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*Original Article*

# Association of Diaphragmatic Function by Ultrasound and WIND Classification in Surgical Intensive Care Unit

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*Abstract*

***Background:*** The issue of weaning patients off mechanical ventilation remains a significant concern within the intensive care unit (ICU). Weaning, as defined by the Weaning according to a New Definition (WIND), is a valuable approach for predicting the probability of successful extubation or potential complications following mechanical ventilation. Ultrasonic diagnostics have emerged as a promising tool for evaluating various aspects of diaphragmatic function.

***Objective:*** To investigate the relationship between ultrasonic diaphragmatic parameters and the WIND classification group.

***Methods:*** This was a prospective observational study in which intubated surgical intensive care unit (SICU) patients were included. Diaphragmatic ultrasounds were performed on these patients. After the patients were discharged from the SICU, they were classified into each WIND group, and the association between the WIND group and diaphragmatic ultrasound parameters was analyzed.

***Results:*** A total of 128 mechanically ventilated patients were included in the study. The majority of atients, 90 (70%), were assigned to the WIND 1 group, while 24 (19%) were assigned to the WIND 2 group, and 8 (6%) were assigned to the WIND 3 group. Additionally, 6 (5%) patients were assigned to the WIND NW group. The median age of the patients was 67, with a range of 53 to 75. The most common type of respiratory failure experienced by the patients was peri-operative, accounting for 68% of cases. There were no significant differences observed in other baseline characteristics among the different groups. However, when examining diaphragmatic thickness at the end inspiration, a statistically significant difference was found on the right side. The WIND 3 group had the lowest measurement of diaphragmatic thickness at 1.5 mm. It is important to note that there were no significant differences in diaphragmatic thickness parameters between the groups.

***Conclusions:*** Diaphragmatic ultrasonography lacks the ability to differentiate between the various WIND groups. However, the success of weaning is different among WIND classifications.

***Keywords:*** Weaning, Mechanical ventilation, Ultrasound, Diaphragm, Diaphragm dysfunction

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## Introduction

After undergoing surgery, a subset of surgical patients may require ongoing mechanical ventilation and are subsequently admitted to the surgical intensive care unit (SICU). A follow-up study conducted at nine training institutions in Thailand between 2011 and 2014[1] revealed that the incidence of respiratory failure among patients in SICUs ranged from approximately 2.1% to 3.7%.[2] It is of paramount importance to ensure proper weaning of patients from mechanical ventilation, as improper procedures can lead to prolonged stays in the intensive care unit and potential complications associated with the ventilator. Conversely, if the weaning process is expedited, it can have detrimental effects on the cardiovascular system, necessitating tracheal intubation and resulting in increased complications and mortality.[3-5]

Consequently, the selection of appropriate patients for the weaning process is crucial. Currently, there exist classifications of patients who have successfully been weaned from ventilators, such as the International Consensus Conference (ICC) and weaning according to a new definition (WIND). These classifications serve as valuable tools in predicting the likelihood of success or complications following ventilator weaning. According to the findings of a previous study conducted by WIND group, it has been demonstrated that utilizing the WIND classification system offers several benefits in predicting a patient's mechanical ventilator weaning group, as compared to the previous ICC classification. The results of this study provide valuable insights into the effectiveness of the WIND classification system in clinical practice.[6,7]

Diaphragmatic dysfunction is a prevalent issue among mechanically ventilated patients, which can prolong the duration of mechanical ventilation and impede successful weaning. In the past, assessing diaphragmatic function necessitated invasive instruments and expert interpretation, rendering it inconvenient for critically ill patients. However, with the advent of high-frequency diagnostic equipment, the function of the diaphragm can now be conveniently evaluated at the patient's bedside.[8] Ultrasonic diagnostics enable the measurement of various aspects of diaphragm function, including diaphragmatic excursion, diaphragmatic thickness, and diaphragmatic contraction speed. These measurements, when combined with other parameters, can serve as indicators for successful weaning from the ventilator.[9-11]

The WIND study did not investigate the correlation between diaphragmatic ultrasound assessment. Therefore, the objective of this study is to investigate whether diaphragmatic function tests can be employed to classify patients who have been weaned from ventilators in surgical ICUs and predict the success of ventilator weaning.

Previous research in the field[12-14] has predominantly focused on the Internal Medicine Intensive Care Unit (ICU), with limited attention given to surgical ICUs. Within the surgical ICU, it is common for perioperative patients to encounter diaphragmatic dysfunction. This dysfunction can have multiple underlying causes, including surgical procedures involving the thoracic or abdominal regions. However, this study aims to address this gap by including a patient cohort consisting of individuals in perioperative status and surgical ICUs.

## Patients and Methods

This is a single center, prospective observational study of SICU patients at Maharaj Nakorn Chiang Mai Hospital during the ethics committee approval period whose diaphragm function were measured with ultrasound during spontaneous breathing trial.

Ethics committee: Faculty of Medicine, Chiangmai University (study code: SUR-2563-07301).

The inclusion criteria for this study encompassed the following parameters: individuals aged 20 years or older, patients who had undergone post-operative procedures, including urgent, emergent, and elective surgeries, individuals who were intubated or had a tracheostomy and were under invasive mechanical ventilation, patients who were deemed ready to undergo a spontaneous breathing trial, and individuals who did not have any contraindications to undergo ultrasonic assessment in the specific anatomical area. Additionally, written informed consent was obtained from all participants in the study.

The exclusion criteria outlined in this study are essential for defining the specific population that will be included in the analysis. By excluding individuals who are pregnant, have neuromuscular disease, diaphragm paralysis, or cannot be properly visualized by ultrasound.

### *Sample size*

| Formula | Previous study | Sample size |
|---|---|---|
| Testing two independent proportion<br>$$n_1 = kn_2$$<br>$$n2 = \frac{(z_{\alpha/2} + z_\beta)^2}{\epsilon^2}\left[\frac{p_1(1-p_1)}{\kappa} + p_2(1-p_2)\right]$$ | Weaning success<br>TFdi < 26%<br>Success = 0.38<br>TFdi > 26%<br>Success = 0.83<br>Incidence of difficult/prolong wean = 0.187[1] | N = 18 per group<br>Incidence = 0.187<br>The calculate at least enrolled = 96.26<br>= ***97 patients***[9,10] |

Estimated dropout rate was estimated to 15% then total sample size was 111 patients.

## *Study protocol*

Patients who were admitted to the Surgical Intensive Care Unit (SICU) and required mechanical ventilation (MV) during the ethics committee approval period were prospectively enrolled at Maharaj Nakorn Chiang Mai Hospital. The diaphragmatic ultrasound examinations were conducted by a surgical resident who was supervised by attending ICU staff. Following the patients' discharge, data on mechanical ventilator usage was obtained from the electronic ICU database. This information was then used to categorize the patients into different WIND groups. Subsequently, the association between the WIND group and various diaphragmatic ultrasound parameters was analyzed.

**WIND Groups**

- Group no weaning (NW): patients never experienced any separation attempt.
- Group 1 (short weaning): the first separation attempt resulted in a termination of the weaning process within 24 hours (successful separation or early death).
- Group 2 (difficult weaning): weaning was terminated after more than 1 day but in less than 1 week after the first separation attempt (successful separation or death).
- Group 3 (prolonged weaning): weaning was still not terminated 7 days after the first separation attempt (by success or death).

*Reproduced from Beduneau G, Pham T, Schortgen F, et al. Epidemiology of Weaning Outcome according to a New Definition. The WIND Study. Am J Respir Crit Care Med. 2017*[7]

## *Diaphragmatic Ultrasound*

All patients were evaluated in a semi-recumbent position within 24 hours of ICU admission using the Esaote® MyLab™ Gamma Ultrasound.

Diaphragm excursion was assessed in the subcostal area, between the mid-clavicular and anterior axillary lines, using the liver or spleen as acoustic windows. Either a cardiac or abdominal probe (1-5 MHz) can be used to identify the diaphragm as a hyperechoic line, which approaches the probe during inspiration. The inspiratory excursion can be easily measured in M-mode, referred to as diaphragm excursion (DE) (Figure 1).

Diaphragm thickness was evaluated at the zone of apposition, between the 8th and 10th intercostal space in the mid-axillary or anterior-axillary line, 0.5 - 2 cm below the costophrenic sinus. To obtain adequate images of diaphragmatic thickness, a linear high-frequency probe (6-13 MHz) is mandatory. At a depth of 1.5 - 3 cm, two parallel echogenic layers can be easily identified: the nearest line represents the parietal pleura, while the deeper one represents the peritoneum. The diaphragm, which is the least echogenic structure between these two lines, can be assessed for thickness and thickening with inspiration.

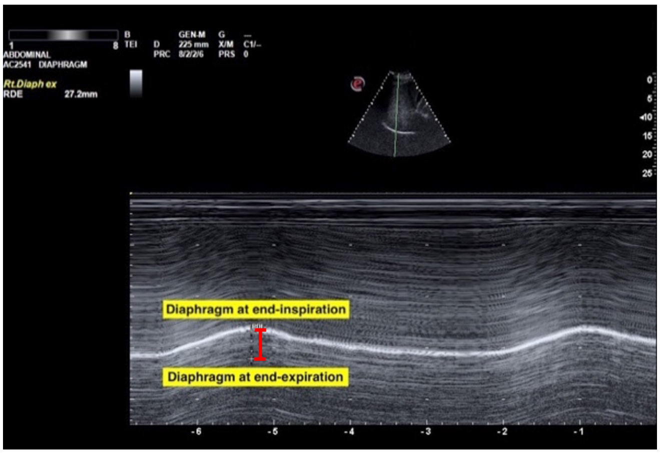


**Figure 1** Diaphragm excursion measurement

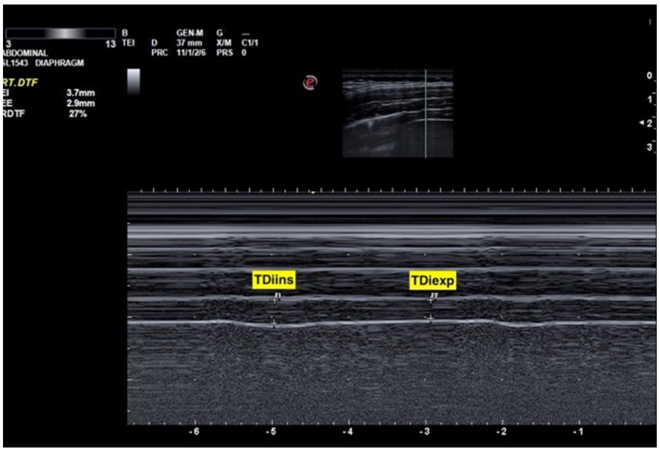


**Figure 2** Diaphragm thickness measurement

This is usually done in M-mode and referred to as diaphragmatic thickness at end inspiration ($TDi_{ins}$) and diaphragmatic thickness at end-expiration ($TDi_{exp}$). The diaphragm thickness fraction (DTF) can be calculated using the formula ($TDi_{ins}$ - $TDi_{exp}$)/ $TDi_{exp} \times 100$. (Figure 2).

## *Data Analysis*

The data in this study are presented using various statistical measures. These measures include counts, percentages, means with standard deviations, and medians with interquartile ranges, as appropriate for the specific data being analyzed. The Kruskal-Wallis H test was employed to analyze the data across the different WIND groups. In statistical analysis, a *p*-value below 0.05 was considered to indicate statistical significance.

## Results

The study began with a cohort of 152 patients. However, 24 individuals were later excluded for various reasons, which are detailed in the accompanying flowchart (Figure 3). As a result, the final sample size for the study consisted of 128 patients. The baseline characteristics of the patients admitted to the Surgical Intensive Care Unit (SICU) are thoroughly presented in Table 1. The results of the study show that, apart from the cause of respiratory failure, specifically peri-operative factors, there were no statistically significant differences observed among the WIND group.

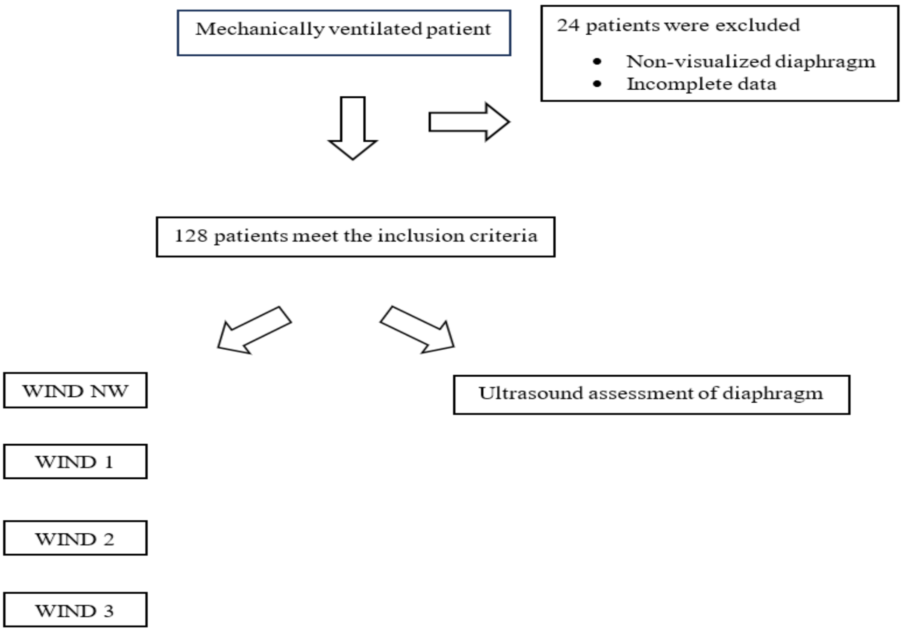


Figure 3 Flow chart of study design and included participants.

**Table 1** Characteristics of WIND group patient in SICU

| Characteristic | All 128 (100%) | WIND NW 6 (4.69%) | WIND 1 90 (70.31%) | WIND 2 24 (18.75%) | WIND 3 8 (6.25%) | *P*-value |
|---|---|---|---|---|---|---|
| **Median age, years (IQR)** | 67 (53-75) | 68.5 (67-72) | 63.5 (50-76) | 69.5 (64-77) | 73 (61.5-80.5) | 0.303 |
| **Sex, male** | 69 (54.33) | 1 (16.67) | 47 (52.22) | 16 (66.67) | 5 (71.43) | 0.117 |
| **ASA** | | | | | | |
| Class 1 | 2 (1.56) | 0 (0.00) | 1 (1.11) | 1 (4.17) | 0 (0.00) | 0.225 |
| Class 2 | 45 (35.16) | 1 (16.67) | 33 (36.67) | 9 (37.50) | 2 (25.00) | |
| Class 3 | 53 (41.41) | 1 (16.67) | 41 (45.56) | 7 (29.17) | 4 (50.00) | |
| Class 4 | 28 (21.88) | 4 (66.67) | 15 (16.67) | 7 (29.17) | 2 (25.00) | |
| Class 5 | 0 (0.00) | 0 (0.00) | 0 (0.00) | 0 (0.00) | 0 (0.00) | |
| **Underlying disease** | | | | | | |
| Hypertension | 64 (50.39) | 3 (50.00) | 41 (46.07) | 15 (62.50) | 5 (62.50) | 0.468 |
| Diabetes | 32 (25.00) | 2 (33.33) | 18 (20.00) | 9 (37.50) | 3 (37.50) | 0.252 |
| COPD | 9 (7.03) | 0 (0.00) | 4 (4.44) | 4 (16.67) | 1 (12.50) | 0.161 |
| CVS disease | 28 (21.88) | 2 (33.33) | 17 (18.89) | 8 (33.33) | 1 (12.50) | 0.364 |
| Cancer | 30 (23.44) | 2 (33.33) | 23 (25.56) | 4 (16.67) | 1 (12.50) | 0.637 |
| Cirrhosis | 10 (7.81) | 0 (0.00) | 7 (7.78) | 3 (12.50) | 0 (0.00) | 0.589 |
| CKD | 18 (14.06) | 1 (16.67) | 14 (15.56) | 3 (12.50) | 0 (0.00) | 0.669 |
| Immunocompromise | 6 (4.69) | 1 (16.67) | 4 (4.44) | 0 (0.00) | 1 (12.50) | 0.239 |
| **Cause of respiratory failure** | | | | | | |
| Hypoxemic | 23 (17.97) | 4 (66.67) | 8 (8.89) | 9 (37.50) | 2 (25.00) | 0.006 |
| Hypercapnic | 2 (1.56) | 0 (0.00) | 2 (2.22) | 0 (0.00) | 0 (0.00) | |
| Peri-operative | 87 (67.97) | 2 (33.33) | 67 (74.44) | 12 (50.00) | 6 (75.00) | |
| Shock | 16 (12.50) | 0 (0.00) | 13 (14.44) | 3 (12.50) | 0 (0.00) | |

The association between diaphragmatic ultrasound parameters and the WIND group is presented in Table 2 and Figure 4. Notably, the diaphragmatic thickness at end inspiration showed statistical significance for the right side, with the WIND 3 group having the lowest measurements (1.6 mm, 2.3 mm, and 1.5 mm, respectively). However, there were no significant differences observed in other diaphragmatic thickness parameters across the groups. Although the WIND 3 group had the highest diaphragm thickness fraction, this difference did not reach statistical significance. In terms of the diaphragmatic excursion parameter, the WIND 2, WIND 1, and WIND 3 groups displayed the highest values, respectively.

Several mechanical ventilator outcomes were found to be statistically significant. These outcomes, between WIND Group 1, 2, and 3, include the number of patients who were successfully weaned from mechanical ventilation (MV) (91.1%, 83.3%, 12.5%, $p < 0.001$) the rate of reintubation (8.9%, 16.7%, 62.5%, $p < 0.001$), the duration of MV days (2, 4, 12, $p < 0.001$) and the length of stay (LOS) in the hospital (3, 6, 22, $p < 0.001$).

**Table 2** WIND group and diaphragmatic parameters association, data was presented in (mm) (IQR) for the diaphragmatic thickness and diaphragmatic excursion and (%) (IQR) for the diaphragmatic thickness fraction.

| Characteristic | All | WIND NW | WIND 1 | WIND 2 | WIND 3 | *P*-value |
|---|---|---|---|---|---|---|
| **$TDi_{ins}$** | | | | | | |
| Right | 2.35 (1.8-2.99) | 2.5 (2.5-2.5) | 2.2 (1.8-2.85) | 3 (2.6-3.7) | 2.4 (1.3-2.7) | 0.054 |
| Left | 2.3 (1.8-2.9) | 2.6 (2.6-2.6) | 2.3 (1.7-2.83) | 2.3 (1.9-3.2) | 2.55 (2.2-2.7) | 0.651 |
| **$TDi_{exp}$** | | | | | | |
| Right | 1.69 (1.3-2.25) | 2 (2-2) | 1.6 (1.2-2.2) | 2.3 (2-3) | 1.5 (0.71-2.1) | 0.047 |
| Left | 1.7 (1.2-2.4) | 1.9 (1.9-1.9) | 1.6 (1.3-2.25) | 2 (1.4-2.7) | 1.75 (0.82-2) | 0.603 |
| **DTF (%)** | | | | | | |
| Right | 33 (24-54) | 28 (28-28) | 32.5 (24.5-54.5) | 32.5 (19-44) | 60 (29-93) | 0.388 |
| Left | 36.5 (24-47.5) | 34 (34-34) | 36.5 (24.5-47) | 29 (21-48) | 53.5 (31-72) | 0.596 |
| **Diaphragmatic excursion** | | | | | | |
| Right | 9.5 (6.85-12.7) | 6.7 (6.7-6.7) | 9.37 (7-13) | 9.7 (6.6-15.1) | 7.2 (5-11.5) | 0.449 |
| Left | 9.1 (6.65-12.55) | 19.9 (19.9-19.9) | 9.15 (6.5-12) | 10.5 (7.4-15.4) | 6.9 (5.4-7.2) | 0.069 |

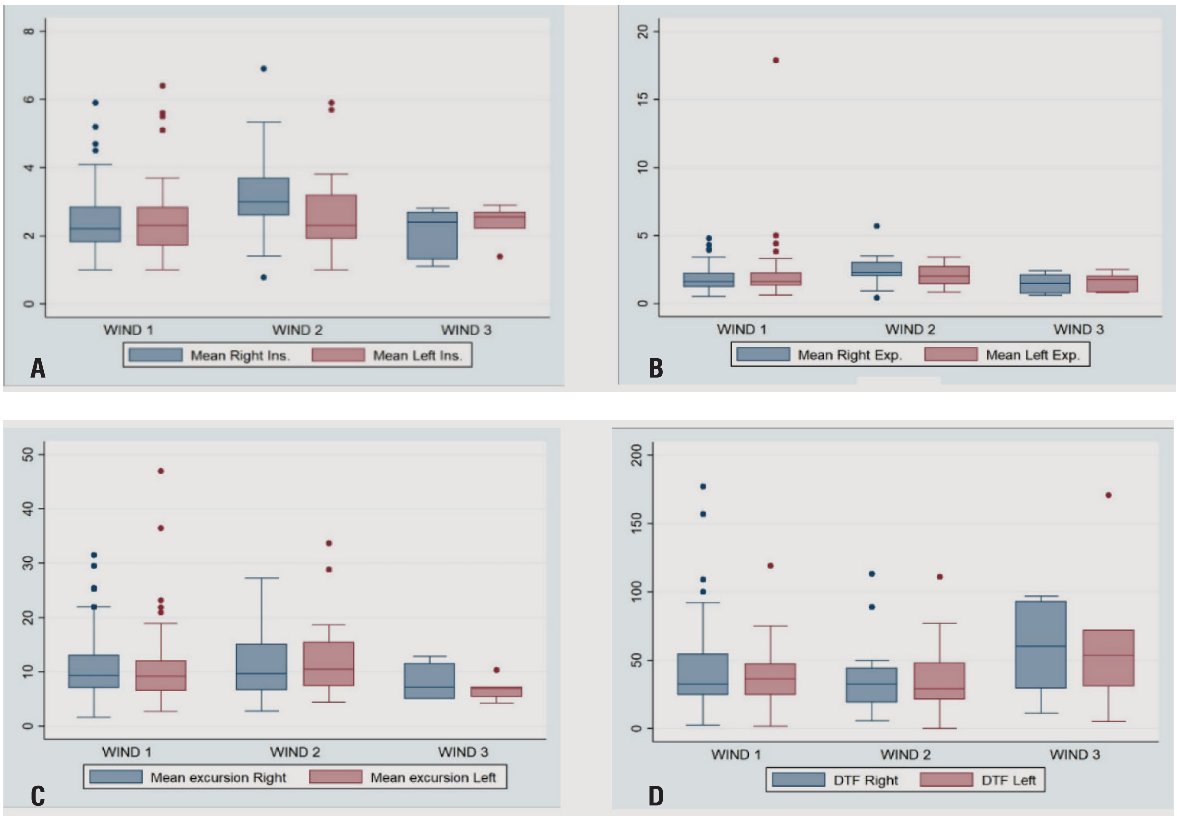


**Figure 4** Boxplot of right and left diaphragmatic thickness at inspiration (A) and expiration (B), right and left diaphragmatic excursion (C), and right and left DTF (D): the central line represents the median value, the box boundaries represent the 25th and 75th percentiles, the lines represent the 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.

**Table 3** WIND group, mechanical ventilator outcomes, and LOS association

| Characteristic | All | WIND 1 | WIND 2 | WIND 3 | *P*-value |
|---|---|---|---|---|---|
| Successful weaning from MV N, % | 107 (83.59) | 82 (91.11) | 20 (83.33) | 1 (12.50) | < 0.001 |
| Interval between intubation and first weaning, days (IQR) | 1 (1-3) | 1 (1-2) | 1 (1-4) | 7 (1.5-8.5) | 0.184 |
| Re-intubation N, % | 19 (14.84) | 8 (8.89) | 4 (16.67) | 5 (62.50) | < 0.001 |
| Interval between re-intubation, days (IQR) | 2 (1-4) | 2 (1-5) | 2.5 (1-38.5) | 3 (1-4) | 0.752 |
| MV days (IQR) | 2 (1-4) | 2 (1-3) | 4 (3-7) | 12 (5-16) | < 0.001 |
| LOS in ICU, days (IQR) | 5 (3-11.5) | 3 (2-8) | 6 (5-12.5) | 22 (17.5-30) | < 0.001 |

## Discussion

The mean diaphragmatic thickness in previous studies[12-14] has been reported to range from 1.5 to 2 mm. Consistent with these findings, the mean diaphragmatic thickness in this study also fell within this range. Previous research has indicated that the diaphragmatic thickness fraction is a reliable measure for assessing respiratory muscle workload during noninvasive mechanical ventilation and predicting extubation success or failure during a trial of spontaneous breathing. However, this study did not observe any significant difference in the measurement of the thickening fraction, which could be attributed to the intricacies involved in the measurement process.

Measuring diaphragmatic thickness poses several challenges. Firstly, due to the relatively small thickness values (between 1.5 and 2 mm), a high-frequency probe, typically a 10 MHz "vascular" probe, is necessary. Secondly, difficulties may arise when dealing with certain patient populations, such as obese individuals. Thirdly, the majority of ultrasound machines have a minimum detectable distance of 0.1 mm, which constitutes roughly 5-7% of the measurement. Consequently, even slight variations introduced by the operator can influence the precision of the measurement. Fourthly, evaluating the left hemidiaphragm can be particularly challenging in some cases to identify the correct position for measuring diaphragmatic parameters. Lastly, there is a lack of available data regarding the learning curve associated with measuring the thickening fraction. These factors collectively contribute to the potential discrepancies between the findings of this study and those of previous studies.

In conclusion, this study aligns with earlier research by reporting a mean diaphragmatic thickness within the established range. However, it did not find any significant difference in the measurement of the thickening fraction, potentially due to the complexities involved in the measurement process. Challenges associated with measuring diaphragmatic thickness include the need for a high-frequency probe, difficulties with certain patient populations, the impact of operator-induced fluctuations, challenges in evaluating the left hemidiaphragm, and a lack of data on the learning curve for measuring the thickening fraction. These factors may help explain the differences observed between this study and previous research.

On the contrary, measuring diaphragmatic excursion using ultrasound is a relatively straightforward procedure. In this study, although the differences were not statistically significant, the values of diaphragmatic excursion were observed to be higher in both groups 1 and 2 of the WIND population compared to group 3, which represents individuals with normal diaphragmatic function. Notably, group 2 exhibited even higher values than group 1, suggesting the need for further investigation to determine whether this difference may be due to early postoperative diaphragmatic dysfunction. Additionally, conducting studies with larger sample sizes and closely monitoring ultrasonographic parameters during mechanical ventilation in the Surgical Intensive Care Unit (SICU) setting is crucial. These efforts will facilitate a more comprehensive analysis and enhance our understanding of the significance of ultrasound parameters in this specific context.

The study conducted by the WIND group aimed to validate the use of the WIND group classification in predicting the outcomes of mechanical ventilation in patients admitted to the Maharaj Nakorn Chiang Mai SICU. From the Table 3, the results of the study showed that the

WIND group classification was effective in predicting the outcomes of mechanical ventilation. This suggests that the WIND group classification can be a useful tool for clinicians in assessing the prognosis of patients requiring mechanical ventilation. However, it is important to highlight that the study also found no correlation between the WIND group classification and ultrasonic diaphragmatic measures.

One limitation of this study is that although we are concerned with the measurement bias by training the residents every rotation and consultant assistant during measurement, the operator bias might also occur. Another limitation arises from the possibility of post-operative diaphragmatic swelling in patients, which might lead to minimal differences in diaphragmatic thickness and excursion among the groups under investigation. Additionally, as mentioned earlier, the study emphasizes that even slight discrepancies introduced by the operator can significantly affect measurement precision. Therefore, to bolster the reliability of the study findings, it is advisable to carry out an intra-observer validation assessment.

## Conclusion

Diaphragmatic ultrasonography lacks the ability to differentiate between the various WIND groups. However, the success of weaning varies among WIND classifications.

## Acknowledgement

The researcher would like to express their sincere gratitude to all individuals who contributed to the successful execution of this study. The completion of this research was made possible through the invaluable guidance and support of our esteemed mentors. Additionally, we would like to acknowledge the collaborative efforts and assistance provided by the surgical research unit, surgical residents, and surgical intensive care unit nurses who are affiliated with the Department of Surgery at the Faculty of Medicine, Chiang Mai University. Their expertise and dedication greatly enhanced the quality and validity of this study.

## Conflict of interest

The authors disclose no conflict of interest.

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