ORIGINAL ARTICLE

Predictors of delayed extubation following lung resection: Focusing on preoperative pulmonary function and incentive spirometry

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Abstract

Background: Delayed extubation is one of postoperative pulmonary complications (PPCs). Preoperative pulmonary function test (PFT) is an important assessment for patients undergoing lung resection. Volume-oriented incentive spirometry (IS) is one of physiotherapies to prevent PPCs. Preoperative PFT and IS volume (IS-v) can reflect the physiologic conditions of respiratory system in patients planning to undergo lung resection. However, the relationship between preoperative PFT/IS-v and delayed extubation in patients undergoing lung resection remains unclear. The study investigated the risk factors and impact of delayed extubation after lung resection. We aimed to achieve early recognition of patients being at a higher risk for developing postoperative delayed extubation after lung resection.

Methods: This retrospective observational 4-year cohort study was conducted in a medical center, Taiwan. A total of 353 enrolled patients receiving thoracic surgery for lung resection were further categorized into the delayed extubation (n = 142, 40%) and non-delayed extubation (n = 211, 60%) groups.

Results: In multivariate logistic regression analyses, age >65 years (adjusted odds ratio [AOR]: 2.60; 95% confidence interval [CI], 1.52-4.45), American Society of Anesthesiologists score >2 (AOR: 1.72; 95% CI, 1.05-2.82), anesthesia time >6hrs (AOR: 1.80; 95% CI, 1.13-2.88), pneumonectomy (AOR: 5.58; 95% CI, 1.62-19.19), and IS-v/inspiratory capacity (IC) ratio (AOR: 2.07; 95% CI, 1.16-3.68) were associated with delayed extubation after lung resection (all $p < 0.05$). Patients with delayed extubation were significantly associated with a higher proportion of other pulmonary complications, reintubation, mortality, and prolonged intensive care unit and hospital stays.

Conclusion: Older age, poor general health status, longer anesthesia time, pneumonectomy, and IS-v/IC ratio could be the independent factors predictive for delayed extubation after lung resection, which was in turn associated with worse outcomes. Preoperative PFT and IS-v were valuable for early recognition of patients being at a higher risk for developing postoperative delayed extubation after lung resection.

Keywords: Delayed extubation; Incentive spirometry; Postoperative complication

1. INTORDUCTION

Delayed extubation is one of postoperative pulmonary complications (PPCs). Postponed extubation is the important issue and associated with high resource utilization and relatively poor outcomes.[1–3] Several preexisting factors before surgery have been identified for risk of developing PPCs, including age >65 years, longer surgery duration, poor general health status, poor nutrition status, smoking status, and chronic obstructive lung disease.[4–6] Notably, the impairment of perioperative lung function is considered as a crucial factor to develop pulmonary complications and delayed extubation after surgery.[7] In patients undergoing lung resection, the existence of air trapping and chronic airflow limitation may increase postoperative ventilatory dysfunction following lung collapse, hypoxemia, pneumonia, and respiratory failure.[7,8] Preoperative pulmonary function test (PFT), including spirometry and static lung volume test, is useful in predicting the occurrence of PPCs or intensive care unit (ICU) admission in different surgical conditions.[9–11] Clinically, PFT is performed for all candidates for lung resection.

Incentive spirometry (IS) device was introduced to clinical since about 1970s.[12] IS sustained maximal inspiration to prevent atelectasis and improve ventilation/perfusion mismatch and it may be helpful for lung reexpansion after major thoracic surgery.[13] IS is also able to improve ventilation and

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recruitment in postoperative recovery.[14] Liu et al[15] demonstrated that the use of IS for patients with lung cancers undergoing surgical resection via video-assisted thoracic surgery (VATS) may reduce hospitalization cost and the risk of pneumonia. Volume-oriented devices are preferable by clinical practical guidelines because of lower imposed work of breathing.[16] However, clinical effectiveness of IS for prevention of PPCs is still controversial.[17] and lack of standardized protocol. Clinical approaches for the target inspiratory volume are variable.[18–20] Cassidy et al[20] suggested volume 1400 to 1770 mL and Celli et al[18] suggested maximal inspiration above residual volume (RV). Bastin et al[21] found that preoperative IS volume (IS-v) was correlated with vital capacity (VC), used as a simple way to follow up postoperative lung function. To our knowledge, there are only a few studies examining the value of preoperative IS-v on predicting the development of PPCs, especially for delayed extubation, in patients undergoing lung resection. Early recognition of the patients at higher risk of delayed extubation may help physicians refine the perioperative management to improve hospital outcomes. However, the predictors and impact of delayed extubation is not yet completely investigated in patients undergoing lung resection.

This study aimed to investigate the perioperative risk factors for delayed extubation (duration of invasive mechanical ventilation [IMV] after operation >2 days) in patients receiving thoracic surgery for lung resection. We focused on the role of preoperative IS-v and PFT in predicting the development of delayed extubation, and we also defined the impact of delayed extubation in patients undergoing lung resection.

2. METHODS

2.1. Design, patients, and setting

This retrospective, observational cohort study was conducted in the Taipei Veteran General Hospital, a 3000-bed tertiary medical center in northern Taiwan. The study was approved by the Taipei Veterans General Hospital's Institutional Ethical Review Board (VGHTPE-IRB No. 97-08-23A) in August 2008. The requirement for informed consent was waived by the IRB based on the institutional guidelines for a retrospective observational study.

Our Department use flow-orientated IS (tri-flow IS) for preoperative respiratory training after January 2007. We aimed to investigate the relationship between IS-v and delayed extubation; therefore, the study period between January 2003 and December 2006 was chosen for enrolling the subjects who performed volume-orientated IS before receiving lung resection. Patients who were admitted to Division of Thoracic Surgery, Department of Surgery and planned to receive elective procedure of thoracotomy or VATS under general anesthesia for lung resection were reviewed during the study period. Subjects were reviewed and enrolled if they (1) receiving the preoperative training of volume-IS, (2) having lung function test, (3) age >18 years, and (4) receiving endotracheal tube intubation and IMV support during operation. Subjects were excluded if they did not have both preoperative forced spirometry and static lung volume measurement.

Rapid shallow breathing index (frequent/tidal volume) before extubation was checked when subjects had stable vital signs during postoperative period. These patients received a T-piece or pressure support ventilation of 5 cmH_2O with PEEP of 5 cmH_2O for 60 minutes as a spontaneous breathing trial (SBT). IMV was discontinued while SBT passed. Finally, patients were extubated depending on the clinician's decision.

2.2. Measurement and definitions

The data including baseline and perioperative characteristics were extracted from medical charts and electronic medical records. During the hospitalization period, postoperative clinical events including collapse of lung, pneumonia, empyema, air leak, reintubation, mortality, and length of stay (LOS) were all recorded. The device of IS is volume-oriented. The volume-IS (COACH device) consists of a flexible tube with a mouthpiece connected to a chamber and volume measurements displayed when patients inhaling. Time spent by the respiratory therapist with each patient before operation. The highest volume of preoperative IS was recorded. The primary outcome measurement was the occurrence of delayed extubation. Failure to liberation from IMV within 48 hours after surgery was definition as delayed extubation.[5] The study patients were categorized into the delayed extubation and non-delayed extubation groups according to the period of postoperative IMV use >2 days and ≤2days, respectively.

General health status of pre-anesthesia evaluation was based on the American Society of Anesthesiologists (ASA) score: ASA I—a normal healthy patient; ASA II—a patient with mild systemic disease; ASA III—a patient with severe systemic disease; ASA IV—a patient with severe systemic disease that is a constant threat to life.[22] Hypoalbuminemia was definite as preoperative serum albumin level less than 3.5 g/dL.[23,24] Pulmonary complication was defined as lung collapse, pneumonia, empyema, and air leak.

2.3. Statistical analysis

Statistical analysis was performed using SPSS version 20.0 (SPSS, Chicago, IL). The Kolmogorov-Smirnov test was used to check the distribution of continuous variables. Continuous variables were described as means (±SD) or medians (interquartile ranges), as appropriate. Categorical variables were described as percentages. Student's *t*-test was used for normally distributed variables. Mann-Whitney *U* test and the Kruskal-Wallis test were used to compare continuous variables with a non-normal distribution. Pearson's chi-square or Fisher's exact test was used to compare categorical variables. Univariate analysis was performed to analyze the clinical factors associated with delayed extubation. Variables associated with delayed extubation ($p < 0.05$) on univariate analysis were included in multivariate logistic regression analysis. Forward method was employed to identify the predictors. Adjusted multivariate logistic regression analysis was conducted including sex and body mass index. We considered a two-tailed *p*-value of <0.05 to indicate significance, and odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. A receiver operating characteristic (ROC) curve analysis was used to check the optimal cutoff point to create dichotomous variables. The relationship between delayed extubation with LOS and hospital stay after operation was analyzed by Kaplan-Meier analysis and log-rank test.

3. RESULTS

3.1. Characteristics of the study patients

A total of 436 patients who underwent thoracic surgery during the study period received preoperative IS training were reviewed. Eighty-three patients were excluded due to lack of data of static lung volume. Three hundred fifty-three subjects, 243 men and 110 women, with median age of 67 (57-74) years were enrolled for analysis in this study. The 95.8% (338/353) of study patients were underwent thoracotomy and 4.2% (15/353) of study patients were performed VATS. The percentage of procedure for lobectomy, wedge resection, pneumonectomy and other procedure in the study patients were 92.6% (325/353), 3.1% (10/353), 4.0% (14/353), and 0.3% (1/353), respectively. The median duration of IMV was 2 (2-3) days, and 40.2% (142/353) study patients received IMV for more than 48 hours.

The study patients were categorized into the delayed extubation (n = 142) and non-delayed extubation (n = 211) groups.

3.2. Risk factors for delayed extubation

The baseline and perioperative characteristics of the study patients with delayed extubation and non- delayed extubation were shown in Tables 1 and 2. The study patients with delayed extubation compared with non-delayed extubation had older age (72 years vs 64 years, $p < 0.001$), higher percentage of age >65 years (68.3 vs 47.4%, $p < 0.001$), previous tuberculosis infection history (7.7 vs 2.8%, $p = 0.035$), ASA level >2 (43.0 vs 26.2%, $p = 0.001$), pneumonectomy (7.7 vs 1.9%, $p = 0.008$), and lower values of preoperative forced expiratory volume in 1 second (FEV_1) (2.10 vs 2.24 L, $p = 0.011$), VC (2.87 vs 3.04 L, $p = 0.022$), inspiratory capacity (IC) (1.73 vs 1.87 L, $p = 0.013$), IC % predicted (86.6 vs 91.3%, $p = 0.044$), and IC/total lung capacity (TLC) ratio (35.2 vs 38.3%, $p < 0.001$), higher RV/TLC ratio (41.0 vs 37.7%, $p < 0.001$), and IS-v/IC ratio (1.17 vs 1.05, $p = 0.005$), lower serum albumin level (4.1 vs 4.2 g/dL, $p = 0.005$) and hemoglobin level (12.8 vs 13.2 g/dL, $p = 0.009$), higher baseline creatinine level (1.0 vs 0.9 mg/dL, $p = 0.017$), longer anesthesia duration (360 vs 345 minutes, $p = 0.009$) and higher percentage of subjects with anesthesia time >6 hours (49.3 vs 35.2%, $p = 0.008$).

3.3. Independent factors for predicting delayed extubation following lung resection

Univariate and adjusted multivariate logistic regression analysis of risk factors was shown in Table 3. The independent factors predictive for delayed extubation were age > 65 years (adjusted odds ratio [AOR]: 2.60; 95% CI, 1.52-4.45, $p < 0.001$), ASA >2 (AOR: 1.72; 95% CI, 1.05-2.82, $p = 0.033$), anesthesia time >6 hours (AOR: 1.80; 95% CI, 1.13-2.88, $p = 0.014$), pneumonectomy (AOR: 5.58; 95% CI, 1.62-19.19, $p = 0.006$), and IS-v/IC ratio (AOR: 2.07; 95% CI, 1.16-3.68, $p = 0.013$). A ROC curve analysis was estimated for IS-v/IC ratio, and the cutoff level was 1.14 (area under curve = 0.577, sensitivity = 51.4%, specificity = 64.5%, $p = 0.014$, 95% CI, 0.52-0.64) chosen while differentiating between delayed extubation and non-delayed extubation. The ratio of developing delayed extubation showed exponentially increased in patients with more independent risk factors (age >65 years, IS-v/IC > 1.14, ASA > 2, Anesthesia time >6 hours and pneumonectomy) (Fig. 1; $p < 0.001$).

Table 1

Baseline characteristics of study patients with and without delayed extubation (n = 353)

	All (n = 353)	Delayed extubation (n = 142)	Non-delayed extubation (n = 211)	*p*
Age (y)	67 (57-74)	72 (63-76)	64 (54-73)	<0.001
Age >65	197 (55.8)	97 (68.3)	100 (47.4)	<0.001
Male	243 (68.8)	101 (71.1)	142 (67.3)	0.446
BMI (kg/m^2)	23.8 ± 3.3	23.7 ± 3.4	23.9 ± 3.2	0.555
Smoking history	191 (54.1)	83 (58.5)	108 (51.2)	0.179
Smoking, pack year	10 (0-45.8)	1.92 (1.65-2.32)	7.5 (0-45)	0.133
Comorbidities				
Hypertension	108 (30.6)	45 (31.7)	63 (29.9)	0.714
CAD	23 (6.5)	8 (5.6)	15 (7.1)	0.582
Diabetes mellitus	36 (10.2)	12 (8.5)	24 (11.4)	0.373
Tuberculosis history	17 (4.8)	11 (7.7)	6 (2.8)	0.035
COPD	16 (4.5)	5 (3.5)	11 (5.2)	0.454
PFT				
FEV_1/FVC (%)	75.2 ± 8.7	75.1 ± 8.7	75.4 ± 10.2	0.822
FEV_1/FVC <70%	91 (25.8)	36 (25.4)	55 (26.1)	0.920
FEV_1 (L)	2.19 ± 0.55	2.10 ± 0.46	2.24 ± 0.60	0.011
FEV_1, %predicted	93.0 ± 17.17	93.2 ± 17.3	92.9 ± 17.1	0.867
VC (L)	2.98 ± 0.65	2.87 ± 0.64	3.04 ± 0.66	0.022
VC, %predicted	95.5 ± 15.1	93.1 ± 16.3	95.5 ± 14.1	0.141
TLC (L)	4.91 ± 0.90	4.91 ± 0.91	4.90 ± 0.90	0.921
TLC, %predicted	99.0 ± 13.1	98.8 ± 13.7	99.0 ± 12.7	0.193
IC (L)	1.82 ± 0.52	1.73 ± 0.53	1.87 ± 0.51	0.013
IC, %predicted	89.4 ± 21.7	86.6 ± 23.0	91.3 ± 20.6	0.044
IC/TLC (%)	37.0 ± 7.9	35.2 ± 8.0	38.3 ± 7.7	<0.001
RV (L)	1.83 (1.51-2.28)	1.92 (1.65-2.32)	1.72 (1.46-2.22)	0.002
RV, %predicted	103 (90-121)	106 (91-122)	103 (88-119)	0.192
RV/TLC (%)	39.0 ± 8.4	41.0 ± 8.2	37.7 ± 8.4	<0.001
FRC (L)	3.08 ± 0.70	3.16 ± 0.70	3.03 ± 0.70	0.092
FRC, %predicted	110.7 ± 20.5	112.1 ± 19.5	109.7 ± 21.1	0.283
DL_{CO}, %predicted	72.9 ± 16.7	71.1 ± 18.4	74.1 ± 15.5	0.107
DL_{CO}/VA, %predicted	90.1 ± 18.7	88.2 ± 20.4	91.4 ± 17.5	0.141
Laboratory data				
Albumin (g/dL)	4.1 ± 0.4	4.1 ± 0.4	4.2 ± 0.3	0.005
Albumin <3.5 g/dL	12 (3.6)	8 (5.8)	49 (2.0)	0.075
Hemoglobin (g/dL)	13.0 ± 1.5	12.8 ± 1.5	13.2 ± 1.5	0.009
Creatinine (mg/dL)	1.0 (0.8-1.1)	1.0 (0.8-1.2)	0.9 (0.8-1.1)	0.017

Data are presented as means ± SD, median (interquartile range), or numbers (%).

BMI = body mass index; CAD = coronary artery disease; COPD = chronic obstructive pulmonary disease; DLCO = carbon monoxide diffusion capacity; FEV_1 = forced expiratory volume in one second; FRC = functional residual capacity; FVC = forced vital capacity; IC = inspiratory capacity; PFT = pulmonary function test; RV = residual volume; TLC = total lung capacity; VA = alveolar volume; VC = vital capacity.

Table 2

Perioperative characteristics and hospital outcome of the study patients with and without delayed extubation (n = 353)

	All (n = 353)	Delayed extubation (n = 142)	Non-delayed extubation (n = 211)	*p*
Preoperative IS-v (L)	2.0 (1.5-2.5)	2.0 (1.5-2.5)	1.8 (1.5-2.5)	0.648
Preoperative IS-v/IC ratio	1.10 ± 0.40	1.17 ± 0.43	1.05 ± 0.37	0.005
ASA >2	116 (33.0)	61 (43.0)	55 (26.2)	0.001
Anesthesia time (min)	360 (315-399)	360 (315-435)	345 (315-390)	0.009
Anesthesia time >6 h	144 (40.9)	70 (49.3)	74 (35.2)	0.008
Thoracotomy	338 (95.8)	138 (40.8)	200 (59.2)	0.274
VATS	15 (4.2)	4 (26.7)	11 (73.3)	0.274
Pneumonectomy	15 (4.2)	11 (7.7)	4 (1.9)	0.008
Tidal volume at postoperative room (mL/kg)	10.4 (10.0-11.0)	10.4 (10.0-11.1)	10.3 (10.0-10.9)	0.591
Fluid status on operation day 1 (mL)	1794 ± 754	1819 ± 842	1776 ± 691	0.614
Postoperative ABG (n = 246)				
pH	7.47 ± 0.07	7.46 ± 0.07	7.48 ± 0.07	0.168
PCO_2 (mmHg)	28.29 ± 6.49	28.52 ± 6.42	28.16 ± 6.55	0.670
P/F ratio	457.68 ± 93.48	462.88 ± 91.10	454.71 ± 94.98	0.515
Pulmonary complication[a]	64 (18.1)	38 (26.8)	26 (12.3)	0.001
Reintubation	9 (2.6)	7 (5.1)	2 (1.0)	0.032
Postoperative ICU stay (d)	2 (1-4)	3 (4-6)	1 (1-2)	<0.001
Postoperative hospital stay (d)	10 (9-14)	12 (10-17)	10 (9-12)	<0.001
Hospital stay (d)	18 (15-23)	20 (16-27)	17 (14-22)	<0.001
Mortality	54 (15.3)	31 (21.8)	23 (10.9)	0.005

Data are presented as means ± SD, median (interquartile range), or numbers (%).
[a]Pulmonary complication denoted collapse, pneumonia, empyema, and air leak.
ABG = arterial blood gas; ASA = the American Society of Anesthesiologists; ICU = intensive care unit; IS-v = incentive spirometry volume; VATS = video-assisted thoracic surgery.

Table 3

Univariate and multivariate logistic regression analysis of risk factors for the delayed extubation in the study patients (n = 353)

	Univariate regression		Multivariate regression[a]		Adjusted regression model	
	OR (95% CI)	*p*	AOR (95% CI)	*p*	AOR (95% CI)	*p*
Age >65 y	2.39 (1.53-3.73)	<0.001	2.16 (1.31-3.57)	0.003	2.60 (1.52-4.45)	<0.001
Sex	1.20 (0.75-1.90)	0.447			0.68 (0.39-1.18)	0.167
BMI	0.98 (0.92-1.05)	0.554			0.97 (0.91-1.05)	0.462
Tuberculosis history	2.87 (1.04-7.95)	0.043	—[a]			
FEV_1 (L)	0.61 (0.41-0.91)	0.016	—[a]			
VC (L)	0.68 (0.49-0.95)	0.023	—[a]			
IC (L)	0.59 (0.39-0.90)	0.014				
IC, %predicted	0.99 (0.98-1.00)	0.045				
IC/TLC (%)	0.95 (0.92-0.98)	<0.001				
RV (L)	0.99 (0.95-1.03)	0.577				
RV/TLC (%)	1.00 (1.00-1.00)	0.579				
IS-v/IC ratio	2.16 (1.25-3.74)	0.006	2.05 (1.15-3.67)	0.016	2.07 (1.16-3.68)	0.013
ASA >2	2.12 (1.35-3.34)	0.001	1.65 (1.00-2.73)	0.051	1.72 (1.05-2.82)	0.033
Anesthesia time (min)	1.00 (1.00-1.01)	0.005				
Anesthesia time >6 h	1.79 (1.16-2.76)	0.009	1.79 (1.16-2.76)	0.016	1.80 (1.13-2.88)	0.014
Pneumonectomy	4.35 (1.36-13.93)	0.013	6.40 (1.67-24.54)	0.007	5.58 (1.62-19.19)	0.006
Albumin (g/dL)	0.43 (0.24-0.79)	0.006	—[a]			
Hypoalbuminemia[b]	3.05 (0.90-10.35)	0.073				
Hemoglobin (g/dL)	0.83 (0.72-0.96)	0.010	—[a]			
Creatinine (mg/dL)	3.07 (1.35-6.99)	0.008	—[a]			

This study was focused on preoperative pulmonary function and incentive spirometry, we selected IS/IC ratio and exclude both IC (%predicted) and IC/TLC ratio for multivariate regression to avoid collinearity within the model.
AOR = adjusted odds ratio; ASA = the American Society of Anesthesiologists; BMI = body mass index; CI = confidence interval; FEV_1 = forced expiratory volume in one second; IC = inspiratory capacity; IS-v = incentive spirometry volume; RV = residual volume; TLC = total lung capacity; VC = vital capacity.
[a]Variables entered into multivariate logistic regression analysis with forward method did not retain in the final model.
[b]Denoted the serum level of albumin <3.5 g/dL.

3.4. Delayed extubation and patient outcomes

A higher proportion of patients with delayed extubation had other pulmonary complications (26.8 vs 12.3%, $p = 0.001$), reintubation rate (5.1 vs 1.0%, $p = 0.032$), longer postoperative ICU stays (3 vs 1 day, $p < 0.001$), postoperative hospital stays (12 vs 10 days, $p < 0.001$), hospital stays (20 vs 17 days, $p < 0.001$), and higher mortality rate (21.8 vs 10.9%, $p = 0.005$) than those without delayed extubation (Table 2). The delayed extubation group had higher proportion of total LOS >21 days and postoperative hospital stay >14 days (all log-rank test $p < 0.001$) (Fig. 2).

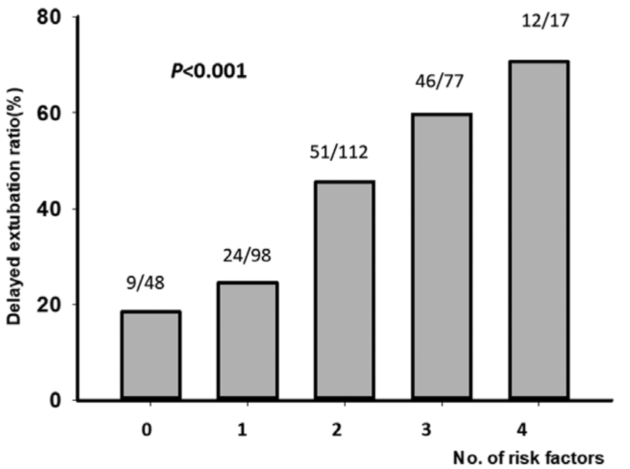

Fig. 1 The ratio of delayed extubation showed exponentially increased in patients with more risk factors. *Risk factors include age >65 y, ASA >2, anesthesia time >6 h, pneumonectomy and IS/IC > 1.14. ASA = the American Society of Anesthesiologists.

4. DISCUSSION

Postoperative delayed extubation, one of PPCs, is common and associated with the large attributable cost.[1–3] Intrathoracic procedures change respiratory physiology with decreased in lung compliance and increased small airway closure may increase work of breathing and impair gas exchange leading respiratory failure and delayed extubation.[25,26] Identification of a subset of patients at higher risk for whom aggressive perioperative management is warranted. In this study, we identified age >65 years, ASA >2, anesthesia time >6 hours, pneumonectomy, and IS-v/IC ratio >1.14 could be the independent predictors for delayed extubation after lung resection. The risk of developing delayed extubation showed exponentially increased in patients with more independent risk factors. Of note, delayed extubation was associated with poor patient outcomes including higher other pulmonary complications, mortality, and prolonged postoperative ICU and hospital stays.

Many mechanisms, such as age-related pulmonary physiology change, anesthesia-related factors, and general cardiopulmonary status affect patient outcomes after operation. Respiratory complications after surgery account for approximately 40% of the perioperative deaths in patients over 65 years of age.[27] Blanc et al[28] identified the risk factors, including right-sided pneumonectomy, chronic cardiac disease, Charlson Comorbidity Index, and carina resection, for early acute respiratory failure after pneumonectomy. Hirosako et al[9] reported that older age, male gender, asthma, gastrointestinal surgery, cardiovascular surgery, and a lower value of FEV_1 % predicted were the predictors for PPCs. Agostini et al[6] demonstrated that current smoking is the risk factor for PPC after VATS lobectomy. Like the previous studies reporting risk factors for PPCs, we identified that older age, poor general health status, longer anesthesia time, and major procedure (eg, pneumonectomy) were the independent factor associated with delayed extubation. Interestingly, our study reported that IS-v/IC ratio could be the independent predictor for delayed extubation after lung resection.

IC is defined as the maximal amount of air that can be inhaled from the end-expiratory lung volume. The direct measure of IC through spirometry has been demonstrated to be simple and reliable. There is no accepted definition for air-trapping and hyperinflation. The low values of IC could reveal more serious air-trapping due to the characteristic of IC reflecting end-expiratory level.[29] IC/TLC could be the indicator for the outcome of chronic obstructive pulmonary disease (COPD) patients.[30–32] Reduction in IC causes increasing FRC when airway obstruction worsens, while TLC does not change significantly.[29] IC/TLC ratio represents the static hyperinflation is related to dyspnea and exercise capacity (dynamic hyperinflation)[31,33] and is a good predictor of mortality in emphysema.[30] Furthermore, IC/TLC also could be a respiratory function parameter for

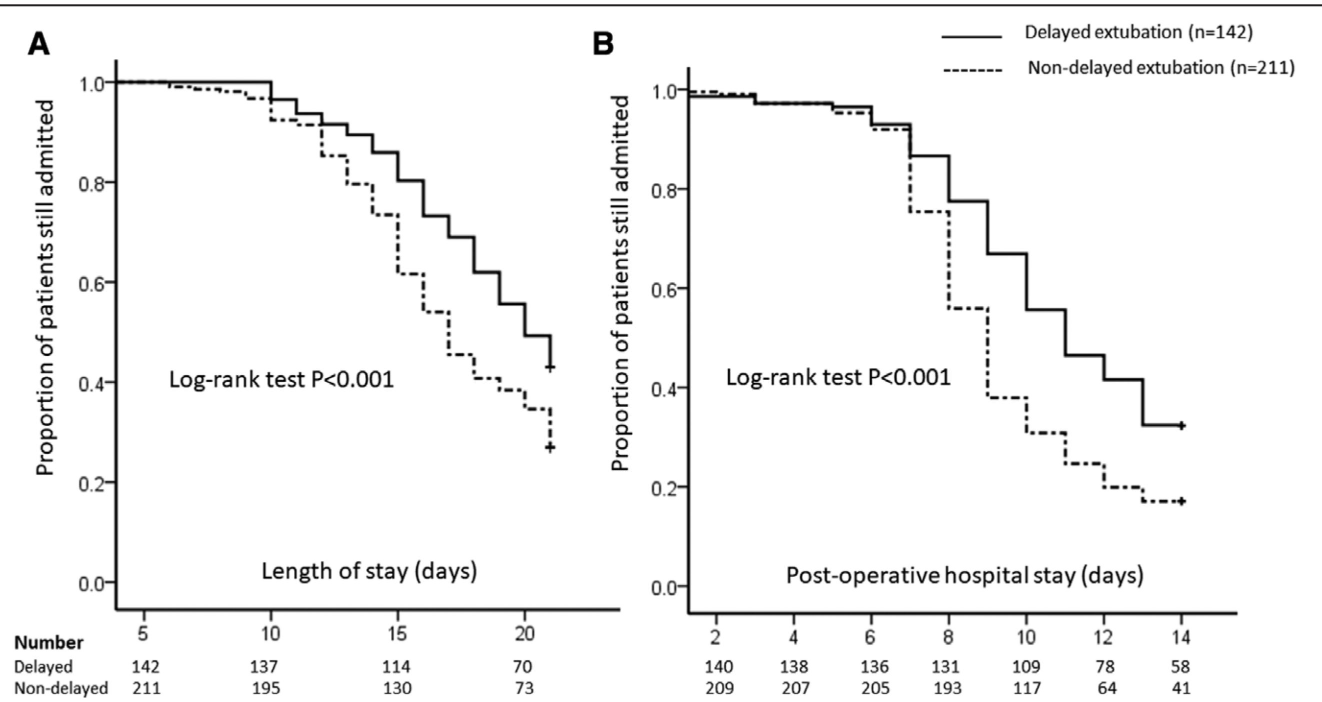

Fig. 2 Kaplan–Meier curves for (A) total length of stay (LOS) >21 d (log-rank test $p < 0.001$) and (B) postoperative hospital stay >14 d (log-rank test $p < 0.001$).

worse outcomes in COPD.[32] Dynamic hyperinflation is clinically recognized in the mechanically ventilated patient with COPD as intrinsic positive end-expiratory pressure (PEEPi). In the critical care setting, assessment of PEEPi and minimization of hyperinflation is important in the management of patients with COPD who are admitted because of acute respiratory failure.[34] More than half of our study patients had smoking history. However, spirometry revealed airflow limitation with FEV_1/FVC ratio <0.7 was only 25.8%. Our result suggested that COPD combined with air-trapping and/or hyperinflation may be underdiagnosis by applying spirometry only in subjects undergoing lung resection. Similar to predicting COPD outcome, combined assessment for IS-v/IC ratio could be utilized to evaluate delayed extubation after lung resection.

IS is one of mechanical maneuver by taking long, slow, and deep breaths to promote lung expansion and better gas exchange and it may be effective in preventing complication for thoracic surgery.[13,35] However, Cattano et al[36] showed that preoperative IS use dose not associated with improvements of IC and that is not useful to prevent postoperative decrease in lung function. In our study, we investigated IS-v/IC ratio. The volume-oriented devices need to sustain maximal inspiration by respiratory effort, which allows a large volume and transpulmonary pressure gradient to reach lung expansion. The higher and lower values of IS-v than normal range may indicate the hyperinflation status and restrictive lung disease respectively. Meanwhile, the subjects developed hyperinflation that the values of IC were lower than normal range. We adjusted IS-v by IC to detect hyperinflation precisely. Therefore, we hypothesis the IS-v could reflect as lung volume. Similar with previous study,[21] our data showed preoperative IS-v was correlated with VC ($R = 0.498$, $p < 0.001$) and TLC ($R = 0.461$, $p < 0.001$) in Supplementary Figure 1, http://links.lww.com/JCMA/A73. The result may suggest that IS-v/IC as a hint of air-trapping or hyperinflation. The identification of air trapping or hyperinflation based on higher IS-v/IC ratio (eg, high IS and low IC values) may help to predict the development of delayed extubation after lung resection in patients with normal spirometry result. Therefore, the maneuver of IS only is used to assess the lung expansion but it is not a good tool to simultaneously identify the hyperinflation and/or air-trapping in patient undergoing lung resection. In addition, preoperative FEV_1 or FEV_1/FVC ratio is not a sensitive factor for predicting delayed extubation after lung resection in our study. To our best knowledge, no existing studies have shown that relationship between IS-v/IC and postoperative delayed extubation. Our findings may achieve early recognition of patients being at a higher risk for postoperative delayed extubation, and then refine the perioperative management and critical care.

Our study had several limitations that warrant discussion. First, this was a single-center retrospective cohort study that introduced some bias. For example, a therapy like IS that requires a high level of adherence in practical. Second, we only recorded the best preoperative IS-v. There was lack of the correlation between postoperative lung function and the development of delayed extubation. Third, we focused patient recruitment on those with lung resection under GA. Only 4.2% of patients underwent VATS surgery. There was no experience for Robotic-assisted thoracoscopic surgery nor non-intubated thoracoscopic surgery in this study period. But, the finding of our result still provided clinical value, especially the pre-operative IS and PFT evaluation.

In conclusion, older age, poor general health status, longer anesthesia times, pneumonectomy, and higher IS-v/IC ratio were the independent factors to predict delayed extubation after lung resection. Delayed extubation was significantly associated with worse outcomes, including higher proportion of other pulmonary complications, reintubation, mortality, and prolonged ICU and hospital stays. Preoperative PFT and IS evaluation were valuable for early recognition of patients being at a higher risk for developing postoperative delayed extubation after lung resection.

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APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://doi.org/10.1097/JCMA.0000000000000264.

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