Original Article

Diaphragm excursion difference as an adjunct predictor marker of postoperative pulmonary complications in video-assisted thoracoscopic surgery: a prospective, observational study

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Background: Video-assisted thoracoscopic surgery (VATS) often leads to a significant number of postoperative pulmonary complications (PPCs). The diaphragm is the primary muscle involved in respiration. Diaphragm ultrasound is increasingly used as a noninvasive and portable tool for evaluating diaphragmatic contractile function. The diaphragm excursion difference (DED) provides a valuable predictive measure for clinical outcomes. This prospective, observational study aimed to evaluate the predictive feasibility of DED in relation to PPCs in patients undergoing VATS.

Methods: Between March and August 2023, a total of 151 patients undergoing VATS were enrolled in the study. Each patient underwent diaphragm ultrasound examinations both before anesthesia and within one hour after extubation. During these examinations, diaphragm excursion (DE) was recorded during quiet breathing (QB) and deep breathing (DB). The DED and diaphragm excursion fraction (DEF) were calculated at these two time points. The primary outcome measured was the incidence of major pulmonary complications occurring within seven days after surgery, while secondary outcomes included the rate of diaphragm dysfunction, duration of hospitalization, oxygenation status, and pain scores on the first and second postoperative days.

Results: Data from 151 patients were analyzed, revealing that 32 patients (21%) developed PPCs. Patients who developed PPCs exhibited a significantly lower postoperative diaphragm excursion during DB (2.27±0.59 *vs.* 3.31±0.99, P<0.001). They also showed a lower postoperative DED (0.94±0.44 *vs.* 1.94±0.91, P<0.001) and a higher DEF (0.59±0.13 *vs.* 0.44±0.12, P<0.001) compared to those without PPCs. In receiver operating characteristic curve analysis, the postoperative DED demonstrated a high sensitivity of 90.6% and a lower specificity of 64.7% for predicting PPCs, with an area under the curve (AUC) of 0.860 and a 95% confidence interval (CI) ranging from 0.788 to 0.926.

Conclusions: After VATS, lower postoperative DED may serve as an additional marker. This can help predict the risk of pulmonary complications.

Keywords: Diaphragm ultrasound; diaphragm excursion difference (DED); video-assisted thoracoscopic surgery (VATS); postoperative pulmonary complications (PPCs)

Submitted Sep 01, 2024. Accepted for publication Dec 20, 2024. Published online Feb 21, 2025.
doi: 10.21037/jtd-24-1454
View this article at: https://dx.doi.org/10.21037/jtd-24-1454

Introduction

Video-assisted thoracoscopic surgery (VATS) has become the primary method for lung resection due to its numerous advantages over traditional thoracotomy, including lower postoperative pain scores, shorter hospital stays, quicker recovery of respiratory function, and reduced costs (1). However, lung volutrauma, barotrauma, and shear stress injuries caused by repeated alveolar collapse and reopening (2) during the one-lung ventilation (OLV) strategy lead to an incidence of postoperative pulmonary complications (PPCs) of 15–37.5% in VATS. This rate is still higher than that of other major surgeries (3,4). Accurate identification of PPCs is vital. Currently, several methods are used, each with its own characteristics and limitations. Chest X-ray (CXR), computed tomography (CT), and magnetic resonance imaging (MRI) are frequently employed imaging technologies (5). CXR is commonly used as it offers a quick overview of the lungs and can detect some obvious PPCs. However, its sensitivity for early or mild cases is limited, and its two-dimensional view may miss some details. CT provides more detailed cross-sectional images and can detect a wider range of PPCs with higher sensitivity, but it involves radiation exposure and is relatively expensive and less portable. MRI, while not using ionizing radiation, is less commonly used for PPCs detection, has lower spatial resolution in some cases compared to CT, and is more expensive and time-consuming. Bronchoscopy is invasive and has associated risks, though it allows direct visualization and sample collection. Combining methods is key, and new tools like diaphragm ultrasound may help, given current limitations.

Although the definition of PPCs is not universally agreed upon, most authors consider them to be a composite outcome (6). Our study chose the European joint task force published guidelines for perioperative clinical outcome (EPCO) as the diagnostic standard for PPCs (7). Several factors can increase the risk of PPCs, including pulmonary diseases, age, tobacco use, nutritional status, surgical site, anesthetic method, and surgery duration (8). Although preoperative education, effective cough exercises, aerobic training, early postoperative activities, and breathing exercises can efficiently improve pulmonary function, recovery takes more than a few months and may not return to preoperative levels (9). Severe PPCs increase morbidity, mortality, and healthcare resource utilization (10). Therefore, predicting, diagnosing, and preventing PPCs in advance are essential to minimize their negative impact.

The diaphragm is the primary respiratory muscle, a dome-shaped structure composed of a central tendon with surrounding peripheral muscle fibers, and is innervated by the ipsilateral phrenic nerve that arises from the cervical nerve roots of C3–C5, accounting for 60–70% of the respiratory workload (11). The phrenic nerve is a crucial nerve in the respiratory system. It is a paired nerve that arises from the cervical nerve roots of C3–C5. It innervates the diaphragm, which is the primary respiratory muscle. The phrenic nerve is responsible for transmitting the motor impulses that cause the diaphragm to contract and relax, thereby playing a vital role in the process of breathing. Diaphragm ultrasound plays a crucial role in the assessment of the diaphragm. It is utilized to evaluate the function and structure of the diaphragm muscle. Diaphragm ultrasound, as a feasible, reproducible, and noninvasive tool, is gradually being used to assess residual muscle relaxation after surgery and evaluate the appropriate moment for weaning from mechanical ventilation (12-14). However, the relationship between diaphragm ultrasound and PPCs has been seldom

Highlight box

Key findings

- After video-assisted thoracoscopic surgery (VATS), lower postoperative diaphragm excursion difference (DED) may serve as an additional marker. This can help predict the risk of pulmonary complications.

What is known and what is new?

- In VATS surgery, the incidence of postoperative pulmonary complications (PPCs) is higher due to alveolar damage caused by the single-lung ventilation strategy. Chest X-ray (CXR), computed tomography (CT), and magnetic resonance imaging (MRI) are commonly used imaging techniques to identify PPCs, but their radiation exposure and non-portability limit widespread application. The diaphragm is the primary respiratory muscle, and diaphragm ultrasound, as a non-invasive and portable tool, is increasingly used to assess diaphragm contraction function. Lower postoperative DED is associated with an increased risk of PPCs in patients undergoing VATS.
- The study found that patients with PPCs had significantly reduced diaphragm excursion during deep breathing and a lower DED, suggesting that DED could be a valuable predictive marker for PPCs.

What is the implication, and what should change now?

- The results of this study suggest that after VATS surgery, healthcare professionals can use DED as an additional indicator to predict the risk of pulmonary complications, which may improve postoperative management and prognosis for patients.

reported. Diaphragm ultrasound parameters include diaphragm excursion (DE), diaphragm thickness (Tdi), diaphragm excursion difference (DED), and diaphragm excursion fraction (DEF). Among these parameters, DE and Tdi are more frequently used in critically ill patients, while only one study has mentioned DED and DEF, which are derived from DE, suggesting that compared with DE and DEF, DED has the highest specificity for recognizing postoperative residual curarization (15).

In our study, we proposed that DED serves as an additional marker to predict PPCs in patients undergoing VATS, and we compared the diagnostic accuracy of diaphragm ultrasound parameters. We present this article in accordance with the TRIPOD reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1454/rc).

Methods

Study approval

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the ethics review board of the First Affiliated Hospital of Chongqing Medical University (No. 2022-222) and informed consent was taken from all individual participants. Additionally, it was registered in the Chinese Clinical Trials Registry (registration number: ChiCTR2300068999) at https://www.chictr.org.cn/.

Study population

From March 2023 to August 2023, patients scheduled for elective unilateral VATS (wedge, segmental, or lobar) via the 5th intercostal anterior axillary line were enrolled.

The inclusion criteria were: (I) aged between 18 and 80 years; (II) American Society of Anesthesiologists (ASA) physical status II–III; (III) voluntary participation; (IV) no preoperative radiotherapy, chemotherapy, or other treatments that could affect diaphragm function.

The exclusion criteria included: (I) severe cardiac diseases, or hepatic and renal dysfunction; (II) preoperative severe pulmonary complications (such as pulmonary infection, pleural effusion, atelectasis, respiratory failure, or cardiopulmonary edema); (III) previous pneumonectomy or diaphragm surgery, or an unpredictable conversion to open thoracotomy; (IV) inability to comprehend the study; (V) unclear ultrasound images; (VI) refusal to participate.

The detachment criteria were: (I) perioperative serious adverse events; (II) postoperative transfer to the intensive care unit.

Anesthesia protocol

All patients were fasted for 6–8 hours. Routine pulse oximetry, electrocardiography, noninvasive blood pressure, and bispectral index (BIS) were monitored. A radial artery cannula was placed under local anesthesia for monitoring arterial pressure and detecting arterial blood gas analysis. Anesthesia was induced using propofol 1.5–2 mg/kg, midazolam 0.06–0.08 mg/kg, sufentanil 0.5–0.6 μg/kg, and vecuronium 0.08–0.12 mg/kg.

After anesthesia induction, an appropriately sized endotracheal double-lumen tube or tracheal catheter with a bronchial blocker was intubated and positioned with the help of fiberoptic bronchoscopy. Anesthesia was maintained with remifentanil (0.15–0.3 μg/kg/min) and propofol (2–4 mg/kg/h), combined with inhalation of sevoflurane 1–2% in FiO_2 of 100% to maintain BIS between 40 and 60.

All patients received volume-controlled mechanical ventilation during OLV. The ventilation setting was a tidal volume (VT) of 6 mL/kg of the ideal body weight and an inspiratory-to-expiratory ratio (I:E) of 1:2. A respiratory rate (RR) of 12–20 cycles/min was used to ensure an end-tidal carbon dioxide partial pressure ($PetCO_2$) of 35–45 cmH_2O, and positive end-expiratory pressure (PEEP) was applied at 5 cmH_2O, provided that the peak airway pressure was less than 30 mmHg. The goals of intraoperative hemodynamics were to maintain narrow arterial pressure fluctuations [avoiding hypotension or hypertension defined as a greater than 20% decrease or increase in mean arterial pressure from baseline (16)] a stable heart rate between 50 and 100 beats/min, and SpO_2 above 90%. Vasoactive agents such as ephedrine, noradrenaline, or phenylephrine, along with recruitment maneuvers, two-lung ventilation, or fiberoptic bronchoscopy adjustments, were used as rescue therapies to avoid severe hypotension, severe bradycardia, and intraoperative hypoxemia.

All patients were transferred to the post-anesthesia care unit (PACU) after surgery. Neostigmine and atropine were used to antagonize residual neuromuscular blockade. Once the patient had adequately cooperative and alert consciousness, smooth spontaneous ventilation, stable hemodynamics, and oxygenation status (SpO_2 more than 96% in FiO_2 of 40% and $PetCO_2$ less than 45 mmHg), the endotracheal double-lumen tube or tracheal catheter

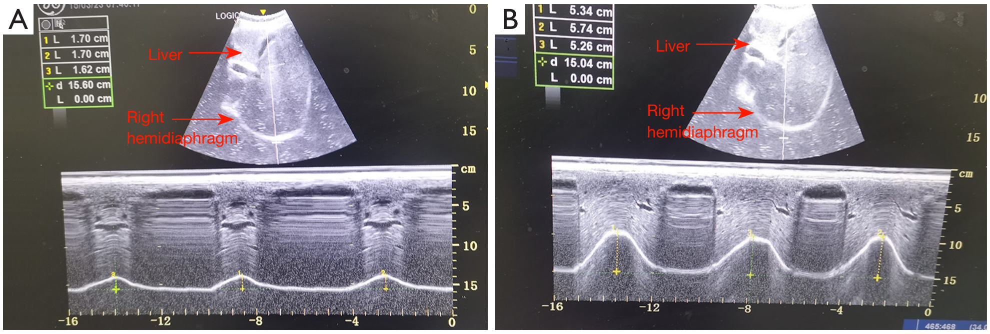

Figure 1 The right hemidiaphragm ultrasound image in one patient when quiet breathing (A) and deep breathing (B). The diaphragm excursion was measured using anatomical M-mode with a 2.5–3.5 MHz transducer, and it was recorded over three consecutive respiratory cycles, indicated by yellow dotted lines between the cursors.

was removed by an experienced anesthesiologist. The surgeons, nurses, and staff in the PACU were blinded to the experimental procedure.

Measurements and assessments

Ultrasonography

A fixed anesthesiologist measured diaphragm excursion on the right hemidiaphragm before anesthesia and within one hour after extubation. The anesthesiologist has completed a fellowship in regional anesthesia and pain management, which included extensive training in ultrasound-guided procedures. Additionally, they have over five years of clinical experience in performing ultrasound measurements for regional anesthesia applications. All examinations were conducted at the bedside while patients were positioned in a supine horizontal position. The curved array transducer was placed on the right chest wall between the midclavicular and anterior axillary lines at the ninth or tenth intercostal space. First, select the two-dimensional mode (B-mode) to locate the liver and portal vein acoustic window. Then switch to anatomical motion mode (M-mode) with a slow sweeping speed to capture at least three consecutive respiratory cycles with consistent amplitude and frequency on the same screen. Diaphragm excursion was recorded after patients performed a few quiet breathing (QB) and deep breathing (DB) respectively; the value of DE was the distance from the trough to the peak of the sine wave (*Figure 1*). These parameters were measured three times, and the average value was calculated. Diaphragm dysfunction was defined as a diaphragm excursion of less than 1 cm during quiet inspiration (17). The DEF was calculated as the DE(QB) divided by the DE(DB), and the DED was defined as the DE(DB) minus the DE(QB), both calculated pre-operatively and post-operatively. The following formulas were used to determine DED and DEF:

$$DED = DE(DB) - DE(QB) \tag{1}$$

$$DEF = DE(QB)/DE(DB) \tag{2}$$

Postoperative analgesia and pain assessment

In our study, we adopted a multimodal analgesia protocol to manage postoperative acute pain. Paravertebral nerve blockade was performed preoperatively in the fifth and sixth intercostal spaces under ultrasound guidance, using 15 mL of 0.33% ropivacaine. Meanwhile, we used patient-controlled intravenous analgesia (PCIA) postoperatively, which consisted of sufentanil (50 µg), ondansetron (4 mg), flurbiprofen axetil (100 mg), and 87 mL of 0.9% normal saline. Continuous wound infusion analgesia (CWA) with local anesthetics was also administered. A Numerical Rating Scale (NRS) (18) was utilized by a designated physician to assess pain levels, where 0 indicates no pain and 10 represents the worst pain imaginable. Ibuprofen codeine sustained-release tablets and flurbiprofen axetil were used as routine postoperative analgesics, while tramadol hydrochloride was administered as a rescue medication when pain became intolerable.

Data collection

Demographic parameters recorded as baseline included age, gender, body mass index (BMI), ASA physical status, preoperative blood routine examination, the Assess Respiratory risk In Surgical patients in Catalonia (ARISCAT) score (19,20), and comorbidities. Intraoperative

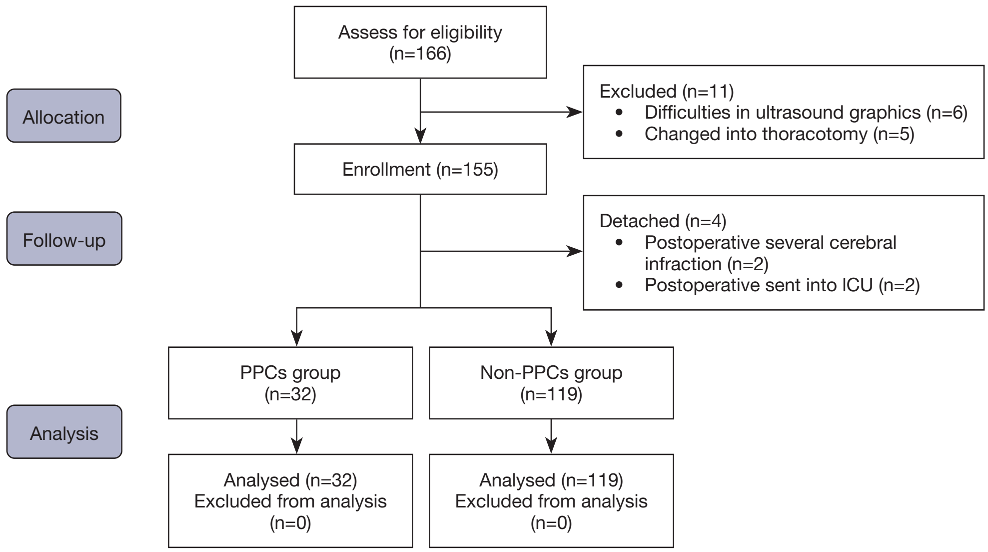

Figure 2 The flowchart of the study. PPCs, postoperative pulmonary complications; ICU, Intensive Care Unit.

information included the type and site of surgery, anesthesia duration, operation duration, the type of tracheal catheter, and frozen-section outcomes. Postoperative indicators included the time to remove the tracheal catheter, duration of stay in the PACU, incidence of PPCs and diaphragm dysfunction, hospitalization duration, NRS pain score, and arterial blood gas analysis outcomes.

Primary and secondary outcomes

The primary outcome of this study was the occurrence of PPCs, defined as any of the following conditions occurring within 7 days after surgery: atelectasis, pneumothorax, pleural effusion, pneumonia, respiratory tract infection, persistent pulmonary air leakage, hypoxemia, or pulmonary hemorrhage. This definition is based on postoperative CXR, sputum or blood cultures, blood routine examinations, and clinical manifestations. The secondary outcomes included the proportion of diaphragm dysfunction, hospitalization duration, oxygenation status, and NRS scores on the first and second postoperative days.

Statistical analysis

The sample size calculation was based on a preliminary experiment conducted using PASS 15.0. We assumed a 20% incidence of PPCs in VATS, with an alpha error of 0.05 and a beta error of 0.1. It was calculated that 140 patients were needed, and we hypothesized a dropout rate of 10%, resulting in a total of at least 154 patients to be recruited for this study. SPSS 26.0 was used for statistical analysis, and GraphPad Prism 9.0 was used for figure-making. Categorical data are presented as numbers or percentages (%) and compared using the Chi-squared test or Fisher's exact test. Continuous data are presented as mean ± standard deviation (SD) or as median and interquartile ranges (IQRs) and compared using the Mann-Whitney *U* test or independent-samples test. Receiver-operating characteristic curve analysis was performed, and the area under the curve (AUC) was plotted to evaluate prognostic accuracy and choose the optimal cut-off value. A P value of less than 0.05 was considered statistically significant.

Results

Patients population

During the study period, 166 patients undergoing VATS were evaluated for initial eligibility. Of these, 151 patients were included in the final analysis, while 15 patients were excluded for the following reasons: 6 had difficulty with ultrasound imaging, 5 required conversion to thoracotomy during the procedure, 2 developed severe cerebral infarction postoperatively, and 2 were admitted to the Intensive Care Unit (ICU) postoperatively due to perioperative anaphylactic shock and cardiac arrest (*Figure 2*).

The baseline demographic and clinical characteristics of participants

The baseline demographic data, details of anesthesia and surgery are shown in *Table 1*. The PPCs group and the non-PPCs group did not show significant differences in preoperative and intraoperative data.

Perioperative tendency in diaphragm ultrasound parameters

There was no statistical difference in preoperative DE(QB) (1.56±0.26 *vs.* 1.67±0.36 cm, P>0.05), DE(DB) (5.47±1.18 *vs.* 5.44±1.31 cm, P>0.05), DED (3.94±1.20 *vs.* 3.70±1.29 cm, P>0.05), DEF (0.30±0.08 *vs.* 0.33±0.10, P>0.05), and postoperative DE(QB) (1.32±0.47 *vs.* 1.37±0.35 cm, P>0.05) between the PPCs group and the non-PPCs group.

In our observations, we found that compared to the non-PPCs group, the postoperative DE(DB) (2.27±0.59 *vs.* 3.31±0.99 cm, P<0.001) and DED (0.94±0.44 *vs.* 1.94±0.91 cm, P<0.001) in the PPCs group were statistically lower, while postoperative DEF (0.59±0.13 *vs.* 0.44±0.12, P<0.001) was significantly higher (*Figure 3*, *Table 2*).

Accuracy of diaphragm ultrasound parameters for the prediction of PPCs

The accuracy of diaphragm ultrasound in predicting PPCs is illustrated in *Figure 4*. Postoperative DE(DB) [R=0.821, 95% confidence interval (CI): 0.743–0.896] and DED (R=0.860, 95% CI: 0.788–0.926) were positively correlated with PPCs, while postoperative DEF (R=0.800, 95% CI: 0.704–0.878) was inversely correlated with PPCs. Among all parameters, DED had the highest AUC, with a sensitivity of 0.906 and a specificity of 0.647 (*Table 3*).

The primary outcome

Thirty-two patients developed PPCs, and the type of PPCs including atelectasis (13/151, 8.6%), pleural effusion (4/151, 2.6%), pneumothorax (2/151, 1.3%), persistent lung leakage (8/151, 5.3%), respiratory infection (3/151, 2.0%), pneumonia (4/151, 2.6%), hypoxemia (1/151, 0.7%) and pulmonary hemorrhage (1/151, 0.7%) (*Table 4*).

The secondary clinical outcomes

Significant differences were observed between the PPCs group and the non-PPCs group. The PPCs group had a longer duration of hospitalization (5.4±2.9 *vs.* 3.5±0.7 days, P<0.001) and a higher incidence of diaphragm dysfunction (25% *vs.* 9%, P=0.02). Conversely, the PaO_2/FiO_2 ratio was lower in the PPCs group (309±80 *vs.* 349±81, P=0.007). No differences were found in the NRS on the first and second postoperative days, the time to remove the tracheal catheter, PACU stay, neutrophil to lymphocyte ratio (NLR), and Systematic Immune Inflammation Index (SII) between the two groups (*Table 5*).

Discussion

In our observational and prospective study, 32 out of 151 patients (21%) developed PPCs during VATS. Our findings show a significant correlation between postoperative DE, DED, and DEF with the occurrence of PPCs. Patients who developed PPCs had significantly lower postoperative diaphragm excursion, DED, and higher DEF compared to those who did not develop PPCs. Additionally, their length of hospital stay and incidence of diaphragm dysfunction were also increased. Notably, DED exhibited a high AUC and sensitivity, further supporting its predictive value for PPCs. The novelty of our study is that while DE(DB), DED, and DEF all demonstrate predictive effects for PPCs, DED shows the highest AUC and sensitivity, making it potentially more suitable for predicting these complications.

In previous studies, diaphragmatic electromyography, transdiaphragmatic pressure measurement, MRI, and phrenic nerve stimulation have been used to detect diaphragm dysfunction. Diaphragm ultrasound is particularly associated with critically ill patients, serving as a noninvasive, real-time, and reproducible bedside tool to predict weaning failure, extubation success, and recognize diaphragm paralysis. Recently, more research on diaphragm ultrasound has been employed in the evaluation of respiratory diseases and the diagnosis of neuromuscular diseases (20,21). Daniel *et al.* investigated that in thoracic surgery, diaphragm dysfunction can persist for at least three days postoperatively and is associated with an increase in hospital stay (22). Similarly, Yu *et al.* found that a preoperative diaphragm Tdi <0.28 cm was associated with an increased incidence of PPCs in robot-assisted laparoscopic prostatectomy (23). In an observational study on upper abdominal surgery, Vanamail *et al.* found that DE(QB) and DE(DB) both decreased on postoperative days 1, 2, and 3 and were associated with PPCs. DE(QB) <1.3 cm or DE(DB) <1.6 cm had a sensitivity of 77% and 75%, with AUCs of 0.653 and 0.675, respectively, for

Table 1 Baseline demographic and clinical characteristics between patients with and without PPCs

Indicators	PPCs group (n=32)	Non-PPCs group (n=119)	P value
Age (years)	55.9±12.1	56.5±12.0	0.81
BMI (kg/m^2)	23.5±3.0	23.6±3.3	0.94
Gender (male/female)	13/19	47/72	0.91
ASA (II/III)	24/8	77/42	0.27
History of smoking			0.77
Yes	7	29	
No	25	90	
Pulmonary function test			
FVC (L)	3.23±0.79	3.24±0.81	0.98
FVC (%pred)	2.99±0.77	2.98±0.69	0.95
FEV_1 (L)	2.35±0.72	2.48±0.66	0.37
FEV_1 (%pred)	2.46±0.62	2.46±0.55	0.37
FEV_1/FVC (%)	74.45±13.08	76.56±10.43	0.37
PEF (L/s)	92.48±19.76	100.26±22.31	0.10
Comorbidity			
Hypertension	3 (9.4)	32 (26.9)	0.06[a]
Diabetes mellitus	2 (6.3)	9 (7.6)	>0.99[a]
Coronary heart disease	0	4 (3.4)	0.59[a]
Novel coronavirus infection (positive/negative)	16/16	63/56	0.84
ARISCAT score	36.1±12.3	36.1±11.5	0.99
Type of tracheal catheter			0.84
Endotracheal double-lumen tube	20	72	
Bronchial blockers	12	47	
Duration of anesthesia (min)	152±54	153±51	0.95
Duration of surgery (min)	104±50	102±45	0.89
Surgical site			0.42
Left	16 (50.0)	48 (40.3)	
Right	16 (50.0)	71 (59.7)	
Postoperative pathological pattern			0.45
Benign	8	21	
Malignant	24	98	
Type of surgery			0.69[a]
Wedge resection	3 (9.4)	19 (16.0)	
Segmentectomy	4 (12.5)	15 (12.6)	
Lobectomy	25 (78.1)	85 (71.4)	

Table 1 (*continued*)

Table 1 (*continued*)

Indicators	PPCs group (n=32)	Non-PPCs group (n=119)	P value
Pre-NLR	1.92±0.92	2.05±1.05	0.50
Pre-MLR	0.20±0.08	0.23±0.11	0.14
Pre-SII	400±245	453±264	0.32
Pre-PaO_2/FiO_2 (mmHg)	419±40	407±47	0.19

Continuous data are presented as mean ± SD. Categorical data are described as number or percentage. [a], the Fisher's exact test. IQR, interquartile range; BMI, body mass index; ASA, American Society of Anesthesiologists; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 s; PEF, peak expiratory flow; ARISCAT, Assess Respiratory Risk In Surgical Patients in Catalonia; NLR, neutrophil to lymphocyte ratio; PPCs, postoperative pulmonary complications; MLR, monocyte to lymphocyte ratio; SII, Systemic Immune Inflammation Index (platelet count × neutrophil count/lymphocyte count); SD, standard deviation.

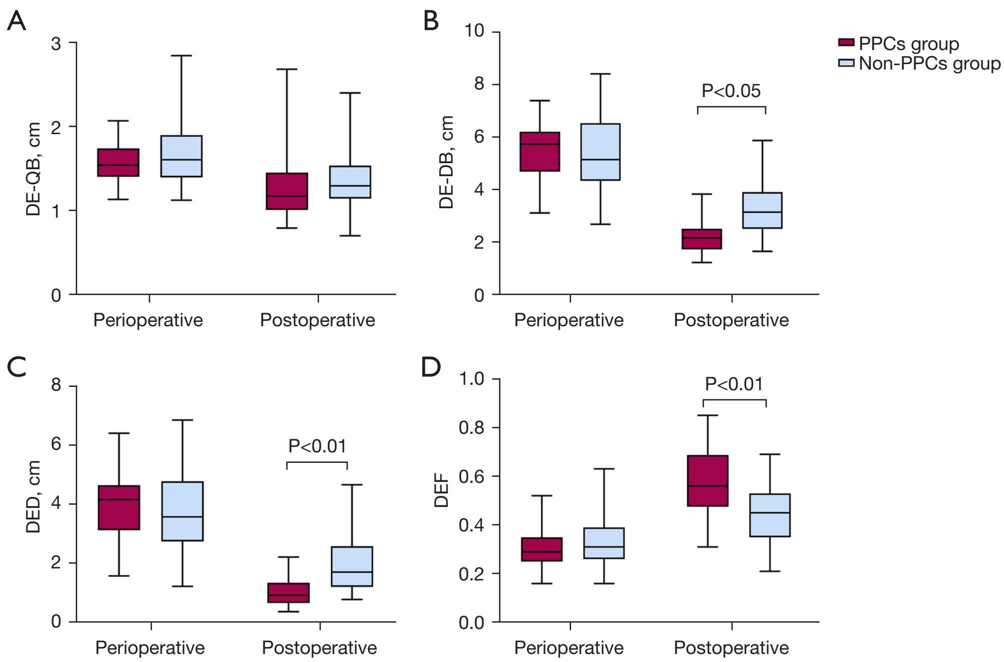

Figure 3 Preoperative and postoperative DE(QB) (A), DE(DB) (B), DED (C) and DEF (D) between PPCs group and non-PPCs group. PPCs, postoperative pulmonary complications; DE, diaphragm excursion; QB, quiet breathing; DB, deep breathing; DED, diaphragm excursion difference; DEF, diaphragm excursion fraction.

predicting PPCs (10).

Diaphragm ultrasound parameters, especially DE and Tdi, were used frequently. However, the ultrasound transducer for acquiring Tdi was positioned at the 8th to 9th intercostal space along the anterior axillary line. This placement can be affected by factors such as wound dressing, body type, and patient position. The normal diaphragm thickness in healthy, spontaneously QB patients was only 1.7–2.2 mm (24), which can contribute to measurement difficulties and errors. In contrast, detecting DE on the right hemidiaphragm is easier and more reproducible than on the left (25). Although there is a certain deviation in the ultrasound cursor angle between experts and trainees, the results of DE were similar (26). Since there was no statistical difference in the surgical site between the two groups in our study, we measured diaphragm excursion only on the right side and calculated its derived parameters. There remains considerable uncertainty about the normal values of DE(DB) and DE(QB). Previous study has reported maximal diaphragm excursion estimates ranging from 6 to 7 cm,

Table 2 Diaphragm ultrasound indicators between patients with and without developing PPCs

Indicators	PPCs group (n=32)	Non-PPCs group (n=119)	*t* value	P value
Pre-DE(QB) (cm)	1.56±0.26	1.67±0.36	1.565	0.12
Pre-DE(DB) (cm)	5.47±1.18	5.44±1.31	0.125	0.90
Pre-DEF	0.30±0.08	0.33±0.10	1.509	0.13
Pre-DED (cm)	3.94±1.20	3.70±1.29	0.961	0.34
Post-DE(QB) (cm)	1.32±0.47	1.37±0.35	0.684	0.60
Post-DE (DB) (cm)	2.27±0.59	3.31±0.99	5.700	<0.001*
Post-DEF	0.59±0.13	0.44±0.12	6.327	<0.001*
Post-DED (cm)	0.94±0.44	1.94±0.91	5.986	<0.001*

Data are presented as mean ± SD. *, P<0.05. PPCs, postoperative pulmonary complications; DE, diaphragm excursion; QB, quiet breathing; DB, deep breathing; DEF, diaphragm excursion fraction; DED, diaphragm excursion difference; SD, standard deviation.

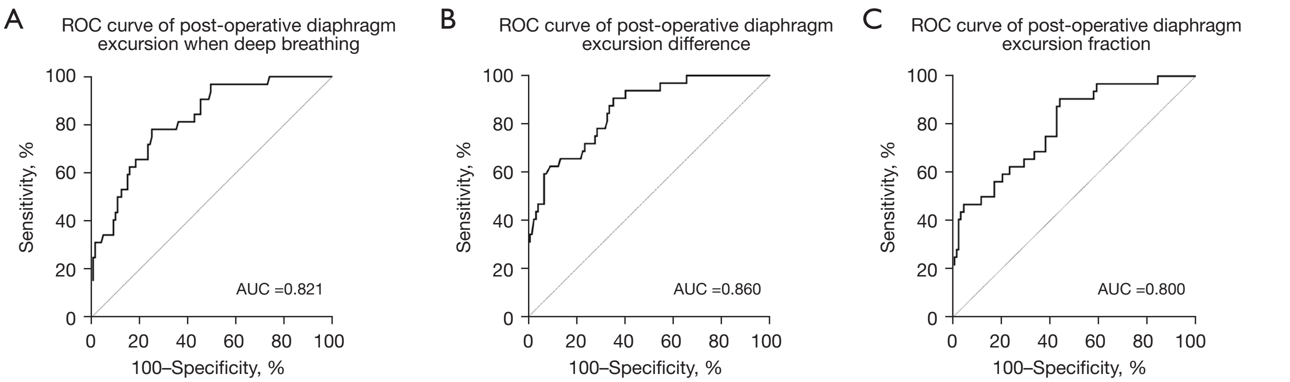

Figure 4 ROC curve of post-operative diaphragm ultrasound indicators. (A) Diaphragm excursion when deep breathing. (B) Diaphragm excursion difference. (C) Diaphragm excursion fraction. AUC, area under the curve; ROC, receiver operator characteristic curve.

Table 3 Diagnostic accuracy of different diaphragm ultrasound parameters after extubation

Indicators	Cut-off	Sensitivity	Specificity	Youden index	AUC (95% CI)
Post-DE(DB) (cm)	2.570	0.781	0.739	0.533	0.821 (0.743–0.896)
Post-DEF	0.455	0.546	0.906	0.452	0.800 (0.704–0.878)
Post-DED (cm)	1.415	0.906	0.647	0.553	0.860 (0.788–0.926)

AUC, area under the curve; CI, confidence interval; DE, diaphragm excursion; DB, deep breathing; DEF, diaphragm excursion fraction; DED, diaphragm excursion difference.

or specifically 6±0.7 and 6.8±0.8 cm (27). In our study, however, DE(DB) ranged from 2.72 to 8.42 cm, with an average of 5.5±1.3 cm. Factors such as age, BMI, ethnicity, and gender may influence diaphragm motion (28).

Risk factors such as preoperative age, smoking status, cardiopulmonary exercise capacity, pulmonary function, and chronic pulmonary diseases (such as chronic bronchitis, chronic obstructive pulmonary disease, pulmonary fibrosis, and pulmonary hypertension) (29), as well as intraoperative OLV strategy, ventilator-associated lung injury (VALI), muscle paralysis caused by general anesthesia, atelectasis, airway closure, postoperative reductions in pulmonary volumes, mucociliary clearance, respiratory muscle function, pain inhibition of respiratory muscles, decreased diaphragm activity, and irritation from chest drainage tubes, can all lead to PPCs (30). The incidence of PPCs increased with surgical incisions close to the diaphragm. Compared to the non-PPCs group, the incidence of diaphragm dysfunction and length of hospitalization in the PPCs group was significantly higher. One possible explanation for this discrepancy is that postoperative diaphragm systolic dysfunction suppresses cough, sputum clearance, and DB, which decreases pulmonary function by exacerbating the redistribution of pulmonary perfusion, ventilation of lower lung fields, and gas exchange ability, further leading to or aggravating PPCs and prolonging hospital stays. This aligns with our findings that atelectasis had the highest incidence of PPCs. Similarly, PPCs also contribute to worse oxygenation status and further prolonged hospital stays.

Table 4 Type and severity of PPCs group

Type of PPCs	Mild	Moderate	Severe
Atelectasis	7 (4.6)	3 (2.0)	3 (2.0)
Persistent pulmonary air leakage	4 (2.6)	4 (2.6)	0
Respiratory tract infection	2 (1.3)	0	1 (0.7)
Pleural effusion	3 (2.0)	0	1 (0.7)
Pneumothorax	2 (1.3)	0	0
Hypoxemia	1 (0.7)	0	0
Pulmonary hemorrhage	0	0	1 (0.7)
Pneumonia	3 (2.0)	1 (0.7)	0

Data are presented as n (%). Mild: results in only temporary harm and would not usually require specific clinical treatment. Moderate: more serious complication but one which does not usually result in permanent harm or functional limitation and usually requires clinical treatment. Severe: results in significant prolongation of hospital stay and/or permanent functional limitation or death. Almost always requires clinical treatment. PPCs, postoperative pulmonary complications.

The ARISCAT risk score was the only score that maintained sufficient predictive power during external validation across 21 models for predicting PPCs (31). It incorporates factors such as age, preoperative SpO_2, operation time, site of surgery, preoperative erythrohemoglobin levels, emergency status of the operation, and respiratory infection history within the past month. In our study, no significant differences were found in sex, age, BMI, smoking status, lung function, comorbidity, and ARISCAT score between the two groups.

The Systematic Immune Inflammation Index (SII) is a novel indicator of inflammation, calculated as platelet count multiplied by neutrophil count divided by lymphocyte count (32). Most studies have reported positive results regarding SII's ability to predict the prognosis of various malignant tumors, including bladder cancer, gynecological cancers, breast cancer, and non-small cell lung cancer (33-35). However, there are no studies on its application for predicting the short-term prognosis of surgical patients; therefore, we included it in our statistical analysis.

Table 5 Postoperative conditions between PPCs group and non-PPCs group

Indicators	PPCs group (n=32)	Non-PPCs group (n=119)	*t* value	P value
Duration of tracheal catheter removal (min)	15±9	16±12	0.559	0.46
Duration of PACU stay (min)	72±21	73±23	0.298	0.96
Post-NLR	7.5±3.4	8.3±4.6	0.948	0.35
Post-MLR	0.54±0.19	0.64±0.30	2.408	0.02*
Post-SII	1,563±925	1,782±1,054	1.083	0.28
Post-PFR (mmHg)	309±80	349±81	0.564	0.007*
NRS on first day after surgery	3.7±2.0	3.8±2.2	0.405	0.69
NRS on second day after surgery	1.9±1.9	2.0±1.5	0.316	0.75
Duration of postoperative hospitalization (days)	5.4±2.9	3.5±0.7	6.655	<0.001*
Diaphragm dysfunction (positive/negative)	8 (25%)/24 (75%)	11 (9%)/108 (91%)	5.692	0.02*

Data are presented as n (%) or mean ± standard deviation. *, P<0.05. PPCs, postoperative pulmonary complications; PACU, post-anesthesia care unit; NLR, neutrophil to lymphocyte ratio; MLR, monocyte to lymphocyte ratio; SII, Systemic Immune Inflammation Index (platelet count × neutrophil count/lymphocyte count); PFR, PaO_2/FiO_2; NRS, Numerical Rating Scale.

Although there was no significant difference in the values of NLR and SII between the PPCs group and the non-PPCs group, this may be attributed to our small sample size and the single blood routine examination conducted on the first day after surgery. Additionally, we did not assess biochemical markers, such as C-reactive protein and interleukin 6 (IL-6), which could better reflect surgical tissue trauma (36).

This study presents several limitations. First, this research is conducted at a single center and involves a small sample size with a short-term follow-up. Future studies should be conducted as multi-center research with a large sample size and long-term follow-up. Second, the duration of the operations in our study was generally short, there were no age restrictions, and the incidence of PPCs was low. Stratified investigations and the establishment of prognostication models may yield more accurate conclusions. The technique's operator dependency is a significant concern. Despite having a proficient anesthesiologist in our study, in a broader clinical setting, varying operator skills can lead to inconsistent examination quality and measurement accuracy. Specialized training is vital for proper diaphragm identification and accurate image interpretation. Patient characteristics also pose challenges. Obesity, for instance, can impede the ultrasound signal due to increased adipose tissue, making diaphragm visualization and excursion measurement difficult. Lung diseases can disrupt normal anatomy and physiology, complicating the interpretation of diaphragm function via ultrasound. Regarding the barriers to routine implementation, the scarcity of widespread training programs for healthcare providers is a major hurdle. Without adequate training, they may be hesitant to adopt this new technology. Resistance to change and the need to adapt to new workflows are also factors. Incorporating diaphragm ultrasound into patient evaluations demands extra time, potentially disrupting the current clinical process. Financially, the costs associated with acquiring and maintaining ultrasound equipment are a consideration for healthcare institutions. Overcoming these barriers is essential for successfully integrating diaphragm ultrasound into standard clinical procedures. By addressing these issues, we can optimize the use of diaphragm ultrasound and better understand its role in relation to PPCs and overall respiratory function assessment.

Conclusions

Our research shows that lower postoperative DED serves as an additional marker in the predictive algorithm for PPCs in patients undergoing VATS, demonstrating high AUC and sensitivity.

Acknowledgments

None.

Footnote

Reporting Checklist: The authors have completed the TRIPOD reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1454/rc

Data Sharing Statement: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1454/dss

Peer Review File: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1454/prf

Funding: None.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1454/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by ethics review board of the First Affiliated Hospital of Chongqing Medical University (No. 2022-222) and informed consent was taken from all individual participants.

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Cite this article as: Yuan R, Xiong W, Ran W, Liang N, Tang J, Cheng L, Yin X, Gao J. Diaphragm excursion difference as an adjunct predictor marker of postoperative pulmonary complications in video-assisted thoracoscopic surgery: a prospective, observational study. J Thorac Dis 2025;17(2):908-920. doi: 10.21037/jtd-24-1454

