Assessment of diaphragmatic movement using ultrasound in weaning of invasively mechanically ventilated patients

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Abstract

Background: Determining the right time to extubate is vital. RSBI and diaphragmatic sonography values may provide useful data for predicting the weaning outcome.

Objectives: This study aimed to evaluate the value of RSBI and diaphragm sonography in predicting the weaning failure in mechanically ventilated patients

Patients and methods: This is a prospective observational study including all the mechanically ventilated patients aged >18 years who required invasive mechanical ventilation for more than 24 hours and eligible for weaning criteria. All the demographic data, comorbidities, laboratory investigations were collected. ABG and RSBI were measured during the weaning trial and diaphragmatic ultrasound parameters including [Diaphragmatic excursion, diaphragmatic thickness, and diaphragmatic thickness fraction].

Results: This study included 100 cases. Of all included cases, 21 cases (21%) were successfully weaned and 79 subjects (79%) had weaning failure. PH at the time of admission was considerably higher among the successful weaning cases, Also SO_2 at time of weaning was higher among successful weaning cases**.** Regarding the weaning parameters, Only RSBI was considerably higher among weaning failure group. DE at time of weaning as it was higher among the successful weaning group (P = 0.00186).

Conclusion: Higher SO2 levels, lower RSBI values, and DTF at weaning were associated with successful weaning, highlighting their potential as predictive factors for weaning outcomes.

Keywords: RBSI; Diaphragmatic ultrasound; Weaning; Mechanical ventilation.

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DOI: 10.21608/svuijm.2023.233472.1679

Received: 2 September, 2023.

Revised: 19 September, 2023.

Accepted: 19 September, 2023.

Published: 11 January, 2024

Cite this article as: Yousra Fouad Waheedy, Alaa Rashad, Haggagy Mansour, Eptehal Mohammed Dongol (2024). Assessment of diaphragmatic movement using ultrasound in weaning of invasively mechanically ventilated patients. *SVU-International Journal of Medical Sciences*. Vol.7, Issue 1, pp: 134-143.

Introduction

Mechanical ventilation is crucial in giving life-sustaining assistance to severely sick patients who have respiratory insufficiency. Successful weaning is contingent upon various elements like muscle strength, cardiac and respiratory health, and metabolic conditions. Acquired weakness due to MV is a significant cause of weaning failure. Ultrasonography helps predict weaning outcomes by evaluating diaphragmatic dysfunction **(Qian et al.,2018).**

The rapid shallow breathing index (RSBI) is a tool for the clinicians to facilitate the process of weaning and provide accurate predictions and decision. **(Burns et al., 2018).** This easily assessed indicator has gained popularity due to its ease of use and its stated specificity for extubation success prediction when compared to other measures **(Yang & Tobin, 1991).**

The RSBI is the indicator that is widely employed for the purpose of screening invasively ventilated patients in order to ascertain their eligibility for participation in a spontaneous breathing trial (SBT). However, it is important to consider the specific ventilation settings at which the Rapid Shallow Breathing Index (RSBI) is assessed, as well as the timing of the RSBI measurement, whether it is conducted before or during a Spontaneous Breathing Trial (SBT) **(Karthika et al., 2016).**

Prolonged mechanical breathing may cause serious complications such as ventilator-induced diaphragmatic dysfunction, which makes effective weaning from the ventilator difficult **(Kocjan et al., 2017; Daniel et al., 2013).** Diaphragmatic ultrasound is non-invasive, radiation-free, widely available, provides immediate and accurate results, and can be repeated at the bedside **(Santana PV et al.,2020)**. Diaphragm sonography values provide useful information for assessing and monitoring mechanically ventilated patients **(Abdelhafeez et al., 2019).**

We aimed to determine the value of assessment of RBSI in predicting weaning outcome in mechanically ventilated ICU patients and to determine value of assessment of diaphragmatic function by ultrasound in predicting the weaning result in mechanically ventilated ICU patients.

Patients and Methods

This is a prospective observational study conducted at Qena University Hospital in the period from January 2022 to January 2023. The study included all the mechanically ventilated patients aged >18 years who required invasive mechanical ventilation in the ICU for more than 24 hours and eligible for weaning criteria. Patients with a history of upper abdominal or thoracic surgery, neuromuscular disorders affecting the diaphragm and phrenic nerve, congenital diaphragmatic disorders, or hospital-acquired pneumonia were excluded.

All the patients were subjected to:

- **A through history taking** including age, sex, body mass index, comorbidities (diabetes mellitus, hypertension, any chronic chest diseases, cardiovascular diseases), and smoking status.
- **A full clinical examination** including the assessment of vital signs [blood pressure, temperature, heart rate, and respiratory rate]
- **The laboratory investigations** including: Complete Blood Count (CBC), C-reactive protein (CRP), serum creatinine, serum albumin, and serum electrolyte levels (potassium, sodium, calcium).
- **Arterial blood gas measurements** at admission and during the weaning trial.
- **Ventilator parameters:** Rapid shallow breathing index (RSBI), positive end expiratory pressure

(PEEP): at time of weaning trials. Rapid Shallow Breathing Index (RSBI): Ratio of respiratory rate (f) to tidal volume (VT).

- RSBI = TV/RR

➢ **Chest X-ray** in a supine position acquired in the posteroanterior or anteroposterior projection.

- **Diaphragmatic examination by ultrasound** done at the bedside in the ICU to assess diaphragmatic excursion, diaphragmatic thickness, and diaphragmatic thickness fraction. The assessment was done at the time of admission, and at the time of weaning from mechanical ventilation.

1. The diaphragmatic excursion

- Technique: by Anterior subcostal approach
- In this method, we used a low-frequency **(5- 10 MHz)** linear probe and the patient should be in the supine or semi-recumbent position when possible. The probe was placed below the right costal margin in the sagittal plane anywhere between midclavicular and anterior axillary line. The probe beam was directed medially, cranially and dorsally to visualize the posterior part of the diaphragm. For the left diaphragm, the probe was placed at the lower intercostal area in the sagittal plane between the anterior axillary line and mid axillary line. The left hemi-diaphragm is frequently more difficult to visualize due to the limited window of the spleen and interference from stomach gas. In B-mode, diaphragm is seen as a bright hyperechoic line surrounding the liver. In this method both right and left domes of the diaphragm were obtained in a single frame and their excursion can be compared in real time. Diaphragm excursion was most easily measured by applying M-mode imaging to the diaphragm dome and measuring the distance from end inspiration to end expiration **(Elew et al., 2022; Kilaru et al., 2021)**. The normal values of the diaphragm excursion ranging from 1-2 cm during tidal breathing and 7-11 cm during deep inspiration as reported by **Gierada et al. (1995)** as shown in (**Fig.1).**

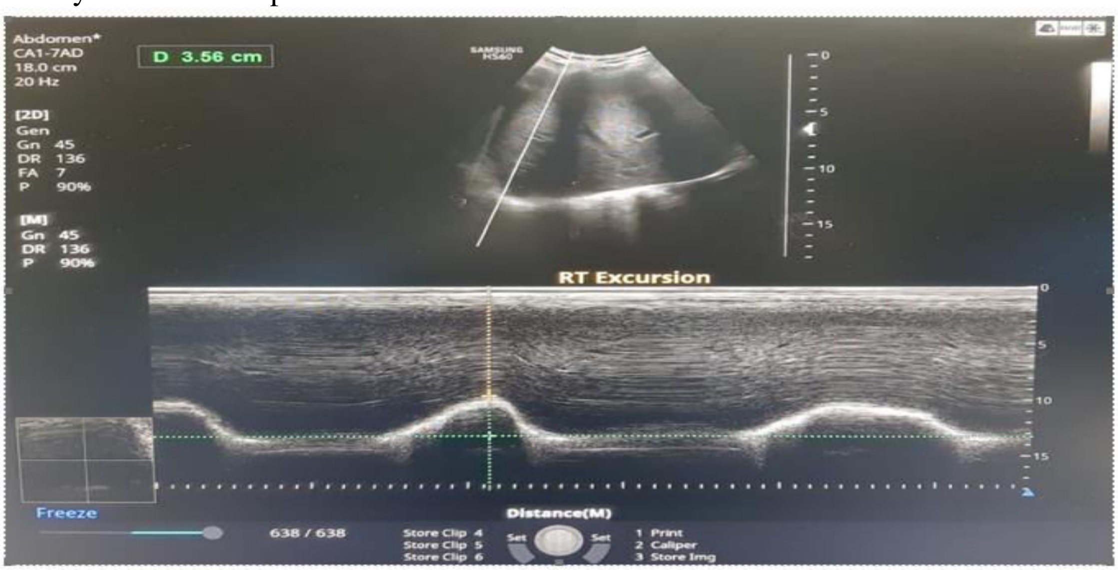

Fig.1.Ultrasound examination of the diaphragm showing measurement of diaphragmatic excursion ; upper part D mode , lower part M mode

2. **The diaphragmatic thickness**,
   - **Technique**: **the zone of apposition**
   - We used a higher-frequency **(> 10 MHz)** linear probe, to view the diaphragm as a three-layered structure, sandwiched between the two echogenic layers of the pleura and the peritoneum. Both B- and M-mode techniques can be used to measure thickness. In patients with normal diaphragmatic function, the thickness ratio of both sides should fall within the range of 0.7 to 1.5 in men and 0.6 to 1.6 in women. Particularly, the upper limit of normality for the differences between the sides is determined to be 1 mm in women and 0.9 mm in men (**Boussuges et al, 2021)** as shown in **(Fig.2).**

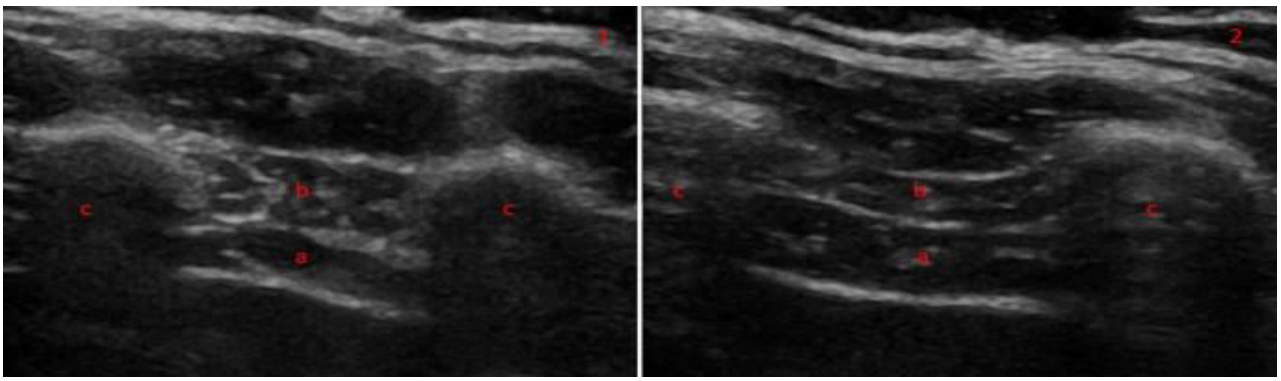

Fig. 2. Diaphragm thickness in B-mode thoracic view at end expiration **(1)** and inspiration **(2)** in a heathy volunteer. The diaphragm can be seen between two echogenic layers **(a)** with the intercostal compartment above **(b)**. The two muscle layers sit between two ribs **(c)** **(Turton et al., 2019)**.

3. **Diaphragmatic Thickness Fraction (DTF)**,
   - it was calculated as the variance between the diaphragmatic thickening at the end of inspiration (DTi) and expiration (DTe), divided by DTe and multiplied by 100 (DTf = |DTi - DTe| / (DTe*100) (**Samanta et al, 2017).** Diaphragm Thickening Fraction (DTF) less than 20% was considered a measure of ultrasonographic diaphragmatic dysfunction in patients on mechanical ventilation, (**Jung et al., 2016).**

Patients were assessed for tolerability of SBT, by fulfilling the following criteria: 1) Hemodynamic stability, 2) Discontinuation of sedative infusion, 3) Cessation of tube feedings and 4) PaO2/FiO2 ratio greater than 200 with PEEP (positive end-expiratory pressure) less than or equal to 5 cmH2O **(Ely, E W et al., 1996)** Then. the patients were be divided into 2 groups according to SBT outcome: weaning success group who passed SBT successfully and weaning failure group who failed SBT.

Statistical Analysis

The statistical analyses were conducted using IBM SPSS (Statistical Program for the Social Science; IBM Corp, Armonk, NY, USA) version 26 for Microsoft Windows to analyze the data. Data were expressed as number and percentage for qualitative variables and mean + standard deviation (SD) for quantitative one.

The comparison was done using:

I- The student "t" test for comparison of means of two independent groups:

II-Mann Whitney test: used to calculate difference between quantitative variables in not normally distributed data in two groups.

III- Chi- square test (X2): used to find the association between row and column variables.

IV- Z-test for percentage: to compare percentage of outcome between the two groups.

Level of significance:

For all above-mentioned statistical tests done, the threshold of significance was fixed at 5% level (P-value).

- P value of > 0.05 indicates non-significant results.

- P value of < 0.05 indicates significant results.

The smaller the P value obtained the more significant are the results.

Ethical considerations:

The ethical approval number: **SVU-MED-CHT019-1-22-2-341**

Results

This study included 100 cases. COPD excerbation was the most common admission diagnosis, accounting for 20% of the cases, followed by bronchopneumonia (17 %) as shown in **Figure (3)**. Of all the included cases, 21 cases (21%) were successfully weaned and 79 subjects (79%) had weaning failure. The mean age of the included cases was 62.91± 18.17 years, with 58% of them were male. There was significant variance between successful and weaning failure groups regarding sex, BMI, some co-morbidities and smoking status as shown in (**Table .1).**

Table 1. Demographic data of the study cohort

Variables	**Successful weaning (N = 21)**	**Weaning failure (N = 79)**	P-Value
Age (Years)	56.48 ± 9.81	64.62 ± 19.49	0.06759
Sex			
• Male	4 (19.05%)	54 (68.35%)	0.00005*
• Female	17 (80.95%)	25 (31.65%)	
BMI (Kg/m^2)	31.04 ± 5.76	34.59 ± 5.34	0.0123*
Co-Morbidities			
DM	6 (28.57%)	45 (56.96%)	0.02071*
HTN	13 (61.9%)	32 (40.51%)	0.07979
Cardiac Disease	7 (33.33%)	45 (56.96%)	0.05406
Smoking status			
• Non smokers	10 (47.62%)	15 (18.99%)	0.00708*
• Stop smoking or ex-smokers	11 (52.38%)	21 (26.58%)	0.02428*
• Current smokers	0 (0%)	43 (54.43%)	0.00001*

BMI: Body Mass Index , DM: Diabetes Mellitus , HTN: Hypertension , COPD: Chronic Obstructive Airway Disease , ILD: Interstitial Lung Disease .* Significant

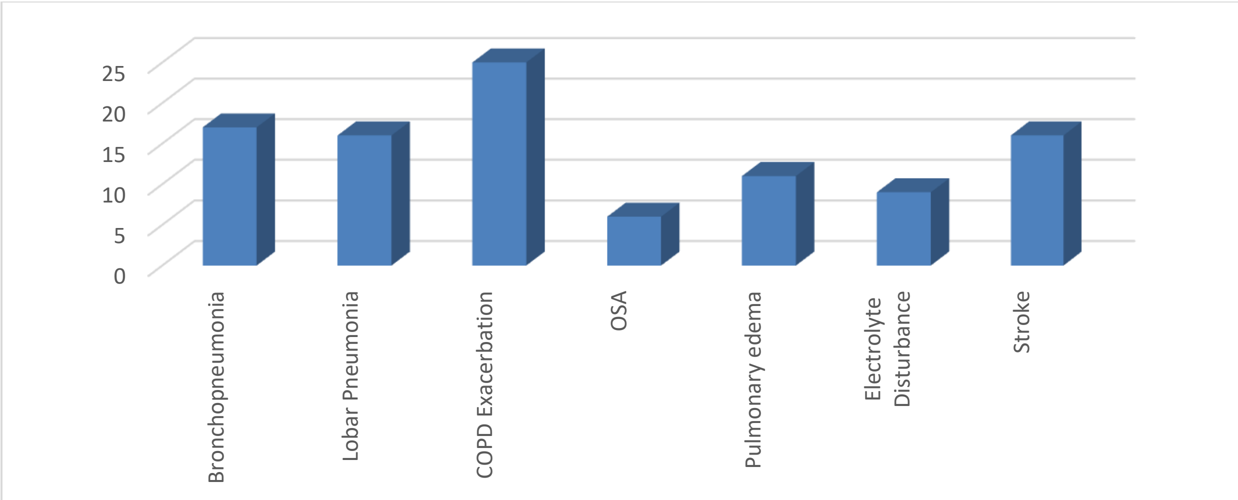

Fig.3. Diagnosis and cause of admission to ICU.

PH at the time of admission was considerably higher among the successful weaning cases, Also SO_2 at time of weaning was higher among successful weaning cases as shown in (**Table .2).**

Table 2. Laboratory investigations of the study population

Variables	Successful weaning (N = 21)	Weaning failure (N = 79)	P. Value
CBC			
• TLC ($\times 10^3/\mu L$)	13.55 ± 5.46	16.39 ± 7.75	0.11834
• HG (g/dl)	11.89 ± 2.42	10.82 ± 2.56	0.08883
• PLT ($\times 10^3/\mu L$)	249.33 ± 113.08	253.46 ± 96.46	0.8671
CRP (mg/L)	26.33 ± 18.73	31.51 ± 28.66	0.43593
Creatinine (mg/dL)	1.29 ± 0.93	1.66 ± 1.57	0.30778
Albumin (mg/dL)	3.32 ± 1.04	3.34 ± 0.72	0.90779
Electrolytes			
• Na (mmol/L)	134.55 ± 8.4	139.98 ± 17.65	0.17492
• K (mmol/L)	3.98 ± 0.82	3.81 ± 0.8	0.38357
• Ca (mmol/L)	0.96 ± 0.14	1 ± 0.21	0.4142
Arterial blood gases: -			
At Admission			
• pH	7.46 ± 0.56	7.19 ± 0.52	0.049*
• $PaCO_2$ (mmHg)	45.57 ± 16.19	42.89 ± 18.68	0.55091
• PaO_2 (mmHg)	64.71 ± 20.07	62.67 ± 17.96	0.65219
• HCO_3 (mmHg)	25.38 ± 5.48	23.33 ± 9.82	0.3613
• SO_2 (%)	84 ± 14.47	85.25 ± 12.3	0.69024
At time of weaning			
• pH	7.66 ± 0.47	7.5 ± 0.76	0.2337
• $PaCO_2$ (mmHg)	47.01 ± 11.65	43.66 ± 13.04	0.28883

• PaO_2 (mmHg)	77.62 ± 11.73	71.21 ± 21.59	0.19479
• HCO_3 (mmHg)	24.41 ± 4.46	22.25 ± 6.14	0.13499
• SO_2 (%)	97.18 ± 8.34	91.91 ± 9.76	0.02571*

Total leukocyte count (TLC), hemoglobin (HG), platelet (PLT), C-reactive protein (CRP), Potassium (K), Sodium (Na), Calcium (Ca), SO2: Oxygen saturation, PO2: Oxygen partial pressure, PCO2: Carbon Dioxide partial pressure
* significant

Regarding the weaning parameters, Only RSBI was considerably higher among weaning failure group as illustrated in (**Table .3**).

Table 3. Ventilator parameters among the study cohort

Variables	Successful weaning (N = 21)	Weaning failure (N = 79)	P. Value
O2 saturation (%)	91.43 ± 8.75	92.22 ± 13.19	0.79692
RR (Breath/Minute)	24.76 ± 5.97	27.48 ± 6.69	0.09424
RSBI	69 ± 41.41	103.87 ± 45.33	0.00193*
PEEP (CmH_2O)	5 ± 0	5.41 ± 1.26	0.1441

Rapid Shallow Breathing Index (RSBI), Positive end-expiratory pressure (PEEP), Respiratory Rate (RR)

There was no significant variance between the two groups regarding all the diaphragm US parameters except for DE at time of weaning as it was higher among the successful weaning group (P = 0.00186) as disclosed in (**Table .4**).

Table .4. Comparison between patients with successful weaning and weaning failure regarding diaphragmatic US results

Variables	Successful weaning (N = 21)	Weaning failure (N = 79)	P. Value
At time of admission			
• DE	1.42 ± 0.56	1.39 ± 0.41	0.74428
• DT	0.3 ± 0.16	0.29 ± 0.11	0.67241
• DTF	31.25 ± 12.33	47.48 ± 20.1	0.07662
At time of weaning			
• DE	1.64 ± 0.44	1.2 ± 0.58	0.00186*
• DT	0.28 ± 0.1	0.27 ± 0.1	0.80815
• DTF	44.83 ± 20.11	44.78 ± 20.22	0.99533

Diaphragmatic excursion (DE), diaphragmatic thickness (DT), diaphragmatic thickening fraction (DTF)* Significant

Discussion

Weaning failure is identified as the failure of SBT or the need for reintubation within 48 h after extubation, occurring in 10–20% of patients, **Heunks, Leo M., and Johannes G. Van Der Hoeven. (2010)**

This study included 100 cases. Of all included cases, 21 cases (21%) were successfully weaned while, 79 cases (79%) had weaning failure. In harmony, **Ferrari et al.**, (2014) also reported 63% failure rate. However, **Vidotto et al., (2011)** summarized that, the weaning failure rate was 20%. Similarly, **Fahmy et al., (2019)** reported (22%) weaning failure rate. **El-Beheidy et al, (2018)** summarized that the frequency of weaning failure was (39.6%). This discrepancy among the diverse studies may be due to the non-uniform rule in study population selection with diverse causes for mechanical ventilation as well as diverse weaning protocols.

In our study, the primary reasons for admission to the ICU were chest diseases including COPD exacerbation ,bronchopneumonia ,bronchiectasis and

OSA accounting for (64 %) of all cases while stroke (16%) ,and pulmonary edema (11%) . Our results were consistent with the study conducted by **(Abdel Rahman et al., 2020)** who presented the causes of admission for cases, revealing that chest problems accounted for the majority (62.3%) of cases, followed by neurological diseases (7.5%), renal complications (9.4%), GIT diseases (9.4%), cardiac diseases (5.7%), and hematology diseases (5.7%).

In this study, successfully weaned group had a lower prevalence of diabetes mellitus, cardiac disease, COPD, combined COPD and ILD, and were more likely to be non-smokers or have quit smoking. In harmony with our study, **GÜRÜN, (2021)** study disclosed similar comorbidities, with slightly higher prevalence rates for hypertension **(64.1%)** and lower rates for diabetes mellitus **(33.3%)** and COPD **(48.7%)** among the weaning success group.

Smoking is another significant factor impacting respiratory health, leading to various lung diseases. Together, obesity and smoking play critical roles in determining the success and difficulties of weaning from mechanical ventilation **(Kacmarek et al., 2021; Grieco & Jaber, 2022)**.

In this study, patients who were successfully weaned had higher mean values of pH and oxygen saturation at time of weaning compared with weaning failure group**. Mabrouk et al**., (2015) also found significant increase in pH among successfully weaned group. In contrast, **Vetrugno et al., 2022)**, They did not find significant variance in SpO2 levels, pH, and PaCO2 levels between the weaning failure and weaning success groups.

In 1991, **Yang and Tobin** employed the Rapid Shallow Breathing Index (RSBI) as a predictor for weaning. In their seminal work, Yang and Tobin (1991) selected the Respiratory System Compliance (RSBI) as the preeminent weaning measure due to its exceptional specificity and sensitivity. We found that the mean rapid shallow breathing index (RSBI) exhibited differences among the successful weaning group when compared with the weaning failure group (p value = 0.00193*).

Assaf, Asmaa, et al., (2019) also found that RSBI showed highly significant decrease in success group compared to failed group pre-weaning trial and during weaning trial . **El-Beheidy et al, (2018)** summarized that, the mean values of RSBI were considerably higher (p<0.001) in failed group compared with success group. Likewise, **Osman & Hashim (2017)** disclosed that RSBI was a significant parameter during studying the predictive parameters for weaning from mechanical ventilation .

Regarding the diaphragmatic ultrasonography parameters, only DE at time of weaning was considerably higher among successful weaning group **(P = 0.00186)**. In agreement with this study, **Hayat et al. (2017)** assessed the diaphragmatic excursion in 100 cases who was mechanically ventilated and fulfilled the criteria of extubation and summarized that, DE was significantly higher in the successfully weaned group with a cut of value of (1.2 cm). Similarly, **Elshazly, Mostafa Ibrahim et al.,(2020)**confirmed similar result.

This prospective cohort study has yielded valuable insights. Nevertheless, it is essential to acknowledge several inherent limitations. Firstly, the study's single-center nature restricts the generalizability of findings to broader populations or diverse healthcare settings. Secondly, the relatively modest sample size of 100 participants may compromise statistical power and precision. The study also did not account for potential confounding variables, such as disease severity or specific weaning protocols, which could have influenced the outcomes. Furthermore, the reliance on ultrasound for diaphragmatic assessment introduces the possibility of interobserver variability, affecting measurement reliability. Despite these constraints, this study serves as a significant stepping stone for further research and underscores the importance of diaphragmatic evaluation in the context of weaning from mechanical ventilation.

Conclusion

These results indicate that higher SO2 levels and lower RSBI values, and DTF at weaning were associated with successful weaning, highlighting their potential as predictive factors for weaning outcomes.

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