Feasibility and Efficacy of Lung Ultrasound to Diagnose Postoperative Hypoxemia-A Prospective Study

Chen Xie
Department of Anesthesiology and Pain Medicine, Zhejiang University School of Medicine Second Affiliated Hospital

Kai Sun
Departmeng of Anesthesiology and Pain Medicine,Zhejiang University School of Medicine Second Affiliated Hospital

Yueyang You
Department of Anesthesiology and Pain Medicine, Zhejiang University School of Medicine Second Affiliated Hospital

Yue Ming
Department of Anesthesiology and Pain Medicine, Zhejiang University School of Medicine Second Affiliated Hospital

Xiaoling Yu
Department of Anesthesiology and Pain Medicine, Zhejiang University School of Medicine Second Affiliated Hospital

Lina Yu
Deparment of Anesthesiology and Pain Medicine, Zhejiang University School of Medicine Second Affiliated Hospital

Jiapeng Huang
Department of Anesthesiology & Perioperative Medicine, University of Louisville

Min Yan (zryanmin@zju.edu.cn)
https://orcid.org/0000-0002-1355-1261

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Abstract

Background Postoperative hypoxemia is associated with morbidity and mortality. We aim to evaluate the feasibility and efficacy of lung ultrasound (LUS) to diagnose pulmonary complications in patients suffering from hypoxemia after general anesthesia, and compare to thoracic computed tomography (CT).

Methods Adult patients received general anesthesia and suffered from hypoxemia in the PACU, were analyzed. Hypoxemia was defined as a SPO_2 less than 92% for greater than 30 seconds on room air. LUS was performed by a trained anesthesiologist once hypoxemia occurred. After LUS examination, each patient was transported to radiology department for thoracic CT scan within 1 hour before returning to the ward.

Results From January 2019 to May 2019, 113 patients (61 men) undergoing abdominal surgery (45 patients, 39.8%), video-assisted thoracic surgery (31 patients, 27.4%), major orthopedics surgery (17 patients, 15.0%), neurosurgery (10 patients, 8.8%) and other surgery (10 patients, 8.8%) were included. CT diagnosed 327 of 1356 lung zones as atelectasis while LUS revealed atelectasis in 311 of the CT-confirmed zones. Pneumothorax was detected by CT scan in 75 quadrants, 72 of which were detected by LUS. Pleural effusion was diagnosed in 144 zones on CT scan and LUS detected 131 of these zones. LUS was reliable in diagnosing atelectasis (sensitivity 98.0%, specificity 96.7% and diagnostic accuracy 97.2%), pneumothorax (sensitivity 90.0%, specificity 98.9% and diagnostic accuracy 96.7%) and pleural effusion (sensitivity 92.9%, specificity 96.0% and diagnostic accuracy 95.1%).

Conclusions Lung ultrasound is feasible, efficient and accurate in diagnosing different etiologies of postoperative hypoxia in the PACU.

Trial Registration:

Clinical trial number: NCT03802175

Registry URL: www.ClinicalTrials.gov

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Background

Hypoxemia is caused by mismatching of pulmonary ventilation and perfusion, intrapulmonary shunting, reduced functional residual capacity, loss of hypoxic pulmonary vasoconstriction, recumbent body position, injured pulmonary secretion clearance, sedatives and muscle relaxants induced transient loss of respiratory muscle tone, and pain.[1] Hypoxemia occurs frequently in the immediate postoperative recovery course in both pediatric and adult patients.[2–4] Prolonged and severe hypoxemia is associated with nausea, vomiting, postoperative cognitive dysfunction, delayed wound healing, surgical site infection, arrhythmias, prolonged hospital stay and death.[5–7]

Rapid diagnosis and appropriate management must be made by the anesthesiologist once hypoxia occurs postoperatively. Chest x-rays (CRX) had been restricted due to the disadvantage of poor quality[8]. Although thoracic computed tomography (CT) is considered the gold standard to elucidate causes of hypoxia, radiation exposure and the need to transfer unstable patients makes CT a less than ideal tool. Bedside lung ultrasound (LUS) has the advantages on sensitivity, accuracy, non-radiation, non-invasiveness, reproducibility and convenience. It has been validated to diagnose atelectasis, pneumonia, pleural effusion and pneumothorax.[9–14]

The primary aim of this study is to evaluate the feasibility and efficacy of lung ultrasound to diagnose pulmonary complications in patients suffering from hypoxemia after general anesthesia in the postanesthesia care unit (PACU), and compare lung ultrasound results with thoracic CT.

Methods

Patients

The study was approved by the review committee of Second Affiliated Hospital of Zhejiang University (IR2018001133, 2018/12/05) and registered at ClinicalTrials.gov (NCT03802175) before patient enrollment. Informed consents were obtained from all patients. Adult patients who received general anesthesia and suffered hypoxemia in the PACU were included in this study. Postoperative hypoxemia was defined as a decreased oxygen saturation measured by pulse oximetry (SPO_2) less than 92% for greater than 30 seconds while on room air 20 minutes after extubation.[15] Exclusion criteria included: covered surgical dressings from opening thoracic or breast surgery preventing ultrasound examination; body mass index (BMI) greater than 40 kg/m^2; lack of cooperation due to cognitive dysfunction; residual muscle relaxants resulted in incomplete recovery of muscle strength (Train of four stimulation, TOF < 0.9); respiratory forgetfulness from residual opioid; hemodynamic instability; anemia; significant bleeding, fever or hypothermia. Besides, patients were withdrawn if SPO_2 decline to 85% or less or admission of intensive care unit (ICU) happened.

Anesthesia Protocol

Before induction of anesthesia, all patients were preoxygenated with an inspiration oxygen fraction (FiO_2) of 1.0. Anesthesia was induced with midazolam 0.05-0.1mg/kg, sufentanil 0.5-0.6 ug/kg, etomidate 0.2-0.4 mg/kg and rocuronium 0.8-1.0 mg/kg. Proper double-lumen endotracheal tube was intubated to perform one-lung ventilation (OLV) during video-assisted thoracoscopic surgery (VATS), whereas common tracheal tube was inserted for two-lung ventilation (TLV) during non-VATS. Continuous intra-venous propofol, remifentanil with inhalational sevoflurane was utilized for anesthesia maintenance after intubation. Supplemental cisatracurium was provided for adequate muscle relaxation when needed. Volume-controlled ventilation with tidal volume of 5-8 mL/kg (5-6 mL/kg for OLV and 6-8 mL/kg for TLV),

respiratory rate (RR) of 12-15 breaths/min, FiO_2 of 0.5-0.6 and positive end-expiratory pressure (PEEP) of 5 cm H_2O was utilized to maintain an end-tidal carbon dioxide pressure ($P_{ET}CO_2$) between 35 and 45 mmHg and a peak airway pressure of less than 30 cmH_2O (specific parameter was adjusted according to the type of surgery and patient's condition). Depth of anesthesia monitoring was completed by bispectral index (BIS) with an appropriate value of 40-60. Before closing chest, each patient undergoing VATS received a recruitment maneuver (RM) by forcing sustaining inspiration at the level of 30-40 cm H_2O airway pressure for 10-20 seconds, then OLV was converted to TLV until extubation. Besides, a chest tube was connected to a water-sealed bottle to provide drainage of any leaked air or fluid. Those undergoing non-VATS did not receive RM. All patients were transported to the PACU after operation. Before extubation, the set of mechanical ventilation in the PACU was same with that in the operating room. Extubation was performed when the following criteria were met: VT > 5 mL/kg; and minimal RR of 11 breaths/min; hemodynamic stability (a maximum variation of mean arterial pressure and heart rate was 20% around the baseline value); normothermia. Neostigmine (0.02mg/kg) was used for reversal of neuromuscular blocking before extubation. After extubation, the patient inhaled oxygen through a face mask at 3-6L/min for about 15 minutes then the face masks were removed. During the next time, patients were supplemented with oxygen again through masks as temporary treatment if the SPO_2 declined to less than 92%.

Lung Ultrasound Examination

With a 2 to 5 MHz convex probe in an ultrasound device (Mindray, Guangdong, China), LUS imaging was performed by two trained anesthesiologists (Chen X, Kai S, both with more than 1 year of ultrasound learning) once hypoxemia occurred. The anterior and posterior axillary lines divided each hemithorax into three regions (anterior, lateral and posterior), each region was further divided into two quadrants (superior and inferior) (Figure 1). The anesthesiologist performed LUS examination from the left lung to the right in the above order. Atelectasis was diagnosed as a tissue-like pattern or hypoechoic juxta-pleural consolidations with hyperechoic static air bronchograms.[10] A juxta-pleural consolidations or tissue-like structure may also indicate pneumonia. However, the visualization of dynamic air-bronchogram helps exclude atelectasis.[16] With a negative predictive value of 100%, presence of lung sliding excluded the diagnosis of pneumothorax.[17] Meanwhile the diagnosis of pneumothorax should combine with the lung point, barcode sign on M mode and absence of lung sliding.[13,18-20] On this basis, the absence of pleural sliding in the anterior, lateral or posterior chest on LUS was defined as small, medium or large size of pneumothorax.[21] Presence of anechoic area fluctuating with respiration identified pleural effusion. [22] Examination of pleural effusion was performed with the patient in the semi-recumbent position. A large pleural effusion was diagnosed when the maximal interpleural distance was more than 25 mm on ultrasonography and effusion must be visible on at least three intercostal spaces. Less than 15 mm of maximal interpleural distance was defined as small effusion.[23] Combined with symptoms such as

dyspnea, a minimum of 3 B-lines in at least two anterior or lateral quadrants in each thorax may benefit for the consideration of pulmonary edema.[24]

LUS scores (0-36, calculated by adding up all the 12 individual quadrant scores) assess aeration changes and a higher grade represents more serious aeration loss but inapplicable for pneumothorax (Figure 2).[25-27] Score 0, healthy lung, equidistant A-lines parallel to the sliding pleura; score 1, moderate aeration loss, no fewer than 3 dispersive B lines originated from the pleural; score 2, serious aeration loss, presence of coalescent B lines with irregular pleural; scoring 3, absolute aeration loss, subpleural consolidation. The stored video of the worst irregularity was analyzed off-line by Chen X and Kai S. In case of disagreement, a third anesthesiologist (Lina Y, with 5 years of ultrasound learning) reviewed the uncertain images and made the final diagnosis.

Computed Tomography Scan

After LUS examination, every patient with stable hemodynamic and spontaneous respiration was transported to radiology department by a nurse anesthetist for thoracic CT scan within 1 hour after LUS examination. During transport, all patients received oxygen through face masks. Scanning from apex to diaphragm with the patient in supine position, the examination was performed with a 128-slice spiral CT device (Siemens, Amberg, Germany). With a window width of 1500 Hounsfield Units and a section thickness of 0.5 mm, all CT sections were stored for reconstruction and computerized analysis. Blinded to our study, a trained radiologist reported the CT findings by judging negative (-) or positive (+) for absence or presence of consolidation, effusion or pneumothorax in the same anatomic quadrant.

Data Collection

Demographic data including gender, age, height, weight, American Society of Anesthetist (ASA) score, BMI, vital signs and smoking habit were recorded. Medical history, pulmonary function test and physical examinations were extracted from the Electronic Medical Record. At bedside, we collected surgical information, duration of mechanical ventilation and PACU stay, time needed for LUS examination and time needed for CT scan (transportation plus CT scan plus oral report). Cumulative opioid dose (calculated by duration and weight), volume of fluid administration (sum of crystalloid and colloid) as well as blood products, arterial blood gas at the end of operation including hemoglobin, arterial partial pressure of oxygen (PaO_2), arterial partial pressure of carbon dioxide ($PaCO_2$) were also recorded.

Statistical Analysis

PASS software (version16.0) was used to calculate the sample size. Estimated the sensitivity and specificity of LUS are based on the previous study (sensitivity 87.7%, specificity 92.1%)[28], assumed the allowable error is 10% and α error of 0.05 (bilateral). The calculated sample size for sensitivity and specificity was 50 cases and 38 cases, respectively. Considering the same sample size was adopted for both LUS examination and CT scan, 100 cases were taken from each group of 50 cases. The total sample size was 110 cases when combined with a dropout rate of 10% at last. A total of 110 patients were needed with previous study and following assumptions: an α error of 0.05, a β value equal to 0.15 and a dropout rate of 10%. With after testing normality distribution, mean ± standard deviation or median (interquartile range) were used to describe continuous variables and comparison of them were performed with a paired-t test or Mann–Whitney U-test as appropriate. Categorical variables were expressed as frequency and percentage, and compared with Chi-squared test or Fisher's exact test. Spearman's correlation coefficient was used to assessed possible factors that may be associated with LUS scores. Correlation coefficient (r) values < 0.3 indicated nearly no correlation, r values between 0.3 and 0.5 indicated weak correlation, r values between 0.5 and 0.8 indicated medium correlation and r values > 0.8 indicated a high level of correlation. Cohen's kappa was used to test for agreement between the observers. Kappa equal to 0-0.20 meaning slight agreement, 0.21-0.40 indicated fair, 0.41-0.60 indicated moderate,0.61-0.80 indicated substantial while 0.81-1 showed almost perfect agreement. SPSS statistical software version 23.0 (IBM Corp, Armonk, NY, USA) was used for data statistics and analysis.

Results

From January to May 2019, 138 adult patients were evaluated for eligibility. Twenty-five patients were excluded and 113 patients were ultimately enrolled (Figure 3). During the study, all the LUS examinations and CT scans were performed successfully and a total of 1356 pairs of ultrasound cine-loops and CT images were stored for all patients. Table 1 summarized the demographic data of these enrollments.

Postoperative hypoxemia in PACU mainly occurred in patients after abdominal surgery (45 patients, 39.8%) and VATS (31 patients, 27.4%), followed by major orthopedics surgery (17 patients, 15.0%), neurosurgery (10 patients, 8.8%) and other types of surgery (10 patients, 8.8%). Eighty-two patients (72.6 %) were diagnosed with atelectasis both by CT and LUS. CT scan diagnosed 327 of 1356 quadrants as atelectasis while LUS revealed the same diagnosis in 311 of the 327 CT-diagnosed quadrants. In patients undergoing non-thoracic surgery, atelectasis was found to be in the posterior zones of both lungs while the remaining atelectasis were discovered only the in operative lung of VATS patients. Among the 82 patients with postoperative atelectasis, 19 patients showed signs of atelectasis on preoperative imageological examination already while the rest atelectasis were newly diagnosed only after surgery.

Twenty-eight patients (24.8 %) (75 quadrants) were diagnosed with pneumothorax by CT scan whereas 72 quadrants of these 75 quadrants were also diagnosed with pneumothorax with LUS. The majority of these pneumothorax patients (26 patients) were in the VATS group and they were mainly distributed in anterior and lateral quadrants. In VATS patients, 11 pneumothorax were small while fifteen were medium in size. The other two patients received partial hepatectomy surgery. The last 2 patients, one was diagnosed with small pneumothorax both by LUS and CT scan, while another one was diagnosed as medium pneumothorax and CT reported an approximate 50% tension pneumothorax.

Pleural effusion was found in 144 quadrants on CT scan in thirty-nine patients (34.5%), primarily exhibited in posterior quadrants. LUS examination detected 131 quadrants with effusion among these CT-diagnosed zones. Nineteen patients (48.7%) carried the diagnosis of pleural effusion on preoperative chest radiograph. The other twenty patients were newly diagnosed in the VATS group, all on the operative sides. One patient was diagnosed with massive pleural effusion on the left side with visible anechoic effusion in the six quadrants.

One patient was diagnosed with diffuse interstitial syndrome due to multiple B-lines in all the 12 lung quadrants and CT scan made the same conclusion. Both LUS examination and CT scan showed no abnormalities in 12 patients.

The time needed for LUS examination was significantly shorter than CT scan (10.8 ± 1.8 minutes versus 26.8 ± 4.2 minutes, $P < 0.001$). Kappa for agreement between the first two observers of atelectasis, pneumothorax and pleural effusion respectively was 0.951 ($P < 0.001$), 0.858 ($P < 0.001$) and 0.964 ($P < 0.001$). To solve the disagreement, the third reviewer mainly devoted to evaluate the diagnosis of pneumothorax. Table 2 showed the findings of LUS and CT scan for diagnosing atelectasis, pneumothorax and pleural effusion. LUS was reliable in the diagnosis of atelectasis (with a sensitivity of 98.0%, specificity of 96.7%, positive predictive value of 93.3%, negative predictive value of 99.1% and diagnostic accuracy of 97.2%), pneumothorax (with a sensitivity of 90.0%, specificity of 98.9%, positive predictive value of 96.0%, negative predictive value of 96.9% and diagnostic accuracy of 96.7%) and pleural effusion (sensitivity of 92.9%, specificity of 96.0%, positive predictive value of 91.0%, negative predictive value of 96.9% and diagnostic accuracy of 95.1%). Among the data we collected, post hoc analyses revealed no correlative factor which influences LUS scores significantly (Table 3). Postoperative typical LUS and corresponding thoracic CT images of atelectasis, pneumothorax, pleural effusion were displayed in Figure 4.

Discussion

Our study showed high accuracy of LUS in diagnosing pulmonary complications such as atelectasis, pneumothorax and pleural effusion, with a high degree of sensitivity and specificity. Consistent with previous publications in both children and adults,[29,30] bedside LUS, is reliable, portable, radiationless and fast in investigating pulmonary pathologic abnormalities. Previous publications on LUS were mostly from emergency departments and ICU, to our knowledge, this is the first study to advocate the application of LUS to investigate hypoxia in PACU. In addition, our study population included various types of surgery and patients with COPD or cardiovascular symptoms were not excluded. This may better reflect the real world experience. Since postoperative thoracic CT is not routinely in clinical practice, LUS in the PACU may help differentiate unexpected respiratory pathologies. Probably, our study could provide clinical significance for timely and appropriate treatment of postoperative hypoxemia in future.

Hypoxemia is primary triggered by atelectasis from compression, gas absorption and loss -of-surfactant.[31] Postoperative atelectasis was associated with pneumonia and could result in delayed discharge.[32] Early detection and treatment of atelectasis was essential for improving prognosis. Due to the advantages like simple, convenient, time-consuming and non-radiation, LUS can be repeated at the bedside. It has been confirmed the sensitivity and specificity of the diagnosis of atelectasis by lung pulse in ultrasound were 93% and 100%, respectively.[33,34] When compared with Magnetic Resonance Imaging (MRI), LUS showed a sensitivity of 88%, specificity of 89% and accuracy of 88% in diagnosing pulmonary atelectasis.[10] LUS demonstrated excellent diagnostic accuracy (97.2%) in our study, higher than reported (90.7%) by Yu X et al.[28] In Yu's study, only patients undergoing elective intracranial surgery and without pre-operative pulmonary comorbidities were enrolled, whereas our study included a heterogeneous patient population for diversity. To eliminate the interference of adipose layer in the ultrasonic image, obese patients (BMI > 40 kg/m^2) were excluded. Considering the safety of patients transferring to CT scan, those with hemodynamic instability were also exclude. Though hypoxemia were more likely occurred in these patients, but the whole study only excluded 3 relevant patients (Fig. 3) and it exert almost no effect on the result. The incidence of atelectasis 72.6% in our study was lower than previous reported 90%[35] which partly was due to routine recruitment maneuvers at the end of VATS group. Though lung-protective strategies such as low TV, a lower FiO_2, higher RR RM and PEEP has been reported to decreased postoperative respiratory complications significantly[36–38] and applied in our anesthesia protocol. However, atelectasis is still occurred frequently in our study. PEEP has been reported as a successful method for improving oxygenation and respiratory function during general anesthesia but the optimal level is still inconclusive.[39–41] Though a PEEP of 5 cmH_2O in our study has referred to previous study, but a higher PEEP may be much more beneficial for reducing atelectasis formation as it had been recommend by some researchers.[42] RM combined with PEEP were also beneficial for reducing atelectrauma[43] but it was only performed in OLV in our study. This may explain the high occurrence of atelectasis in non-VATS group. Till now the optimal systematization of RM remains a matter of debate as findings identified a potential danger of excessive RM during OLV toward increased mortality.[44] Under perioperative ultrasound-guided recruitment maneuvers and moderate PEEP, incidence of atelectasis and postoperative hypoxemia decreased in both infants and pediatric cardiac patients.[42,45,46] To detect the

effects of different levels of PEEP and RM to postoperative pulmonary complications by lung ultrasound still need more researches.

Similar to Xirouchaki et al' s findings, our study showed LUS was effective in the diagnosis of pneumothorax.[47] Absence of lung sliding or B-line to diagnose pneumothorax by LUS has sensitivity of 88–100%.[48,49] Our study further confirmed the 90% sensitivity to diagnose pneumothroax with LUS. Because thorax was opened for VATS, the pneumothorax was deemed as residual gas. Patella et al. demonstrated that LUS could also effectively and accurately evaluate the small amount of pneumothorax remaining after thoracic drainage, which was faster and more accurate than CXR.[48,50]. Shumbusho's study had suggested LUS may be alternative to CXR for the follow-up of pneumothorax after tube thoracostomy due to it's superior sensitivity and portability.[51] Wei et al advocated the use of daily LUS in the postoperative period to enhance recovery after thoracic surgery [52]. Similar with prior publications,[53–55] we demonstrated that LUS was sensitive and specific to diagnose pleural effusion with added benefits of convenience and safety. Compared with traditional methods, placing the thorax tube for fluid drainage under ultrasound guidance is safer and more effective, and can reduce the incidence of pneumothorax.[56] The severity of hypoxemia depended on effusion size and patient's cardiopulmonary condition, while prompt diagnosis of pleural effusion is vital to evaluate the optimal therapeutic choice. Effusion drainage ultrasound guidance would relieve compression atelectasis of the adjacent lung and improve respiratory mechanics and oxygenation.

Although LUS is an operator-dependent skill and adequate training is needed for effective clinical usage, but it can be readily learnt with a very simple device. See et al had confirmed that after only 3 h of lung ultrasound self-study and an average of 15 patients scan, accuracy of diagnosis in trainees with no prior ultrasound experience would achieve 95.4% while the medial scanning duration was only 12 min.[57] In Zhan' s study, the implementer was a pediatric resident with no expert supervision and minimal practical ultrasound experience but could also complete LUS examination accurately.[11] Compared to experts, inexperienced resident physicians in emergency medicine with 30 min LUS learning can effective identify B-lines with more than 80% sensitivity and specificity.[58] After brief training, surgical residents or medical students could also perform LUS well and interpret accurately.[51,59] To improve diagnostic reliability, the ultrasound were performed and evaluated by two researchers with long-term training in our study. The result showed high agreement in the two observers while the disagreement mainly in pneumothorax probably because diagnosis of pneumothorax by ultrasound should base on multiple signs.

There are several limitations of our study. First, the 1 h time interval between LUS examination and CT scan and the suction impact of water seal bottle may create false-positive results, while the obstruction of ultrasound views by the scapula and ribs could introduce false-negative results. Second, the presence of consolidation on LUS alone was insufficient for diagnose pneumonia[60]. In recent study by Zhou et al.,[61] the combination of LUS and procalcitonin had a better diagnostic value for pneumonia. Timely diagnosis of suspected aspiration pneumonia by LUS intraoperatively may beneficial for patients but still need more researches in our future work. Last, patients undergoing cardiac surgery were not included

whose atelectasis and hypoxemia were more prominent after cardiopulmonary bypass than other surgery.

Conclusions

In conclusion, we showed that application of LUS to diagnose etiologies of hypoxemia in the PACU is feasible and prompt. LUS was sensitive and specific to diagnose pulmonary complications when compared to thoracic CT scan.

Abbreviations

abbreviations	full name
CRX	chest x-rays
CT	computed tomography
LUS	lung ultrasound
PACU	postanesthesia care unit
SPO_2	pulse oximetry
BMI	body mass index
TOF	train of four stimulation
ICU	intensive care unit
FiO_2	inspiration oxygen fraction
OLV	one-lung ventilation
VATS	video-assisted thoracoscopic surgery
TLV	two-lung ventilation
RR	respiratory rate
PEEP	· positive end-expiratory pressure
$P_{ET}CO_2$	end-tidal carbon dioxide pressure
BIS	bispectral index
RM	recruitment maneuver
ASA	American Society of Anesthetist
PaO_2	arterial partial pressure of oxygen
$PaCO_2$	arterial partial pressure of carbon dioxide
MRI	Magnetic Resonance Imaging

Declarations

Ethics approval and consent to participate: The study was approved by the review committee of Second Affiliated Hospital of Zhejiang University (IR2018001133, 2018/12/05) and registered at ClinicalTrials.gov (NCT03802175) before patient enrollment. Informed consents were obtained from all patients.

Consent for publication: Not applicable

Availability of data and materials: The datasets generated and/or analysed during the current study are not publicly available due to the manuscript has not been received yet but are available from the corresponding author on reasonable request.

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Authors' contributions

Name: CX, **Contribution:** made substantial contributions to the conception and design of the work; the acquisition, analysis, interpretation of data; drafted the work and substantively revised it

Name: KS, **Contribution:** made substantial contributions to the conception and design of the work; the acquisition, analysis, interpretation of data; the creation of new software used in the work; drafted the work

Name: YY, **Contribution:** made substantial contributions to the conception and design of the work; the acquisition, analysis, interpretation of data; the creation of new software used in the work;

Name: YM, **Contribution:** made substantial contributions to the conception and design of the work; the acquisition, analysis, interpretation of data

Name: XY, **Contribution:** made substantial contributions to the conception and design of the work

Name: LY, **Contribution:** made substantial contributions to the conception and design of the work; the creation of new software used in the work

Name: JH, **Contribution:** the acquisition, analysis, interpretation of data; the creation of new software used in the work; drafted the work and substantively revised it

Name: MY, **Contribution:** made substantial contributions to the conception and design of the work; drafted the work and substantively revised it

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Our study adheres to CONSORT guidelines and we have provided the CONSORT checklist in the supplementary information.

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Tables

Table1. Patients Characteristics (N=113)

Variables	Mean (SD) / median (IQR)
Age(y)	60.1 (12.0)
Sex, M/F(N)	61/52
Height (cm)	164.0 (7.5)
Weight (cm)	66.1 (10.8)
BMI (kg/m^2)	24.5 (3.3)
ASA, 1/2/3 (N)	7/96/10
SPO_2(%)	90.0 (89.0, 91.0)
Duration of mechanical ventilation (min)	220.0 (162.5, 285.0)
Total infusion (mL)	1500.0 (1000.0, 1500.0)
Duration of PACU stay (min)	105.0 (85.0, 137.5)
LUS score	13.0 (11.0,16.0)
Smoking status, N (%)	
Current	10 (8.8)
Previous	11 (9.7)
Never	92 (81.4)
Type of surgery, N (%)	
Neurosurgery	10 (8.8)
Thoracoscopic surgery	31 (27.4)
Abdominal surgery	45 (39.8)
Major orthopedics surgery	17 (15.0)
Others	10 (8.8)

Data were described as mean ± standard deviation or median and inter-quartile range as appropriate.

LUS score was described in patients without pneumothorax(N=85).

Abbreviations: SD, standard deviation; IQR, inter-quartile range; M, male; F, female; BMI, Body Mass Index; ASA, American Society of Anesthesiologists classification; SPO_2, oxygen saturation measured by pulse oximetry; PACU, postanesthesia care unit; LUS, lung ultrasound

Table 2a. Agreement between LUS and CT for atelectasis diagnosis

	LUS		
CT	+	-	Total
+	305	22	327
-	6	651	657
Total	311	673	984

Table 2b. Agreement between LUS and CT for pneumothorax diagnosis

	LUS		
CT	+	-	Total
+	72	3	75
-	8	253	261
Total	80	256	336

Table 2c. Agreement between LUS and CT for pleural effusion diagnosis

	LUS		
CT	+	-	Total
+	131	13	144
-	10	314	324
Total	141	327	468

Table2. Agreement between LUS and CT of pulmonary complications for accumulated quadrants

Table 3. Correlation between possible factors and lung ultrasound scores (N=85)

Variables	Correlation Coefficient (r)	*P*
Sex (M/F)	0.229	0.035
Age (y)	-0.041	0.707
BMI (kg/m^2)	-0.127	0.246
SPO_2 (%)	-0.244	0.024
Smoking	-0.039	0.725
Duration of mechanical ventilation (min)	-0.127	0.245
Type of surgery	0.075	0.494
Sufentanil dose (ug/kg/h)	0.125	0.253
Total infusion (mL)	0.046	0.677
Transfusion (Y/N)	-0.156	0.155

Lung ultrasound score was recorded and analyzed in patients without pneumothorax.

Abbreviations: LUS, lung ultrasound; M, male; F, female; BMI, Body Mass Index; SPO_2, oxygen saturation measured by pulse oximetry.

Figures

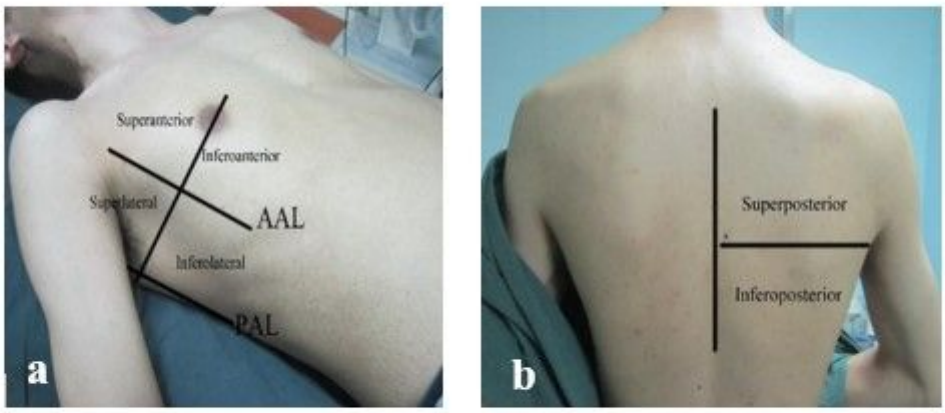

Figure 1

Hemithorax partition during lung ultrasound examination. (a, b) Each hemithorax was divided into 6 quadrants by anterior and posterior axillary lines. Abbreviations: AAL, anterior axillary line; PAL, posterior axillary line.

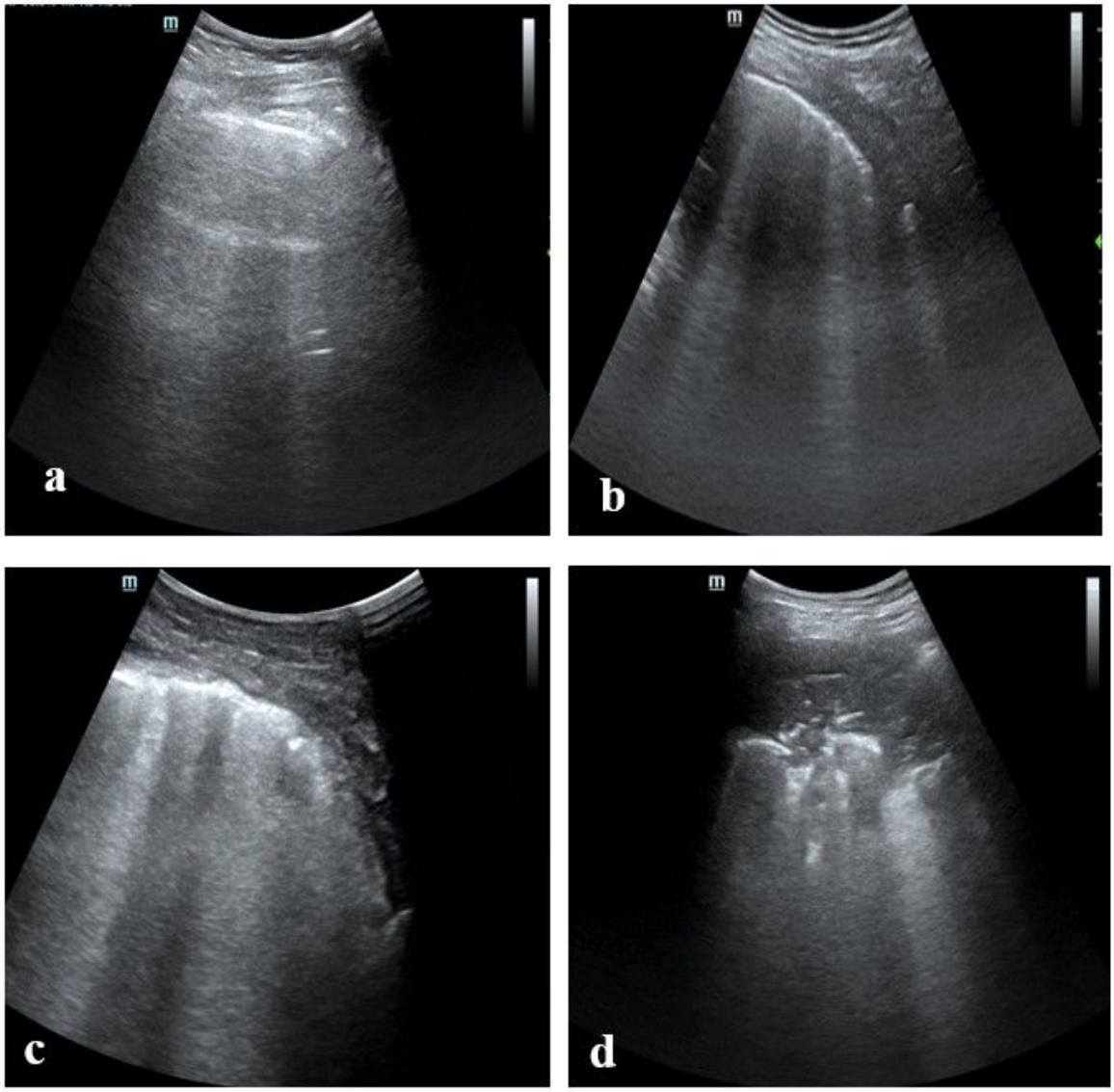

Figure 2

Lung ultrasound signs with different scores. (a), score 0, healthy lung, equidistant A-lines parallel to the sliding pleura; (b), score 1, moderate aeration loss, no fewer than 3 dispersive B lines originated from the pleural; (c), score 2, serious aeration loss, presence of coalescent B lines with irregular pleural; (d), score 3, absolute aeration loss, subpleural consolidation.

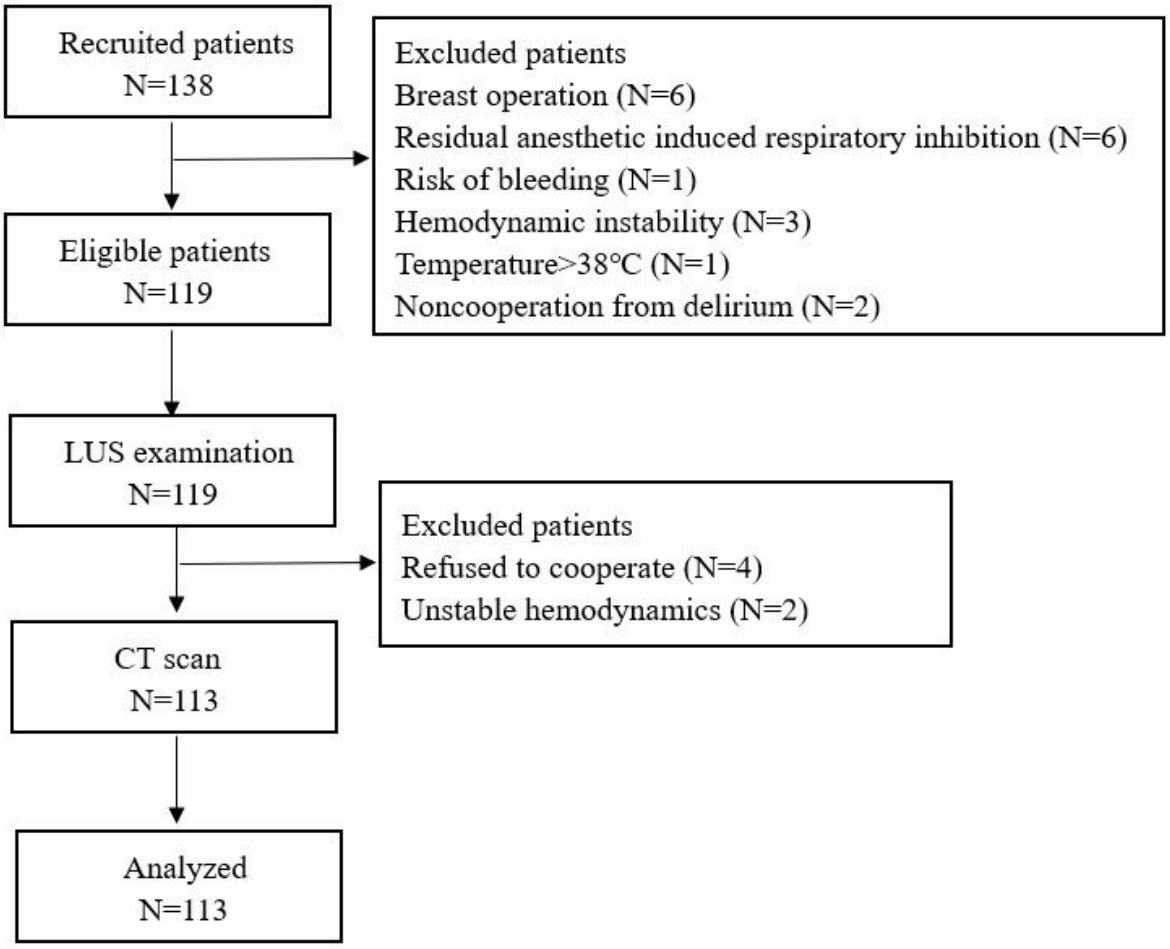

Figure 3

Flowchart of patient participants. Abbreviations: LUS, lung ultrasound; CT, computed tomography

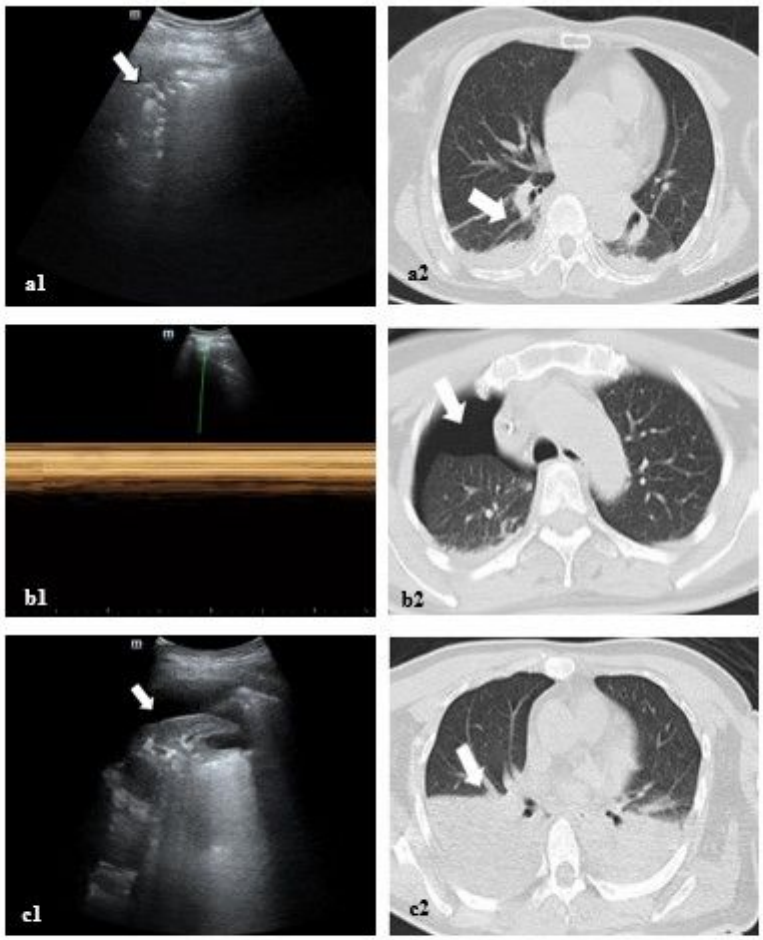

Figure 4

Typical pulmonary pathologies in both LUS and thoracic CT in the same regions. (a1), Typical LUS signs of atelectasis in the dorsal quadrant of the lung presented as tissue-like patterns (left, white arrow), (a2) CT signs of corresponding regions presented as a crescent shape (right, white arrow). (b1) Typical LUS on M-mode of pneumothorax in the anterior quadrant of the lung presented as bar code sign, (b1) CT signs of corresponding regions presented as very low density gas window (right, white arrow). (c1) Typical LUS of pleural effusion in the dorsal quadrant of the lung presented as anechoic area (left, white arrow), (c2) CT signs of corresponding regions presented as a half moon (right, white arrow). Abbreviations: LUS, lung ultrasound; CT, computed tomography

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