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ORIGINAL ARTICLE

Lung ultrasound on first postoperative day predicts out-of-hospital pulmonary complications following video-assisted thoracic surgery

A prospective cohort study

ZiYun Lu, Hang Sun, Shujie Niu, Min Wang, Yiwei Zhong and Bingbing Li

BACKGROUND The integration of enhanced recovery after surgery (ERAS) protocols into the peri-operative management of video-assisted thoracic surgery (VATS) has facilitated rapid patient recovery, enabling discharge within 48 h. However, postoperative pulmonary complications (PPCs) postdischarge pose significant concerns for patient welfare. Despite the established utility of lung ultrasound (LUS) in diagnosing the causes of dyspnoea, the effectiveness of quantitative LUS in predicting PPCs after VATS remains uncertain.

OBJECTIVES To determine whether quantitative LUS performed 24 h after surgery can identify patients with a higher risk of developing PPCs within 30 days after discharge from hospital.

DESIGN Single-centre prospective cohort study.

SETTING Academic tertiary care medical centre.

PATIENTS Adults scheduled for elective VATS under general anaesthesia from November 2022 to January 2023.

MAIN OUTCOME MEASURES This primary aim was to verify the association between lung ultrasound score (LUSS) on postoperative day 1 (POD1) and PPCs. The secondary aim was to identify other relevant peri-operative factors closely related to PPCs and establish a model capable of predicting the risk of PPCs in patients undergoing fast-track VATS.

RESULTS Of the 200 recruited patients, 182 completed the LUS examination and 30-day follow-up. Of these, 66 (36.2%) developed various types of PPCs. These patients had a higher LUSS on POD 1 ($P < 0.001$), and more subpleural consolidation areas compared to those without PPCs ($P < 0.001$). Receiver-operating characteristics (ROC) analysis identified the optimal LUSS cut-off value at 6 points for predicting the occurrence of PPCs, with an area under the curve (AUC) of 0.838 (95% CI, 0.768 to 0.909). Patients with PPCs had higher rates of immune system diseases and ARISCAT score, longer hospital stay and procalcitonin levels, increased frequency of lobar resection, longer durations of surgical and mechanical ventilation, and greater incidence of unplanned hospital readmissions within 30 days postdischarge, compared with those without PPCs (all $P < 0.001$). Multivariable logistic regression analysis indicated that the comorbidity of immune system disease, along with postoperative 24 h LUSS, were independent risk factor for PPCs within 30 days after VATS.

CONCLUSION LUSS on POD 1 emerged as an independent risk factor for PPCs in fast-track VATS patients and reliably predicted the occurrence of PPCs within 30 days of hospital discharge.

TRIAL REGISTRATION ClinicalTrials. gov No. ChiCTR2200065865.

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From the Department of Anaesthesiology, Nanjing Drum Tower Hospital, the Affiliated Hospital of Nanjing University Medical School, Nanjing, China (ZL, HS, SN, MW, YZ, BL)

Correspondence to Bingbing Li, MD, PHD, Department of Anaesthesiology, Nanjing Drum Tower Hospital, the Affiliated Hospital of Nanjing University Medical School, 321 Zhongshan Road, Nanjing 210008, China.
E-mail: icecolor@163.com

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KEY POINTS

- We investigated whether the results of quantitative LUS examination performed on postoperative day 1were associated with pulmonary complications within 30 days after VATS.
- The global lung ultrasound score was associated with an increased risk of PPCs.
- Lung ultrasound performed on the first postoperative day reliably identified higher risk for out-of-hospital pulmonary complications.

Introduction

Postoperative pulmonary complications (PPCs) are commonly defined as new-onset pulmonary disorders occurring post procedure. They encompass upper respiratory tract infections, pneumonia, acute respiratory dysfunction, pleural effusion, and pneumothorax, among others, and have been defined.[1] The reported prevalence of PPCs following various major procedures varies between 2.8 and 40%, contingent upon surgical procedure and how PPCs are defined.[2,3] Immediate PPCs within the first postoperative week (POD 7) have a significant negative impact on early inpatient recovery.[4] PPCs occurring within 30 days after hospital discharge are not uncommon and are also a primary cause of unplanned readmissions or outpatient clinical visits. Out-of-hospital PPCs, such as pneumothorax, mediastinal emphysema, and massive pleural effusion, negatively affect the long-term recovery and may lead to unexpected mortality. Bhangu *et al.* reported a 51.2% incidence of PPCs within 30 days postsurgery in patients with SARS-coronavirus 2 infection; the incidence of PPCs after surgery is frequently underestimated.[5]

The integration of enhanced recovery after surgery (ERAS) protocols into peri-operative management reduced the length of hospital stay following video-assisted thoracic surgery (VATS). Most of these patients either had no intraprocedural complications or early postprocedural complications. Evaluating the incidence of inpatient PPCs becomes impractical in patients subjected to fast-track thoracic surgery programs, but PPC after discharge was one of the key factors responsible for retarding recovery following VATS. Therefore, early identification of high-risk patients for PPCs allows preemptive intervention and enhanced monitoring, facilitating timely treatment adjustments and ensuring their smooth recovery.

Several predictive scoring models, including the ARISCAT and PERISCOPE scores have been created,[1,6,7] but these assessment scales have limitations when identifying patients at risk of developing PPCs at later stages. Quantitative lung ultrasound (LUS) can quantify the extent of global lung injury based on the severity of specific pulmonary disorder in different thoracic regions. A French centre found that LUS can predict weaning failure in acute respiratory distress syndrome (ARDS) patients and PPCs after general anaesthesia.[8] Although a good correlation between LUS score (LUSS) and computed tomography (CT) has been preliminarily verified in assessing regional and global lung aeration based on the B-pattern in the previous scoring system, the B-pattern only represents a small part of diverse lung disorders. Monastesse *et al.*[9] proposed that the LUS sign of subpleural consolidation should be incorporated into the scoring system to achieve a more precise and comprehensive assessment.

The prevalence of 30-day PPCs after hospital discharge, and associated risk factors in fast-track VATS patients, remains undetermined. The effectiveness of quantitative LUS in predicting PPCs after VATS is poorly delineated. This study's primary aim was to verify the association between LUSS on POD1 and PPCs. The secondary aim was to identify other relevant peri-operative factors closely related to PPCs and establish a valuable predictive model capable of predicting the risk of PPCs in patients undergoing fast-track VATS.

Methods

Ethical approval

Ethical approval for this study (2022-228-02) was provided by Institutional Ethics Committees of Nanjing Drum Tower Hospital, Nanjing, China on 16 June 2022. Written informed consent was obtained from all individuals or a legal surrogate.

Study design and patients

This prospective, observational, single-centre study was conducted in a single division of the Department of Thoracic Surgery at our hospital, the minimally invasive thoracoscopic lung surgery day-care unit. We included adults aged at least 18 years old scheduled for elective VATS under general anaesthesia and who were ASA physical status 1 to 3. We excluded those with serious PPCs requiring treatment during admission, with technical problems with the ultrasound, with duration of surgery longer than 3 h, those with preoperative history of acute lung injury and adverse reactions to anaesthetics, with heart failure (New York Heart Association class >2), severe hepatic and renal dysfunction, history of lung resection and with Global Initiative on Chronic Obstructive Pulmonary Disease (GOLD)[10] at least 3 (FEV1 < 50% predicted), or history of previous exacerbation.

Ultrasound protocol

The bedside LUS examinations were conducted using the same portable imaging machine (Mindray, Shenzhen, China). Two certified investigators, with advanced LUS training and a minimum of 3 years of experience in LUS, performed the scans. A linear probe (5.0 to

10.0 MHz) was used for intercostal lung views, assessing the anterior and lateral chest walls through longitudinal or transverse scans. For the posterolateral and posterior chest walls, a convex array probe (2.0 to 6.0 MHz) was employed.

Patients were positioned semi-recumbent during the examination. Each hemithorax was divided into six areas, delineated by vertical anterior and posterior axillary lines and horizontal mamillary lines. The modified scoring system by Monastesse *et al.*[9] was used for calculating LUSS. Four ultrasound aeration grades were defined for each area: normal aeration (score 0), characterised by an A-profile or 0 to 2 B lines; small loss of aeration (score 1), indicated by at least three well defined B lines or multiple small subpleural consolidations separated by a normal pleural line; moderate loss of aeration (score 2), identified by multiple coalescent B lines or subpleural consolidations separated by an irregular pleural line; and severe loss of aeration (score 3), marked by severe consolidations with diameters exceeding $1 \times 2\,cm^2$. The score for each region was determined based on the most severe ultrasound pattern observed, resulting in a global score ranging from 0 to 36 points. Representative ultrasonographic images for each grading are depicted in Fig. 1. Each patient underwent LUS examination either 24 h postoperatively or on the first morning after surgery. LUSS calculations were performed by the investigator conducting the LUS examination, whereas another researcher recorded LUSS values based on saved images.

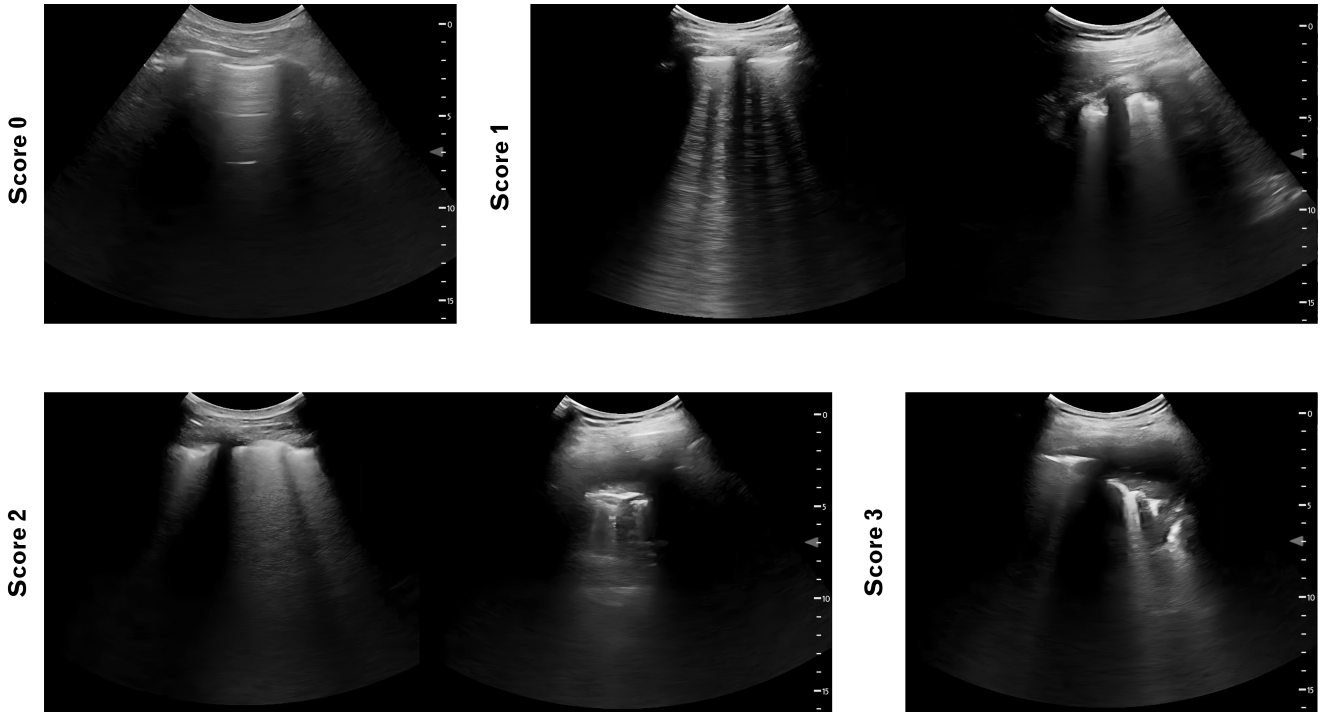
Preoperative management

All patients followed a standardised ERAS protocol according to EATS[11] and our routine clinical practice. On arrival, patients received dedicated preoperative education, counselling and risk assessment. All patients were screened preoperatively for nutritional status, weight loss, anaemia and pulmonary function. Smoking was forbidden for at least 4 weeks before surgery. Clear fluids were allowed up until 2 h before the induction of anaesthesia and solids until 6 h before. No premedication was routinely used. Standard antibiotic prophylaxis of 1.5 g of cefuroxime or 0.6 g of clindamycin was administered intravenously 30 min before surgery.

Anaesthesia protocol and ventilator settings

The patients were placed in the lateral decubitus position with the surgical side upwards in the preanaesthesia room and received an ultrasound-guided thoracic paravertebral nerve block (TPVB) block. The thoracoscopic operating-port was established at the T3∼5 intercostal region in the middle axillary line. The T3∼5 paravertebral space was frequently selected as the multiple puncture site. Patients received a 7 ml bolus of ropivacaine hydrochloride 0.375% at each level of T3∼5. Patients were transferred to the operating room after dermatomal testing with a cotton stick soaked with ice-cold 0.9% saline to assess loss of sensation over the thoracic dermatomes in the middle axillary line. All received monitoring with electrocardiography, pulse oximetry, invasive blood

Fig. 1 Typical ultrasound patterns and corresponding scores for lung aeration quantification.



pressure, end-tidal CO_2, and bispectral index (BIS). General anaesthesia was induced using midazolam (0.05 mg kg^{-1}), 1% propofol (2 mg kg^{-1}), fentanyl (4 μg kg^{-1}), and tracheal intubation was facilitated with muscle relaxant. Total intravenous anaesthesia was conducted with 2% propofol (6 to 8 mg kg^{-1} h^{-1}), remifentanil (0.20 to 0.25 μg kg^{-1} min^{-1}), cis-atracurium (1 to 2 μg kg^{-1} min^{-1}) to maintain a targeted BIS between 40 and 60. The intra-operative mechanical ventilation protocol followed lung-protective ventilation strategies mentioned in an earlier study.[12] The settings for two-lung ventilation were: a tidal volume 6 to 8 ml kg^{-1}, PEEP 5 cmH_2O, FiO_2 0.5 to 0.8, inspiratory to expiratory ratio 1 : 2, and respiratory rate adjusted to maintain $ETCO_2$ 35 to 45 mmHg. The settings for one-lung ventilation were: a tidal volume of 4 to 6 ml kg^{-1}, PEEP of 5 cmH_2O, FiO_2 of 1.0, inspiratory to expiratory ratio 1 : 2. The respiratory rate was adjusted to maintain $ETCO_2$ at 35 to 45 mmHg. Recruitment manoeuvres were performed immediately following tracheal intubation and at the end of the surgery by manual inflation with a pressure of 30 cmH_2O for 15 to 20 s. Every patient received patient-controlled intravenous analgesia for postoperative analgesia before transfer from the postanaesthesia care unit (PACU). We routinely evaluate the patients' grip strength and ability to sustain a head lift off the bed over 5 s before extubation, supported by a TOF watch monitoring the quantitative neuromuscular block, to avoid residual muscle relaxion. We confirmed every patient had a TOF ratio at least 0.9 before extubation. All patients had a Steward Score[13] of at least 5 before being discharged from the PACU.

Postoperative management

Following return to the ward, patients received standardised ERAS postoperative care as follows:

(1) Clinicians determined the need for postoperative antibiotics based on clinical signs of infection and laboratory indicators.
(2) Multimodal analgesia, including patient-controlled intravenous analgesia (PCA) and nonsteroidal anti-inflammatory drugs were administered to maintain a numerical pain rating scale less than 4. Serratus anterior muscle plane blockade was used as rescue analgesia for patients experiencing breakthrough pain.
(3) Patients with a high risk of thrombosis (Capirini score >3) received low-molecular-weight heparin to prevent deep vein thrombosis and pulmonary embolism.
(4) Patients at moderate or high risk of postoperative nausea and vomiting (PONV) received multimodal pharmacological prophylaxis or treatment.
(5) Patients were encouraged to ambulate on the first postoperative day. Walking capacity was assessed using the 6-min walk distance test. The patients were encouraged to voluntarily cough, and sputum expectoration was further enhanced by chest vibrator apparatus.
(6) Chest tubes were removed when daily drainage volume was less than 300 ml. Patients were discharged following chest tube removal. According to hospital management regulations, patients unable to be discharged within 48 to 36 h were transferred to another ward, precluding the completion of day-Care management protocol.

Follow-up for postoperative pulmonary complications

All patients were prospectively followed for 30 days after discharge. An anaesthesiologist blind to the study assessed outcomes from hospital discharge until postoperative day 30. PPCs were defined as clinical, radiological or intervention-requiring respiratory complications, including pneumonia, pleural effusion, pneumothorax, ARDS, pulmonary oedema, re-intubation or respiratory failure. New-onset clinically significant pleural effusions requiring pharmacological or invasive interventions were also classified as PPCs. Prolonged air leak (>5 days) was included in the PPCs definition based on previous studies and clinical relevance. Patients were considered negative for PPCs if they remained free from any respiratory complications 1 month after discharge.

Data collection

Personal characteristics, comorbidities, surgical and anaesthesia details, hospital length of stay, occurrence of PONV, and postoperative C-reactive protein (CRP) and procalcitonin (PCT) levels were extracted from electronic medical records.

Primary and secondary outcomes

The primary outcome was the incidence of 30-day PPCs after fast-track VATS. Secondary outcome was to validate feasibility and effectiveness of the quantitative LUS on predicting PPCs.

Statistical analysis

In this prospective pilot study, the sample size was estimated by using the LUSS to distinguish between those with or without PPCs. According to our preliminary experiments, we found a difference of at least four points between the patients with PPCs and those without. We hypothesised that a minimum difference of four points was considered as clinically significant, and that, in combination with a standard deviation (SD) of two points, were used for the calculations. With a 5% α risk, including 90 patients in each group (180 in total) was required to provide 90% power to show a significant difference between the two groups. Expecting a 10% dropout, a minimum of 200 individuals were required. Normally distributed data was tested by Shapiro–Wilk W test. Results are expressed as the mean ± SD or median [interquartile range (IQR)] for quantitative variables. Categorical variables are expressed as percentage and absolute numbers. Student's two-sample t test and Mann Whitney U test were used for numerical data. χ^2 and Fisher exact

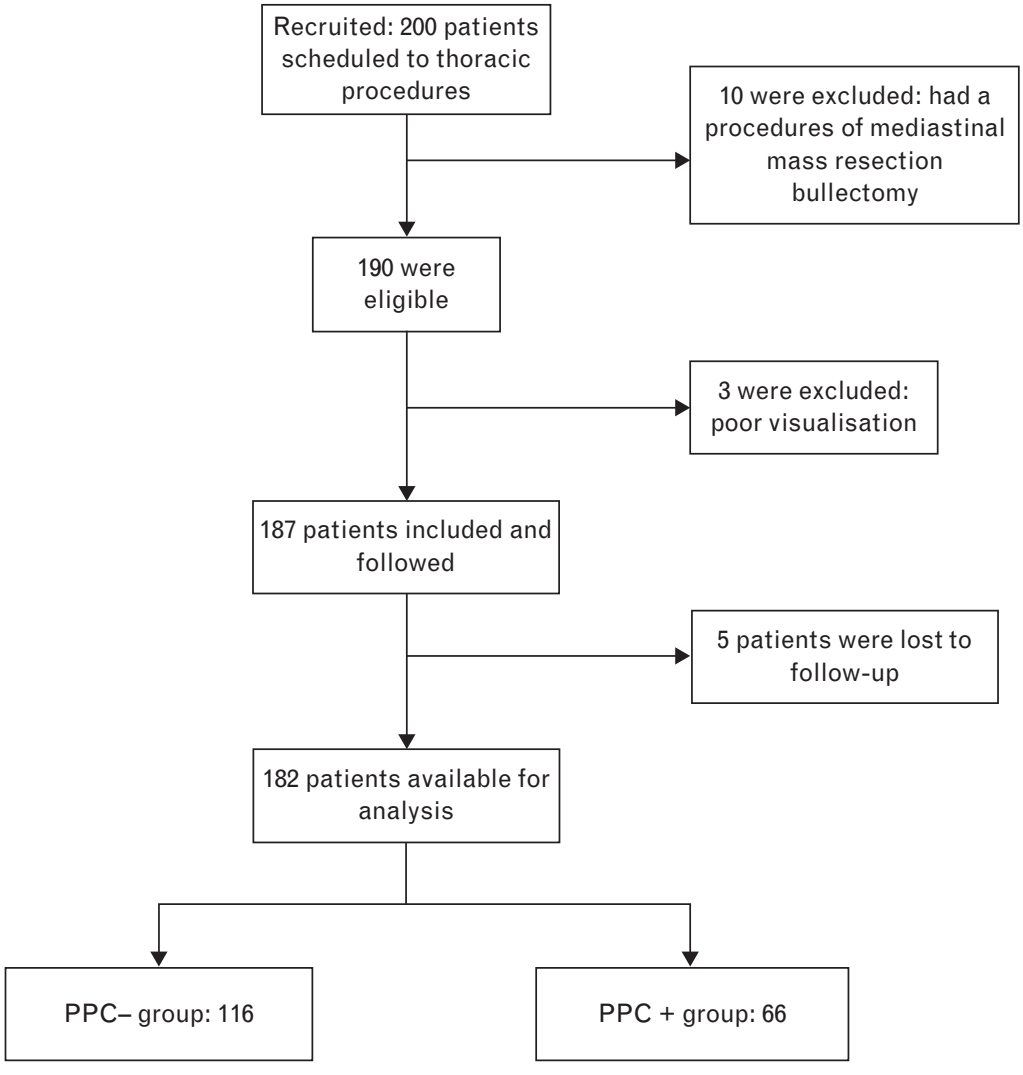
test were used for categorical data. To determine the diagnostic value of LUS in occurrence of PPCs, the receiver-operating characteristics (ROC) curve was generated. Wilcoxon's method was used to estimate the area under the ROC curve (AUC). Cut-off points were obtained by Youden index. To evaluate the association between PPCs and plausible variables, a multivariable logistic regression was performed. Univariate logistic regression analyses were used to identify risk factors linked to PPCs risk. The variables yielding *P* less than 0.1 were incorporated into a multivariable logistic regression model. Age and sex were used as adjusting variables of clinical judgement. According to the variables screened by univariate and multivariate analyses, a predictive nomogram was generated. Meanwhile, a predicator of variance inflation factor (VIF) greater than 5 was interpreted as indicating multicollinearity and was excluded from final model. The accuracy of the nomogram was verified by calibration curves. Intra-observer agreement was assessed by calculating interclass correlation coefficient (ICC). All *P* values were two-tailed and the limit of statistical significance was set to *P* less than 0.05. All analyses were conducted using R statistical language (R 3.5.1) and IBM SPSS Statistics 26.0 software.

Results

Patient characteristics

We consecutively enrolled 200 patients undergoing the fast-track VATS during the period from November 2022 to January 2023 in the Department of Thoracic Surgery in our hospital. Of these, 10 did not meet the inclusion criteria, 3 with subcutaneous emphysema had poor quality ultrasound images incapable of delineating the lung pathological changes, and 5 were lost to follow-up, leaving 182 for analysis (Fig. 2).

Fig. 2 Study flow diagram.



PPC−, patients without postoperative pulmonary complications; PPC+, patients with postoperative pulmonary complications.

Incidence of 30-day pulmonary complications in video-assisted thoracic surgery

Sixty-six patients (36%) developed at least one type of PPC in this study, consisting of pleural effusion in 44 (67%), pneumonia in 11 (17%) pneumothorax in 4 (6%), respiratory insufficiency in 3 (5%), atelectasis in 2 (3%) and air leak (classification II) more than 5 days (3%) (Table S1, http://links.lww.com/EJA/B75). Fifty-six percentage of PPCs were detected 2 weeks after hospital discharge (Table S2, http://links.lww.com/EJA/B75). In the cohort of 66 patients with PPCs, 3 were re-admitted secondary to pneumonia and 1 patient had an unplanned outpatient visit. The personal details of the patients either developing PPCs or not, and peri-operative data are summarised in Table 1.

Association between lung ultrasound and 30-day pulmonary complications

The different LUS findings, together with the sum of scores of the lung disorders are depicted in Table 2. The median [IQR] global LUSS in the patients with PPCs was higher compared with those without PPCs (8 [6 to 11] versus 2 [1 to 4], $P < 0.001$). The ranges of subpleural consolidation were larger in the patients with PPCs than those without PPCs; the median areas of lung consolidation were 2 [1 to 3] and 0 [0 to 1] ($P < 0.001$), respectively.

Table 1 Baseline characteristics and peri-operative data according to postoperative pulmonary complications

Variable	PPC+ ($n = 66$)	PPC− ($n = 116$)	*P* value
Male	17 (26)	36 (31)	0.50
Age (years)	52 [45 to 58]	53 [38 to 59]	0.37
BMI (kg m^{-2})	23.8 [21.4 to 25.6]	23.4 [21.3 to 26.2]	0.98
ASA III	2 (2)	3 (5)	0.46
Comorbidities			
Hypertension	8 (12)	17 (15)	0.66
Diabetes mellitus	2 (3)	2 (2)	0.62
History of coronary artery disease	0	1 (1)	1.00
Abnormal lung function	4 (6)	3 (3)	0.42
History of blood system disease	2 (3)	5 (4)	0.71
History of immune system disease	5 (8)	1 (1)	**0.02**
Preoperative haemoglobin (g l^{-1})	134.5 [125.7 to 134.0]	134.0 [126.0 to 145.5]	0.97
ARISCAT score	27 [24 to 35]	27 [24 to 27]	**0.023**
Surgery type			
Wedge resection	31 (47)	74 (64)	0.051
Lobar resection	21 (32)	17 (15)	**0.008**
Segmentectomy	14 (21)	25 (22)	1.00
Surgical technique			0.188
Uniportal VATS	48 (73)	95 (81)	
Two-port VATS	18 (27)	18 (19)	
Incision site			0.641
Left chest	28 (42)	45 (38)	
Right chest	38 (58)	71 (62)	
Pathological type			0.115
Adenocarcinoma in situ	18 (27)	51 (44)	
Minimally invasive adenocarcinoma	18 (27)	27 (23)	
Invasive adenocarcinoma	18 (27)	17 (15)	
Benign tumour	12 (18)	20 (17)	
Operation time (min)	72.5 [55 to100]	60.0 [45 to 70]	**0.002**
Intubation method			0.180
Single-lumen endotracheal tube	3 (5)	15 (13)	
Double-lumen endotracheal tube	50 (76)	78 (67)	
Laryngeal mask	13 (20)	23 (20)	
Intra-operative mechanical ventilation			
Time on mechanical ventilation (min)	95 [75 to 130]	85 [60 to 110]	**0.009**
The highest SpO_2 during surgery (%)	99 [96.7 to 100]	99 [98 to 100]	0.531
$ETCO_2$ (mmHg)	40.5 [34 to 46]	40 [36 to 47]	0.671
Fluid balance (ml kg^{-1} min^{-1})	0.14 [0.11 to 0.18]	0.16 [0.11 to 0.22]	0.079
Intra-operative vasopressors	13 (20)	21 (18)	0.844
Analgesic method			
Patient-controlled analgesia	66 (100)	116 (100)	/
Oral tramadol plus paracetamol	7 (11)	15 (13)	0.814
PONV	10 (15)	30 (26)	0.099
Elevation of PCT[a]	10 (15)	7 (6)	**0.041**
Unplanned hospital readmission within 30 days after discharge	3 (5)	0	**0.046**
Length of hospital stay	2.6 [2.4 to 2.7]	2.4 [2.2 to 2.5]	**0.019**
Unplanned emergency department or outpatient visit within 30 days after discharge	2 (3)	5 (8)	1.00

Data are given as *n* (%) or median [IQR]. *P* values in bold indicate <0.05. PCT, procalcitonin; PONV, postoperative nausea and vomiting; PPC, postoperative pulmonary complications; VATS, video-assisted thoracic surgery. [a]PCT >0.5 ng m^{-1}.

Table 2 LUS characteristics according to postoperative pulmonary complications

Variable	PPC+ ($n=66$)	PPC− ($n=116$)	*P* value
LUS total	8 [6 to 1]	2 [1 to 4]	**<0.001**
B-patterns[a]	48 (73)	85 (73)	1.00
Area of consolidation	2 [1 to 3]	0 [0 to 1]	**<0.001**

Data are given as median [IQR], or *n* (%). *P* values in bold indicate <0.05. LUS, lung ultrasound; LUSS, lung ultrasound score; PPC, postoperative pulmonary complication. [a] Whether 2 or more regions had 3 or more B-lines in a longitudinal plane.

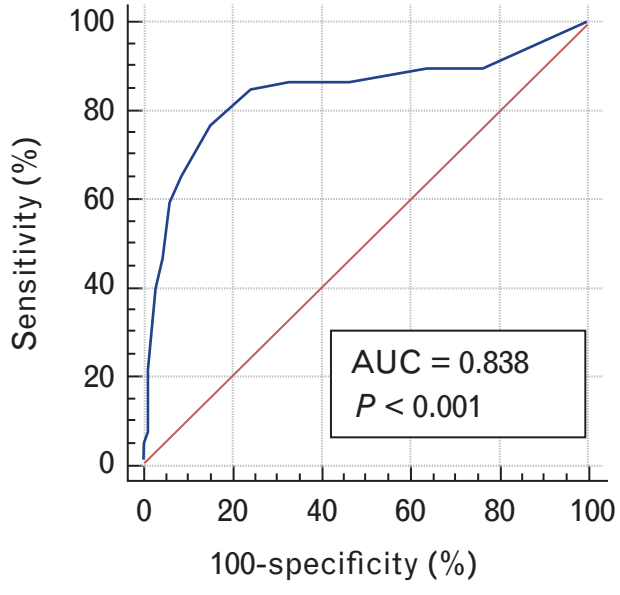
There was no significant difference in the number of B-lines and pleural effusion incidence between two groups ($P=1.00$). The AUC of ROC-LUSS was 0.838 (95% CI, 0.768 to 0.909), as shown in Fig. 3, indicating that LUSS on POD 1 reliably predicted PPCs in the VATS patients postoperatively. The optimal cutoff value determined by the Youden index was 6 points with sensitivity 0.773 and specificity 0.845. Positive and negative likelihood ratios were 4.98 and 0.20, respectively.

Peri-operative relevant risk factors predicting 30-day pulmonary complications

Univariate logistic regression analyses identified eight variables that were associated with the incidence of PPCs within 30 days after VATS. They were the global LUSS and area of subpleural consolidation, history of autoimmune system disease, duration of operation, intra-operative mechanical ventilation, the type of VATS, PCT value and ARISCAT score. A predictive nomogram incorporating these variables was established to gauge globality and each domain of PPCs. Before constructing the nomogram, VIF were calculated to examine multicollinearity. The VIF of time on mechanic ventilation and operation time were >5 (Table S3, http://links.lww.com/EJA/B75). Because the operative time was reflected in the ARISCAT, we deleted operation time in this stage. Figure 4a shows an example of using the nomogram to predict the probability PPCs for a given patient. The total score was calculated based on the individual scores according to the nomogram. ROC analyses revealed the AUC for this nomogram to be 0.889, as shown in Fig. 4b. Figure 4c further exhibited good agreement between actual predicted odds of PPCs. For internal validation, we used the bootstrap method with 200 bootstrap repetitions and leave-one-out cross validation. The results remained largely unchanged between iterations, with a mean concordance index of 0.878 and 0.911, indicating the nomogram for PPCs had considerable discriminative and calibrating abilities.

In multivariate regression analysis, immune system disease and global LUSS were validated to be independent risk factors after adjusting the covariates. The duration of mechanical ventilation, lobar resection, elevation of PCT, the length of hospital stay and area of consolidation had no strong association with PPCs (Table 3). Excellent inter-observer agreement (ICC = 0.974) was achieved (Table S4, http://links.lww.com/EJA/B75).

Fig. 3 The receiver-operating characteristics curve for postoperative 1d lung ultrasound score in the predication of postoperative pulmonary complications. The area under the receiver-operating characteristics curve was 0.838 (95% CI, 0.768 0.909). CI, confidence interval.



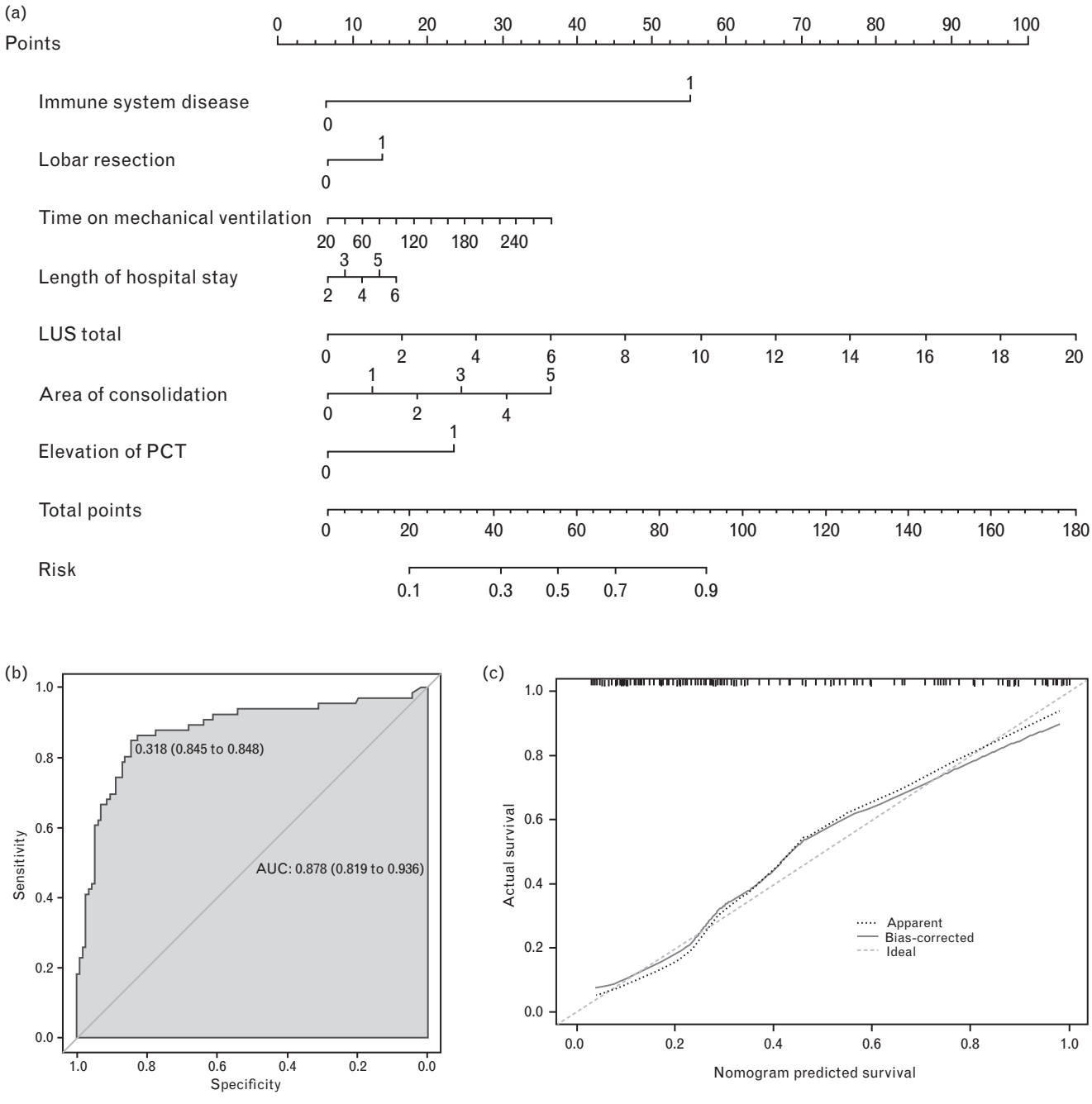
Discussion

In this study, the incidence of PPCs within 30 days postdischarge was 36% in VATS patients. We found that a LUSS exceeding 6 on POD 1 reliably predicted out-of-hospital PPCs in VATS patients, with an AUC of 0.838. Additionally, we developed a predictive nomogram capable of stratifying the risk of 30-day out-of-hospital PPCs in these patients. Notably, a high global LUSS and a comorbidity of autoimmune disease were identified as independent risk factors for out-of-hospital PPCs in VATS patients.

The prevalence of PPCs within 30 days postdischarge was approximately 36%, with 96% occurring after POD 7. The primary types of PPCs included respiratory infections, pneumothorax and pleural effusion; no grade III or higher PPCs, as classified by the Clavien–Dindo system, were reported in the study. Colquhoun *et al.*[14] and Li *et al.*[15] reported PPC rates following thoracic surgery of 11.4 to 15.7% and 25 to 26%, respectively. The higher incidence in our study may be attributed to varying definitions and durations of PPCs across studies.

Although quantitative LUS is widely used to predict outcomes in various clinical contexts, the optimal timing for LUS and its correlation with PPCs remain unclear.

Fig. 4 (a) Nomogram model for prognostic prediction of development of postoperative pulmonary complications; (b) the receiver-operating characteristics curve for the predication of postoperative pulmonary complications in this nomogram. The area under the receiver-operating characteristics curve was 0.878 (95% CI, 0.819 to 0.936). (c) Calibration curves for nomogram-based assessment for the cohort.



Zieleskiewicz *et al.*[16] found that LUS performed in the PACU could predict PPCs and respiratory failure in major surgery patients, although with a modest AUC of 0.64. Szabó *et al.*[17] reported that LUS performed 24 h after surgery had a significant predictive value for PPCs (AUC = 0.896). Immediate LUSS in the PACU may not accurately reflect the progression of lung disorder after surgery because of inadequate pain control and immobility in the ward, but the LUSS at 24 h proves to be a more suitable measure for evaluating the extent of lung injury when compared with immediate LUSS. Our study confirmed that a 24 h LUSS closely correlates with out-of-hospital PPCs (AUC = 0.838). To our knowledge, this is the first study to explore the

Table 3 Multivariate analyses of the associations between variables

Variables	Multivariable OR (95% CI)	*P* value
History of immune system disease	18.64 (1.43 to 242.3)	**0.025**
Time on mechanical ventilation	1.01 (0.99 to 1.02)	0.658
Lobar resection	1.66 (0.55 to 4.99)	0.365
Elevation of PCT[a]	2.93 (0.75 to 11.35)	0.119
Length of hospital stay	1.06 (0.57 to 1.96)	0.851
LUS total	1.31 (1.06 to 1.61)	**0.011**
Area of consolidation	1.71 (0.84 to 3.50)	0.164

P values in bold indicate <0.05. CI, confidence interval; LUSS, lung ultrasound score; OR, odds ratio; PCT, procalcitonin; PPC, postoperative pulmonary complication. [a] PCT > 0.5 ng ml^{-1}.

association between early postoperative LUSS and PPCs after VATS.

Our study identified a LUSS threshold of 6 for predicting PPCs, which is lower than the median score of 12 reported by previous studies.[16] This discrepancy may be because of our use of the modified scoring system proposed by Monastesse *et al.*,[9] where the sign of small subpleural consolidations (<2 cm^2) was categorised as 1 or 2 points of pulmonary disorder, in contrast to the previous scoring system where a similar consolidation disorder was assigned 3 points. Additionally, our cohort included otherwise healthy patients undergoing minimally invasive VATS, resulting in less severe lung injury compared to major open surgery.

Our findings are consistent with those from Hungary, where 24 h LUSS was a reliable predictor of PPCs.[17] Dureau *et al.*[18] also demonstrated that incorporating LUS findings into diagnostic criteria improved the detection of early postoperative pneumonia after major cardiac surgery. Furthermore, the finding that autoimmune disease was a strong predictor of PPCs is consistent with Doran *et al.*,[19] who found that rheumatoid arthritis patients had a significantly higher risk of infection requiring hospitalisation. This increased risk is probably because of the synergistic effects of immune system impairment and postoperative inflammation.[20,21] However, because of the small sample size and the unbalanced distribution of the two groups, the 95% CI was too large to verify that autoimmune disease was an independent risk factor for PPCs. It is necessary to further expand the sample size for verification.

This study has several limitations. First, as a single-centre study with only 182 patients, the generalisability of our findings may be limited. Second, LUS was performed only once on POD 1, which may not capture dynamic changes in lung injury. Third, preoperative LUS was not conducted, raising uncertainties about the preoperative respiratory status of the cohort. However, the chest CT scan was routinely conducted preoperatively in this cohort. The lung pathological changes can be assessed using chest CT scan. All individuals in the present study were in relatively good physical status and exhibited nearly normal lung images except the solitary or multiple nodule lesions, which was consistent with the low numerical rating scale of LUS, according to our pilot study. Fourth, image acquisition was sometimes affected by surgical bandages and subcutaneous emphysema. Lastly, PPCs were considered as a dichotomous variable rather than a graded categorical variable; using the Clavien–Dindo classification would allow for a more nuanced assessment of PPCs.[22]

Conclusion

In conclusion, a LUSS exceeding 6 on POD 1 identifies patients at risk of developing PPCs within 30 days after fast-track VATS. We recommend incorporating routine LUS examinations into thoracic ERAS guidelines to enhance postoperative care.

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