



Original Research Article

Association of diaphragmatic ultrasound parameters with preoperative pulmonary function tests and postoperative respiratory complications in patients undergoing major abdominal surgeries: A prospective observational study

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Abstract

Background and Aims: Diaphragmatic dysfunction is an often-overlooked cause of respiratory compromise in postsurgical patients. Point-of-care ultrasonography (USG) is a valuable tool for real-time assessment of diaphragmatic excursion, thickness, and thickening fraction. This study aimed to evaluate the correlation between preoperative diaphragm ultrasound parameters and pulmonary function test (PFT) results, and their association with postoperative pulmonary complications (PPCs).

Methods: This prospective observational pilot study included 60 adult patients (aged 18–60 years, ASA I–III) undergoing elective major abdominal surgery. Preoperative PFTs were conducted one day prior to surgery, recording Breath Holding Time, Vital Capacity, Forced Vital Capacity, Peak Expiratory Flow Rate, and Maximum Inspiratory Capacity (MIC). Diaphragm ultrasound was performed to assess diaphragmatic excursion (left and right), thickness (at maximum inspiration and expiration), and thickening fraction. Postoperative pulmonary complications and the need for ventilatory support were recorded.

Results: There was a significant association ($p < 0.05$) between lower preoperative PFT and diaphragm ultrasound values and the requirement for postoperative ventilatory support. Among all measured parameters, MIC and left hemidiaphragm excursion demonstrated the highest diagnostic accuracy in predicting PPCs, with MIC < 1.51 L showing $>94\%$ sensitivity and 100% specificity, and left diaphragmatic excursion < 2.01 cm showing $>88\%$ sensitivity and $>92\%$ specificity.

Conclusion: Preoperative pulmonary function and diaphragm ultrasound parameters are significantly associated with the need for postoperative ventilatory support in patients undergoing major abdominal surgery. Diaphragm ultrasound correlates well with PFTs and can serve as a non-invasive predictive tool for identifying patients at risk of postoperative pulmonary complications.

Keywords: Pulmonary function test, Diaphragmatic excursion, Diaphragmatic thickness, Diaphragmatic thickening fraction, Postoperative pulmonary complications.

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1. Introduction

The diaphragm is the principal muscle of respiration. Diaphragmatic dysfunction is an underestimated cause of respiratory impairment in postsurgical patients.¹ Abdominal surgeries increase the risk of postoperative diaphragmatic dysfunction due to reflex inhibition of phrenic motor output from visceral afferents.^{2–4}

Historically, monitoring for a diaphragmatic excursion, diaphragmatic thickness, and diaphragmatic thickening fraction has been onerous due to the need for complex equipment and expertise such as fluoroscopy, trans diaphragmatic pressure measurement, and computerized tomography. Point-of-care ultrasonogram (USG) is a

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promising modality for real-time monitoring of diaphragmatic excursion, thickness, and thickening fraction.

Ultrasound can be used either to assess motion of the diaphragm dome or changes in diaphragm thickness as it contracts.^{5,6} The movement of the diaphragm correlates well with vital capacity and lung compliance.^{7,8}

The preoperative and postoperative changes in the diaphragmatic excursion, thickness, and thickening fraction and their correlation with preoperative pulmonary function and postoperative pulmonary complications have not been investigated in major abdominal surgeries.

The aim of this study was to determine whether diaphragmatic excursion, diaphragmatic thickness, and diaphragmatic thickening fraction performed in the preoperative period correlate with preoperative pulmonary function test and respiratory reserve of the patients and postoperative pulmonary complications (PPC).

2. Methodology

This prospective observational pilot study was conducted over a one-year period from October 2022 to October 2023 and included 60 adult patients. Ethical approval was obtained from the Institute's Ethics Committee (IEC code: 2022-152-IMP-EXP-50), and the study was registered at the Clinical Trials Registry of India (CTRI/2023/05/053197). Written informed consent was obtained from all participants.

Patients aged 18 to 60 years, classified as ASA physical status I to III, scheduled for elective major abdominal surgery under general anaesthesia with endotracheal intubation were included. Patients were required to be alert, cooperative, and free from major neurological deficits. Exclusion criteria included ASA IV status and pre-existing unilateral or bilateral diaphragmatic paralysis.

On the day before surgery, preoperative pulmonary function tests (PFTs) were performed, including measurement of Breath Holding Time, Forced Vital Capacity (FVC), Peak Expiratory Flow Rate (PEFR), Maximum Inspiratory Capacity (MIC), and Functional Residual Capacity (FRC).

Following PFTs, bedside diaphragm ultrasonography was conducted using a Sono site Edge II portable ultrasound machine. Parameters measured included diaphragmatic excursion, thickness at maximum inspiration and expiration, and thickening fraction for both left and right hemidiaphragms.

Diaphragmatic excursion was assessed in a semi-recumbent position (20°–40° incline). Using the liver and spleen as acoustic windows for the right and left hemidiaphragms respectively, a low-frequency curvilinear probe was placed below the costal margin along the mid-clavicular line in a longitudinal plane. The probe was angled

cephalad to allow the ultrasound beam to align perpendicularly with the posterior third of the diaphragm. Once visualized in B-mode, M-mode was used to measure diaphragmatic motion (**Figure 1**).

The diaphragm excursion was measured on the vertical axis of the M-mode tracing (cm) from the beginning. Diaphragmatic thickness was measured in the zone of apposition (ZOA) during both inspiration and expiration. High frequency linear probe was placed in the 8th or 9th intercostal space between anterior and midaxillary lines and the thickness of the muscle was measured at a distance of 0.5–2cm from the costophrenic sinus. (**Figure 1**)

Diaphragmatic thickening fraction was calculated as–

$$\frac{\text{Thickness at end inspiration} - \text{Thickness at end expiration}}{\text{Thickness at end expiration}} \times 100$$

On the day of surgery, following standard fasting protocols, patients were transferred to the operating room, and standard ASA monitors were applied. General anaesthesia was administered using a standardized protocol: intravenous fentanyl (2–3 mcg/kg), followed by titrated intravenous propofol (1–2.5 mg/kg) and vecuronium (0.1 mg/kg) to facilitate endotracheal intubation. Anaesthesia was maintained with sevoflurane (1–2 MAC) in an oxygen–air mixture, along with intermittent doses of fentanyl and vecuronium, as required. Intraoperative anaesthetic management was otherwise at the discretion of the attending anaesthesiologist.

Postoperative analgesia was provided via either patient-controlled epidural analgesia (PCEA) or intravenous patient-controlled analgesia (IV PCA) pump, aiming to maintain a Numeric Rating Scale (NRS) pain score of ≤3. Postoperative respiratory complications were documented, including respiratory failure requiring ventilatory support in the form of non-invasive or invasive mechanical ventilation, along with the duration of ventilator support in hours or days.

At the conclusion of surgery, patients were classified into two groups: Group A included patients who underwent an extubation trial and were successfully extubated; Group B comprised those who failed the extubation trial and required postoperative ventilatory support. Patients who were continued on mechanical ventilation without an extubation trial—due to reasons such as hemodynamic instability, hypothermia, or prolonged surgical duration—were excluded from the study. All patients were monitored for 72 hours postoperatively for the development of respiratory insufficiency.

2.1. Statistical analysis

As this was a pilot study, a total of 60 patients were included. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. Comparisons between the two

groups were made using the independent samples t-test for continuous variables. Receiver Operating Characteristic (ROC) curve analysis was performed to assess the diagnostic accuracy of preoperative pulmonary function tests and diaphragm ultrasound parameters in predicting postoperative ventilatory requirement. The area under the ROC curve (AUROC) was calculated for each parameter. For each significant variable, three cutoff values were explored, and an optimal threshold was selected based on sensitivity and specificity values greater than 50%. A p-value of <0.05 was considered statistically significant. Data analysis was performed using SPSS version 23.0 (IBM Corp., Chicago, IL, USA).

3. Results

Patients were divided into two groups based on the need for postoperative ventilatory support. Group A consisted of 42 patients who were extubated on table and did not require postoperative ventilation, while Group B included 18 patients who required postoperative ventilatory support. A CONSORT flow diagram (**Figure 2**) outlines patient enrollment and reasons for exclusion from the study.

Demographic characteristics were comparable between the two groups, with no statistically significant differences

(**Table 1**). The types of elective major abdominal surgeries performed are detailed in **Table 2**.

Pulmonary function test (PFT) parameters—including Breath Holding Time, Forced Vital Capacity, Peak Expiratory Flow Rate, Functional Residual Capacity, and Maximum Inspiratory Capacity (MIC)—were significantly lower in patients who required ventilatory support (Group B), with p-values < 0.001 (**Table 3**). Similarly, diaphragm ultrasound parameters—including diaphragmatic excursion, thickness, and thickening fraction—were also significantly reduced in Group B, with p-values ranging from 0.002 to 0.001 (**Table 3**).

Given the strong association between these parameters and postoperative ventilatory outcomes, receiver operating characteristic (ROC) curve analysis was performed to evaluate their diagnostic accuracy. The area under the ROC curve (AUROC) for PFT parameters ranged from 85% to 100%, with MIC demonstrating the highest predictive accuracy. For diaphragm ultrasound variables, AUROC values ranged from 77% to 91%, with left hemidiaphragm excursion showing the greatest diagnostic value (**Table 4, Figure 3**).

Table 1: Demographic data of study population

Variables	Total (60)	Group A (ventilatory support not needed) n=42	Group B (Required ventilatory support) n=18	p value
Age(years)	43.9±13	41.9±13	48.2±12	0.08
Weight(kg)	56.9±10	56.7±8.6	57.3±12.9	0.848
Height(cm)	159.4±8.5	159.6±8.5	158.9±8.8	0.783
BMI(Kg/m ²)	22.4±3.8	22.4±3.6	22.5±4.4	0.979
Duration of surgery(hours)	7.69±1.25	7.5±1.2	8.1±1.2	0.07

BMI: Body mass index

Table 2: Various types of surgeries

Types of surgeries	Total no.
Whipple's Procedure	8
Esophagectomy	3
Extended cholecystectomy	10
Radical cholecystectomy	5
Abdomino-perineal resection and low anterior resection	4
Gastrectomy and Gastrojejunostomy	5
Roux en Y Hepato-Jejunostomy	10
Exploratory laparotomy	1
Splenectomy	5
Frey's procedure	2
Hemicolectomy	3
Hepatectomy	2
Proctocolectomy	1
Cystopericystectomy	1

Sensitivity and specificity analyses based on optimal cutoff values are summarized in **Table 5**. An MIC of <1.51 L predicted the need for postoperative ventilatory support with >94% sensitivity and 100% specificity, while a left

diaphragmatic excursion of <2.01 cm had >88% sensitivity and >92% specificity for predicting postoperative pulmonary complications (PPCs).

Table 3: Distribution of pulmonary function tests and diaphragmatic ultrasound parameters between patients with or without ventilatory support in postoperative period (N=60)

Variables	Total	Group A (Patients who could be extubated on table) n=42	Group B (Required ventilatory support) n=18	p value
Breath Holding Time (seconds)	28.6±6.9	30.4±7.2	24.4±3.6	<0.001
Forced Vital Capacity (percentage)	79±14.3	85.4±8.6	64±13.7	<0.001
Peak Expiratory Flow Rate (percentage)	76.9±21.5	83.6±16.4	61.1±23.9	0.001
Functional Residual Capacity (percentage)	77.8±11.9	83.8±5.6	63.7±10.7	<0.001
Maximum Inspiratory Capacity(litres)	1.7±0.3	1.9±0.2	1.3±0.2	<0.001
Diaphragm Excursion [L] (cm)	2.1±0.3	2.3±0.2	1.8±0.3	<0.001
Diaphragm Excursion [R] (cm)	2.1±0.4	2.2±0.4	1.8±0.3	<0.001
Diaphragm Thickness Insp. [L] (cm)	0.3±0.1	0.3±0	0.2±0.1	<0.001
Diaphragm Thickness Insp.[R] (cm)	0.3±0.1	0.3±0	0.2±0.1	<0.001
Diaphragm Thickness Exp.[L] (cm)	0.2±0	0.21±0	0.2±0	0.002
Diaphragm Thickness Exp.[R] (cm)	0.2±0	0.21±0	0.2±0	<0.001
Diaphragmatic Thickening Fraction [L] (%)	48.6±16.4	53.1±14.7	38±15.8	0.002
Diaphragmatic Thickening Fraction [R] (%)	46.5±15.1	50.7±13.2	36.7±14.9	0.002

Data are presented in mean± Standard deviation compared by independent samples t test. p value <0.05 significant

L: Left, R: Right, Insp: Inspiration, Exp: Expiration

Table 4: Diagnostic accuracy of the different pulmonary function tests and diaphragmatic ultrasound variables for prediction of postoperative ventilatory requirement in study cohort (N=60)

Test Result Variable(s)	AUROC	p value	95% Confidence Interval of AUROC	
			Lower Bound	Upper Bound
BHT (sec)	0.85	<0.001	0.75	0.94
FVC (percentage)	0.92	<0.001	0.81	1.00
PEFR (percentage)	0.82	<0.001	0.68	0.96
FRC (percentage)	0.95	<0.001	0.88	1.00
MIC(Litres)	1.00	<0.001	0.99	1.00
DE Left(cm)	0.91	<0.001	0.80	1.00
DE Right(cm)	0.86	<0.001	0.74	0.99
DT Inspiration Left(cm)	0.85	<0.001	0.72	0.98
DT Inspiration Right (cm)	0.83	<0.001	0.68	0.97
DT Expiration Left(cm)	0.77	<0.001	0.59	0.94
DT Expiration Right(cm)	0.80	<0.001	0.63	0.96
DTF Left (percentage)	0.80	<0.001	0.66	0.94
DTF Right (percentage)	0.80	<0.001	0.65	0.94

AUROC: Area under the Receiver operating characteristics curve. p<0.001 significant

BHT: Breadth holding time, FVC: Forced vital capacity, PEFR: Peak expiratory flow rate, FRC: Functional residual capacity, MIC: Maximum inspiratory capacity, DE: Diaphragm excursion, DT: Diaphragm thickness, DTF: Diaphragmatic thickening fraction, AUROC: Area under receiver operating characteristics curve

Table 5: Sensitivity and specificity of the different pulmonary function tests and diaphragm variables parameters for prediction of postoperative ventilatory requirement in the study cohort (N=60)

Variable	Cut-off value	Sensitivity (%)	Specificity (%)
Breath Holding Time (seconds)	25.50	61.1	85.7
	27.50	72.2	76.2
	28.50	88.9	66.7
Forced Vital Capacity (percentage)	68.50	77.8	97.6
	75.50	88.9	90.5
	78.50	88.9	81
Peak Expiratory Flow Rate (percentage)	66.50	66.7	97.6
	71.00	72.2	81
	72.50	77.8	81
Functional Residual Capacity (percentage)	73.00	88.9	100
	74.50	88.9	97.6
	76.00	88.9	90.5
Maximum Inspiratory Capacity (litres)	1.46	88.9	100
	1.51	94.4	100
	1.54	94.4	97.6
Diaphragmatic Excursion [L] (cm)	1.95	83.3	97.6
	2.01	88.9	92.9
	2.04	88.9	88.1
Diaphragmatic Excursion [R] (cm)	1.82	72.2	95.2
	1.95	77.8	88.1
	2.02	88.9	81
Diaphragmatic thickness insp.[L] (cm)	0.23	72.2	100
	0.24	72.2	97.6
	0.25	72.2	95.2
Diaphragmatic thickness inspiration [R](cm)	0.22	72.2	100
Diaphragmatic Thickness expiration [L] (cm)	0.17	66.7	95.2
	0.18	72.2	92.9
	0.19	72.2	88.1
Diaphragmatic Thickness expiration [R] (cm)	0.16	61.1	100
	0.17	72.2	92.9
	0.20	77.8	64.3
Diaphragmatic thickening fraction [L] (%)	34.85	61.1	95.2
	36.15	66.7	92.9
	46.70	77.8	61.9
Diaphragmatic thickening fraction [R] (%)	32.44	55.6	97.6
	37.75	72.2	78.6
	43.90	77.8	69
Cut-off were chosen based on the criteria to detect at least 50% of sensitivity and specificity using receiver operating characteristics curve analysis. As value increases, chances of ventilatory requirement decreases. Outcome of interest: ventilatory requirement in postoperative period after major abdominal surgery			

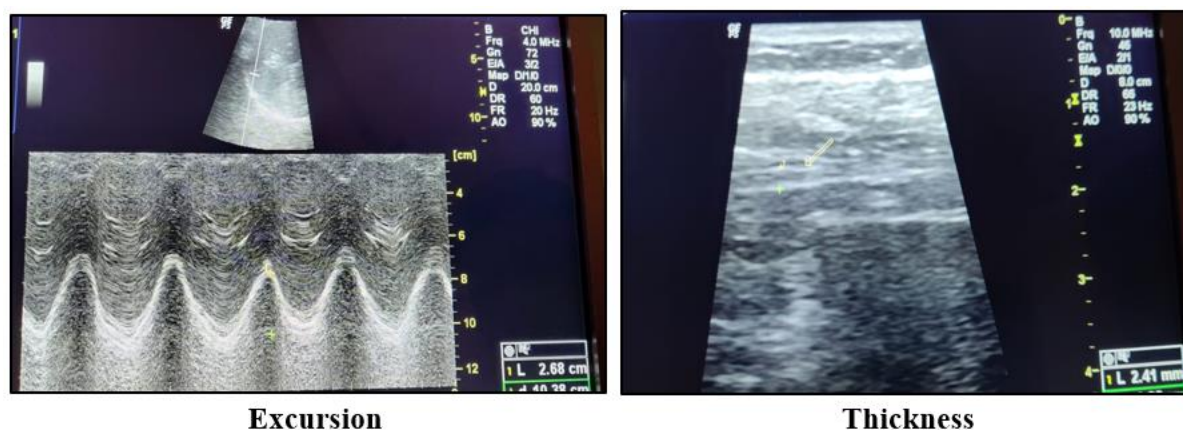


Figure 1: Measurement of diaphragmatic excursion and Diaphragmatic thickness

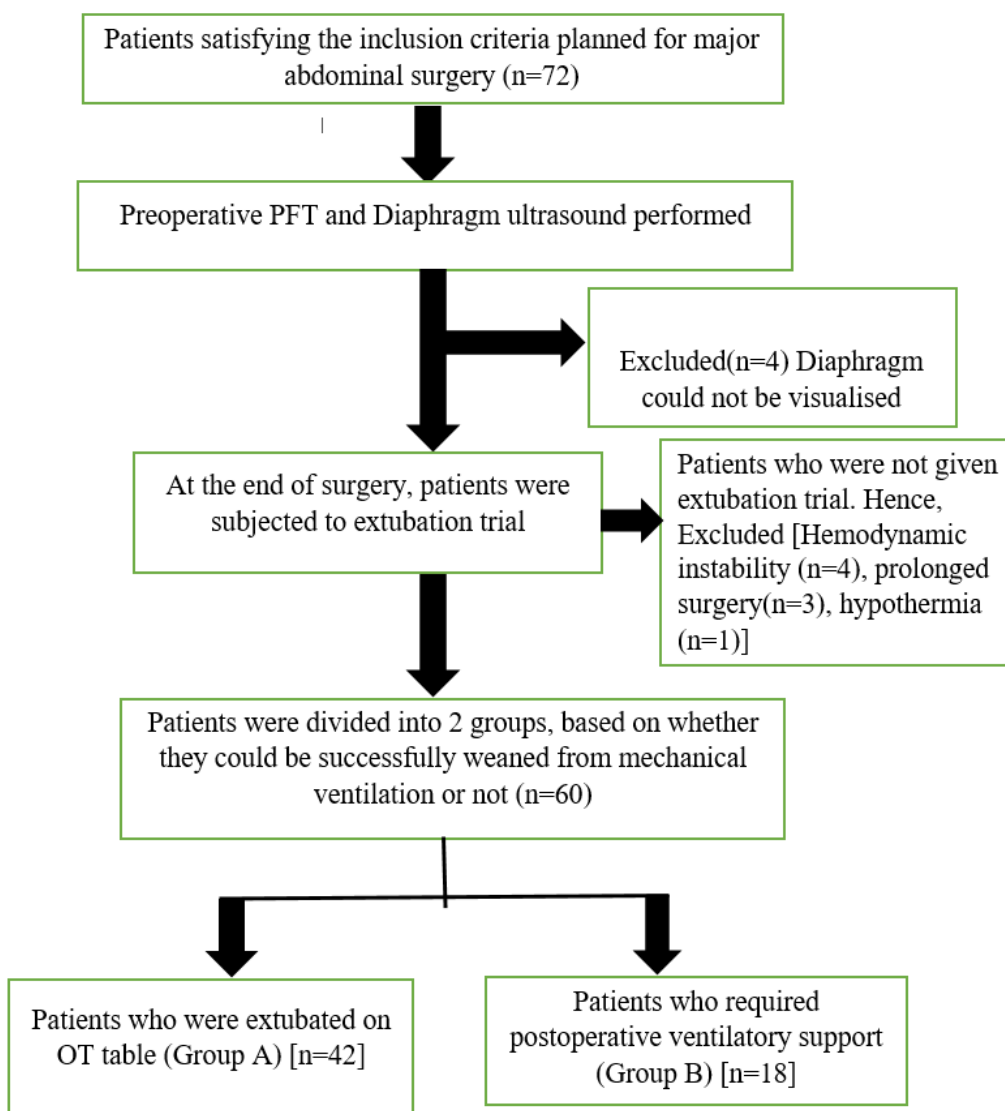


Figure 2: Consort diagram

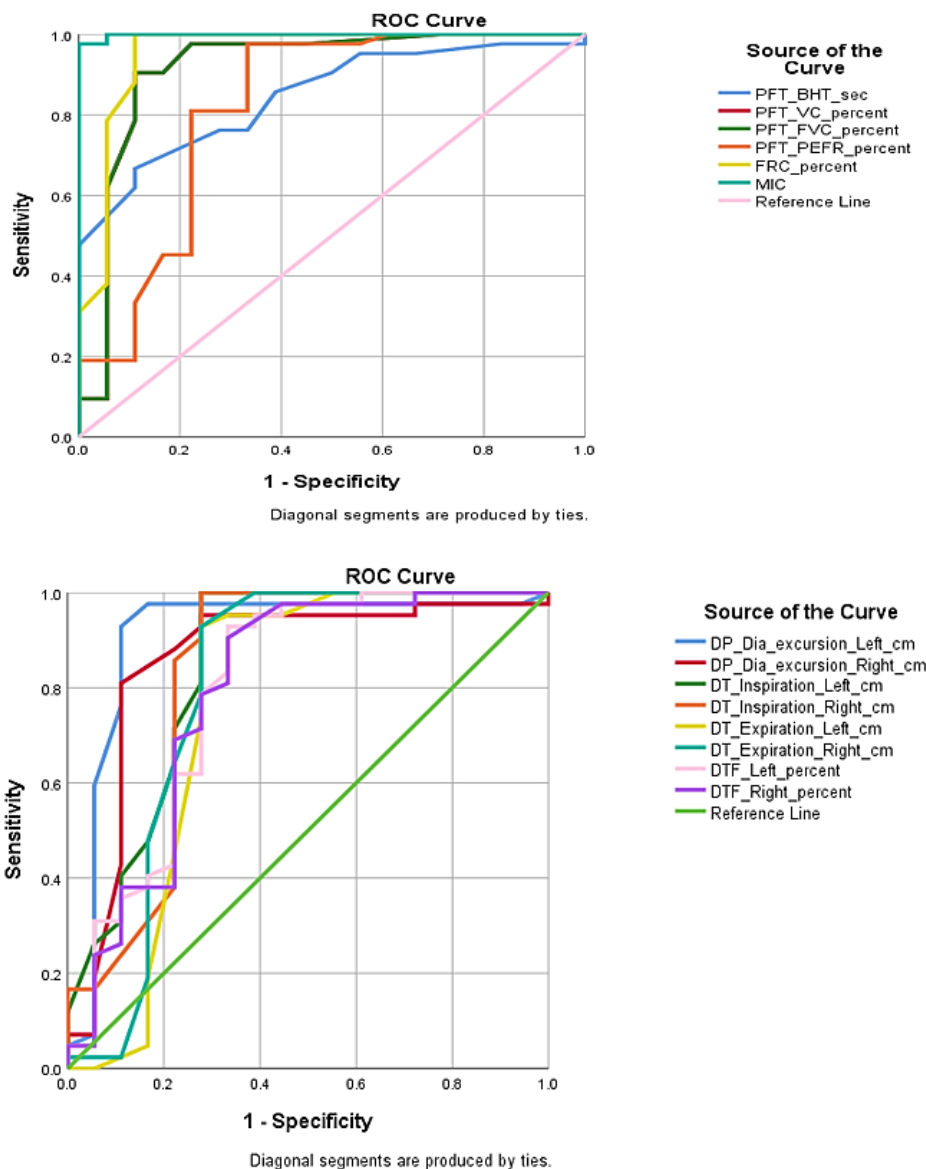


Figure 3: ROC for PFT parameters and diaphragm ultrasound parameters in predicting ventilatory support in postoperative period

4. Discussion

A total of 60 patients were included in the analysis, with 42 patients successfully extubated on table (Group A) and 18 patients requiring postoperative ventilatory support (Group B). Patients in Group B demonstrated significantly lower values across multiple pulmonary function test (PFT) parameters compared to those in Group A. Our study identified a significant association between preoperative pulmonary function tests and diaphragmatic ultrasound parameters with the need for postoperative ventilatory support in patients undergoing major abdominal surgery. Diaphragmatic ultrasound variables—specifically diaphragmatic excursion, thickness, and thickening fraction—correlated well with preoperative PFTs in predicting the requirement for postoperative ventilation.

Yuki Tajima et al. conducted a study involving 1,236 patients undergoing colorectal cancer surgery, analyzing forced vital capacity (FVC), one-second forced expiratory volume (FEV1), %VC (FVC/predicted VC), and FEV1/FVC ratio in relation to postoperative pulmonary complications (PPCs). They found that %VC may serve as a predictor of PPCs, with lower %VC identified as a risk factor for postoperative complications.⁹ Consistent with this, our study found maximum inspiratory capacity (MIC) to have the best diagnostic accuracy.

Similarly, Chinyelu Uchenna Ufoaroh et al. conducted a prospective study assessing the association between preoperative pulmonary assessment and PPCs, finding that predicted percentages of FEV1 and FVC were significantly lower in patients who developed PPCs.¹⁰ Our findings align with this, as FVC values were significantly lower in patients requiring postoperative ventilatory support.

In a large retrospective study involving 31,827 patients who underwent spirometry within three months prior to surgery—including thoracic and upper abdominal procedures—Hyung Jun Park et al. identified lower FVC as an independent risk factor for PPCs, prolonged ICU stay, and in-hospital mortality.¹¹ Our study similarly observed that patients with reduced FVC values were more likely to develop PPCs requiring ventilatory support.

Tak Kyu Oh et al. retrospectively observed that a 1% increase in preoperative FVC was associated with a 2% reduction in PPC incidence in patients undergoing laparoscopic gastric or colorectal cancer surgery. However, they reported no significant association between FEV1 (%) or FEV1/FVC (%) and PPCs.¹² Our findings emphasize the role of lower FVC values in predicting PPCs.

Among all PFT parameters analyzed, MIC demonstrated the highest diagnostic accuracy for predicting PPCs, with a cutoff of <1.51 L yielding over 94% sensitivity and 100% specificity. Other parameters such as Breath Holding Time, Forced Vital Capacity, and Peak Expiratory Flow Rate also predicted PPCs when below certain thresholds. These results suggest that all adult patients scheduled for major abdominal surgery should undergo comprehensive PFT during pre-anesthetic evaluation, with rigorous preoperative optimization for those with values below critical levels.

A key objective of this study was to evaluate whether diaphragmatic ultrasound parameters correlate with PFT values and PPCs. Diaphragmatic excursion of the left hemidiaphragm exhibited the best diagnostic accuracy, with values <2.01 cm predicting PPCs with over 88% sensitivity and 92% specificity.

Prasanna V et al. conducted a prospective observational study in adults undergoing upper abdominal surgery, assessing diaphragmatic excursion (DIA) via ultrasound on the right and left hemidiaphragm during quiet and deep breathing before surgery and on postoperative days 1, 2, and 3. They reported that a diaphragmatic excursion of 1.6 cm on the left side during deep breathing had a 75% sensitivity for predicting PPCs.¹ Our study's finding of diaphragmatic excursion <2.01 cm on the left side with >88% sensitivity corroborates and extends these findings.

A meta-analysis by Qian Z et al. involving 436 patients aimed to evaluate diaphragmatic dysfunction (DD) as a predictor of weaning outcomes. They reported that diaphragmatic excursion demonstrated 85% sensitivity and 84% specificity for predicting successful weaning.¹³ Kim SH et al. conducted a single-center observational study on 35 patients undergoing open liver resections, analyzing both PFT and diaphragmatic ultrasound parameters. Their findings suggested that vital capacity had the strongest correlation with postoperative pulmonary dysfunction. In contrast, our study found that maximum inspiratory capacity (MIC) had the best correlation with postoperative pulmonary

complications (PPCs). Regarding diaphragmatic parameters, Kim et al. identified a diaphragmatic excursion of 3.6 cm with 94% sensitivity and 84% specificity for predicting PPCs.⁷ In our cohort, diaphragmatic excursion of 2.01 cm yielded 88.9% sensitivity and 92.9% specificity for PPC prediction.

Theerawit et al. studied 68 adult ICU patients requiring mechanical ventilation. Rather than assessing diaphragmatic excursion, they analyzed the time to peak inspiratory amplitude of the diaphragm, where a value >0.8 seconds had 92% sensitivity but only 46% specificity for predicting successful weaning. Their results for diaphragmatic thickness and thickening fraction were similar to ours; however, no significant differences were found between successful and failed weaning groups based on ultrasound parameters.¹⁴

Palkar A et al. performed diaphragm ultrasound in 73 mechanically ventilated ICU patients at three time points: initiation of triggering, 30 minutes into spontaneous breathing trial (SBT), and post-extubation. Twenty patients failed the extubation trial. They concluded that consistent diaphragmatic excursion (DE) measurements over time are more reliable for predicting successful weaning. Mean DE of 2.1 cm was associated with successful weaning, while 1.7 cm was linked to weaning failure.¹⁵ Similarly, in our study, the mean DE of the left hemidiaphragm was 2.3 ± 0.2 cm in patients not requiring postoperative ventilatory support, whereas those requiring support had a mean DE less than 1.8 ± 0.3 cm.

Filippi et al. evaluated a new weaning index based on diaphragm thickening fraction (DTF) assessed by ultrasound. They observed significant differences in diaphragm thickness between total lung capacity (TLC) and residual volume (RV) in patients who succeeded versus failed spontaneous breathing trials. They concluded that DTF assessment by ultrasound may perform similarly to other weaning indices.¹⁶ Our study found that a DTF of 46.7% for the left hemidiaphragm and 43.9% for the right hemidiaphragm predicted PPCs with 77.8% sensitivity.

Occasionally, patients are unable to perform PFT optimally due to difficulty understanding instructions or coordinating with the equipment. Our study demonstrates that diaphragmatic ultrasound, which correlates well with PFT values, can serve as a valuable alternative in such cases.

We performed both PFT and diaphragmatic ultrasound preoperatively. While postoperative measurements might provide further insights, the presence of surgical drains and dressings often limits ultrasound window access, making postoperative evaluation challenging.

Our study focused exclusively on patients undergoing open abdominal surgery, thus the effects of abdominal insufflation during laparoscopic or robotic surgeries on diaphragmatic function remain unexplored. Future studies

should include these minimally invasive procedures to better understand their impact on diaphragmatic dysfunction.

5. Conclusion

There is a significant association between preoperative pulmonary function tests and preoperative diaphragm ultrasound parameters with the requirement of postoperative ventilatory support in patients undergoing major abdominal surgery. Diaphragm ultrasound parameters such as diaphragmatic excursion, diaphragmatic thickness, and diaphragmatic thickening fraction correlate well with preoperative pulmonary function tests in predicting the requirement of postoperative ventilatory support.

6. Source of Funding

None.

7. Conflict of Interest

None.

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