Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Early Prediction of Postoperative Pulmonary Complications After Esophagectomy Using Lung and Diaphragmatic Ultrasound: A Multicenter Prospective Study

Cédric Cirenei

cedric.cirenei@chu-lille.fr

Centre Hospitalier Universitaire de Lille

Lucie Auptitgendre

Centre Hospitalier Universitaire de Clermont-Ferrand

Anais Crey

Centre Hospitalier Universitaire de Rouen

Maxime Leroy

Centre Hospitalier Universitaire de Lille

Damien Rousseleau

Centre Hospitalier Universitaire de Lille

Thomas Godet

Centre Hospitalier Universitaire de Clermont-Ferrand

Jérémy Falcone

Centre Hospitalier Universitaire de Lille

Julie Veziant

Centre Hospitalier Universitaire de Lille

Julien Labreuche

Centre Hospitalier Universitaire de Lille

Eric Kipnis

Centre Hospitalier Universitaire de Lille

Thomas Clavier

Centre Hospitalier Universitaire de Rouen

Emmanuel Futier

Centre Hospitalier Universitaire de Clermont-Ferrand

Gilles Lebuffe

Centre Hospitalier Universitaire de Lille

Research Article

Keywords: postoperative pulmonary complications, lung ultrasound, diaphragmatic ultrasound, diaphragmatic dysfunction, esophagectomy

Posted Date: February 24th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8810768/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: Competing interest reported. CC received fees from Grünenthal for speaking. He also received benefits from Fisher & Paykel Healthcare: participation in meetings. He also received travel and hospitality support from Getinge AB. EK received consultancy, meeting and presentation fees from Shionogi, MSD France and Pfizer; consultancy and presentation fees from Takeda and Getinge AB; presentation fees from LFB. No potential conflict of interest relevant to this article was reported for others authors.

Abstract

Background:

Postoperative pulmonary complications (PPCs) remain the leading cause of morbidity and mortality after esophagectomy. Bedside tools enabling early identification of patients at risk are lacking. This study aimed to assess the ability of lung (LUS) and diaphragmatic ultrasound (DUS) to predict PPCs within seven postoperative days (POD).

Methods:

Multicenter prospective observational study in France including adult patients undergoing elective thoracic esophagectomy between August 2022 and March 2025. LUS and DUS were performed daily. The primary endpoint was the occurrence of at least one PPC within seven PODs. Predictive performance was assessed using multivariable logistic regression and receiver-operating-characteristic (ROC) analyses.

Results:

Among 275 patients, 115 (41.8%) developed PPCs. LUS on POD0 was associated with PPCs (OR 1.36, 95%CI 1.25-1.48) with an AUC of 0.74 (0.74 95%CI 0.68-0.80). LUS score on POD1 was higher in patients with PPCs (9.8±4.5 vs 5.2±3.4; p <0.001) and independently predicted PPCs (OR 1.18 [95% CI, 1.08–1.30]; p < 0.001). Higher diaphragmatic excursion in deep breathing was protective against PPCs (OR 0.96 [0.92–0.99]; p = 0.02). Alveolar consolidation on POD1 was the strongest categorical predictor of PPCs (adjusted OR 7.74 [95% CI, 3.24-18.47]; p < 0.001). The area under the ROC curve reached 0.80 [0.75-0.86] for LUS, 0.84 [0.79-0.89] for DUS in deep breath, and 0.89 [0.88-0.90] for the multivariable model.

Conclusion:

LUS obtained immediately after extubation (POD0) provides early prognostic information for PPCs after esophagectomy, while POD1 LUS and DUS add complementary value and support accurate early risk stratification.

Introduction

Postoperative pulmonary complications (PPCs) are among the most frequent and serious adverse events after major surgery, and their burden is particularly high following esophagectomy [1–3]. In this setting, PPCs are consistently reported as the leading cause of postoperative morbidity and are strongly associated with increased mortality and prolonged length of stay, underscoring the need for early identification and prevention strategies [4].

Point-of-care lung ultrasound (LUS) has emerged as a valuable bedside tool for detecting early pulmonary complications [5–7]. Several studies in major abdominal and thoracic surgeries have demonstrated that LUS performed on postoperative day (POD) 1 has predictive value for subsequent PPCs [8,9]. In a recent multicenter prospective cohort after major abdominal surgery, a higher LUS score on POD1 was significantly associated with PPCs within the following days, with good specificity and positive predictive value [9].

Diaphragmatic dysfunction is another relevant determinant of postoperative pulmonary outcome and has been associated with increased risk of PPCs and worse prognosis in the intensive care unit (ICU) [10,11]. Diaphragmatic ultrasound (DUS) provides a feasible and reproducible method to assess diaphragmatic excursion and thickening fraction at the bedside. Small studies have suggested that reduced diaphragmatic excursion after thoracic surgery correlates with higher PPC rates, but evidence remains limited and mostly single-center [11,12]. While LUS primarily captures parenchymal alterations such as atelectasis, effusion, or consolidation, DUS reflects the mechanical component of respiration[12–14], offering complementary insights into postoperative pulmonary vulnerability.

Given these considerations, we hypothesized that LUS and DUS performed on POD0 and POD1 would be independently associated with the occurrence of PPCs after esophagectomy. The primary objective of this multicenter prospective observational study was to assess the predictive performance of LUS score on POD0 for PPCs occurring within the first postoperative week. Secondary objectives were to evaluate the performance of LUS and DUS on POD1 and to establish a predictive model on POD1 integrating LUS, DUS, and clinical variables to improve early identification of patients at risk of PPCs.

Materials and Methods

Study design

This was a multicenter observational prospective study conducted in three university hospitals in France. Patient recruitment occurred between August 2022 and March 2025. This cohort study is reported in accordance with the STROBE statement for observational studies[15]. Given that lung and diaphragmatic ultrasound were evaluated as index tests for postoperative pulmonary complications, items relevant to diagnostic test accuracy were also aligned with the STARD guideline[16]. Completed STROBE and STARD checklists are provided in the Supplemental Digital Content.

Ethical considerations

The study was approved by French central ethics committee (Comité de Protection des Personnes Ouest-IV, Nantes, July 5, 2022, IRB number 2022-A00655-38). Due to the non-interventional design of the study, the need for signed informed consent was waived. Oral and written information were required, and patients could refuse to participate in the study at any time. The information document was given to all

patients included in the study. Trial was registered prior to enrolment of first patient with ClinicalTrials.gov (NCT05453760) on July 7, 2022.

Population

Patients aged 18 years old or over who were scheduled for elective esophagectomy were eligible for the study. Exclusion criteria were: i) chronic obstructive pulmonary disease - stage 2 or higher (forced expiratory volume in one second under 50%), ii) pulmonary emphysema, iii) history of lung surgery, iv) inability to understand oral information. All patients were admitted to the ICU as standard practice for postoperative care. Patients who were admitted to the ICU without having been extubated were excluded.

Study protocol

Patients were recruited during the pre-anesthetic visit the day before surgery. Demographic and perioperative variables are detailed in the Supplemental Digital Content. In the protocol submitted to the ethics committee, the primary objective was the prognostic value of LUS performed within 1 hour after extubation (POD0), while DUS and daily assessments were pre-specified as secondary/exploratory objectives.

Before enrolling their first patient, each center completed a remote introductory course on LUS zones [6] and standardized DUS measurement conditions [17,18], followed by a run-in phase before site activation; all examiners held at least level 2 critical care ultrasound certification. LUS and DUS were performed within 1 hour after extubation (POD0) and then daily until POD5 using a between 2-5 MHz convex probe. LUS was acquired bilaterally across 12 regions (6 per hemithorax: anterior/lateral/posterior, each upper/lower); the worst pattern per region was scored 0–3 (0, normal/A-lines or ≤2 B-lines; 1, ≥3 well-spaced B-lines; 2, coalescent B-lines/white lung; 3, consolidation), and summed to a global score (0–36) [6,8,19]. Diaphragmatic excursion was measured in a 30-degree position after ≥3 quiet breaths and during deep inspiration; three measurements were obtained and the best value recorded, with adequate analgesia ensured to limit pain-related breathing artifacts (see protocol in supplemental). Ultrasound assessments were performed while the patient was breathing spontaneously, without ventilatory support.

LUS and DUS were performed by trained anesthesiologist investigators who were not involved in clinical care and were blinded to patient data and study status at the time of ultrasound acquisition; no duplicate acquisitions were performed.

Surgical and anesthetic management

All patients received multimodal analgesia. Central or peripheral regional analgesia was provided depending on the center pain management protocols and/or patient preference. Anesthetic induction was performed according to standard practice and at the discretion of the anesthesiologist in charge of the patient. Patients were intubated with a double-lumen left-side tube or a single-lumen tube allowing the use of a bronchial blocker to exclude the patient's right lung. Intraoperative ventilation was performed as standard practice: tidal volume of 6-8 $ml.kg^{-1}$ predicted body weight during two-lung ventilation, 4-6 $ml.kg^{-1}$ during one-lung ventilation, titrated positive end-expiratory rate of 5 cmH_2O or higher, and a respiratory rate adjusted to maintain end-tidal carbon dioxide between 35 and 45 mmHg. Alveolar recruitment maneuvers were also performed each 30 minutes according to the center's practices. All patients were scheduled to elective esophagectomy with right thoracic incision. Surgery was categorized by open (laparotomy and thoracotomy), hybrid minimally invasive (laparoscopy and thoracotomy or laparotomy and thoracoscopy) and, totally minimally invasive esophagectomy (laparoscopy and thoracoscopy). Patients underwent hemodynamic monitoring, including invasive blood pressure monitoring and monitoring of systolic ejection volume monitoring. Patients were planned to be extubated in the operating room at the end of surgery, after which they would be admitted to the ICU. As this was an observational study, the postoperative ventilatory management strategy was not protocolized, and escalation criteria were left to local practices.

Outcome and Postoperative pulmonary complications

All patients were prospectively followed until hospital discharge to record clinical data. The occurrence of the first PPC within the first 7 POD was considered the primary endpoint. PPCs were defined according to the European Perioperative Clinical Outcome definitions (eTable 1) [20]. PPCs were recorded as a composite outcome of the occurrence of at least one of the following pulmonary complications: atelectasis, pneumonia, aspiration pneumonia, pleural effusion, acute respiratory failure (ARF) and, pneumothorax. In each center, PPCs were adjudicated by two independent clinicians who systematically reviewed the medical records. These adjudicators were not involved in the acquisition of LUS and DUS and were blinded to the detailed LUS/DUS measurements and intraoperative ventilatory data at the time of outcome classification. The severity of postoperative complications and anastomotic leakage was also reported.

Sample size calculation

Based on an expected 35% incidence of PPCs [4,21] within 7 days after surgery, and assuming a null hypothesis AUC of 0.70 versus an alternative of 0.80 for LUS score at POD0, with α=5% and β=20%, a total of 249 patients were required. Due to administrative procedures leading to a delay in opening the third center, we requested and obtained regulatory approval to increase the number of subjects required to 275.

Statistical analysis

Categorical variables are presented as n (%). Continuous variables are presented as mean ± SD or median [IQR], as appropriate. Normality was assessed graphically and with the Shapiro–Wilk test. Groups were compared by PPC status using Student's t-test or Mann–Whitney U-test for continuous variables, and chi-square or Fisher's exact test for categorical variables. Discrimination was assessed using the area under the ROC curve (AUC), and optimal cutoffs were derived from the Youden index.

Associations between clinical variables, POD1 LUS/DUS, and PPCs were assessed using univariate logistic regression. A secondary objective was to develop a POD1 prognostic model integrating LUS and DUS variables with clinical predictors (age, preoperative hemoglobin, smoking status and the surgical approach) to improve early risk stratification for PPCs. The log-linearity assumption was evaluated with restricted cubic splines [22]. Variables with $p<0.05$ in univariate analysis were entered into a multivariable logistic regression model built by backward selection, and final multivariable estimates were obtained after multiple imputation.

Missing data on outcomes and pre-specified confounders were handled using multiple imputation by chained equations (MICE) with a regression-switching approach (m = 10 imputations). The imputation procedure was performed under the missing-at random assumption, using all patients' characteristics at baseline. Predictive mean matching method for quantitative variables and logistic regression models (binary, ordinal or polynomial) for qualitative variables were used [23]. Regression coefficients and their standard errors estimated from each imputed dataset were combined using Rubin's rules [24].

The performance of the final multivariable logistic regression was evaluated using the AUC. Internal-validation was applied on this multivariable model using 200 bootstraps resampling on imputed data to estimate the c-statistic corrected for over-optimism. All tests were two-tailed, and the threshold for statistical significance was set to $p<0.05$. All analyses were performed using SAS software (version 9.4, SAS Institute Inc., Cary, NC, USA).

Results

Population

Between August 2022 and March 2025, 288 patients were screened and 275 were included (figure 1). Most patients were male (223 (81.1%)), with a mean age of 63.7 ± 10.2 years-old. Overall, 115 (41.8%) patients developed a PPC within POD7. The median time to PPC diagnosis was 3.0 [2.0-3.5] days postoperatively (Table 1). The most common PPC was acute respiratory failure occurring in 53 (19.3%) patients followed by pneumonia (43 (15.6%)), atelectasis (24 (8.7%)), pleural effusion requiring of thoracocentesis (38 (13.8%)), aspiration pneumonitis (9 (3.3%)) and pneumothorax (9 (3.3%)). Intraoperative ventilatory parameters were comparable between patients who experienced PPCs and who did not (eTable 2). Patients who developed PPCs appeared to have more severe complications

(Dindo-Clavien ≥3) and, longer ICU and hospital stays (Table 2). Patients experiencing PPC appeared to have more anastomotic leakage.

The distribution of LUS scores by area examined is shown in eTable 3. LUS and DUS findings on POD0 by PPC status are shown in Table 2. Patients who developed PPCs had higher LUS (8.7±4.2 vs 5.4±3.9, p<0.001), and alveolar consolidations were more frequent (64.8 vs 7.1%, p<0.001). DUS also differed between groups: patients with PPCs had lower diaphragmatic excursion during quiet breathing (15.6±7.6 vs 20.1±6.4 mm, p<0.001) and deep breathing (26.4±13.5 vs 40.8±13.7 mm, p<0.001). The POD0 deep-to-quiet excursion ratio was reduced (1.8±0.4 vs 2.1±0.5, p<0.001).

Primary outcome

On POD0, LUS score was significantly higher in the group of patients with PPCs compared to non-PPCs group (odds ratio [OR],1.36; CI 95%, 1.25-1.48; p<0.001) (Table 2).The area under the ROC curve (ROC AUC) for LUS on POD0 was 0.74 (95% CI, 0.68-0.80) with 7 as the most predictive LUS threshold value(Figure 2).

Secondary outcomes

On POD1, LUS score was was discriminant for prediction of PPCs.The ROC AUC for LUS on POD1 was 0.80 (95% CI, 0.75-0.86), with 9 as the most predictive LUS threshold value (Figure 3).

Distributions of LUS, diaphragmatic excursion, and the deep-to-quiet excursion ratio are shown in eFigure 1. DUS showed good discrimination for PPC prediction (Figure 2), with POD1 diaphragmatic excursion AUC of 0.76 (95% CI, 0.69-0.82), most predictive threshold value of 16 mm and the highest individual performance for diaphragmatic excursion in deep breathing (AUC 0.84, 95% CI 0.79–0.89; threshold 31 mm). Combining LUS and DUS improved discrimination (AUC 0.89, 95% CI 0.85–0.94; eFigure 2). POD0 measurements were less predictive than POD1; AUC 0.74 (95% CI (0.67-0.80) for quiet-breathing excursion threshold 17 mm; eFigures 3,4).

In component-specific analyses, a higher LUS (POD0 and POD1) was consistently associated with the main PPCs (ARF, pneumonia, and pleural effusion) while a higher diaphragmatic excursion during deep breathing was protective. The only exception for LUS was atelectasis, for which the association was not significant at POD0 but became significant at POD1 (see Supplemental Digital Content, eTable 4 and 5)

In univariable analyses (Table 3), higher POD1 LUS was associated with PPCs (OR 1.36, 95% CI 1.25–1.48), whereas diaphragmatic excursion was protective during both quiet (OR 0.87, 95% CI 0.83–0.92 per mm) and deep breathing (OR 0.89, 95% CI 0.87–0.92 per mm). Alveolar consolidation was the strongest categorical predictor (OR 24.1, 95% CI 11.6–50.0), and the DUS ratio (deep/quiet) was also associated with PPCs (OR 0.23, 95% CI 0.19–0.28); open surgical approach was associated with PPCs (OR 3.47, 95% CI 1.35–8.90).

In multivariable analysis, greater deep diaphragmatic excursion (OR 0.96, 95%CI 0.92-0.99), higher preoperative SpO_2(OR 0.77 95%CI 0.62-0.95), and age (OR 0.97, 95%CI 0.93-0.99) were independently protective, while alveolar consolidation (OR 7.74, CI95% 3.24-18.5) and higher LUS (OR 1.18, 95%CI 1.07-1.31) on POD1 remained independently associated with PPCs; the final model achieved an AUC of 0.89 (95% CI 0.88–0.90) (Figures 4), and non-retained variables are reported in eTable 6.

Discussion

In this prospective multicenter study, both LUS and DUS performed on POD0 and POD1 were independently predictive of PPCs occurring within POD7 after elective esophagectomy. To date, postoperative prognostic studies have evaluated LUS or DUS separately and to our knowledge, this is the first study integrating both LUS and DUS findings to predict PPCs in this high-risk surgical population. Our findings highlight that early postoperative ultrasound assessment on POD 0 and POD1 provides relevant, bedside, non-invasive predictors of PPCS.

The incidence of PPCs in our cohort (41.8%) is consistent with previous large observational studies, in which PPCs are the predominant cause of postoperative morbidity and mortality following esophagectomy [4,21]. The median time to PPC diagnosis (3 days) aligns with the known postoperative trajectory of respiratory decline, typically peaking between POD2 and POD4 [25]. Therefore, early recognition of patients at risk of PPCs could allow increased opportunity to initiate preventive measures and potentially reduce postoperative morbidity.

Predictive value of LUS on POD0 and 1

LUS on POD0 and 1 demonstrated a strong predictive performance for PPCs (AUC of 0.74 and 0.80 respectively), consistent with prior studies reporting ability of LUS to predict PPCs [8]. In major abdominal surgery, POD1 LUS has yielded AUC values of 0.77 to 0.82 for PPC prediction, which closely mirrors our findings [8,9]. The higher discrimination observed for LUS on POD1 compared with POD0 suggests that relevant ultrasonographic patterns may become more apparent over the first 24 hours, potentially reflecting evolving atelectasis/derecruitment and early postoperative inflammatory changes.. By POD1, higher LUS scores, alveolar consolidations, and pleural effusions were consistently observed in patients who later experienced PPCs, supporting this standardized timepoint as optimal for risk stratification. Our study confirms the prognostic value of LUS in another high-risk surgical population and suggests that LUS findings as early as postoperative day one can identify esophagectomy patients at increased risk of PPCs, before overt respiratory failure occurs.

Diaphragmatic dysfunction as a complementary predictor

DUS findings on POD1 also differed markedly between groups. Patients with PPCs exhibited reduced diaphragmatic excursion both at quiet and deep breathing, reflecting impaired contractility.

Diaphragmatic excursion in deep breathing had the best individual predictive performance (AUC = 0.84), comparable to results reported after thoracic surgery [26]. These findings corroborate that postoperative diaphragmatic dysfunction contributes substantially to pulmonary morbidity [11,12]. This may be explained by the fact that esophageal surgery *via* the diaphragmatic hiatus and a thoracic incision may lead to diaphragmatic dysfunction or paresis, thereby impairing respiratory mechanics [27]. Recent perioperative cohorts have shown that reduced diaphragmatic excursion, abnormal thickening fraction, or increased echodensity after upper abdominal or video-assisted thoracic surgeries are associated with PPCs and prolonged ventilation [28,29]. In critically ill patients, several studies and meta-analyses have demonstrated that DUS-derived indices predict weaning outcomes and extubation failure [30,31]. Our findings extend these observations to esophagectomy and show that early postoperative DUS provides independent prognostic information for PPCs even after adjustment for clinical risk factors and LUS findings, supporting the concept that diaphragmatic dysfunction is a key determinant of postoperative respiratory morbidity in this setting.

Combination of LUS and DUS

Risk stratification tools such as the ARISCAT score have been developed to estimate the risk of PPCs in general surgical populations [2,32]. However, their performance in complex procedures like esophagectomy remains uncertain, as they were derived from heterogeneous surgical cohorts, rely on non-specific items, and do not incorporate dynamic perioperative physiological changes. In our study, we therefore built a multivariable model that initially included clinical variables. Some of these clinical variables were retained as independent predictors of PPCs, whereas others were not. Importantly, the addition of POD1 ultrasound variables – LUS score, presence of alveolar consolidation, and diaphragmatic excursion during deep inspiration – substantially improved the predictive performance of the model, yielding an AUC of 0.89 [0.88–0.90]. This suggests that integrating early postoperative LUS and DUS with established clinical risk scores may refine PPC risk stratification after esophagectomy.

Another key finding of our study is that LUS and DUS capture complementary aspects of respiratory vulnerability after esophagectomy. LUS reflects the degree and distribution of lung aeration loss, atelectasis, and interstitial syndrome, while DUS provides a functional assessment of the main inspiratory muscle. The fact that both modalities remained independently associated with PPCs in multivariable models suggests that a combined lung–diaphragm ultrasound strategy may refine postoperative risk stratification beyond either modality alone. Future work should evaluate whether ultrasound-guided pathways, such as early physiotherapy, non-invasive ventilation, or targeted analgesia in high-risk patients identified by LUS/DUS, can reduce PPC rates.

Strengths and limitations

The main strengths of this study include its prospective multicenter design, large sample size, standardized ultrasound methodology, predefined PPCs definitions, and blinded outcome assessment.

The combined evaluation of parenchymal and diaphragmatic indices offers novel insight into postoperative pulmonary physiology. However, some limitations should be acknowledged. First, PPCs were analyzed as a composite endpoint, potentially encompassing heterogeneous processes. The clinical implications of ARF and pneumonia are likely to differ from those of pleural effusion or aspiration pneumonitis. Second, LUS and DUS were performed by multiple operators without interobserver reproducibility testing. Third, although the position in which the ultrasounds were performed was standardized, this was not noted in the case report form. Fourth, preoperative diaphragmatic function was not evaluated, preventing comparison with baseline values like others studies [26]. Fifth, pain scores at the time of ultrasound were not systematically collected; residual pain-related limitation of deep inspiration may have influenced DUS measurements. Sixth, while the observational design establishes association, it does not prove causality, and residual confounding factors cannot be excluded. Finally, we focused on esophagectomy patients, and extrapolation to other thoraco-abdominal procedures should be cautious.

Future perspectives

The feasibility, repeatability, and bedside availability of LUS and DUS are suitable for integration into enhanced recovery and perioperative care pathways. Future work should externally validate these results and determine whether LUS and DUS can be incorporated into multivariable predictive models integrating clinical and intraoperative data. Interventional trials could investigate whether ultrasound-guided management—targeting physiotherapy intensity, oxygen therapy, or noninvasive ventilation—reduces PPC rates. Broader application of this combined ultrasound approach should also be evaluated in other high-risk thoraco-abdominal procedures.

Conclusion

In summary, early postoperative LUS and DUS assessments provide complementary and independent information on pulmonary risk after esophagectomy. Their combined use on POD1 allows accurate prediction of PPCs and could help tailor postoperative respiratory management. Future studies should validate these findings and explore whether ultrasound-guided interventions can improve clinical outcomes.

Abbreviations

ARF
acute respiratory failure
AUC
area under the curve
DUS
diaphragmatic ultrasound

ICU
intensive care unit
IQR
interquartile range
LUS
lung ultrasound
POD
postoperative day
PPC
postoperative pulmonary complication

Declarations

- ***Ethical Approval and Consent to participate:***

The study was approved by French central ethics committee (Comité de Protection des Personnes Ouest-IV, Nantes, July 5, 2022, IRB number 2022-A00655-38). Due to the non-interventional design of the study, the need for signed informed consent was waived. Oral and written information were required, and patients could refuse to participate in the study at any time. The information document was given to all patients included in the study. Trial was registered prior to enrolment of first patient with ClinicalTrials.gov (NCT05453760) on July 7, 2022.

- Consent for publication: Not application

- Availability of supporting data: The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request, provided that the data manager of Lille University Hospital gives permission.

- ***Competing interests:*** CC received fees from Grünenthal for speaking. He also received benefits from Fisher & Paykel Healthcare: participation in meetings. He also received travel and hospitality support from Getinge AB. EK received consultancy, meeting and presentation fees from Shionogi, MSD France and Pfizer; consultancy and presentation fees from Takeda and Getinge AB; presentation fees from LFB. No potential conflict of interest relevant to this article was reported for others authors

- ***Funding:*** No funding was received for this study.

- ***Authors' contributions :*** CC conceived the study, interpreted the data and drafted the first version of the manuscript. LA, AC, DR, TG, JF and JV contributed to patient recruitment and data acquisition. ML and JL performed the statistical analyses and provided methodological advices. GL, EF, TC, EK and TG supervised the study and critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

- ***Acknowledgements :*** The authors would like to thank the research coordinators at Lille University Hospital for their help with the coordination of the study.

References

1. Fernandez-Bustamante A, Frendl G, Sprung J, Kor DJ, Subramaniam B, Martinez Ruiz R, et al. Postoperative Pulmonary Complications, Early Mortality, and Hospital Stay Following Noncardiothoracic Surgery: A Multicenter Study by the Perioperative Research Network Investigators. JAMA Surg. 2017;152:157. https://doi.org/10.1001/jamasurg.2016.4065.
2. Canet J, Gallart L, Gomar C, Paluzie G, Vallès J, Castillo J, et al. Prediction of Postoperative Pulmonary Complications in a Population-based Surgical Cohort. Anesthesiology. 2010;113:1338–50. https://doi.org/10.1097/ALN.0b013e3181fc6e0a.
3. Law S, Wong K-H, Kwok K-F, Chu K-M, Wong J. Predictive factors for postoperative pulmonary complications and mortality after esophagectomy for cancer. Ann Surg. 2004;240:791–800. https://doi.org/10.1097/01.sla.0000143123.24556.1c.
4. D'Journo XB, Boulate D, Fourdrain A, Loundou A, van Berge Henegouwen MI, Gisbertz SS, et al. Risk Prediction Model of 90-Day Mortality After Esophagectomy for Cancer. JAMA Surg. 2021;156:836–45. https://doi.org/10.1001/jamasurg.2021.2376.
5. Xie C, Sun K, You Y, Ming Y, Yu X, Yu L, et al. Feasibility and efficacy of lung ultrasound to investigate pulmonary complications in patients who developed postoperative Hypoxaemia-a prospective study. BMC Anesthesiol. 2020;20:220. https://doi.org/10.1186/s12871-020-01123-6.
6. Lichtenstein D, Goldstein I, Mourgeon E, Cluzel P, Grenier P, Rouby J-J. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. Anesthesiology. 2004;100:9–15. https://doi.org/10.1097/00000542-200401000-00006.
7. Reissig A, Copetti R, Mathis G, Mempel C, Schuler A, Zechner P, et al. Lung ultrasound in the diagnosis and follow-up of community-acquired pneumonia: a prospective, multicenter, diagnostic accuracy study. Chest. 2012;142:965–72. https://doi.org/10.1378/chest.12-0364.
8. Zieleskiewicz L, Papinko M, Lopez A, Baldovini A, Fiocchi D, Meresse Z, et al. Lung Ultrasound Findings in the Postanesthesia Care Unit Are Associated With Outcome After Major Surgery: A Prospective Observational Study in a High-Risk Cohort. Anesth Analg. 2021;132:172–81. https://doi.org/10.1213/ANE.0000000000004755.
9. Boussier J, Lemasle A, Hantala N, Scatton O, Vaillant J-C, Paye F, et al. Lung Ultrasound Score on Postoperative Day 1 Is Predictive of the Occurrence of Pulmonary Complications after Major Abdominal Surgery: A Multicenter Prospective Observational Study. Anesthesiology. 2024;140:417–29. https://doi.org/10.1097/ALN.0000000000004855.
10. Sasaki N, Meyer MJ, Eikermann M. Postoperative respiratory muscle dysfunction: pathophysiology and preventive strategies. Anesthesiology. 2013;118:961–78.

https://doi.org/10.1097/ALN.0b013e318288834f.

11. Nørskov J, Skaarup SH, Bendixen M, Tankisi H, Mørkved AL, Juhl-Olsen P. Diaphragmatic dysfunction is associated with postoperative pulmonary complications and phrenic nerve paresis in patients undergoing thoracic surgery. J Anesth. 2024;38:386–97. https://doi.org/10.1007/s00540-024-03325-5.
12. Spadaro S, Grasso S, Dres M, Fogagnolo A, Dalla Corte F, Tamburini N, et al. Point of Care Ultrasound to Identify Diaphragmatic Dysfunction after Thoracic Surgery. Anesthesiology. 2019;131:266–78. https://doi.org/10.1097/ALN.0000000000002774.
13. Berthoud V, Nguyen M, Vinay J, Perrot J, Pages P-B, Guinot P-G, et al. Increase in Diaphragm and Expiratory respiratory muscles thickness is not associated with postoperative pulmonary complications after thoracic surgery: a prospective ultrasound cohort study. Anaesth Crit Care Pain Med. 2025;101683. https://doi.org/10.1016/j.accpm.2025.101683.
14. Pensier J, Guerrero MA, Berger-Estilita J, Borgstedt L, Zaher AMS, Jaber S, et al. Perioperative ventilation support, what clinicians and searchers must know. Anaesth Crit Care Pain Med. 2025;44:101554. https://doi.org/10.1016/j.accpm.2025.101554.
15. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet. 2007;370:1453–7. https://doi.org/10.1016/S0140-6736(07)61602-X.
16. Bossuyt PM, Reitsma JB, Bruns DE, Gatsonis CA, Glasziou PP, Irwig L, et al. STARD 2015: an updated list of essential items for reporting diagnostic accuracy studies. BMJ. 2015;351:h5527. https://doi.org/10.1136/bmj.h5527.
17. Matamis D, Soilemezi E, Tsagourias M, Akoumianaki E, Dimassi S, Boroli F, et al. Sonographic evaluation of the diaphragm in critically ill patients. Technique and clinical applications. Intensive Care Med. 2013;39:801–10. https://doi.org/10.1007/s00134-013-2823-1.
18. Itagaki T, Akimoto Y, Takashima T, Oto J. Ultrasonographic Assessment of the Diaphragm. Diagnostics. Multidisciplinary Digit Publishing Inst. 2024;14:1481. https://doi.org/10.3390/diagnostics14141481.
19. Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby J-J. Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. Am J Respir Crit Care Med. 2011;183:341–7. https://doi.org/10.1164/rccm.201003-0369OC.
20. Jammer I, Wickboldt N, Sander M, Smith A, Schultz MJ, Pelosi P, et al. Standards for definitions and use of outcome measures for clinical effectiveness research in perioperative medicine: European Perioperative Clinical Outcome (EPCO) definitions: a statement from the ESA-ESICM joint taskforce on perioperative outcome measures. Eur J Anaesthesiol. 2015;32:88–105. https://doi.org/10.1097/EJA.0000000000000118.
21. Duff A-M, Lambe G, Donlon NE, Donohoe CL, Brady A-M, Reynolds JV. Interventions targeting postoperative pulmonary complications (PPCs) in patients undergoing esophageal cancer surgery: a

systematic review of randomized clinical trials and narrative discussion. Dis Esophagus. 2022;35:doac017. https://doi.org/10.1093/dote/doac017.

22. Harrell FE, Lee KL, Mark DB. Multivariable prognostic models: issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors. Stat Med. 1996;15(19960229):361–87. https://doi.org/10.1002/(SICI)1097-0258.)15:4%253C361::AID-SIM168%253E3.0.CO;2-4.
23. van Buuren S, Groothuis-Oudshoorn K. mice: Multivariate Imputation by Chained Equations in R. J Stat Softw. 2011;45:1–67. https://doi.org/10.18637/jss.v045.i03.
24. Rubin D. Multiple Imputation for Nonresponse in Surveys | Wiley Series in Probability and Statistics [Internet]. 1987 [cited 2023 Aug 28]. https://onlinelibrary.wiley.com/doi/book/10.1002/9780470316696. Accessed 28 Aug 2023.
25. Li X-F, Jin L, Yang J-M, Luo Q-S, Liu H-M, Yu H. Effect of ventilation mode on postoperative pulmonary complications following lung resection surgery: a randomised controlled trial. Anaesthesia. 2022;77:1219–27. https://doi.org/10.1111/anae.15848.
26. Yan T, Yu Q, Li C-Q, Xu Z-Z, Ma J-H, Xie M, et al. Maximal inspiratory diaphragmatic ultrasound predicts postoperative pulmonary complications after upper abdominal surgery. Ann Intensiv Care. 2025;15:121. https://doi.org/10.1186/s13613-025-01531-2.
27. Okura K, Hasegawa K, Sakamoto R, Takahashi Y, Nagaki Y, Wakita A, et al. Association Between Preoperative Diaphragm Thickening Fraction and Postoperative Pulmonary Complications Following Thoracoscopic Esophagectomy. Respir Care. 2025;70:1429–38. https://doi.org/10.1089/respcare.12686.
28. Fu X, Wang Z, Wang L, Lv G, Cheng Y, Wang B, et al. Increased diaphragm echodensity correlates with postoperative pulmonary complications in patients after major abdominal surgery: a prospective observational study. BMC Pulm Med. 2022;22:400. https://doi.org/10.1186/s12890-022-02194-6.
29. Yuan R, Xiong W, Ran W, Liang N, Tang J, Cheng L, et al. Diaphragm excursion difference as an adjunct predictor marker of postoperative pulmonary complications in video-assisted thoracoscopic surgery: a prospective, observational study. J Thorac Disease [Internet] AME. 2025. https://doi.org/10.21037/jtd-24-1454. [cited 2025 Nov 18];17. Publishing Company.
30. Mahmoodpoor A, Fouladi S, Ramouz A, Shadvar K, Ostadi Z, Soleimanpour H. Diaphragm ultrasound to predict weaning outcome: systematic review and meta-analysis. Anaesthesiol Intensive Ther. 2022;54:164–74. https://doi.org/10.5114/ait.2022.117273.
31. Parada-Gereda HM, Tibaduiza AL, Rico-Mendoza A, Molano-Franco D, Nieto VH, Arias-Ortiz WA, et al. Effectiveness of diaphragmatic ultrasound as a predictor of successful weaning from mechanical ventilation: a systematic review and meta-analysis. Crit Care. 2023;27:174. https://doi.org/10.1186/s13054-023-04430-9.
32. Canet J, Sabaté S, Mazo V, Gallart L, de Abreu MG, Belda J, et al. Development and validation of a score to predict postoperative respiratory failure in a multicentre European cohort: A prospective,

observational study. Eur J Anaesthesiol. 2015;32:458–70.
https://doi.org/10.1097/EJA.0000000000000223.

Tables

Tables are available in the Supplementary Files section.

Figures

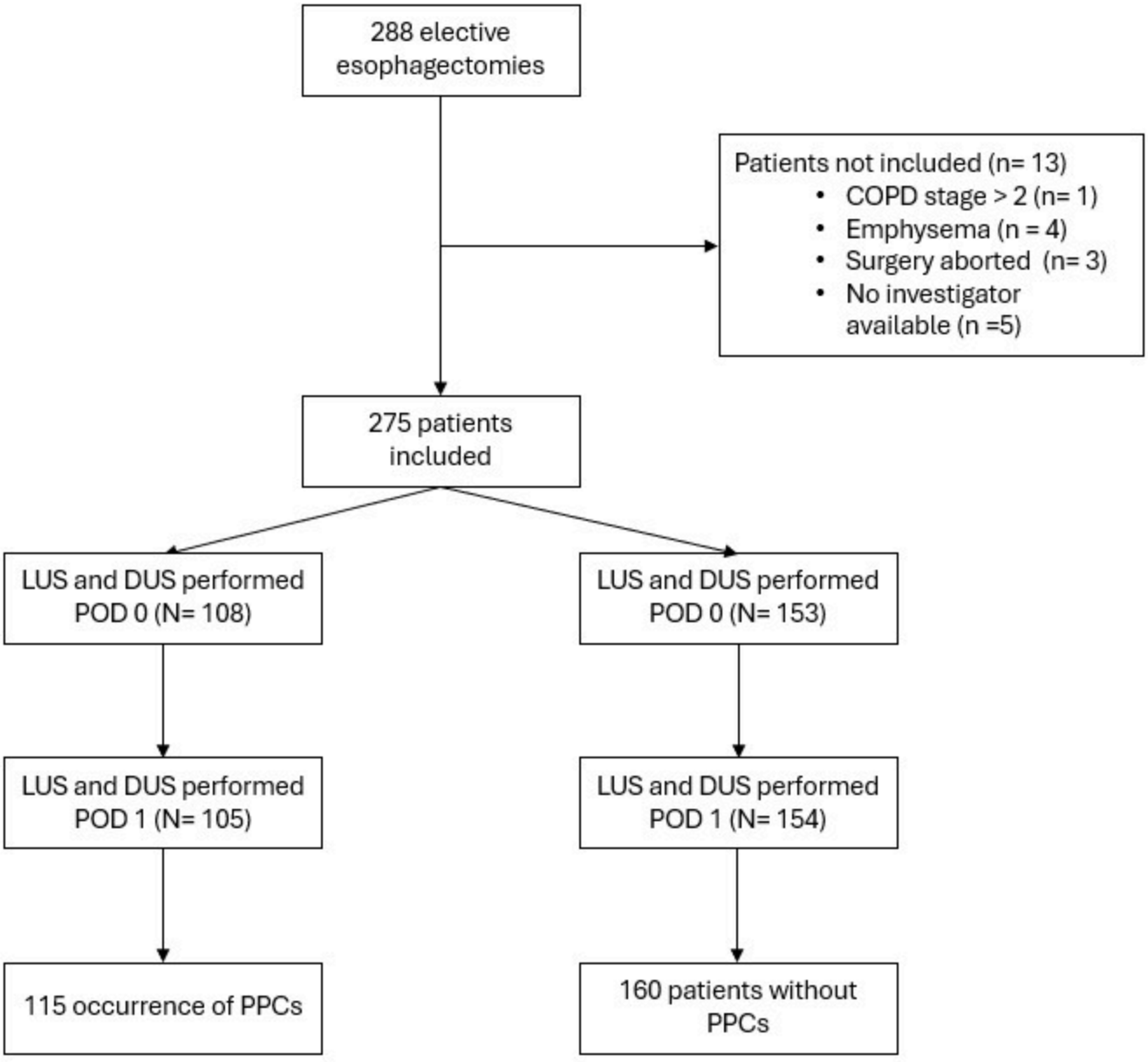


Figure 1

Participant flow diagram for the multicenter esophagectomy cohort.

The figure shows the number of adult patients screened for eligibility, excluded with reasons, and included in the final cohort, as well as those with available postoperative day-1 lung ultrasound (LUS), diaphragmatic ultrasound (DUS), and postoperative pulmonary complication (PPC) status within 7 days after surgery.

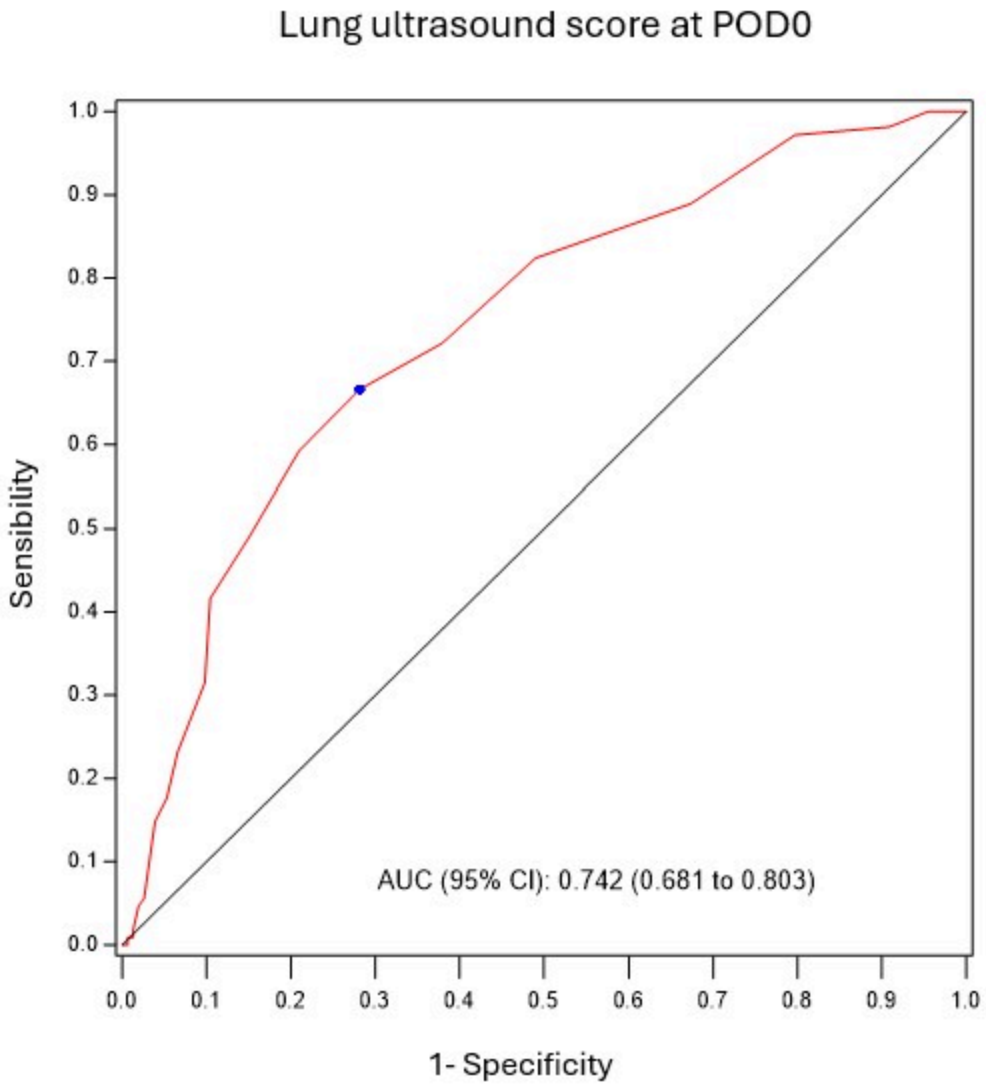


Figure 2

ROC curve of lung ultrasound score at postoperative day 0 for prediction of postoperative pulmonary complications.

Area under the curve (AUC) values with 95% confidence intervals are reported in the figure. Threshold of 7, Sensibility = 0.67 and specificity = 0.72.

DUS : diaphragmatic ultrasound ; LUS : lung ultrasound score; POD0 : postoperative day 0

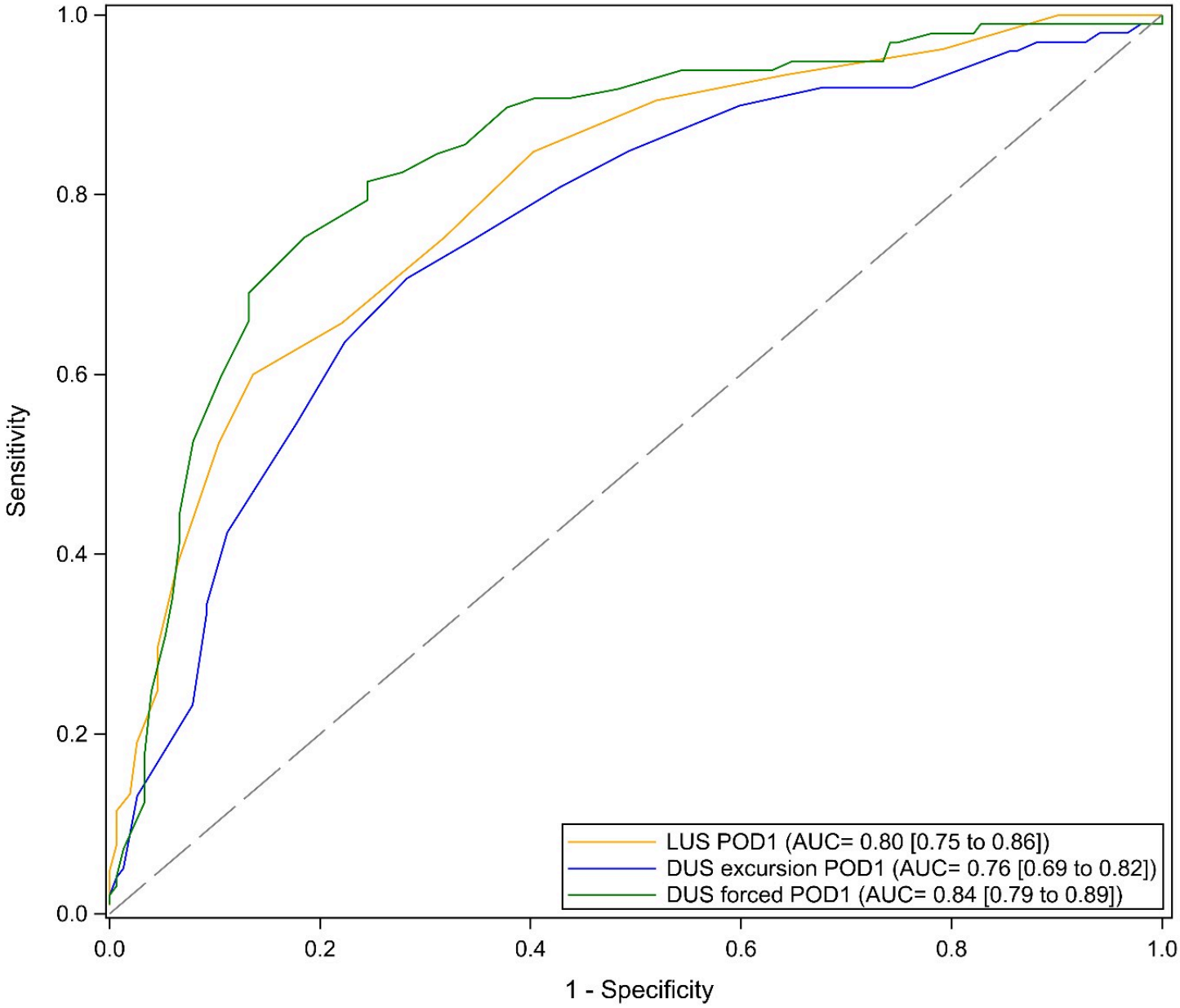


Figure 3

Receiver operating characteristic (ROC) curves of lung ultrasound score (LUS) and diaphragmatic ultrasound (DUS) on postoperative day 1 for prediction of postoperative pulmonary complications (PPCs) within 7 days after esophagectomy.

Area under the curve (AUC) values with 95% confidence intervals are reported in the figure.
Abbreviations: DUS: diaphragmatic ultrasound; LUS: lung ultrasound; POD1: postoperative day one; ROC: receiver operating characteristics.

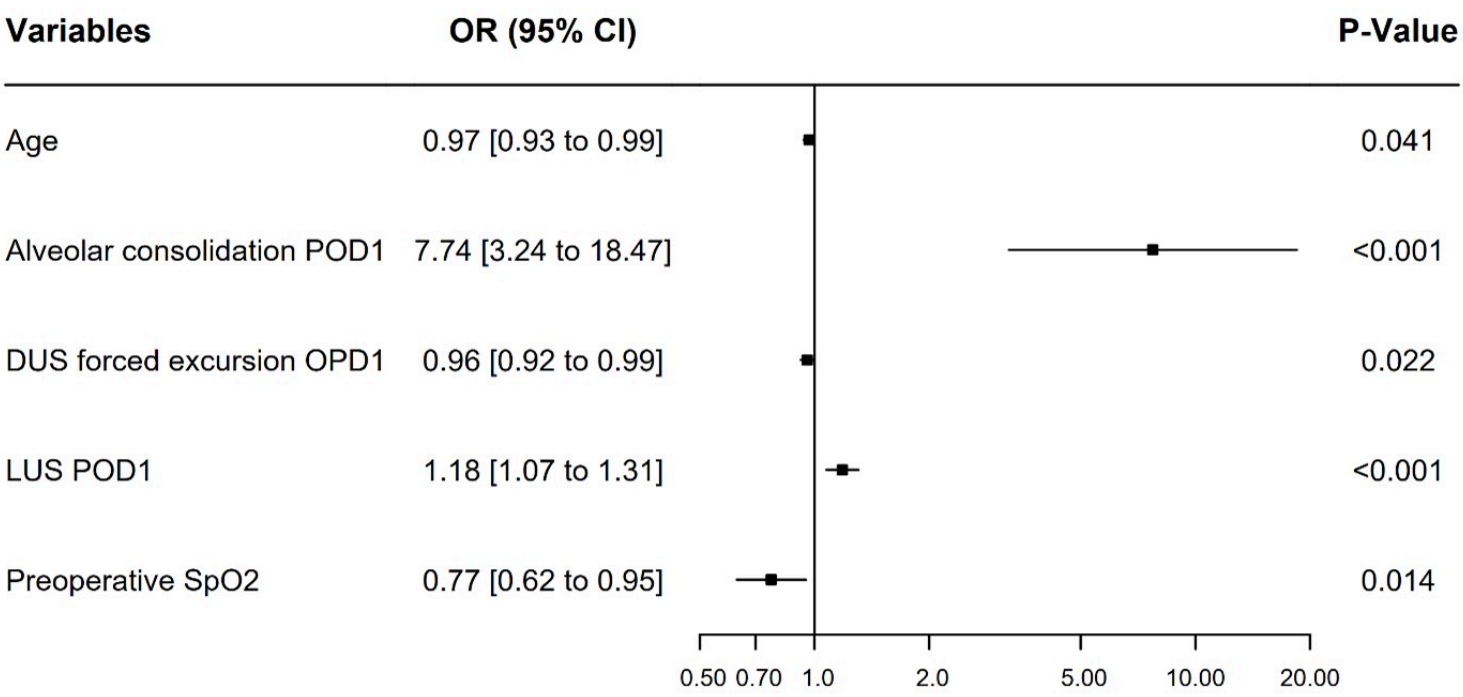


Figure 4

Forest plot of the multivariable logistic regression model for prediction of postoperative pulmonary complications.

Odds ratios (ORs) with 95% confidence intervals (CI) are shown for age, preoperative oxyhemoglobin (SpO_2), postoperative day-1 (POD1) alveolar consolidation, lung ultrasound score (LUS), and diaphragmatic ultrasound (DUS) forced excursion .

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx
- Table2.docx
- Table3.docx
- OESOLUSprotocolsupplemental2.docx
- Supplemental27012026.docx
- STROBEchecklistv4combinedPlosMedicine.docx