

Ultrasonic Assessment of Diaphragm Function in the Ventilator Liberation of Perioperative Patients

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Abstract

Objective: Diaphragm ultrasonography can predict weaning failure; however, only a small number of studies include the majority of surgery patients. This study seeks to investigate the feasibility of diaphragm ultrasonography-guided ventilator separation in intubated surgical patients.

Patients and Methods: This prospective observational study was conducted in postoperative mechanical ventilated patients at Surgical ICU, Maharaj Nakorn Chiang Mai Hospital, from September 2020 to September 2022. Diaphragm thickness (TDi) and diaphragm excursion (DE) were measured with ultrasonography during spontaneous breathing trials. We analyzed the correlation of diaphragm function to weaning success or failure. A weaning failure was defined as death or reintubation within 7 days after extubation (whether post-extubation noninvasive ventilation was used or not).

Results: 105 mechanically ventilated patients were prospectively recruited in the weaning failure group, 15 patients, and 90 patients in the weaning success group. The overall weaning failure rate was 14.29%. Patients who had undergone thoracic surgery significantly failed weaning more than those who had not (33% vs 11%, p -value 0.023). TDi at inspiration and expiration, both left and right diaphragm, DTF, and left DE did not differ significantly between patients who succeeded or failed ventilator weaning. Only right DE significantly differed between groups which were 6.7 [6.4-8.4] mm and 9.6 [7.4-14] mm (p -value 0.016) in the weaning failure group and success group, respectively. According to the ROC curve, a cutoff value of right diaphragm excursion > 7.3 mm was associated with a successful weaning with a sensitivity of 76.92%, a specificity of 69.23%, a positive predictive value of 93.75%, and a negative predictive value of 33.34%.

Conclusions: This study shows that in our cohort of postoperative patients, the assessment of right diaphragm excursion by ultrasound potentially predicts weaning success with a cutoff value > 7.3 mm (sensitivity of 76.92%, a specificity of 69.23%).

Keywords: Diaphragm, Ultrasound, Weaning, Perioperative, Surgery

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INTRODUCTION

Some surgical patients commonly require post-operative ventilation support and intensive care. According to a THAI-SICU study, the incidence of respiratory failures in surgical ICUs was 2.1-3.7%.¹ Patients who require mechanical ventilation spend roughly 15837.4 baht more than patients who do not.² Delayed ventilator weaning resulted in prolonged mechanical ventilation time, which in turn prolonged ICU stay and pulmonary complications like ventilator-associated infections³⁻⁵ and ventilator-induced lung injury.⁶⁻⁸ Early weaning can potentially result in extubation failure and cardiovascular complications, both of which can be fatal.⁹ Therefore, choosing the right patients for weaning and extubation is necessary. In addition to muscle weakness, malnutrition, neurologic dysfunction, and cardiac dysfunction, diaphragm dysfunction is one of the causes of weaning failure.¹⁰

Critical patients frequently experience diaphragm dysfunction,¹¹ which increases mortality and length of mechanical ventilation.¹² Diaphragm dysfunction can be brought on by a variety of conditions, including sepsis, ventilator-induced diaphragmatic dysfunction (VIDD), and ICU-acquired diaphragm weakness.¹³ Diaphragm dysfunction can also result from upper abdominal¹⁴⁻¹⁶ and cardiac surgery.¹⁷

Many parameters have been developed over the years to determine whether or not patients will succeed in weaning themselves off of their ventilators and being extubated, such as spontaneous minute ventilation, maximum inspiratory pressure (P_Imax), rapid shallow breathing index (RSBI), and tracheal airway occlusion pressure of 0.1 seconds (P_{0.1}).¹⁸ RSBI is one of the most reliable and feasible parameters for predicting whether a patient will successfully separate from a ventilator.^{19,20}

In the past, evaluation of diaphragm function was only possible using invasive instruments or exposure to radiation. The results also required an expert to interpret them.²¹ It was, therefore, impractical to assess diaphragm function in a patient receiving critical care. Nowadays, however, ultrasonography quality has increased and is

practical in many scenarios, including bedside assessment of critically sick patients and the evaluation of diaphragm function. Diaphragmatic excursion, diaphragmatic thickness, and diaphragmatic contraction speed can all be determined using ultrasonographic diaphragm examination.²² Ultrasonic diaphragm assessment is effective at predicting ventilator separation success,²³⁻²⁵ with sensitivity and specificity of 0.85 (95% CI 0.77-0.99) and 0.74 (95% CI 0.66-0.8),²⁴ respectively, according to several systematic reviews and meta-analyses. Nevertheless, few studies include most of the patients who have undergone surgery.

This study aims to determine whether intubated surgical patients can successfully separate from their ventilators by using diaphragm ultrasonography.

PATIENTS AND METHODS

This is a single-center, prospective observational study conducted on SICU patients at Maharaj Nakorn Chiang Mai Hospital from September 2020 to September 2022, in which diaphragm function was measured using ultrasound during a spontaneous breathing trial. The study was approved by the Ethics Committee of the Faculty of Medicine, Chiangmai University (study code: SUR-2563-07301). The inclusion criteria for this study are as follows: patients must be 20 years of age or older, including those who have undergone urgent, emergent, or elective surgeries. The patients should also be intubated or have a tracheostomy and be under invasive mechanical ventilation. Additionally, the patients must be ready to undergo a spontaneous breathing trial. There should be no contraindications to performing ultrasonic assessments in the relevant anatomical area, and the patient must have provided written informed consent. The exclusion criteria for this study include pregnancy, the presence of neuromuscular disease, and diaphragm paralysis. Additionally, patients who cannot be properly visualized for diaphragm assessment through ultrasound will be excluded. The sample size, calculated with an estimated 15% dropout rate, was 106 patients (Supplement 1).

Supplement 1 Sample size calculation

Formula	Previous study	Sample size
Estimation of sample size from AUC	Weaning success	Total estimated N
$n = \frac{Z_{\alpha}^2 V(\overline{AUC})}{d^2}$	predictability (AUC) = 0.90	= 91.8
$V(\overline{AUC}) = (0.0099xe^{-a^2/2}) \times (6a^2 + 16)$	Precision of estimation (d) = 0.05	= 92 patients
$a = \varphi^{-1}(AUC) \times 1.414$		
φ^{-1}		
= inverse of standard normal distribution		
= 0.9284		

The estimated dropout rate was 15%, and the total sample size was 106 patients.

Study protocol

When the inclusion criteria were reached, a spontaneous breathing trial was attempted. All patients were evaluated in a semi-recumbent position (30–45 degrees) within 2 hours of the spontaneous breathing trial (SBT) period. Then, each diaphragm was evaluated by B-mode and M-mode ultrasound using Esaote® MyLab™ Gamma Ultrasound. Weaning index parameters were recorded. All patients who did not fail the SBT would be extubated. Criteria for failure to the SBT were the following: change in mental status, onset of discomfort, diaphoresis, respiratory rate > 35 breaths/min, hemodynamic instability (heart rate > 140, systolic blood pressure > 180 or < 90 mmHg), or signs of increased work of breathing. Weaning failure (or separation failure) was defined as death or reintubation within 7 days after extubation (whether post-extubation noninvasive ventilation was used or not).²⁶

The intensive care unit staff or radiologists trained the doctors who performed diaphragm ultrasounds until diaphragm ultrasound proficiency was certified.

Diaphragmatic ultrasound²⁷⁻²⁹

1. Diaphragm excursion

The liver or spleen is used as an acoustic window in the subcostal area, between the mid-clavicular and anterior axillary lines. A cardiac or abdominal probe (1–5 MHz) can be used. The diaphragm is identified as a hyperechoic line (produced by the pleura tightly adherent to the muscle) that approaches the probe during inspiration. The inspiratory excursion can be easily measured in M-mode (Diaphragm excursion; DE).

2. Diaphragm thickness

At the zone of apposition, between the 8th and 10th intercostal space in the mid-axillary or antero-axillary line, 0.5–2 cm below the costophrenic sinus. A linear high-frequency probe (6–13 MHz) is mandatory to obtain adequate diaphragmatic thickness images. At a depth of 1.5–3 cm, two parallel echogenic layers can be easily identified: the nearest line is the parietal pleura, and the deeper one is the peritoneum. The diaphragm is the less echogenic structure in between these two lines. This approach is utilized to assess the thickness of the diaphragm and thickening with inspiration (Diaphragmatic thickness at end inspiration; TD_{iins}, Diaphragmatic thickness at end-expiration; TD_{iexp}), usually in M-mode. Diaphragm thickness fraction (DTF) can be calculated from $\left(\frac{TD_{iins} - TD_{iexp}}{TD_{iexp}} \right) \times 100$

Data analysis

Data are presented as mean (SD) or median [inter-quartile range] when appropriate. The χ^2 test, with Fisher correction when appropriate, was used for comparisons among categorical variables. Continuous variables were compared with the student *t*-test, Mann-Whitney U test, and Wilcoxon sign rank test. Receiver operating characteristic (ROC) curve analysis was performed to assess the diaphragm ultrasound ability to discriminate between patients who succeeded in weaning and those who failed. A two-tailed *p*-value of less than 0.05 was taken to indicate statistical significance.

RESULTS

A total of 152 patients were enrolled in this study. Of these, 47 patients were excluded due to incomplete data records, inability to perform diaphragmatic ultrasound, non-intubation status, or not undergoing surgery. This left 105 participants for the final analysis, comprising 15 patients in the weaning failure group and 90 patients in the weaning success group (Figure 1). The weaning failure rate was 14.29%, consistent with the findings from the WIND study.²⁶ The baseline characteristics of the two groups were not statistically significantly different, except for a higher prevalence of immunocompromised status and thoracic operations in the weaning failure group (Table 1).

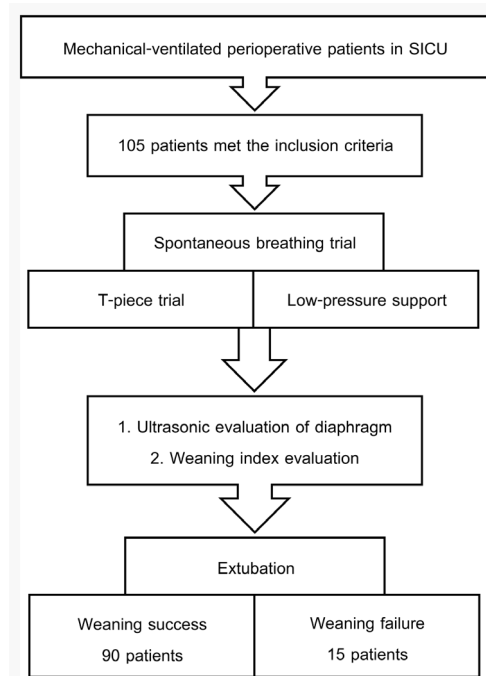


Figure 1 Flow chart of study design and included participants

Table 1 Characteristic data of the extubated patients

Characteristic	All n = 105 (%)	Weaning failure 15 (14.29%)	Weaning success 90 (85.71%)	P-value
Age (year)	65 [54-74]	70 [64-75]	64 [51-74]	0.113
BMI (kg/m²)	21.93 [19.53-24.44]	23.83 [21.48-26.67]	21.76 [19.38-24.22]	0.057
Male	59 (56.73)	9 (64.29)	50 (55.56)	0.540
ASA				0.928
Class 1	1 (0.95)	0 (0.00)	1 (1.11)	
Class 2	39 (37.14)	5 (33.33)	34 (37.78)	
Class 3	42 (40.00)	7 (46.67)	35 (38.89)	
Class 4	23 (21.90)	3 (20.00)	20 (22.22)	
Class 5	0 (0.00)	0 (0.00)	0 (0.00)	
Comorbidity				
Hypertension	52 (50.00)	11 (73.33)	41 (46.07)	0.051
Diabetes	27 (25.71)	5 (33.33)	22 (24.44)	0.466
COPD	6 (5.71)	0 (0.00)	6 (6.67)	0.303
CVS disease	23 (21.90)	5 (33.33)	18 (20.00)	0.248
Cancer	27 (25.71)	2 (13.33)	25 (27.78)	0.236
Cirrhosis	4 (3.81)	0 (0.00)	4 (4.44)	0.405
CKD	14 (13.33)	0 (0.00)	14 (15.56)	0.101
Immunocompromise	5 (4.76)	3 (20.00)	2 (2.22)	0.003
Surgery				
Abdominal	54 (51.43)	5 (33.33)	49 (54.44)	0.130
Thoracic	15 (14.29)	5 (33.33)	10 (11.11)	0.023
Vascular	23 (21.90)	4 (26.67)	19 (21.11)	0.630
Urologic	11 (10.48)	0 (0.00)	11 (12.22)	0.152
Head, neck, and soft tissue	5 (4.76)	0 (0.00)	5 (5.56)	0.350
Duration of MV	2 (1-4)	3.5 (2-8.5)	2 (1-4)	0.078
Reason for MV				0.488
Hypoxemic	17 (16.19)	4 (26.67)	13 (14.44)	
Hypercapnic	0 (0.00)	0 (0.00)	0 (0.00)	
Peri-operative	81 (77.14)	10 (66.67)	71 (78.89)	
Shock	7 (6.67)	1 (6.67)	6 (6.67)	

Diaphragm thickness during inspiration and expiration did not differ significantly between patients who succeeded or failed ventilator weaning for both the left and right diaphragms. In the weaning failure group, the mean thickness of the right and left diaphragm during inspiration and expiration was 2.4 mm, 1.5 mm, 2.5mm, and 1.5 mm, respectively. In the weaning success group, the mean thickness of the right and left diaphragm during inspiration and expiration was 2.3 mm, 1.7 mm, 2.3 mm, and 1.63 mm, respectively. Therefore, there was no

significant difference in DTF between patients who failed and those who succeeded in weaning. Right, Diaphragm excursion was 6.7 [6.4-8.4] mm in the weaning failure group and 9.6 [7.4-14] mm in the weaning success group, with a statistically significant difference between the two groups. However, the left diaphragm excursion did not differ significantly. None of the ventilator weaning indices differed between patients who failed and those who succeeded in weaning (Table 2). Figure 2 shows a DTF(a) and DE(b) boxplot.

Table 2 Diaphragm ultrasound and weaning index in weaning failure and success groups

Parameters	All 105	Weaning failure 15 (14.29%)	Weaning success 90 (85.71%)	P-value
TD_{ins} (mm)				
Right	2.3 [1.73-3]	2.4 [1.4-2.8]	2.3 [1.8-3]	0.675
Left	2.3 [1.8-2.83]	2.5 [1.9-2.7]	2.3 [1.8-2.83]	0.756
TD_{exp} (mm)				
Right	1.7 [1.2-2.4]	1.5 [0.85-2.2]	1.7 [1.26-2.4]	0.525
Left	1.62 [1.3-2.2]	1.5 [0.9-2.0]	1.63 [1.3-2.2]	0.412
DTF (%)				
Right	35 [23.75-54]	56 [28-61]	34 [23-50]	0.117
Left	37.25 [21.5-49.35]	56 [31-63]	36 [21-47]	0.068
DE (mm)				
Right	9.33 [6.8-13]	6.7 [6.4-8.4]	9.6 [7.4-14]	0.016
Left	9.1 [6.7-12.5]	7.8 [5.4-13]	9.15 [6.75-12.25]	0.792
Spontaneous MV	7.5 [6.5-9.5]	8.52 [6.37-9.9]	7.46 [6.5-9.4]	0.551
Spontaneous RR	18 [14-20]	18 [16-22]	17.5 [14-20]	0.120
Spontaneous VT	420 [354-523]	398 [300-502]	420 [357-524]	0.404
TV by weight	7.38 [6.36-9.67]	6.94 [5.59-7.71]	7.65 [6.4-9.94]	0.116
P 0.1	-2 [-3.9, -1.2]	-2 [-5.6, -1.1]	-2 [-3.55, -1.2]	0.824
NIF	-20 [-28, -15]	-20 [-28, -11]	-20.5 [-27.5, -15]	0.842
Cdyn	57.14 [48-71.4]	56.86 [42.8-75]	57.57 [48.3-66.79]	0.994
RSBI	41 [27-51]	40 [22-53]	41 [27.5-50.5]	0.930
Duration of SCIU stay	4 [2-10]	19 [12-23]	3 [2-7]	< 0.001
Mortality	14 [13.33]	7 [46.67]	7 [7.78]	< 0.001

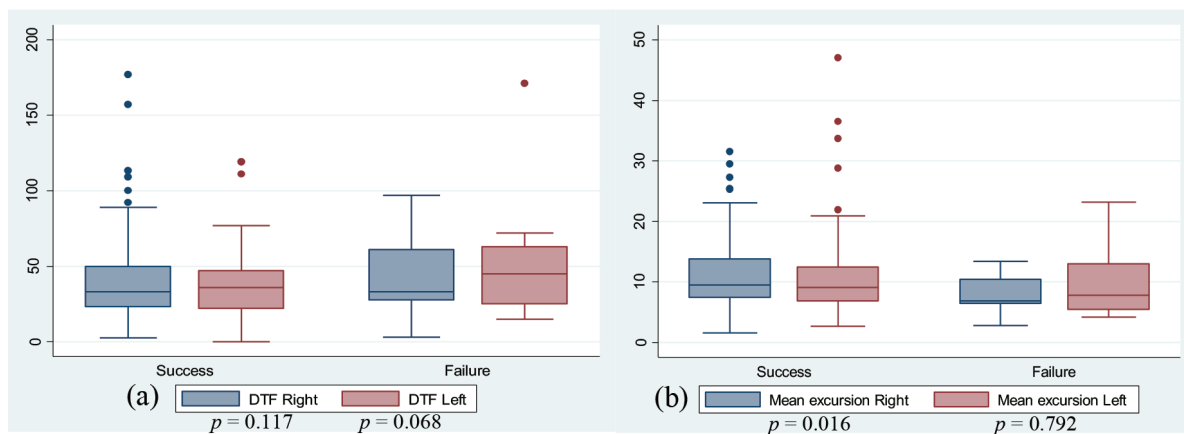


Figure 2 Boxplot of DTF(a) and DE(b): the central line represents the median value, the box boundaries represent the 25th and 75th percentiles, the lines represent the lowest datum within 1.5 inter-quartile range (IQR) of the lower quartile and the highest datum within 1.5 IQR of the upper quartile, and the circles represent outlier values.

According to the ROC curve, a cutoff value of right diaphragm excursion > 7.3 mm was associated with successful weaning, with a sensitivity of 76.92%, a specificity

of 69.23%, a positive predictive value of 93.75%, and a negative predictive value of 33.34% (Figure 3).

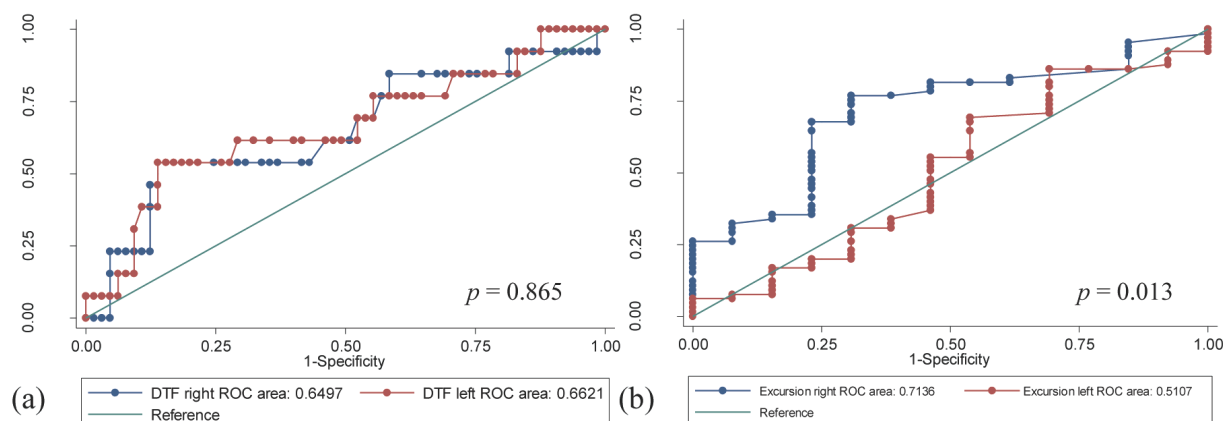


Figure 3 ROC curve for DTF (a) and DE (b): DTF right and left shows ROC area (95% CI), 0.6497 (0.47-0.83) and 0.6621 (0.48-0.84), respectively (p -value 0.865). DE right and left shows ROC area (95% CI), 0.7136 (0.57-0.86) and 0.5107 (0.32-0.7), respectively (p -value 0.013)

The length of ICU stays, and mortality rate was higher in the patients who failed to wean than in those who succeeded: 19 [12-23] vs. 3 [2-7] days and 46.7% vs. 7.78%, respectively (Table 2).

DISCUSSION

This study shows that right diaphragm excursion > 7.3 mm is potentially useful in predicting weaning success in postoperative patients with a sensitivity of 76.92% and a specificity of 69.23%. However, there was no difference in diaphragm thickness between patients who failed or succeeded in weaning. Other ventilator weaning indexes were also not significantly different between the two groups.

Ultrasound is a technology that is increasingly used in intensive care units. It is used for central line placement, fluid responsiveness, and, recently, diaphragm function.²⁷ Numerous studies today demonstrate that diaphragm ultrasound can be used to evaluate diaphragm function. Valette's study in medical ICU patients showed that the diaphragm dysfunction criteria were excursion < 10 mm or paradoxical movement during inspiration.³⁰ Another study in the medical ICU by Kim used right and left diaphragm excursion > 14 mm and > 12 mm to predict weaning success, with a sensitivity of 60%, a specificity of 76%, and an ROC area of 0.68.²²

To our knowledge, few studies include postoperative patients. For example, E.R. Ali and colleagues' study, which included only 6 postoperative patients from a total of 60 patients, showed that mean diaphragm thickness > 2

mm, DTF $> 30\%$, and DE > 15 mm can predict successful weaning.³¹ M. Zambon's systemic review of diaphragm ultrasound concluded that diaphragm dysfunction was DE < 10 -14 mm and DTF < 30 -36%.²⁵ Nevertheless, our study, which includes only postoperative patients, shows that only the right DE may potentially predict successful weaning. Surgery may cause diaphragm malfunction, which could account for why there is no significant difference between diaphragm thickness and DTF. Ford and colleagues' study showed reduced diaphragm activity in the postoperative period, with a shift from predominantly abdominal to rib cage breathing.³² The same effect of the surgery on the diaphragm was also demonstrated in B. Dureuil's study.¹⁴ The weaning index from this study does not significantly differ between patients who failed and those who succeeded in weaning, probably because we included only those who succeeded in SBT.

Our study has some limitations. The first is that many different physicians performed diaphragm ultrasound, which is operator dependent. Future studies designed to demonstrate intra- and inter-observer variability are required. The validity of the diaphragm ultrasound parameter from our study is limited to postoperative patients.

CONCLUSION

This study shows that in our cohort of postoperative patients, the assessment of right diaphragm excursion by ultrasound potentially predicts weaning success with a cutoff value > 7.3 mm (sensitivity of 76.92%, a specificity of 69.23%).

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CONFLICT OF INTEREST

The authors disclose no conflict of interest.

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