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ORIGINAL RESEARCH

Prediction of Postoperative Pulmonary Complications in Geriatric Patients with Hip Fracture Using Lung Ultrasonography Score and Diaphragmatic Mobility

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Purpose: Postoperative pulmonary complications (PPCs), common in geriatric patients with hip fractures, are associated with increased morbidity and mortality rates. Bedside ultrasonography may improve perioperative pulmonary risk stratification. This study aimed to evaluate the predictive value of the lung ultrasonography score (LUS) and diaphragmatic mobility (DM) for PPCs and identify the optimal index.

Patients and Methods: This prospective observational study included 192 geriatric patients with hip fractures who underwent surgery. One day preoperatively, LUS and DM were assessed at bedside. All patients received general anesthesia combined with a regional block and were followed up for 30 days postoperatively for the occurrence of PPCs. Receiver operating characteristic (ROC) curve analysis and multivariate logistic regression were used to evaluate predictive performance and adjust for confounders.

Results: PPCs occurred in 28.64% (55/192) of the patients. LUS and DM exhibited moderate predictive efficacies for PPCs (LUS: AUC = 0.740, 95% CI: 0.653–0.826; DM: AUC = 0.733, 95% CI: 0.655–0.812). At a cutoff value of LUS > 5 cm, the negative predictive value reached 81.9%, and at a cutoff value of DM < 3.7 cm, the negative predictive value reached 87.6%. After multivariable adjustment, a LUS> 5 and DM < 3.7 cm remained independent predictors of PPCs (LUS > 5: adjusted OR = 6.363, 95% CI: 2.609–15.515; $P < 0.001$; DM < 3.7 cm: adjusted OR = 5.011, 95% CI: 2.106–11.923; $P < 0.001$). Integration of LUS (LUS > 5) and DM (DM < 3.7 cm) with ARISCAT significantly improved predictive performance (AUC = 0.851 with the integrated model vs. 0.684 with ARISCAT alone; DeLong's $P < 0.001$).

Conclusion: LUS and DM effectively predicted PPCs in geriatric patients with hip fractures. The integration of LUS and DM with ARISCAT markedly enhances predictive accuracy, suggesting that lung and diaphragmatic ultrasound may serve as useful bedside tools for perioperative respiratory risk assessment.

Keywords: postoperative pulmonary complications, geriatric patients, hip fracture, ultrasonography

Introduction

As life expectancy increases worldwide, so does the morbidity of geriatric hip fractures.[1] Postoperative pulmonary complications (PPCs) are common in geriatric patients undergoing hip fracture surgery, with a reported incidence of 33.3% (168/504).[2] PPCs are associated with prolonged postoperative tracheal intubation, increased healthcare costs, and higher mortality.[3] Identifying risk factors for PPCs in geriatric patients with hip fractures is essential to improve perioperative prevention and management strategies.

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Although the ARISCAT, which is widely used to predict PPCs, and the Activities of Daily Living (ADL) scale, which is applied to predict postoperative mortality, both demonstrate good predictive value, these scoring systems lack specific assessments of pulmonary conditions and respiratory mechanics parameters.[4–6] Pulmonary abnormalities and impaired pulmonary function are associated with the development of PPCs.[7,8] Lung ultrasound enables quantitative assessment of pulmonary conditions using the lung ultrasound score (LUS).[9,10] Diaphragmatic mobility (DM), which is associated with changes in pulmonary function, can be measured using diaphragmatic ultrasound.[11] Furthermore, bedside ultrasonography features the advantages of rapid operation, repeatability, radiation-free examination, and non-invasiveness. Currently, studies on the value of bedside ultrasonography in PPCs remain relatively limited. Therefore, we hypothesized that integrating LUS and DM, measured by bedside ultrasound, into a predictive model would enhance risk stratification for PPCs in geriatric patients with hip fractures.

Therefore, we conducted an observational study of 192 geriatric patients with hip fractures who underwent surgical treatment at a tertiary orthopedic hospital in China to identify the optimal LUS and DM parameters for predicting PPCs and evaluate their predictive performance.

Materials and Methods

Study Design

This single-center prospective observational study was conducted at HongHui Hospital, Xi'an JiaoTong University (Xi'an, China). The study protocol was approved by the Institutional Review Board. The trial was designed in accordance with the principles of the Declaration of Helsinki and was registered in the Chinese Clinical Trial Registry (ChiCTR2500102101). Written informed consent was obtained from patients with normal communication capacity. For those with Alzheimer's disease, hearing or reading impairments, consent was obtained from their legally authorized representatives.

Participants

Inclusion criteria were age >65 years, hospital admission for hip fracture, and scheduled surgical management. Exclusion criteria comprised multiple fractures; acetabular, periprosthetic, or pathological hip fracture; perioperative cardiovascular or cerebrovascular accidents; unplanned surgery or discharge during follow-up; and refusal to participate.

Measurement Technique

Bedside ultrasonography, including lung and diaphragmatic assessment, was performed by two experienced ultrasonologists who were blinded to the study objectives. Examinations were conducted prior to the surgery using a convex transducer. Twelve anatomical regions were defined on the chest wall (Figure 1). Each region was scored according to predefined criteria (Figure 2), and the cumulative score of the 12 regions was defined as the lung ultrasonography score.

Diaphragmatic mobility was assigned a curved array probe positioned in the subcostal region between the mid-clavicular and anterior axillary line (Figure 3). Participants were instructed to perform maximal exhale followed by maximal inhalation. The distance between the highest and lowest points of the diaphragm was measured (Figure 4), and the mean of bilateral measurements was calculated as diaphragmatic mobility.

Anesthesia Protocol

General anaesthesia combined with a fascia iliaca block was administered to all patients. Anaesthesia was induced with midazolam 0.1 mg kg^{-1}, sufentanil 0.25 μg kg^{-1}, propofol 1.5–2.0 mg kg^{-1}, and rocuronium 0.6 mg kg^{-1}. Anaesthesia was maintained with remifentanil 0.1–0.2 μg $kg^{-1}\cdot min^{-1}$ and sevoflurane 1.0–1.5%, targeting a bispectral index of 40–60. Fascia iliaca block was performed using 30–40 mL of 0.25% ropivacaine. Neuromuscular blockade was continuously monitored, and residual blockade was reversed with neostigmine.

Volume-controlled ventilation was used throughout surgery. Tidal volume was set at 6–8 mL kg^{-1} predicted body weight, with PEEP of 6–8 cm H_2O. The inspiratory-to-expiratory ratio was 1:2, and the respiratory rate was adjusted to maintain end-tidal carbon dioxide at 35–40 mm Hg. The fraction of inspired oxygen was maintained below 0.5. In case of SpO2 <95%, rescue therapy, including increased inspired oxygen and recruitment manoeuvres, was initiated immediately.

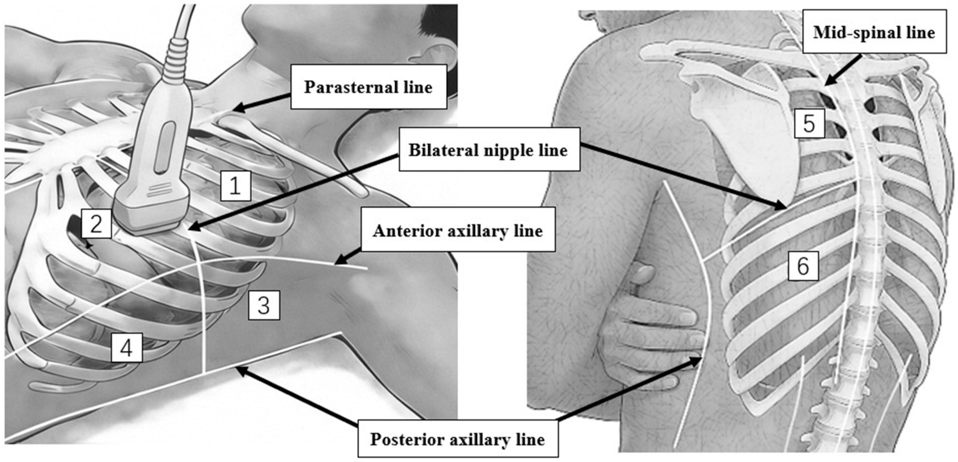

Figure 1 Chest wall regions assessed by ultrasonography. Schematic representation of chest wall regions evaluated during ultrasonographic examination. Based on anatomical landmarks defined by the parasternal, anterior axillary, posterior axillary, and mid-spinal lines, each hemithorax is divided into anterior, lateral, and posterior regions. Each region is further subdivided into superior and inferior subregions by the bilateral nipple line. 1: Anterior superior; 2: Anterior inferior; 3: Lateral superior; 4: Lateral inferior; 5: Posterior superior; 6: Posterior inferior.

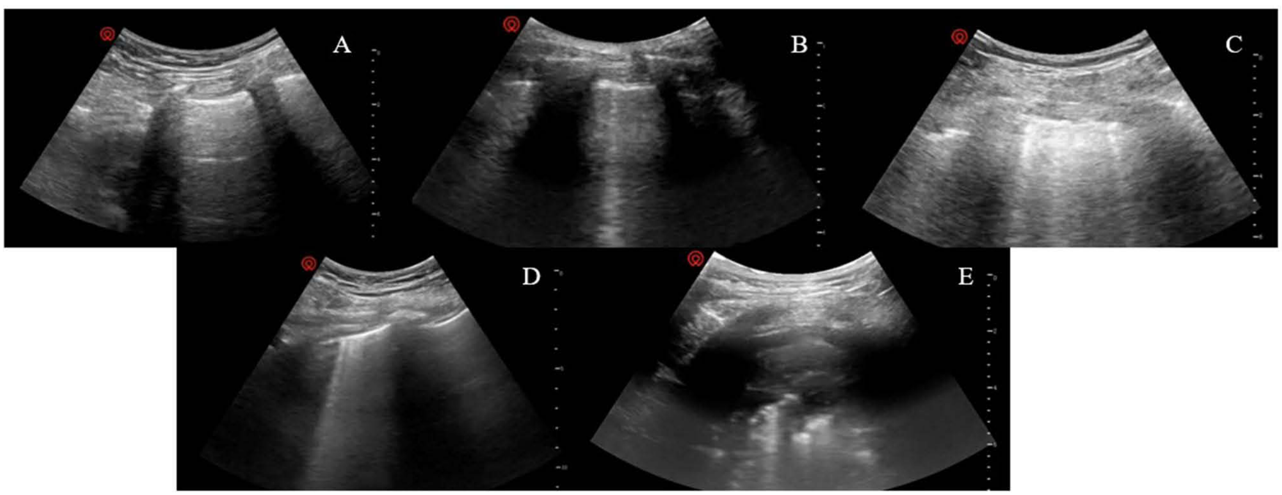

Figure 2 Lung ultrasound scoring criteria. The lung ultrasound scoring system is used for regional assessment. (**A**) score 0, only A-lines visible; (**B**) score 0, ≤ 2 B-lines; (**C**) score 1, ≥ 3 well-spaced B-lines; (**D**) score 2, coalescent B-lines; (**E**) score 3, tissue-like pattern. The final score assigned to each region corresponds to the highest score observed within that region.

Before induction of anaesthesia, lactated Ringer's solution was administered intravenously at 5 mL kg^{-1}, followed by continuous infusion at 5 mL kg^{-1} h^{-1}. Haemodynamic management was guided by a continuous non-invasive arterial pressure system. Boluses of 3 mL kg^{-1} lactated Ringer's solution were administered every 15 min to maintain pulse pressure variation (PPV) ≤14%. Additional boluses were given if PPV remained >14% for ≥5 min or stroke volume increased by >10%, until PPV ≤14% was achieved. If mean arterial pressure (MAP) remained <60 mm Hg despite fluid optimisation or if MAP <60 mmHg was accompanied by PPV ≤14% and SV increase <10%, vasopressor therapy was initiated with ephedrine 6 mg intravenously (maximum cumulative dose 30 mg). If required, norepinephrine was continuously infused at 0.05 µg kg^{-1} min^{-1}.

Data Collection

Data on the following patient-related risk factors were collected: age, sex, height, weight, American Society of Anesthesiologists (ASA) physical status class, smoking status (within two months before surgery), chronic obstructive pulmonary disease (COPD), stroke, diabetes, heart failure, recent respiratory infection (within one month before surgery), and preoperative hypoxemia (SpO_2 ≤ 90% or partial pressure of arterial oxygen < 60 mmHg on room air); results of

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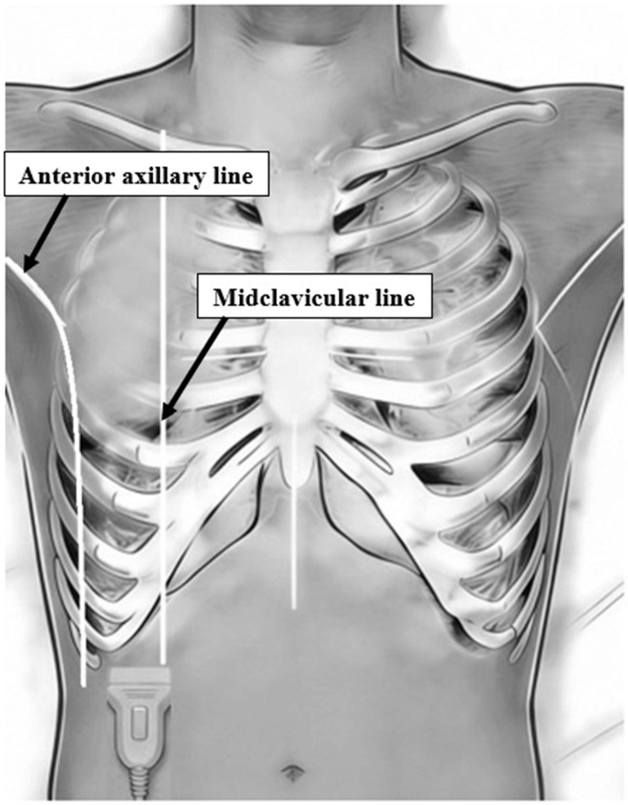

Figure 3 Probe placement for assessment of diaphragmatic mobility. Schematic diagram illustrating the positioning of the curved array ultrasound probe for diaphragmatic mobility assessment. The probe was placed in the subcostal region between the midclavicular and anterior axillary lines to visualise diaphragmatic excursion during respiration.

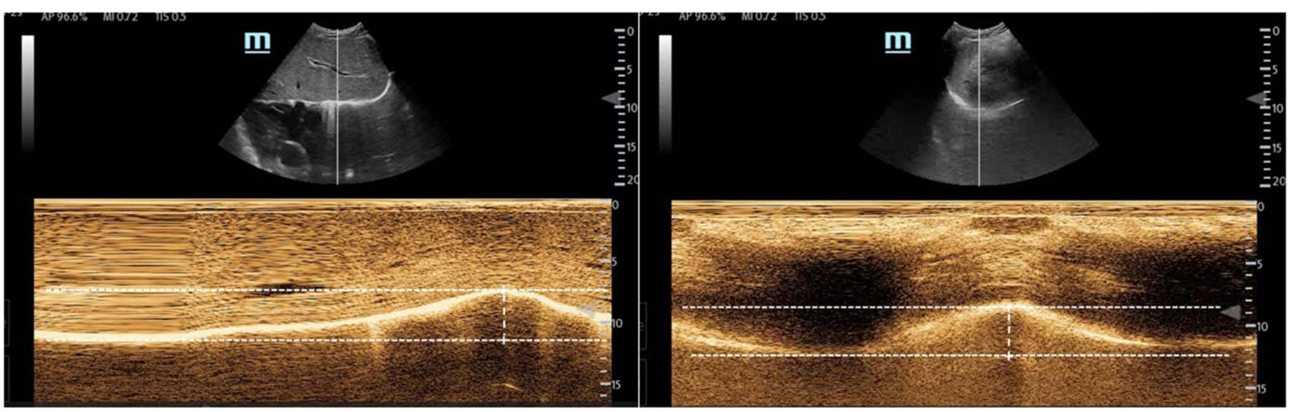

Figure 4 Measurement of diaphragmatic mobility. Representative ultrasound image showing diaphragmatic excursion. Diaphragmatic mobility is defined as the distance (mm) between the highest and lowest positions of the diaphragm on the ultrasound image.

ultrasonography: LUS and DM; procedure-related risk factors: surgical type and duration, intravenous fluid volume, and perioperative blood transfusion volume; and laboratory parameters included serum creatinine, hemoglobin, and serum albumin levels.[12–14]

All participants were followed for 30 days post-surgery for PPC occurrence, as defined by the European Perioperative Clinical Outcome Guidelines.

Potential Sources of Bias and Control Measures

Potential sources of selection bias include non-randomized enrollment and selective inclusion, which may lead to a non-representative study population. This was addressed by consecutive enrollment of all eligible patients. Measurement bias may arise from inconsistencies in ultrasound performance and interpretation among investigators, and to address this, the agreement between measurements performed by the two sonographers was evaluated prior to study initiation (Supplementary material). Information bias could result from incomplete baseline data collection and inaccurate follow-up outcome recording, which was mitigated by double-checking all the data and having two independent clinicians jointly diagnose PPCs to avoid misdiagnosis and under diagnosis. Confounding bias may be introduced by factors such as age, sex, COPD, and operative duration, potentially contributing to spurious associations between ultrasound indicators and PPCs, which was controlled by collecting detailed baseline data and adjusting for confounding variables in a multivariate logistic regression model.

Sample Size Calculation

The sample size was estimated based on the hypothesis that the expected area under the receiver operating characteristic curve (AUC) for LUS and DM in predicting PPCs would exceed 0.65.

Previous evidence indicates an incidence of PPCs of 33.3% in geriatric patients with hip fractures.[2] Using PASS software, a two-sided test with a significance level of $\alpha = 0.05$ and 90% power ($\beta = 0.10$) indicated that 174 participants would be required. The sample size was increased from 174 to 209 to account for a potential 20% nonresponse rate.

Statistical Analysis

Statistical analyses were conducted using SPSS software. Categorical variables were analyzed using the chi-squared test or Fisher's exact test. Independent sample *t*-tests were used for normally distributed continuous variables, whereas the Mann–Whitney *U*-test was used for non-normally distributed variables.

Univariate logistic regression analysis was performed to assess the association between preoperative LUS and DM and the development of PPCs. Further analysis was performed using receiver operating characteristic (ROC) curves to determine predictive performance. The optimal cutoff values for significant LUS and DM were identified by maximizing the Youden index, and the resulting sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated.

Univariate logistic regression was used to screen for potential risk factors of PPCs. Candidate predictors included variables ($P < 0.05$) in the univariate analysis and the individual components of the ARISCAT. Subsequently, a multivariable logistic regression model was constructed using the enter method to evaluate the independent predictive value of LUS and DM, while adjusting for confounders (variable selection combined univariate and multivariate stepwise regression; Forward LR avoided multicollinearity, and confounders were adjusted via multivariate analyses).

LUS, DM, and ARISCAT were integrated to establish a combined predictive model. The predictive performance of this combined model was compared with that of the standalone ARISCAT model. Multivariable logistic regression models (enter method) were used to estimate odds ratios (ORs) and their 95% confidence intervals (CIs) for both models. The DeLong method was used to assess differences in the area under the curve (AUC) and to compare model discrimination.

Statistical analysis of this study was performed by professional statisticians. The statisticians remained blinded to participant information and clinical outcomes throughout the analysis process.

Results

Between May 2025 and November 2025, 209 patients were enrolled, 192 of whom were included in the final analysis (Figure 5). PPCs occurred in 28.64% (55/192) of the patients. Specifically, 23.64% (13/55) patients presented with respiratory infection, 20.00% (11/55) with respiratory failure, 5.45% (3/55) with pleural effusion, 18.18% (10/55) with atelectasis, 1.82% (1/55) with pneumothorax, 3.64% (2/55) with bronchospasm, and 27.27% (15/55) with multiple PPCs

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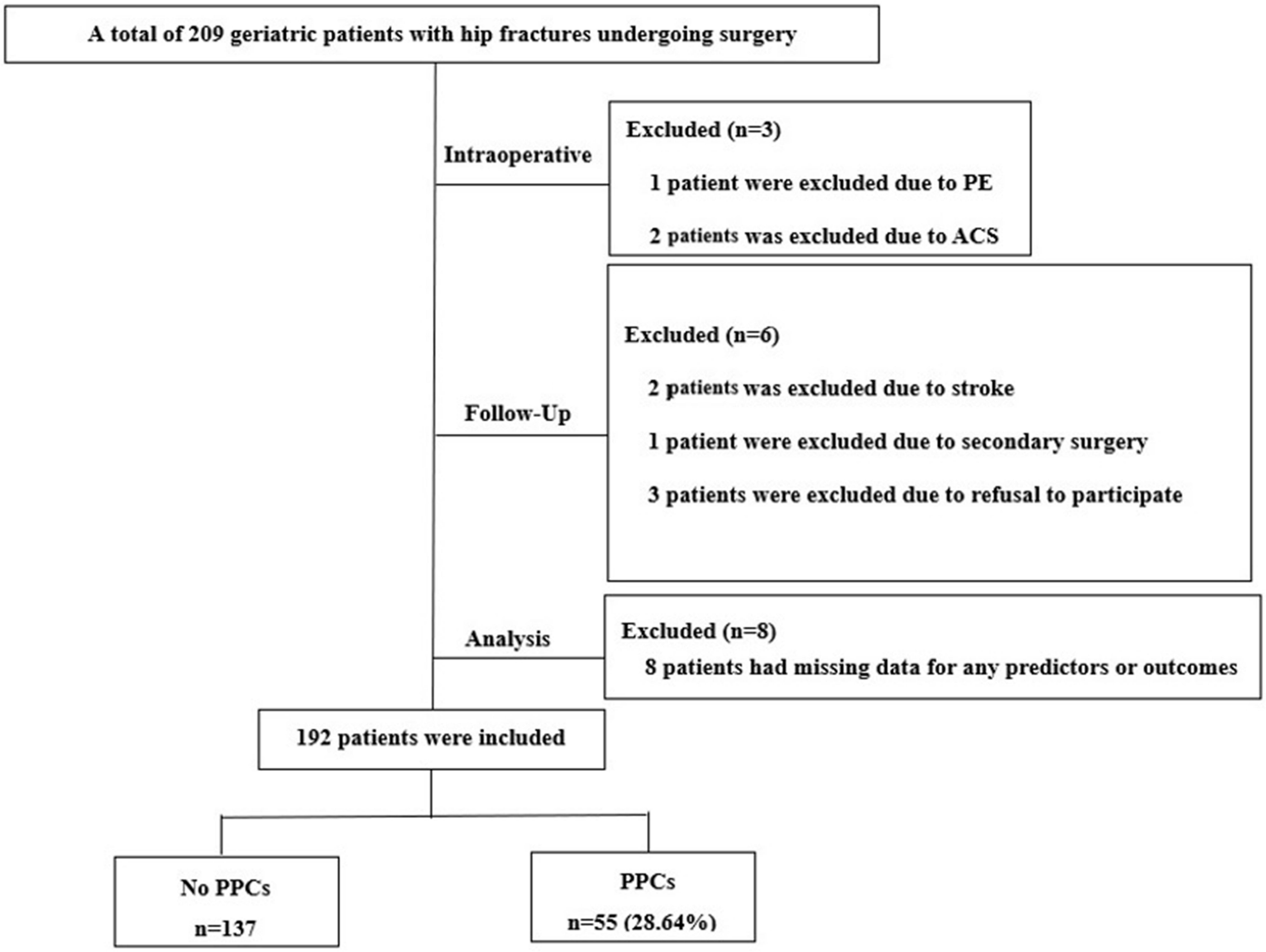

Figure 5 Study flowchart. PE, pulmonary embolism; ACS, acute coronary syndrome; PPCs, postoperative pulmonary complications.

(two or more PPCs mentioned above). The postoperative length of hospital stay, the incidence of unexpected ICU admission, and the mortality rate were significantly higher among patients with respiratory infections and multiple PPCs (Table 1).

The clinical and perioperative characteristics, stratified by PPC development, are presented in Table 2. Univariate analyses demonstrated that a higher LUS (OR = 1.344, 95% CI: 1.212–1.490; $P < 0.001$) and decreased DM (OR = 0.561, 95% CI: 0.433–0.726; $P < 0.001$) were both significantly associated with an elevated risk of developing PPCs (Figure 6). ROC analysis demonstrated that the AUC was 0.740 for LUS (95% CI: 0.653–0.826; $P < 0.001$) and 0.733 for DM (95%

Table 1 Postoperative Length of Hospital Stay, ICU Admission, and Mortality According to the Type of PPCs

	No-PPCs	Respiratory Infection	Respiratory Failure	Pleural Effusion	Atelectasis	Pneumothorax	Bronchospasm	Multiple PPCs
Number	137	13	11	3	10	1	2	15
Postoperative length of hospital stay, days median (IQR)	3.0 (2.0, 6.0)	14.0 (6.0, 20.0)	7.0 (4.0, 11.0)	7.0 (5.0, 12.0)	3.0 (3.0, 7.0)	7.0 (5.0, 10.0)	5.0 (4.0, 7.0)	17.0 (11.0, 21.0)
ICU admission n (%)	4 (2.91%)	3 (20.07%)	1 (9.09%)	0	0	1	0	3 (20.00%)
30-day mortality n (%)	1 (0.72%)	1 (7.69%)	0	0	0	0	0	1 (6.66%)

Abbreviations: PPCs, postoperative pulmonary complications; ICU, Intensive Care Unit.

Table 2 Clinical and Perioperative Characteristics of Patients Stratified by Postoperative Pulmonary Complications (PPCs)

Variables	PPCs	Non- PPCS	Overall	P
Number	55	137	192	
Age, years, mean ± SD	79.56 ± 5.61	77.75 ± 5.33	78.27 ± 5.45	0.038*
Sex, n				0.869
Women	24	58	82	
Men	31	79	110	
BMI, kg·m^{-2}, mean ± SD	23.52 ± 3.81	22.35 ± 3.88	22.69 ± 3.89	0.060
ASA physical status class, n				0.008*
≤ II	27	95	70	
≥ III	28	42	122	
Stroke[a], n				0.779
No	44	112	156	
Yes	11	25	36	
COPD[b], n				0.045*
No	32	100	132	
Yes	23	37	60	
Heart failure[c], n				0.000*
No	36	121	157	
Yes	19	16	35	
Diabetes, n				0.304
No	49	114	163	
Yes	6	23	29	
Smoking status, n				0.028*
No	34	106	140	
Yes	21	31	52	
Time from injury to surgery, n				0.010*
≤ 48 h	37	115	152	
> 48 h	18	22	40	
Lung ultrasonography score, median (IQR)	6.0 (1.0, 9.0)	1.0 (0.0, 4.0)	2.0 (0, 6.0)	0.000*
Diaphragmatic mobility, cm, median (IQR)	3.2 (2.5, 3.2)	5.3 (3.2, 5.4)	3.2 (3.2, 5.3)	0.000*
Recent respiratory infection, n				0.008*
No	33	108	141	
Yes	22	29	51	

(*Continued*)

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Table 2 (Continued).

Variables	PPCs	Non- PPCS	Overall	P
Preoperative hypoxemia, n				0.019*
No	40	119	159	
Yes	15	18	33	
Hypoalbuminemia (serum albumin < 35 g L^{-1}), n				0.003*
No	24	112	146	
Yes	21	25	46	
Anemia (Hb ≤ 10 g dL^{-1}), n				0.014*
No	39	118	157	
Yes	16	19	35	
Elevated serum creatinine (serum creatinine > 1.3 mg dL^{-1}), n				0.108
No	48	129	177	
Yes	7	8	15	
Operation type, n				0.745
PFNA	17	35	52	
Hip Arthroplasty	47	93	140	
Duration of surgical, min, mean ± SD	120.51 ± 31.64	131.56 ± 29.41	123.68 ± 31.35	0.027*
Intravenous fluid volumes, mL·kg^{-1}·h^{-1}, mean ± SD	7.50 ± 0.80	7.51 ± 0.81	7.50 ± 0.88	0.888

Notes: [a]Stroke includes fresh and delayed cerebral ischemia and hemorrhage in computed tomography or magnetic resonance imaging. [bc]COPD and heart failure were diagnosed by a pulmonologist and a cardiologist, respectively. *Significance at p-value < 0.05.
Abbreviations: PPCs, postoperative pulmonary complications; BMI, body mass index; ASA, American Society of Anesthesiologists; COPD, chronic obstructive pulmonary disease; PFNA, proximal femoral nail antirotation.

CI: 0.655–0.812; P < 0.001) (Figure 7). The complete diagnostic performance parameters, including sensitivity, specificity, PPV, and NPV, are presented in Table 3.

The optimal cutoff values for LUS and DM were 5 and 3.7 cm, respectively. Patients with LUS > 5 had a significantly higher incidence of PPCs than those with LUS ≤ 5 (60.41% [29/48] vs 18.05% [26/144]; P < 0.001). Similarly, patients

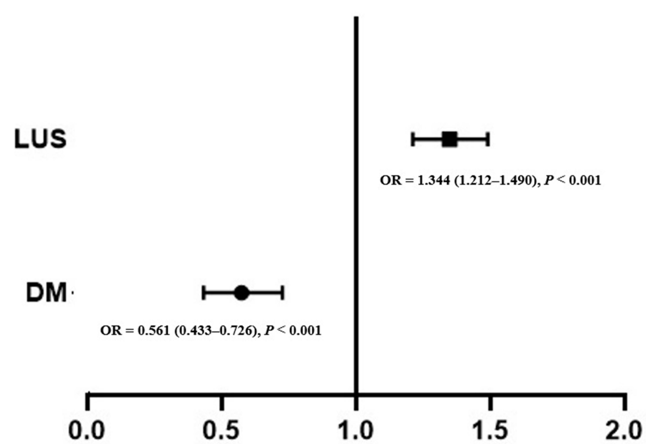

Figure 6 Univariate analysis of lung ultrasonography score and diaphragmatic mobility for predicting postoperative pulmonary complications.

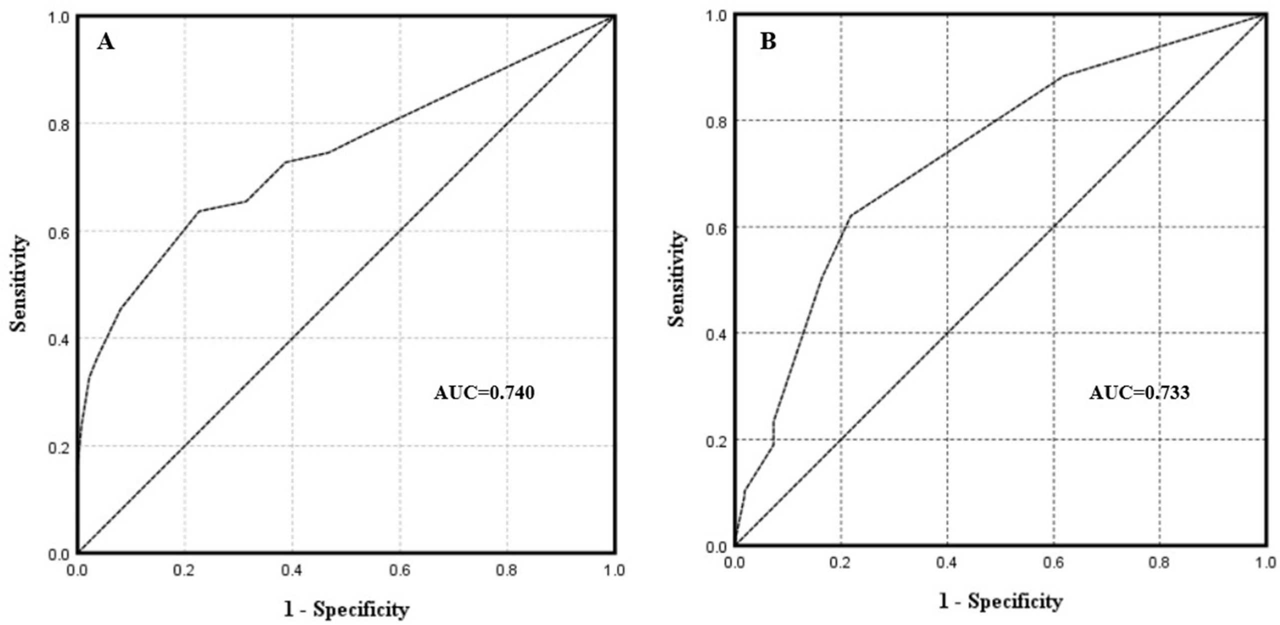

Figure 7 Predictive values of lung ultrasonography score (**A**) and diaphragmatic mobility (**B**) for postoperative pulmonary complications.

with DM < 3.7 cm had a significantly higher incidence of PPCs than those with DM ≥ 3.7 cm (45.26% [43/95] vs. 12.37% [12/97], P < 0.001).

After adjustment for 13 covariates (univariate P < 0.05 candidates), elevated LUS (LUS > 5) and decreased DM (DM < 3.7 cm) remained independently associated with an increased risk of PPCs (LUS: adjusted OR = 6.363, 95% CI: 2.609–15.515, P < 0.001; DM: adjusted OR = 5.011, 95% CI: 2.106–11.923, P < 0.001) (Figure 8). ROC analysis demonstrated LUS (LUS > 5) and DM (DM < 3.7 cm) exhibited a moderate discriminatory ability (LUS > 5: AUC = 0.694, 95% CI: 0.606–0.783; DM < 3.7 cm: AUC = 0.701, 95% CI: 0.621–0.781) (Figure 9). The integration of bedside ultrasound indices (LUS > 5, DM < 3.7 cm) and ARISCAT achieved a significantly higher AUC of 0.851 (95% CI: 0.795–0.907), with a statistically significant difference compared to ARISCAT alone (AUC = 0.684, 95% CI: 0.601–0.768) (DeLong's P < 0.001) (Table 4 and Figure 9).

Discussion

The incidence of PPCs was 28.64% (55/192), lower than the 33.3% previously reported.[2] By examining the underlying causes, we identified two key factors that contributed to this issue: intraoperative fluid management and intraoperative

Table 3 Diagnostic Performance of Lung Ultrasound Score and Diaphragmatic Mobility for Predicting Postoperative Pulmonary Complications (PPCs)

Risk Factors	Lung Ultrasonography Score	Diaphragmatic Mobility
Cut-off value	5	3.7
Sensitivity	0.636	0.620
Specificity	0.774	0.782
PPV	0.604	0.452
NPV	0.819	0.876

Abbreviations: PPCs, postoperative pulmonary complications; PPV, positive predictive value; NPV, negative predictive value.

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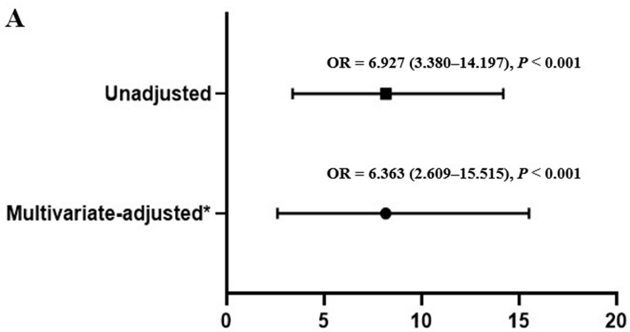

Figure 8 Univariate and multivariable logistic regression analysis of lung ultrasonography score >5 (**A**) and diaphragmatic mobility < 3.7 cm (**B**) for predicting postoperative pulmonary complications. *After adjustment for 13 covariates (univariate P < 0.05 candidates).

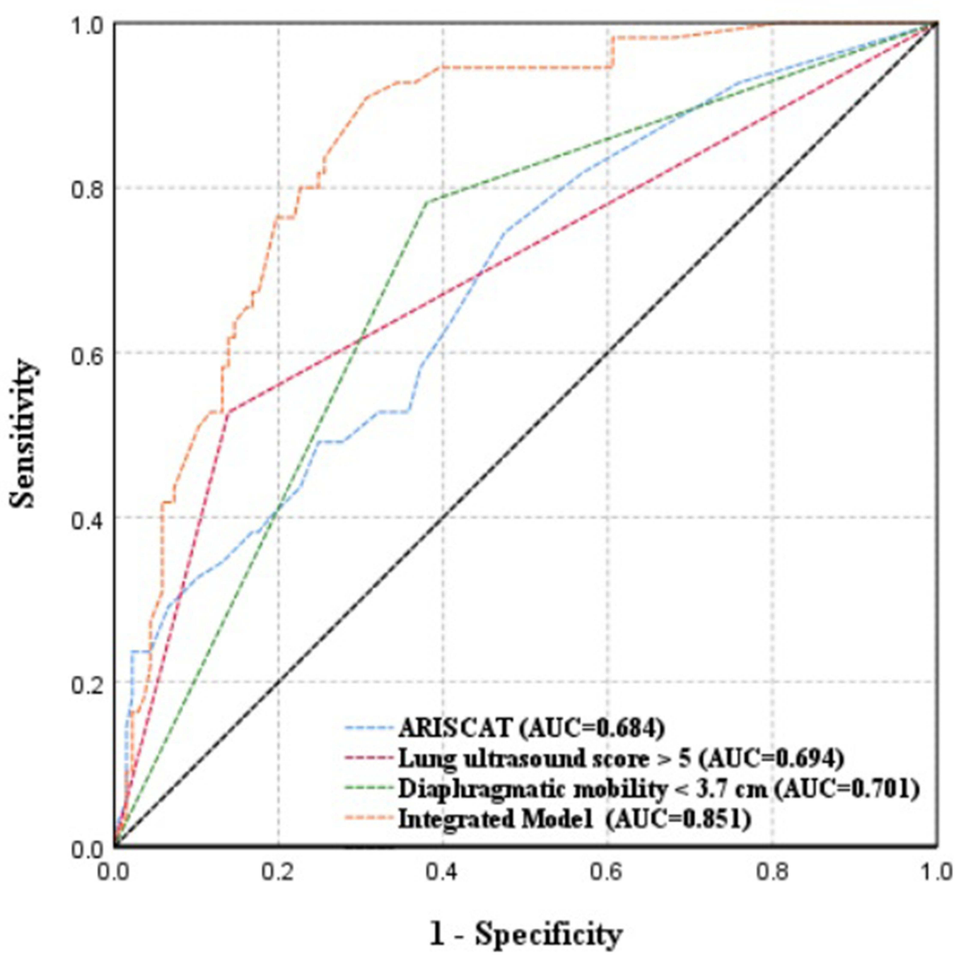

Figure 9 Predictive values of lung ultrasonography score >5, diaphragmatic mobility < 3.7 cm, ARISCAT model, and Integrated Model (combining lung ultrasonography score > 5, diaphragmatic mobility < 3.7 cm, and ARISCAT) for predicting postoperative pulmonary complications.

ventilation strategy, both of which are closely associated with the occurrence of PPCs.[15,16] In this study, all patients received goal-directed fluid therapy and lung-protective ventilation strategies.

In this prospective observational study, we included bedside ultrasound findings (LUS and DM) in addition to the risk factors for PPCs identified in previous studies. LUS and DM have been identified as predictors of PPCs in geriatric patients with hip fractures. ROC analysis showed that LUS and DM had moderate predictive abilities for PPCs. The

Table 4 Multivariate Analysis of Predictors in Two Models for Postoperative Pulmonary Complications (PPCs)

Multivariate Analysis OR (95% CI), n= 192		
Predictors	**ARISCAT Model**	**Integrated Model***
Aged > 80 yr	1.670 (0.855–3.263)	1.626 (0.753–3.509)
Preoperative hypoxemia ($SpO_2 \leq 90\%$)	2.430 (1.077–5.483)	2.513 (0.981–6.440)
Recent respiratory infection	2.243 (1.108–4.537)	1.494 (0.649–3.438)
Preoperative anemia (Hb ≤ 10 g/dL)	2.277 (1.035–5.011)	2.643 (1.049–6.660)
Duration of surgery > 2 h	1.153 (0.590–2.255)	1.634 (0.731–3.649)
Lung ultrasound score > 5		6.892 (2.935–16.182)
Diaphragmatic mobility < 3.7 cm		4.515 (2.019–10.098)

Note: *The model constructed by combining lung ultrasonography score > 5, diaphragmatic mobility < 3.7 cm, and ARISCAT.
Abbreviations: PPCs, postoperative pulmonary complications; OR, Odds ratio; CI, Confidence interval; ARISCAT, Assess Respiratory Risk In Surgical Patients In Catalonia.

optimal cutoff values were 5 cm for LUS and 3.7 cm for DM; both exhibited high NPV (81.9% for LUS and 87.6% for DM), which is clinically valuable for early identification of low-risk patients. Multivariate analysis confirmed that LUS > 5 cm and DM < 3.7 cm were independent predictors of PPCs. The integration of LUS, DM, and ARISCAT resulted in significantly superior predictive performance compared with ARISCAT alone.

In elderly patients, different subtypes of PPCs share interrelated pathophysiological mechanisms that originate from pulmonary lesions and impaired respiratory mechanics.[7,8] These mechanisms often coexist and exacerbate each other. Normal lung tissue maintains a precise air-fluid balance, which is critical for sustaining normal gas exchange function.[17] Pathological conditions, including insufficient ventilation or increased exudation in lung tissue, can disrupt the air-fluid balance of the lung parenchyma.[18] Changes in the lung tissue air-fluid ratio manifest as characteristic signs on lung ultrasonography images, including A-lines, B-lines, the shred sign, and the tissue-like pattern.[19] Quantitative lung ultrasonography scoring has become an established method for evaluating pulmonary disease severity and treatment response.[20,21] A prospective observational study conducted across 11 hospitals in Italy found that, among older adults with hip fractures, patients who developed postoperative pneumonia had a significantly higher preoperative lung ultrasound score than those in the non-pneumonia group.[9] The diaphragm serves as the primary respiratory muscle that contributes to > 60% of the changes in thoracic volume during respiration.[22] DM is an important indicator of diaphragmatic function.[23] Several studies have shown a relationship between DM and lung function changes.[24–26] Patients with decreased DM exhibit altered respiratory mechanics due to reduced pressure and diaphragmatic pressure.[11,27,28] DM is correlated with forced expiratory volume in 1 s (FEV_1) and maximal voluntary ventilation (MVV),[29] reductions of which are associated with the occurrence of PPCs.[30,31] Furthermore, DM is correlated with six-minute walking distance, dyspnea, and the severity of COPD.[25,32]

Herein, LUS > 5 cm and DM < 3.7 cm enabled clinically meaningful risk stratification with a high negative predictive value, effectively identifying patients at low risk of PPCs. This may help reduce unnecessary monitoring and medical costs and optimize the allocation of medical resources. The feasibility of lung and diaphragmatic ultrasonography stems from its convenience, speed, reproducibility, and ability to provide immediate bedside assessment, enabling seamless integration into the preoperative evaluation workflow.

However, LUS and DM measurements exhibit only moderate sensitivity and specificity, as well as a low positive predictive value, underscoring the need to combine these indices with existing clinical risk models. ARISCAT is a clinical model widely used for predicting PPCs. In this study, five of the seven predictors were included in the ARISCAT model (surgical site and emergency status were standardized in accordance with the study's inclusion criteria). ROC analysis showed that the ARISCAT model exhibited moderate discriminative performance (AUC = 0.684). The

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model integrating LUS (LUS > 5), DM (DM < 3.7 cm), and ARISCAT significantly improved the prognostic predictive performance (AUC = 0.851 vs. ARISCAT alone; ΔAUC = +0.167, P = 0.000). Its predictive performance was also superior to that of Xue's model (0.82, 95% CI: 0.75–0.89) and the CARDOT score (0.73, 95% CI: 0.61–0.85).[4] This suggests that bedside ultrasound assessment (lung and diaphragmatic ultrasonography) is a promising adjunct tool for predicting PPCs. LUS and DM showed complementarity with ARISCAT in risk stratification for PPCs.; ARISCAT captures patients' general clinical characteristics, while LUS and DM quantitatively assess perioperative pulmonary lesions and respiratory mechanics.

This study had some limitations. First, proficiency in bedside lung ultrasound is a prerequisite for the effective clinical application of this predictive model; thus, training in ultrasound operations for anesthesiologists is essential. Second, our institution prefers general anesthesia combined with a regional nerve block to neuraxial anesthesia since it provides analgesia and has minimal impact on postoperative motor function.[33] This limits the extrapolation of our findings to other institutions where neuraxial anesthesia is the standard technique. Third, a potential risk of model overfitting exists due to the ratio of covariates to events in this study. Future studies may further validate the robustness of the model using cross-validation to reduce bias attributable to overfitting. Finally, this was a single-center study. Additional multicenter studies with larger sample sizes are needed to validate the reliability and generalizability of the conclusions drawn in this study.

Conclusion

This study suggests that bedside ultrasound may serve as a functional assessment tool for the risk stratification of PPCs in elderly patients with hip fractures. Although combining real-time ultrasound assessment with the preoperative ARISCAT risk index may help identify high-risk patients, the clinical value and applicability of this approach warrant further validation in larger, more diverse cohorts to ensure its reliability and generalizability.

Abbreviations

PPCs, Postoperative pulmonary complications; LUS, Lung ultrasonography score; DM, Diaphragmatic mobility; ARISCAT, Assess Respiratory Risk In Surgical Patients In Catalonia; ASA, American Society of Anesthesiologists; AUC, Area under the receiver operating characteristic curve; COPD, Chronic obstructive pulmonary disease; ROC, Receiver-operating characteristiccurve; OR, Odds ratio; CI, Confidence interval; PPV, Positive predictive value; NPV, Negative predictive value.

Data Sharing Statement

The data analyzed in this study is subject to the following licenses/restrictions: the datasets used and analysed during the current study are available from the corresponding author on reasonable request. Requests to access these datasets should be directed to Jianhong Hao, haojianhong@xashhyy9.wecom.work, or haojianhong722@163.com.

Ethics Approval and Consent to Participate

Ethical approval for this study (2025XJHH-018) was provided by the Ethics Committee of Honghui Hospital, Xi'an Jiaotong University, Xi'an, Shaanxi Province, China (Chairperson, Professor Kun Zhang) on 3 May 2025. The trial was designed in accordance with the principles of the Helsinki Declaration and registered at the Chinese Clinical Trial Registry (Chatr: 2500102101, main researcher: Jianhong Hao, registration date: 8 May 2025). Written informed consent was obtained from patients with normal communication capacity. For those with Alzheimer's disease, hearing or reading impairments, consent was obtained from their legally authorized representatives.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare no competing interests.

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