Acute and Critical Care 2025 November 40(4):557-566
https://doi.org/10.4266/acc.003984
| pISSN 2586-6052 | eISSN 2586-6060

Thoracic fluid content by electrical cardiometry versus diaphragmatic excursion by ultrasound for the prediction of weaning success in patients with lung congestion

Shawky Meselhy Elshaer[1], Ahmed Mostafa Abdelhamid[2], Enas Wageh Mahdy[2], Samar Rafik Amin[2]

[1]Department of Critical Care Medicine, Benha Faculty of Medicine, Benha University, Benha, Egypt
[2]Department of Anesthesia and Intensive Care, Benha Faculty of Medicine, Benha University, Benha, Egypt

Background: Predicting the weaning outcomes is critical, since premature or delayed extubation is associated with an increased risk of mortality. This study aimed to compare two physiological indices, thoracic fluid content (TFC) and diaphragmatic excursion (DE), for predicting weaning success in mechanically ventilated patients.

Methods: This observational cohort study involved 100 mechanically ventilated patients with congested lungs who were eligible for weaning. Patients' TFC and DE were measured using electrical cardiometry and ultrasonography, respectively, before starting the spontaneous breathing trial. Following extubation, patients were grouped into successful and failed-weaning groups, with failure defined as reintubation or a need for non-invasive ventilation within 48 hours. Respiratory and cardiovascular variables were compared. The receiver operating characteristic (ROC) curve was used to assess the ability of TFC and DE to predict weaning success.

Results: Successful weaning occurred in 73 patients (73%) and failed weaning occurred in 27 patients (27%). The two groups' baseline characteristics were comparable; however, TFC and DE were significantly different between the failed- and successful-weaning groups ($P<0.001$). The area under the ROC curve (AUC) exhibited moderate predictive abilities of both the TFC and DE in predicting weaning success (AUC, 0.805; cutoff $<40\ k\Omega^{-1}$ and AUC, 0.774; cutoff >1.45 cm). In the cardiac patient subgroup, TFC exhibited high predictive ability (AUC, 0.861), but DE did not achieve comparable results (AUC, 0.750).

Conclusions: Both TFC and DE are significant predictors for successful weaning from mechanical ventilators. In particular, a TFC of $<40\ k\Omega^{-1}$ demonstrated an excellent ability to predict weaning success in patients with low ejection fraction.

Key Words: electric impedance; mechanical ventilation; pulmonary edema; thoracic fluid content; ultrasonography; weaning

Original Article

Received: October 11, 2024
Revised: August 4, 2025
Accepted: August 20, 2025

Corresponding author
Samar Rafik Amin
Department of Anesthesia and Intensive Care, Benha Faculty of Medicine, Benha University, 7 Ahmed Maher St, Benha, Al Qalyubia 13512, Egypt
Tel: +20-128-779-3991
Email: samar.rafik@fmed.bu.edu.eg

INTRODUCTION

Many physicians inaccurately predict weaning outcomes, with positive and negative predictive values of only about 50% and 67%, respectively [1]. Consequently, choosing the appropriate timing for extubation is crucial to avoid complications such as nosocomial pneumonia or an increased mortality risk [2]. Among the various pathophysiological mechanisms that can hinder weaning, respiratory failure and cardiovascular dysfunction are the most common contributors. Several parameters linked to these systems have been explored as potential predictors of weaning outcomes, including diaphragmatic dysfunction and pulmonary edema [3]. A novel, non-invasive marker attracting interest is thoracic fluid content (TFC), which inversely correlates with transthoracic electrical bioimpedance. TFC reflects the total fluid volume—both intravascular and extravascular—within the chest cavity. It has demonstrated promising results in assessing volume status in a variety of clinical settings and has recently been proposed as a potential predictor of weaning outcomes [4]. Originally measured using thoracic bioimpedance equipment, TFC can now be assessed using electrical cardiometry technology, making it easier for junior physicians and even paramedics to apply. This approach displays TFC as numerical values with minimal fluctuation, making interpretation straightforward and reducing inter-observer variability [5].

Meanwhile, diaphragmatic ultrasound, a safe, portable, and cost-effective tool, allows for evaluating both functional and structural aspects of the diaphragm. Parameters such as diaphragmatic excursion (DE), diaphragmatic thickness, and diaphragmatic thickness fraction (DTF) have all been identified as possible indicators of weaning outcomes [6]. The current study hypothesized that DE and TFC, as two non-invasive measures of neuromuscular and cardiopulmonary function, respectively, may be useful in various clinical settings and have varying predictive accuracies for weaning outcomes. To predict effective liberation from mechanical ventilation (MV) in critically ill patients with lung congestion, the present study aimed to assess and compare the diagnostic performances of TFC and DE.

KEY MESSAGES

- Lung congestion is a significant cause for failed weaning, particularly in cardiac patients.
- Thoracic fluid content (TFC) can be measured as a numerical value using electrical cardiometry that represents the change in thoracic electrical bioimpedance in response to the change in total intrathoracic water content.
- The involvement of multiple assessment indices, such as TFC and diaphragmatic excursion, before a trial of weaning is crucial to be able to recognize hidden factors that could interfere with the weaning process.

MATERIALS AND METHODS

The study was approved by the Institutional Review Board of Benha Faculty of Medicine (No. MD 10-4-2023). The protocol was pre-registered online at ClinicalTrials.gov with a unique identifying number (NCT05947942), and informed written consent was obtained from all patients or their first-degree relatives.

This prospective observational study was carried out in the critical care department of a university hospital, during the period from July 2023 to June 2024. The Strengthening the Reporting of Observational Studies in Epidemiology statement checklist was followed for the reporting of observational studies. The study enrolled intensive care unit (ICU) patients of either sex, aged 18–65 years old, with pulmonary congestion as defined by chest radiography (i.e., by the presence of enlarged vessels in the lungs apex, peri-bronchial haze, peri-hilar cuffing, Kerley B lines, and interstitial edema), who were mechanically ventilated for more than 48 hours and were eligible for weaning according to the treating physician, who followed the critical care unit weaning protocols.

The study excluded patients with pleural or pericardial effusions, confirmed through combined chest x-ray and bedside ultrasound, to isolate pure pulmonary congestion. Additional characteristics that led to exclusion included ascites; pneumothorax; body mass index ≥35 mg/m^2; pregnancy; a history of neuro-muscular diseases; the presence of chest tube drains, burns, or wounds that would interfere with electrode application; and a history of abdominal, thoracic, head, and neck surgery or trauma.

Weaning Process

According to our ICU protocol, the attending physician was responsible for the decision to conduct a spontaneous breath trial (SBT) and to liberate the patient from MV. All physical findings and investigations accompanied by a full history of the patients, including their symptoms, demographic profile, and anthropometry, were collected. Readiness-to-wean criteria [7] included resolving the primary reason for intubation as well as having a satisfactory cough without excessive secretions, a respiratory rate (RR) of <30 breaths/min, a PaO_2 value of >60 mm Hg, an inspired oxygen fraction of ≤0.4, a positive end-expiratory pressure (PEEP) of ≤8 cm H_2O, and an optimal pH to stabilize the patient's respiratory and cardiovascular status.

The ventilatory settings for the SBT were adjusted to the pressure-support mode, with 5 cm H_2O selected for pressure support and 5 cm H_2O used for PEEP. After 30 minutes of SBT, the weaning parameters were re-examined, and the decision to extubate the patient was made by the ICU physician, who was unaware of the patient's diaphragmatic ultrasound and cardiometry results.

Weaning success was defined as the ability to maintain spontaneous breathing for at least 48 hours following extubation without the need for reintubation or non-invasive ventilation. Patients were reintubated due to tachypnea (high RR, i.e., >35 breaths/min), oxygen saturation <90% or PaO_2 <60 mm Hg on an inspired oxygen fraction of 40%, increased activity of accessory muscles of respiration, or obvious facial signs for respiratory distress. Additionally, the need for unplanned non-invasive ventilation within 48 hours was considered an instance of ventilation failure, in line with prior studies [8,9] that link this intervention to underlying respiratory decompensation.

Non-invasive Electrical Cardiometry Measurements

Before beginning the SBT, each patient's TFC was measured using an electrical cardiometry tool (ICON; Osypka Medical) in the supine position. After sterilization with alcohol, the electrical cardiometry system was linked to four electrodes attached to the patient's skin. Two electrodes were positioned on the left side of the patient's neck, behind the ear, and above the mid-clavicular point, and the other two electrodes were placed at the left mid-axillary line. The measured TFC was recorded for 30 seconds, and the mean value between the highest and lowest readings was obtained.

Diaphragmatic Ultrasonography Measurements

With the patient in a semi-recumbent position, DE was measured using a low-frequency 3–5-MHz curvilinear probe (LOGIQ F8 Expert; GE Healthcare). All patients underwent an ultrasound assessment of the right hemidiaphragm due to the existence of a better hepatic acoustic window. The probe was positioned perpendicular to the chest wall, at the right subcostal area, between the anterior and mid-axillary lines, parallel to the intercostal spaces, and angled cranially to observe the diaphragm dome. The DE in centimeters was determined by taking the highest displacement from the baseline as visualized in M-mode (Figure 1A).

DTF was also assessed in this position (semi-recumbent position) by asking the patients to deeply inspire to total lung capacity and completely expire to residual volume. In B-mode, the distance from the center of the pleural line to the center of the peritoneal line was measured for the thickness of the diaphragm. DTF percentage was then determined by multiplying the difference between the end-inspiratory thickness and end-expiratory thickness, which was subsequently divided by the end-expiratory thickness, by 100. For analysis, measurements of DTF were obtained for three breaths, and the mean value among them was used (Figure 1B). A successful-weaning group and a failed-weaning group were created based on patient outcomes. Additional subgroup analysis was carried out for patients with and without cardiac dysfunction. Patients were classified as cardiac patients (ejection fraction <40%) or non-cardiac patients (ejection fraction ≥40%) based on the results of transthoracic echocardiography conducted prior to the SBT.

Study Measurements

The primary outcome was the accuracy of TFC and DE to predict weaning success as determined by the area under the receiver operating characteristic curve (AUC). The secondary outcomes included diaphragmatic thickness fraction (DTF); the Rapid Shallow Breathing Index (RSBI), which was determined by dividing RR by the tidal volume; the Acute Physiology And Chronic Health Evaluation (APACHE) II score; PCO_2, PaO_2, and the PaO_2/FiO_2 ratio (arterial oxygen partial pressure to inspired oxygen fraction ratio); the SBT-day fluid balance;

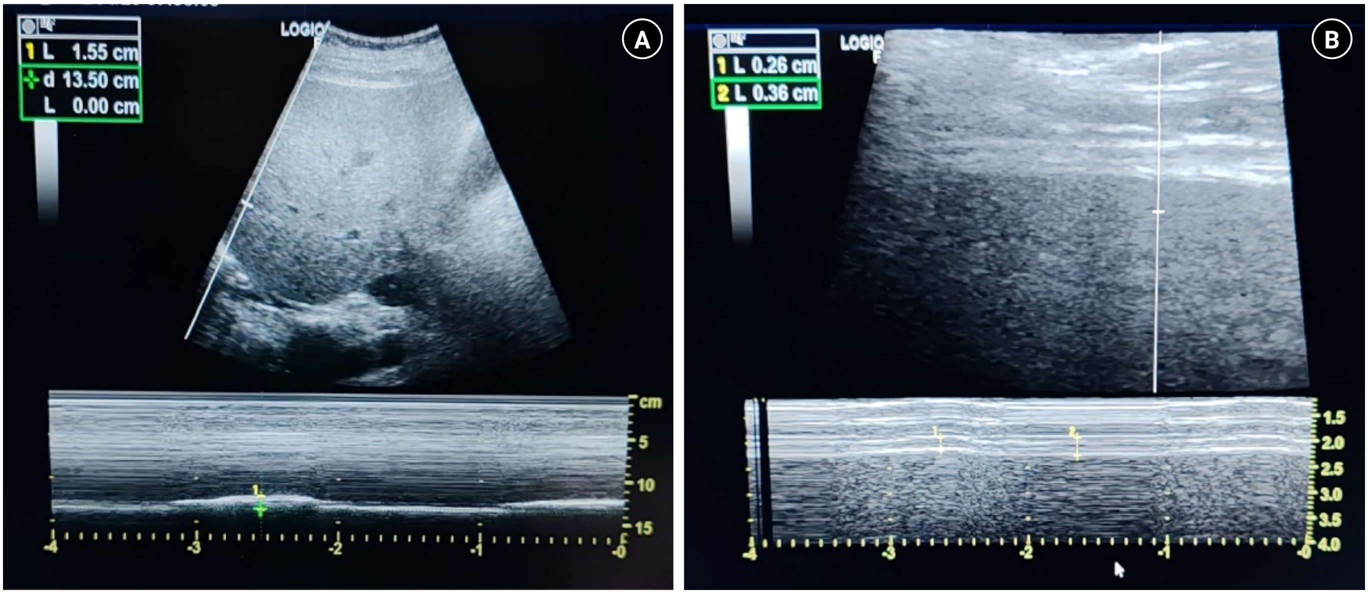

Figure 1. Ultrasound assessment of diaphragmatic function. (A) Diaphragmatic excursion measurement, showing a 1.55-cm displacement during spontaneous breathing. (B) Diaphragm thickening fraction (DTF) measurement, showing end-expiratory thickness (0.26 cm) and end-inspiratory thickness (0.36 cm) yielding a DTF of 38%.

and vital signs (heart rate, mean arterial pressure, and RR). Data were measured at baseline and 5 minutes prior to the SBT initiation. Additionally, the duration of both the ICU and hospitalization stays, the incidence of adverse events such as tracheostomy and ventilator-associated pneumonia, and the 28-day mortality rate were recorded.

Statistical Analysis

The sample size needed to provide at least moderate diagnostic accuracy (AUC >0.7) for TFC to predict weaning success in critically ill patients on MV was determined using MedCalc version 18.2.1 (MedCalc Software). Weaning failure prevalence was found to be 33% [10], with a 0.05 type-I error, 80% power, and a 0.5 AUC null hypothesis. Eighty patients were determined to be the minimum number of participants required, with at least 20 patients experiencing unsuccessful weaning and 60 patients achieving successful weaning.

Statistical analysis was executed via the SPSS version 25.0 (IBM Corp.). Data normality was checked using the Shapiro-Wilk test. Qualitative variables were expressed as frequencies and percentages. Quantitative variables were expressed in the form of mean±standard deviation or median and interquartile range values. For data analysis, the chi-square test or Fisher's exact test was applied for categorical variables, while an unpaired t-test or the Mann-Whitney U-test was applied for continuous variables as appropriate. P<0.05 was considered statistically significant. Receiver operating characteristic (ROC) curves were constructed to test the performance of seven indices for predicting weaning success (APACHE II score, RR, P/F ratio, RSBI, DE, DTF, and TFC), through the estimation of sensitivity, specificity, and AUC. A comparative analysis of AUCs was conducted using DeLong's test in MedCalc to assess statistical differences between the predictive performance of TFC, DE, and DTF.

RESULTS

A total of 122 eligible patients were screened. Eleven patients were eliminated due to meeting the exclusion criteria, which included pleural effusion, pneumothorax, and chest abnormalities that interfered with cardiometry signals. Also, six patients had unsatisfactory ultrasound imaging, and five patients declined to participate. For the study's final analysis, 100 patients were available (Figure 2). Seventy-three patients (73%) were extubated successfully and did not require any ventilatory support for at least 48 hours post-extubation. The remaining 27 patients (27%) failed extubation, with 15 subsequently re-intubated and 12 requiring unplanned non-invasive MV within 48 hours. Sixty-one individuals (61%) had cardiac ejection fraction values of <40%. In the subgroup of patients with poor cardiac contraction, 49 (80.3%) were successfully extubated, while extubation in 12 (19.7%) failed.

The patient demographic criteria and basic clinical data, including causes of invasive ventilation, the duration of ventilation before SBT, the SBT-day fluid balance, the RR, and hemodynamic variables were comparable in both groups of patients, i.e., the failed- and successful-weaning groups. However, the baseline APACHE II score was higher in the failed-weaning group, with a mean difference of 4.49 points between the groups (P=0.013) (Table 1). The weaning parameters measured before the SBT revealed a significant decrease in both DE and DTF in the failed-weaning group compared to the successful-weaning group (P<0.001 for both). Additionally, TFC values were significantly higher in the failed-weaning group (39.0±8.0 kΩ^{-1}) compared to the successful-weaning group (32.8±7.4 kΩ^{-1}, P<0.001). Moreover, the RR was significantly higher in the failed-weaning group (22.48±5.34 breaths/min) compared to the successful group (19.6±4.1 breaths/min, P=0.016). The RSBI was higher in the failed group, but the difference did not reach statistical significance (P=0.051) (Table 2). Successfully weaned patients experienced significantly shorter ICU and hospital stays; they also demonstrated lower 28-day mortality, lower tracheostomy, and ventilator-associated pneumonia incidence rates than those in the failed-weaning group (P<0.001) (Table 2).

The ROC curve was employed to measure the diagnostic accuracy of the weaning parameters to predict successful liberation from MV (Figure 3); ultimately, it revealed a moderate predictive ability for TFC in predicting the success of weaning

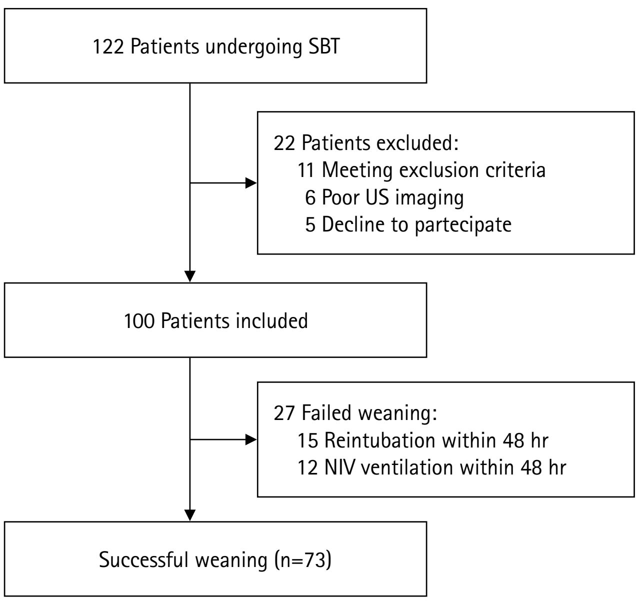

Figure 2. Study flowchart. SBT: spontaneous breathing trial; US: ultrasound; NIV: non-invasive ventilation.

Table 1. Demographic data and baseline clinical characteristics

Variable	All patients (n=100)	Successful weaning (n=73)	Failed weaning (n= 27)	P-value
Age (yr)	53±11	52±11	56±11	0.155
Male sex (%)	56 (56.0)	40 (54.8)	16 (59.3)	0.689
BMI (kg/m^2)	24.3±4.7	24.2±4.5	24.4±5.4	0.878
APACHE II score	21.4±7.4	20.2±6.9	24.7±8.0	0.013[a)]
Hb (g/dl)	10.4±1.9	10.3±1.9	10. 8±2.1	0.284
Ejection fraction (%)	43.4±12.0	42.1±11.9	46.7±12.0	0.098
Cause of MV				0.497
Cardiac	61 (61.0)	46 (63.1)	15 (55.6)	
Non-cardiac	39 (39.0)	27 (36.9)	12 (44.4)	
HR (beat/min)	85.9±13.1	85.5±13.7	87.2±11.2	0.513
MAP (mm Hg)	75.4±7.24	75.6±7.3	74.9±7.1	0.640
RR (breath/min)	18.1±3.8	17.7±3.8	19.3±3.7	0.075
SBT day fluid balance	−543.0±713.9	−630.4±678.6	−306.0±765.7	0.060
Duration of MV until SBT day	3.4±1.43	3.3±1.4	3.9±1.5	0.064

Values are presented as mean±standard deviation or number (%).
BMI: body mass index; APACHE: Acute Physiology and Chronic Health Evaluation; MV: mechanical ventilation; HR: heart rate; MAP: mean arterial pressure; RR: respiratory rate; SBT: spontaneous breathing trial.
a) Denotes statistical significance.

Table 2. Weaning parameters measured before the SBT and clinical outcomes

Variable	All patients	Successful weaning	Failed weaning	P-value
RR (breath/min)	20.4±4.7	19.6±4.1	22.5±5.3	0.016[a]
Tidal volume (ml)	387.9±69.1	392.4±64.6	375.9±80.1	0.290
$PaCO_2$ (mm Hg)	41.1±4.0	40.7±4.0	42.4±4.0	0.058
PaO_2 (mm Hg)	84.2±5.9	84.7±5.9	82.7±5.5	0.126
P/F ratio (mm Hg)	246.1±45.0	249.8±43.9	236.0±47.2	0.191
RSBI (breaths/min/L)	57.8±20.5	55.4±18.8	64.3±23.6	0.051
DE (cm)	1.7±0.6	2.0±0.7	1.4±0.5	0.009[a]
DTF (%)	49.6±19.4	56.3±18.2	31.6±7.4	0.004[a]
TFC ($k\Omega^{-1}$)	35.4±8.4	33.0±7.4	41.2±8.1	0.000[a]
ICU stay (day)	7.5±3.5	6.2±2.4	11.3±3.4	0.000[a]
Hospital stay (day)	11.3±5.0	9.3±3.2	16.7±4.9	0.000[a]
Tracheostomy	12 (12.0)	3 (4.1)	9 (33.0)	0.000[a]
VAP	24 (24.0)	9 (12.3)	14 (51.8)	0.000[a]
28-Day mortality	14 (14.0)	4 (5.5)	10 (37.0)	0.000[a]

Values are presented as mean±standard deviation or number (%).
SBT: spontaneous breathing trial; RR: respiratory rate; P/F ratio: arterial oxygen partial pressure to inspired oxygen fraction ratio; RSBI: rapid shallow breathing index; DE: diaphragmatic excursion; DTF: diaphragm thickening fraction; TFC: thoracic fluid content; ICU: intensive care unit; VAP: ventilator-associated pneumonia.
a) Denotes statistical significance.

(AUC [95% CI], 0.805 [0.68–0.88]; P<0.001), with a sensitivity of 80.8% and specificity of 66.7% at a cutoff value of <40 $k\Omega^{-1}$. Regarding diaphragmatic ultrasound measurements, DE also showed a moderate predictive ability, with an AUC (95% CI) of 0.774 (0.68–0.87) (P<0.001), sensitivity of 78.1%, and specificity of 55.6% at a cutoff value >1.45 cm. However, DTF demonstrated high predictive performance, with an AUC (95% CI) of 0.892 (0.83–0.95) (P<0.001), sensitivity of 82.2%, and specificity of 81.5% at a cutoff value of >36.0%. Meanwhile, other variables (e.g., P/F ratio, RSBI) failed to predict weaning failure or showed a low predictive ability (e.g., APACHE II score, RR) (AUC <0.70) (Figure 3, Table 3). Statistical comparison between the AUCs using DeLong's test revealed that DTF was significantly superior to both TFC (P=0.03) and DE (P=0.01), while the difference between TFC and DE was not statistically significant (P=0.12).

In the cardiac subgroup, TFC showed higher predictive ability (AUC [95% CI], 0.861 [0.75–0.97]; P<0.001) compared to the non-cardiac subgroup (AUC [95% CI], 0.703 [0.54–0.87]; P<0.001). The TFC sensitivity and specificity values were 89.8% and 75.0%, at a cutoff value of <40 $k\Omega^{-1}$ in cardiac patients. Meanwhile, the DE AUC demonstrated a high predictive ability in the non-cardiac subgroup only, but the DFT AUCs were high in both the cardiac and non-cardiac subgroups (Table 4).

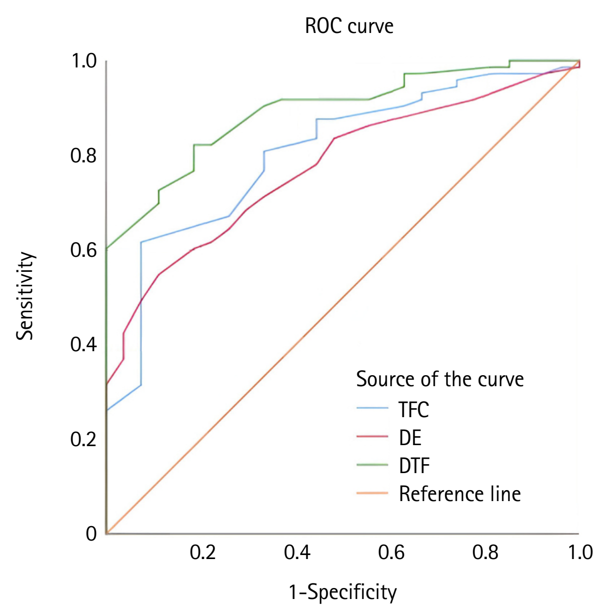

Figure 3. Receiver operating characteristic (ROC) curve for the ability of thoracic fluid content (TFC), diaphragmatic excursion (DE), and diaphragmatic thickness fraction (DTF) to predict weaning success.

DISCUSSION

The present study was designed to compare two weaning indices determined by bedside non-invasive tools, TFC measured by electrical cardiometry and DE measured by ultraso-

Table 3. Accuracy of different parameters in predicting weaning success in all patients

Variable	Cutoff value	AUC	Sensitivity (%)	Specificity (%)	95% CI
APACHE II score	19.5	0.671	57.5	77.8	0.55–0.79[a)]
RR (breath/min)	22.5	0.644	78.1	48.1	0.52–0.77[a)]
P/F ratio (mm Hg)	204.5	0.606	82.2	40.7	0.47–0.7[a)]
RSBI (breaths/min/L)	63.5	0.607	69.9	55.6	0.48–0.7[a)]
TFC (kΩ^{-1})	40.0	0.805	80.8	66.7	0.68–0.88[a)]
DE (cm)	1.45	0.774	78.1	55.6	0.68–0.87[a)]
DTF (%)	36.0	0.892	82.2	81.5	0.83–0.95[a)]

AUC: area under the receiver operating characteristic curve; APACHE: Acute Physiology and Chronic Health Evaluation; RR: respiratory rate; P/F ratio: arterial oxygen partial pressure to inspired oxygen fraction ratio; RSBI: rapid shallow breathing index; TFC: thoracic fluid content; DE: diaphragmatic excursion; DTF: diaphragm thickening fraction.
a) Denotes statistical significance.

Table 4. Accuracy of TFC, DE, and DTF in predicting weaning success in cardiac and non-cardiac patients

Variable	Cutoff value	AUC	Sensitivity (%)	Specificity (%)	95% CI
TFC (kΩ^{-1})					
Cardiac patients	40.0	0.861	89.8	75.0	0.75–0.97[a)]
Non-cardiac patients	40.0	0.703	62.5	66.7	0.54–0.87[a)]
DE (cm)					
Cardiac patients	1.45	0.750	67.3	66.7	0.60–0.89[a)]
Non-cardiac patients	1.45	0.822	79.2	66.7	0.69–0.95[a)]
DTF (%)					
Cardiac patients	36.0	0.853	83.7	75.0	0.75–0.95[a)]
Non-cardiac patients	36.5	0.929	79.2	86.7	0.85–1.00[a)]

TFC: thoracic fluid content; DE: diaphragmatic excursion; DTF: diaphragm thickening fraction; AUC: area under the receiver operating characteristic curve.
a) Denotes statistical significance.

nography, for predicting weaning success in MV patients with lung congestion. TFC showed a moderate predictive ability in the total population (AUC, 0.805; cutoff value <40 kΩ^{-1}), which increased to a high predictive ability (AUC, 0.861; cutoff value <40 kΩ^{-1}) in the cardiac subgroup. Meanwhile, DE's ability to predict weaning success was moderate in both the total population and cardiac subgroup (AUC, 0.774 and 0.750, respectively). DTF demonstrated an excellent predictive ability (AUC >0.85) in the total population and both the cardiac and non-cardiac subgroups. However, due to the relatively small number of patients in the non-cardiac subgroup, the generalizability of the findings in this group should be interpreted with caution. Other indices (APACHE II, RR, P/F ratio, RSBI) showed a low predictive ability (AUC <0.7) for weaning success.

Lung congestion is a significant cause of failed weaning, particularly in cardiac patients. The weaning process itself may induce lung congestion due to increased left ventricular afterload and preload resulting from changes in intrathoracic pressure during spontaneous breathing [11]. TFC numerically represents total extravascular and intravascular thoracic fluid volumes, which alter the thoracic cavity's resistance to electric current. Consequently, elevated TFC values may indicate hypervolemia or lung congestion—both of which have been recognized as risk factors for unsuccessful weaning trials [12].

Our findings regarding the predictive value of TFC are supported by previous research across various patient populations. Fathy et al. [4] assessed the TFC in critically ill surgical patients and found a moderate predictive ability for weaning failure in the general population (AUC, 0.69; cutoff >50 kΩ^{-1}), which increased markedly in patients with impaired cardiac function (AUC, 0.93). Although their study focused on trauma and emergency surgical patients with reduced cardiac contractility, the observed enhancement of TFC's predictive value in cardiac subgroups aligns with our results (AUC, 0.861 in cardiac patients), supporting the role of TFC as a useful non-invasive weaning predictor, particularly in patients with lung congestion and cardiac dysfunction. Similarly, Elbagoury et al. [13] reported an excellent predictive accuracy of TFC in adult patients following open cardiac surgery, with an AUC of 0.97 at 30 minutes into the SBT and a cutoff of <45 $k\Omega^{-1}$. Furthermore, a significant predictive ability of TFC has also been observed in neonates, with high sensitivity and specificity at a cutoff of <44 $k\Omega^{-1}$ for successful weaning prediction [14].

The ability of TFC to predict weaning outcomes has been suggested to be stronger in patients with decreased ejection fraction, most likely because the consequences of lung congestion are generally more prominent in cardiac patients [4]. This assumption is supported by a randomized controlled trial conducted by Mekontso Dessap et al. [15], who observed that using brain natriuretic peptide as a hypervolemia marker in cardiac patients can guide the weaning process, leading to superior outcomes compared to those achieved with use of the conventional weaning protocol.

It is critical to acknowledge the technological limits of TFC measurement with electrical cardiometry. External factors that can affect TFC reading accuracy include electrode location, patient movement during measurement, differences in skin impedance, and the presence of subcutaneous edema. These variables may induce measurement variability and compromise the diagnostic consistency [16]. While these limitations did not appear to have a major impact on TFC performance in our investigation, in the cardiac subgroup in particular, they should be considered when interpreting data and using this technique in everyday practice.

On the other hand, the use of ultrasound to identify changes in diaphragm size or function has been extensively investigated as a valid, practical, and non-invasive method to predict successful liberation from MV [17]. In our study, the failed-weaning group had lower DE and DTF values than the successful-weaning group ($P<0.001$), and the optimal cutoffs for DE and DTF were >1.45 cm and >36.0%, respectively, for predicting weaning success. Our results are consistent with the outcomes of a systematic review investigating the ability of diaphragmatic ultrasound to anticipate successful liberation from MV. The review analyzed four studies, two of which evaluated DE, while the other two assessed DTF, and concluded that ultrasonographic measurements of the diaphragm can predict weaning failure or successful extubation, with the most sensitive and specific cutoff values for excursion being 1.1–1.4 cm and those for thickening fraction being 30%–36% [18].

The present study also revealed a superior ability of DTF to anticipate weaning success, with greater sensitivity and specificity compared to DE. This outcome is supported by two meta-analyses: Llamas-Álvarez et al.'s meta-analysis [19], which reported a high pooled AUC of >0.85 for DTF, with significantly greater specificity than DE, and Parada-Gereda et al.'s study [20], which noted an acceptable diagnostic accuracy for both DE and DTF in predicting successful extubation after MV (AUC >0.85). However, subgroup analysis according to cardiac status showed that sensitivity and specificity were higher for DTF, whereas they were lower for DE. Interestingly, DTF maintained its high predictive value even in the cardiac subgroup, outperforming TFC. This may be attributed to the fact that DTF reflects a direct assessment of diaphragmatic contractility, the final common pathway for successful ventilation. Unlike TFC, which assesses fluid overload (an indirect contributor to weaning failure), DTF provides a functional measure of the diaphragm's ability to sustain ventilation. This distinction explains DTF's greater reliability across patient populations. Clinical evidence confirms that diaphragmatic dysfunction develops rapidly during MV and frequently emerges as the primary determinant of weaning failure, irrespective of cardiac function or fluid status [21].

Contrary to our findings, a recent study by Saccheri et al. [22] indicated that the prevalence of diaphragm dysfunction at the time of weaning was similar in patients with successful and unsuccessful extubation, and that it did not affect long-term survival. However, it is important to note that their cohort predominantly included post-surgical patients, which may explain the differing results from our medical ICU population. Furthermore, the work of Dres et al. [23] demonstrated that diaphragmatic dysfunction was associated with a higher incidence of weaning-induced pulmonary edema, occurring nearly three times more frequently in these patients. Therefore, while diaphragmatic function plays a key role in weaning readiness, it remains essential to evaluate additional causes of SBT failure, particularly weaning-induced pulmonary edema, which is a common and potentially reversible factor.

Our study has several limitations. First, our cohort was selected early in the weaning phase, when patients were eligible for a spontaneous breathing trial but not extubation, and the clinical implications of this choice require further investigation. Second, the identification of pre-existing pulmonary edema was made using chest radiography rather than the reference method, which involves measuring pulmonary artery occlusion pressure. However, instead of using a pulmonary artery catheter, which is currently considered an invasive method during the weaning process, current protocols rely on alternative non-invasive techniques to identify pulmonary edema [24]. Third, the definition of weaning failure included both reintubation and the use of non-invasive ventilation, which, although reflective of real-world clinical practice [25], may introduce heterogeneity in outcome classification. Fourth, although we compared individual predictors of weaning success, we did not develop a multivariate predictive model that integrates these parameters. Such a model could potentially enhance diagnostic accuracy. Finally, the non-cardiac subgroup included only 39 patients, which may have reduced the statistical power to identify significant differences and could compromise the robustness of subgroup-specific findings. Therefore, results from the non-cardiac group should be considered with caution, and future studies with larger sample sizes are needed to confirm these observations.

Lower TFC and higher DE were associated with successful weaning from MV in critically ill patients with congested lungs, with moderate predictive ability in the total study population. However, the diagnostic accuracy, sensitivity, and specificity were higher for TFC and lower for DE in patients with low ejection fraction. This study highlights the value of bedside, non-invasive tools such as electrical cardiometry and diaphragmatic ultrasound in identifying factors that may complicate the weaning process. While each parameter offers individual predictive value, future research should focus on developing composite models that integrate multiple clinical and physiological indices to improve the practical utility of bedside tools.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING

None.

ACKNOWLEDGMENTS

None.

ORCID

Shawky Meselhy Elshaer https://orcid.org/0000-0002-8916-1403
Ahmed Mostafa Abdelhamid https://orcid.org/0000-0001-8374-8804
Enas Wageh Mahdy https://orcid.org/0000-0001-9631-5768
Samar Rafik Amin https://orcid.org/0000-0002-1122-6692

AUTHOR CONTRIBUTIONS

Conceptualization: SME, SRA, AMA. Methodology: SME, EWM. Formal analysis: SRA, AMA. Data curation: SRA. Project administration: AMA, EWM. Writing—original draft: SME, SRA. Writing—review & editing: SRA, EWM. All authors have read, reviewed, and approved the final manuscript.

REFERENCES

1. Baptistella AR, Sarmento FJ, da Silva KR, Baptistella SF, Taglietti M, Zuquello RÁ, et al. Predictive factors of weaning from mechanical ventilation and extubation outcome: a systematic review. J Crit Care 2018;48:56-62.
2. Thille AW, Harrois A, Schortgen F, Brun-Buisson C, Brochard L. Outcomes of extubation failure in medical intensive care unit patients. Crit Care Med 2011;39:2612-8.
3. Routsi C, Stanopoulos I, Kokkoris S, Sideris A, Zakynthinos S. Weaning failure of cardiovascular origin: how to suspect, detect and treat—a review of the literature. Ann Intensive Care 2019;9:6.
4. Fathy S, Hasanin AM, Raafat M, Mostafa MM, Fetouh AM, Elsayed M, et al. Thoracic fluid content: a novel parameter for predicting failed weaning from mechanical ventilation. J Intensive Care 2020;8:20.
5. Narula J, Kiran U, Malhotra Kapoor P, Choudhury M, Rajashekar

P, Kumar Chowdhary U. Assessment of changes in hemodynamics and intrathoracic fluid using electrical cardiometry during autologous blood harvest. J Cardiothorac Vasc Anesth 2017;31:84-9.

6. Theerawit P, Eksombatchai D, Sutherasan Y, Suwatanapongched T, Kiatboonsri C, Kiatboonsri S. Diaphragmatic parameters by ultrasonography for predicting weaning outcomes. BMC Pulm Med 2018;18:175.
7. Schmidt GA, Girard TD, Kress JP, Morris PE, Ouellette DR, Alhazzani W, et al. Liberation from mechanical ventilation in critically ill adults: executive summary of an official American College of Chest Physicians/American Thoracic Society clinical practice guideline. Chest 2017;151:160-5.
8. Ornico SR, Lobo SM, Sanches HS, Deberaldini M, Tófoli LT, Vidal AM, et al. Noninvasive ventilation immediately after extubation improves weaning outcome after acute respiratory failure: a randomized controlled trial. Crit Care 2013;17:R39.
9. Gupta A, Singh O, Juneja D. Clinical prediction scores predicting weaning failure from invasive mechanical ventilation: role and limitations. World J Crit Care Med 2024;13:96482.
10. Spadaro S, Grasso S, Mauri T, Dalla Corte F, Alvisi V, Ragazzi R, et al. Can diaphragmatic ultrasonography performed during the T-tube trial predict weaning failure? the role of diaphragmatic rapid shallow breathing index. Crit Care 2016;20:305.
11. Goudelin M, Champy P, Amiel JB, Evrard B, Fedou AL, Daix T, et al. Left ventricular overloading identified by critical care echocardiography is key in weaning-induced pulmonary edema. Intensive Care Med 2020;46:1371-81.
12. van de Water JM, Mount BE, Chandra KM, Mitchell BP, Woodruff TA, Dalton ML. TFC (thoracic fluid content): a new parameter for assessment of changes in chest fluid volume. Am Surg 2005;71:81-6.
13. Elbagoury MM, Hikel KE, Elgebaly AS, Abdelrahman RS, Abu Sabaa MA. Thoracic fluid content measured by electrical cardiometry as a predictor of weaning outcomes from mechanical ventilator in adult patients after cardiac surgery: a prospective, observational study. Bali J Anesthesiol 2024;8:7-13.
14. Abdou RM, Ibrahim MJ. Thoracic fluid content: a novel parameter for prediction of successful weaning of neonates on mechanical ventilation. A prospective observational study. Ann Neonatol 2024;6:102-16.
15. Mekontso Dessap A, Roche-Campo F, Kouatchet A, Tomicic V, Beduneau G, Sonneville R, et al. Natriuretic peptide-driven fluid management during ventilator weaning: a randomized controlled trial. Am J Respir Crit Care Med 2012;186:1256-63.
16. Trinkmann F, Berger M, Michels JD, Doesch C, Weiss C, Schoenberg SO, et al. Influence of electrode positioning on accuracy and reproducibility of electrical velocimetry cardiac output measurements. Physiol Meas 2016;37:1422-35.
17. Turton P, AlAidarous S, Welters I. A narrative review of diaphragm ultrasound to predict weaning from mechanical ventilation: where are we and where are we heading? Ultrasound J 2019;11:2.
18. Zambon M, Greco M, Bocchino S, Cabrini L, Beccaria PF, Zangrillo A. Assessment of diaphragmatic dysfunction in the critically ill patient with ultrasound: a systematic review. Intensive Care Med 2017;43:29-38.
19. Llamas-Álvarez AM, Tenza-Lozano EM, Latour-Pérez J. Diaphragm and lung ultrasound to predict weaning outcome: systematic review and meta-analysis. Chest 2017;152:1140-50.
20. Parada-Gereda HM, Tibaduiza AL, Rico-Mendoza A, Molano-Franco D, Nieto VH, Arias-Ortiz WA, et al. Effectiveness of diaphragmatic ultrasound as a predictor of successful weaning from mechanical ventilation: a systematic review and meta-analysis. Crit Care 2023;27:174.
21. Goligher EC, Dres M, Fan E, Rubenfeld GD, Scales DC, Herridge MS, et al. Mechanical ventilation-induced diaphragm atrophy strongly impacts clinical outcomes. Am J Respir Crit Care Med 2018;197:204-13.
22. Saccheri C, Morawiec E, Delemazure J, Mayaux J, Dubé BP, Similowski T, et al. ICU-acquired weakness, diaphragm dysfunction and long-term outcomes of critically ill patients. Ann Intensive Care 2020;10:1.
23. Dres M, Rozenberg E, Morawiec E, Mayaux J, Delemazure J, Similowski T, et al. Diaphragm dysfunction, lung aeration loss and weaning-induced pulmonary oedema in difficult-to-wean patients. Ann Intensive Care 2021;11:99.
24. Teboul JL. Weaning-induced cardiac dysfunction: where are we today? Intensive Care Med 2014;40:1069-79.
25. Boles JM, Bion J, Connors A, Herridge M, Marsh B, Melot C, et al. Weaning from mechanical ventilation. Eur Respir J 2007;29:1033-56.