET exercise load						
Unable to finish seven-MET load	47 (8.0%)	13 (13.0%)	0.102	15 (26.3%)	20 (36.4%)	0.160
Disturb due to dyspnoea	13 (2.2%)	6 (6.0%)	0.033	8 (14.0%)	15 (27.3%)	0.054
Minimum SpO_2	96.2±2.6	94.7±4.3	0.013	92.8±5.4	90.1±6.6	0.022
Minimum SpO_2 <90%	14 (2.4%)	10 (10.0%)	<0.001	12 (21.1%)	20 (37.0%)	0.035
Decrease SpO_2	1.3±2.4	2.8±3.9	0.001	4.5±4.9	6.8±6.2	0.028
EOD >4%	45 (7.8%)	22 (22.0%)	<0.001	22 (37.3%)	32 (61.5%)	0.011

Groups were classified by the predicted postoperative (PPO) FEV_1 and PPO D_{LCO}.
%D_{LCO}, percentage of diffusing capacity of the lung for carbon monoxide; EOD, exercise oxygen desaturation; $FEV_{1.0}$, forced expiratory volume in 1 s; FVC, forced vital capacity; MET, metabolic equivalent; PO_2, partial pressure of oxygen; SpO_2, percutaneous oxygen saturation; VC, vital capacity.

p<0.001) (figure 2). The cut-off values of minimum and decreased SpO_2 were 90% and 4%, respectively, even in the TFT, and a significant difference was observed depending on the presence or absence of complications. The cardiopulmonary morbidity rate was 42% in patients whose desaturation was >4% and 23.5% in patients whose desaturation was ≤4% (p=0.012).

Table 5 Stepwise logistic regression analysis of postoperative complications

Predictors	OR	95% CI	P value
30%–60% group			
EOD >4%	2.39	1.43 to 4.00	0.001
Age	0.96	1.11 to 2.73	<0.001
Sex (male)	1.74	1.11 to 2.73	0.016
<30% group			
EOD >4%	2.28	1.03 to 5.04	0.042
Sex (male)	3.76	2.28 to 1.032	0.030

Groups were classified by the predicted postoperative (PPO) FEV_1 and PPO D_{LCO}.
.D_{LCO}, diffusing capacity of the lung for carbon monoxide; EOD, exercise oxygen desaturation; FEV_1, forced expiratory volume in 1 s.

DISCUSSION

Our results revealed that the desaturation during a low technology test is useful in predicting postoperative cardiopulmonary complications, not only in the 30%–60% group, but also in the <30% group where CPET is recommended.

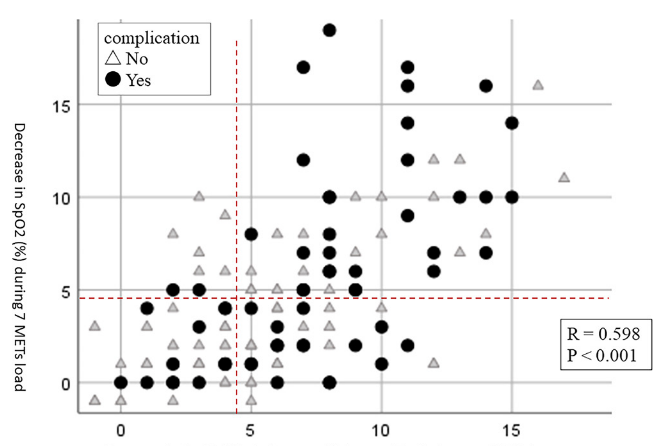

Figure 2 This is a scatter diagram of the value of percutaneous oxygen saturation (SpO_2) decrease during the load test by the master method and the two-flight test. The values of the two groups present a correlation (R=0.598; p<0.001). METs, metabolic equivalents.

The grouping reported by ACCP guidelines was based on PPO FEV_1 and D_{LCO}, and postoperative mortality and morbidity are completely different in each group.[12] FEV_1 and D_{LCO} have a weak correlation; however, both are indicators of postoperative complications[13,14]; hence, it is important to check data for both. D_{LCO} is measured in only 27.3% of cases in Japan,[15] but 629 of 799 (78.7%) non-low-risk patients were evaluated based on the D_{LCO} criteria in this study. D_{LCO} should always be measured for risk assessment. In the whole study cohort, the 30-day and 90-day mortality rates were 0.6% and 1.3%, respectively, similar to previous report.[16] However, patients with PPO D_{LCO} or PPO FEV_1 <30% had significantly higher mortality and morbidity rates than patients in other groups (30-day mortality rate, 1.8%; 90-day mortality rate, 4.5%). In previous reports, patients with PPO D_{LCO} or PPO FEV_1<30% presented a very high risk of postoperative complications[16] and poor prognosis[17,18]; hence, risk assessment using CPET is recommended. CPET is an important indicator of postoperative complications and prognosis.[19] However, in many facilities, CPET cannot be performed, including our hospital. Therefore, all patients were evaluated using a low technology test in this study. Moreover, it was shown that patients with EOD <4% in the 30%–60% group had more complications than those with EOD >4% in the <30% group with performing a simple exercise load. Using oxygen desaturation during a low technology test, it was possible to predict complications with higher accuracy than using PPO FEV_1 or PPO D_{LCO} alone. As reported by Brunelli *et al*,[20] a low technology test is also helpful for high-risk patients.

The effectiveness of the simple load test has been reported in several studies[1,2,4,10,20,21] as it is a simple test and there is no equipment requirement. The SCT,[10,20] 6MWT[21] and SWT[4] are often performed; however, exercise tests are only prescribed by 24% of physicians before lung cancer surgery.[2] This low rate is thought to be influenced by the availability of a variety of stress tests and the complexity of the evaluation items. Most of the indicators of the load test use a degree of achievement, such as the number of steps and walking distance; however, this is complicated, and some studies have reported that they are not indicators.[22,23] Various evaluation criteria have been reported for the SCT, and meta-analyses revealed that the maximum climb height is a useful indicator.[24] There were four cohort studies, in which the assessment of oxygen saturation used in this study was useful, but the data were not pooled owing to differences in loading methods and reference values. Previous works have suggested that simple SCT set at 12 m[25] or a combination of the measured daily ambulatory activity using a pedometer and the $\%D_{LCO}$ can be used as surrogate indicators for oxygen consumption measurement.[26] However, none of them have reached the point of general use.

The comparison between the TFT and the MDT in this study showed that desaturation during exercise is useful regardless of the type of load methods. There were 181 patients who underwent both MDT (equivalent to seven-MET load) and TFT (equivalent to four-MET load). The actual load completion rate was 83.4% for MDT and 100% for TFT, as expected, because of the difference in exercise intensity. However, the average of SpO_2 decrease was higher for the TFT. This inverse relationship between exercise completion rate and SpO_2 value suggests that exercise intensity and SpO_2 are not necessarily related. It is suggested that desaturation of >4% during exercise load is a variable predictor regardless of the load method and intensity. It is important to perform an exercise stress test and to evaluate SpO_2 during exercise, as the type of exercise method may be chosen according to the characteristics of the facility and the patient's condition. In this study, the MDT was used for exercise load as it is widely used as a preoperative evaluation system in exercise ECG in our institute. This enabled us to evaluate exercise tolerance, symptoms and SpO_2 with a uniform load.

This study had several limitations. As this was a single-centre study, statistical limitations resulting from selection bias were inevitable. There were many cases of advanced lung cancer with poor respiratory function, and thoracotomy tended to be performed for high-risk patients. Minimally invasive surgery has been difficult to perform for high-risk patients who are more likely to benefit from minimally invasive surgery. We performed an additional study of only patients who underwent lobectomy to avoid surgical bias, but the complication predictors did not change (online supplemental table 1). Another limitation was the existence of excluded cases. The respiratory and circulatory complications in patients with an inappropriate exercise load were 8% (online supplemental table 2), which was not a particularly high complication rate compared with the target cases in this study. However, there may be high-risk cases with arrhythmia and existing ischaemic heart disease.[27] Other evaluations should be performed for cases, in which the exercise load is inappropriate. The last limitation is that the MDT is a less widely used loading method. Shiono *et al* reported on the relationship between MDT and outcome after pulmonary resection, and incomplete MDT was associated with non-cancer-specific survival but not with postoperative complication.[28] In this study, the MDT was used with an emphasis on uniformly applying the same exercise load to a large number of patients and we investigated not only whether MDT was completed but also changes in SpO_2 as indicators. Approximately 22.8% of patients underwent both the MDT and TFT in this study. It was useful to demonstrate the importance of desaturation during exercise.

CONCLUSION

A low technology test is valuable for patients with either PPO FEV_1 or PPO D_{LCO} <60%. EOD is a predictor of postoperative complications. SpO_2 should be measured when performing exercise tests. As for the index of desaturation, a rate >4% reported by the SCT was valid by the MDT and TFT in this study.

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Contributors MF planned the study. MF, SN and KS contributed to the study design. MF, TM, AH, KT and SO contributed to the data collection. SN contributed to cohort definition and statistical analysis. KS is responsible for the overall content as gurantor. All authors contributed to revision and final approval of the manuscript.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval This study involves human participants and was approved by the Ethics Committee of the Juntendo University School of Medicine (no. 2016085) and performed in accordance with the guidelines of the Declaration of Helsinki and its subsequent amendments. Informed consent was obtained in the form of opt-out on a website.

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Data availability statement No data are available. The data are available from the corresponding author on reasonable request. The data are not publicly available due to privacy reasons.

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