ORIGINAL ARTICLE

Application of Lung, Heart and Diaphragm Ultrasound for Predicting Weaning Outcome of Mechanical Ventilation

Ibrahim A. Mohsen [a], Mamdouh H. Al-Tahan [b], Fawzy M. Omar [a], Ahmed A. I. Eid [a,*]

[a] Department of Chest Diseases, Faculty of Medicine for Boys, Al-Azhar University, Cairo, Egypt
[b] Department of Cardiology, Faculty of Medicine for Boys, Al-Azhar University, Cairo, Egypt

Abstract

Background: ***Patients in a critical condition require mechanical ventilation (MV) as a life support system. Successful weaning affects morbidity and mortality once the primary illness resolves.***

Aim and objectives: ***To determine whether ultrasound of the heart, lungs, and diaphragm can improve the prediction of weaning outcomes in mechanically ventilated patients at El-Hussein University Hospital's respiratory ICU.***

Patients and methods: ***From January 2023 through September 2024, at El-Hussein University Hospital, researchers examined 100 respiratory intensive care unit patients who were on mechanical ventilation. The research got the green light from the local Ethics Committee at Al-Azhar University's Faculty of Medicine.***

Results: ***Very significant (p-value<0.001) by statistical standards, decreased RSBI of patients with successful weaning (mean=48.8±7.8, range=30-65) when compared with patients of weaning failure (mean=61.5±8.6, range=33- 72). Very significant (p-value<0.001) by statistical standards, the increased diaphragmatic excursion of patients with successful weaning(mean=1.45±0.13, range=1.21-1.74) when compared with patients of weaning failure(mean=0.95±0.29, range=0.22- 1.41).***

Conclusion: ***Weaning failure was linked to left ventricular systolic and diastolic dysfunction in intensive care unit patients who were mechanically ventilated. It may be helpful to identify individuals who are prone to fail weaning by assessing their lung aeration, diaphragmatic function, and left ventricular systolic and diastolic function prior to starting the weaning process.***

Keywords: Ultrasonography; Weaning outcome; MV

1. Introduction

Prior to extubation, the spontaneous breathing trial (SBT) is a commonly utilized evaluation tool.[1] However, Deab and Bellani[2] noted that using the SBT results to predict the weaning success limits the accuracy of weaning. Research has shown that following a successful SBT, the occurrence of reintubation might vary from 3% to 30%.[3]

Weaning failure owing to cardiopulmonary decompensation cannot be predicted using SBT to assess cardiopulmonary reserve. There are a number of physiological changes that can induce heart, lung, and diaphragm dysfunctions during the transition from positive-pressure ventilation to spontaneous breathing, such as intrathoracic pressure. This can result in a weaning failure.[4]

Weaning failure risk factors have been identified using portable ultrasound because of its widespread use.[5]

Weaning failure can be detected by evaluating left ventricular (LV) diastolic function.

By evaluating the loss of lung aeration, lung ultrasonography reliably predicts respiratory difficulty following extubation. Echocardiography and lung ultrasonography, when used together, can increase the accuracy of weaning outcome predictions, according to previous research.[6]

The aim of this study is to find out if patients on mechanical ventilation in the respiratory ICU at El-Hussein University Hospital can have their weaning results better predicted by taking ultrasounds of their diaphragm, heart, and lungs.

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* Corresponding author at: Chest Diseases, Faculty of Medicine for Boys, Al-Azhar University, Cairo, Egypt.
E-mail address: ahmed.ibrahim.eid89@gmail.com (A. A. I. Eid).

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2. Patients and methods

From January 2023 through September 2024, at El-Hussein University Hospital, researchers examined 100 respiratory intensive care unit patients who were on mechanical ventilation.

The research was approved by the local Ethics Committee at Al-Azhar University's Faculty of Medicine.

Weaning failure includes patients failing the initial SBT and patients with post extuba-tion distress. Post extubation distress is defined as reintubation or need for res-cue noninvasive ventilation within 48 hrs following extubation.[7]

SBT success was defined when patients fulfilled all the following criteria: heart rate <130 b/min or variation <20%, systolic blood pressure between 90 and 180 mmHg, respiratory rate <35/min without recruitment of accessory respiratory muscles, SpO_2 >90% with an O_2 supply <9L/min and $PaCO_2$< 45 mmHg, and an efficient cough.

An informed consent was obtained from the patients' relatives. We recorded and reported the following for every patient: age and sex, clinical diagnosis (medical or surgical), number of days in the hospital, reason for mechanical ventilation, total number of days on mechanical ventilation, and any preexisting heart or lung conditions.

Inclusion criteria:

Patients who have met the requirements for weaning off mechanical breathing after at least 48 hours, following the improvement or elimination of the initial reason for the intervention.

Weaning criteria:

The necessary hemodynamic and respiratory parameters for SBT are as follows: the following parameters must be met: an arterial line (all lines were inserted in a completely aseptic manner), a minute ventilation rate (MV) of 5-8 liters per minute, a maximal inspiratory pressure (MIP) of -20 to -30 cm H_2O, a respiratory rate (RR) of 30 breaths per minute or less, a rapid shallow breathing index (RSBI) of 104 or less, a PaO_2/FIO_2 ratio of at least 150, with FIO_2 not to exceed 0.40, a SpO_2 level of 92%, a PaO_2 level of 60, a PEEP of 8 cm H_2O, a heart rate of 60-100 beats per minute, and a systolic blood pressure range of 90-150 mm H. Hypotensive with a hemoglobin level of 8 g/dl or more; free of neuromuscular blocking medicines or continuous sedative infusion; GCS greater than 8; and requiring no more than 200 ng/kg/min of vasopressors, such as adrenaline or noradrenaline, at minimum. [8]

Exclusion criteria:

Paraplegic patients with spinal cord injuries above C8, those with a body mass index (BMI) of 35 or higher, those with tracheostomies, those with severe ICU-acquired neuropathy or cardiac arrhythmias, and those with scheduled preventive noninvasive ventilation.

Methods:

A lung ultrasound was conducted using a 5-MHz microconvex probe.

Diaphragmatic Ultrasound:

The diaphragm thickness was measured using a linear ultrasonic probe that was set to B mode and operated at 7-10MHz. Our scans of the right hemidiaphragm were taken at the midaxillary line, between the eighth and tenth intercostal gaps, which is perpendicular to the chest wall at the site of diaphragm and rib cage separation. Each patient in the trial had their head propped up 20–40 degrees the whole time. The end-inspiration and end-expiration were guided by a flow time curve.

The percent change in diaphragmatic thickening between end-expiration and end inspiration was calculated as (thickness at end-inspiration (Tinsp.) −thickness at end expiration (Texp.) /thickness at end expiration(Texp.))×100 (Tinsp – Texp/Texp) and was called diaphragmatic thickening fraction (DTF).

Lung Ultrasound Technique:

Each lung was divided into three zones and underwent examination anteriorly and posteriorly using B-mode to assess the degree of lung aeration, with a total of 12 zones to be examined. The final score, ranging between 0 and 36, is the sum of the values, between 0 and 3, assigned to the LUS patterns visualized in each of the 12 regions examined. The 12 anterior, lateral and posterior areas are defined by anatomic landmarks as stated in the consensus conference recommendations for point of- care LUS.

Each region of interest was identified according to anatomical landmarks: from the sternum to the anterior axillary line for anterior lung regions, from the anterior to the posterior axillary line for lateral lung regions, and from the posterior axillary line to the spine for posterior lung regions. Upper and lower parts of the anterior, lateral, and posterior lung region were determined using the horizontal mammary line.

The four ultrasound patterns identified for each area correspond to degrees of lung aeration. LUS was calculated thereafter according to the observed worst ultrasound pattern:

Normal aeration, LUS=0, Moderate loss of lung aeration (multiple, well-defined B lines), LUS=1, Severe loss of lung aeration (multiple coalescent B lines), LUS=2, and Lung consolidation, LUS=3.

Finally, the LUS of each part was accumulated to obtain the total LUS for each patient (maximum 36 points).

Diaphragmatic excursion:

In order to evaluate the range of diaphragmatic movement, the M-mode approach was used with the convex probe inserted subcostally parallel to the intercostal space.

Echocardiography:

All patients were evaluated in a left or supine position with the probe in a standard parasternal long-axis with an apical four- or two-chamber view. Left ventricular ejection fraction, the peak early (E) and peak atrial (A) velocity transmitral flow from pulsed-wave Doppler, and early diastolic mitral annulus velocity (e’) based on tissue Doppler imaging were measured. The E/A ratio, E/e’ ratio, and left-atrial pressure (LAP) were calculated on the basis of the measured indicators.

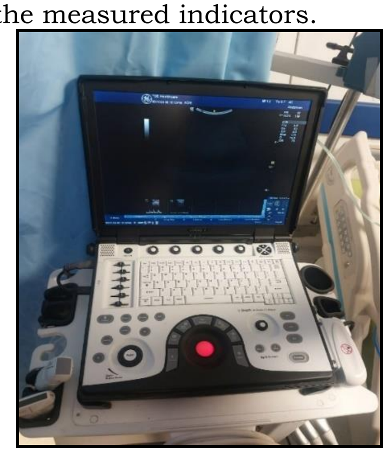

Figure 1. Ultrasonography apparatus(LOGIQ e) used in this study.

Statistical analysis:

SPSS 24 was used for data analysis. Qualitative data were presented as percentages and frequencies. The mean±standard deviation was used to display numeric data. The average of a set of discrete numbers is precisely their sum divided by their total number. The distribution of values was measured using standard deviation (SD). When the standard deviation was low, the values were close to the mean, and when it was large, the values were more dispersed.

The following tests were done:

The independent sample T-test (T) was utilized to compare two groups. When comparing data that was not parametric, we utilized the chi-square test. By utilizing ROC curves, the sensitivity, specificity, threshold value, PPV, and NPV were computed. A sensitive test is one that can identify the existence of the disease. The likelihood of a bad outcome in the absence of the condition is what we mean when we talk about specificity. In the event of a positive test result, the positive predictive value represents the likelihood of sickness. When a test comes back negative, the negative predictive value indicates the probability that the disease does not exist. Probability (P-value) significance was defined as a P-value less than 0.05, extreme significance as a P-value less than 0.001, and insignificance as a P-value greater than 0.05.

3. Results

Table 1. Demographic information for every patient under study.

		STUDIED PATIENTS (N=100)	
SEX	Male	68	68%
	Female	32	32%
AGE(YEARS)	Mean±SD	57.9±6.9	
	Min-Max	47-78	
BMI(KG/M^2)	Mean±SD	25.7±1.6	
	Min-Max	22-28	

This table showed the description of demographic data in all studied patients. As regard sex, there were 68-males(68%) and 32-females(32%) in the studied patients. As regard age, the mean age of all studied patients was 57.9±6.9 years with minimum age of 47-years and maximum age of 78-years. As regard BMI, the mean BMI of all studied patients was 25.7±1.6 kg/m2 with minimum BMI of 22kg/m2 and maximum BMI of 28kg/m2, (table 1).

Table 2. Description of weaning outcome in all studied patients.

		STUDIED PATIENTS (N=100)	
WEANING OUTCOME	Success	60	60%
	Failure	40	40%

The results of weaning for each subject in the study were detailed in this table. Among the patients whose weaning attempts were monitored, sixty had success and forty had failure, (table 2).

Table 3. Correlation between weaning outcome and clinical data.

		WEANING OUTCOME				STAT. TEST	P-VALUE
		Success (N=60)		Failure (N=40)			
CAUSE OF MV	COPD	29	48.3%	21	52.5%	X2=0.34	0.952
	Pneumonia	26	43.3%	16	40%		NS
	ILD	4	6.7%	2	5%		
	PE	1	1.7%	1	2.5%		
MV DURATION (HOURS)	Mean±SD	123.1±24.9		179.1 ±31.2		T=9.9	<0.001
	Range	90-210		89-230			HS
ICU STAY(DAYS)	Mean±SD	9.6±2.2		13.±1.7		T=10.1	<0.001
	Range	7-17		10-16			HS

T:independent sample T-test.

HS:p-value<0.001 is considered highly significant. X2:Chi-square test. NS:p-value>0.05 is considered non-significant.

No statistically significant correlation(p-value=0.952) between weaning outcome and causes of MV of the studied patients. In patients with successful weaning, MV was due to COPD in 29-patients(48.3%), pneumonia in 26-patients(43.3%), ILD in 4-patients(6.7%) and PE in 1-patient(1.7%). In patients with weaning failure, MV was due to COPD in 21-patients(52.5%), pneumonia in 16-patients(40%), ILD in 2-patients(5%) and PE in 1-patient(2.5%).

High statistically significant(p-value<0.001) decreased MV duration of patients with successful weaning(mean=123.1±24.9, range=90-210) when compared with patients of weaning failure(mean=179.1±31.2, range=89-230).

High statistically significant(p-value<0.001) decreased ICU stay of patients with successful weaning (mean=9.6±2.2, range=7-17) when compared with patients of weaning failure(mean=13.8±1.7, range=10-16), (table 3; figures 2&3).

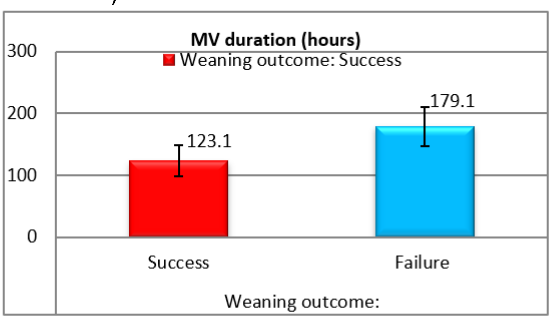

Figure 2. Correlation between weaning outcome and MV duration.

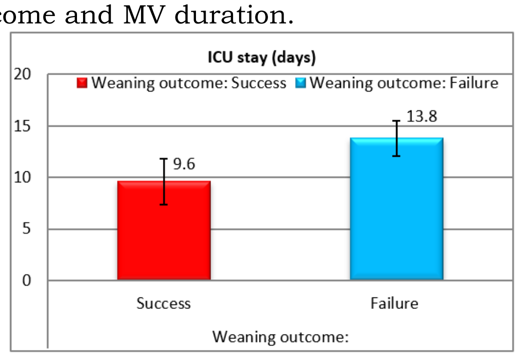

Figure 3. Correlation between weaning outcome and ICU stay.

Table 4. Correlation between weaning outcome and Lung US.

		WEANING OUTCOME		T	P-VALUE
		Success (N=60)	Failure (N=40)		
LUNG US SCORE	Mean±SD	10.2±2.9	15.4±3.1	8.4	<0.001
	Range	6-21	8-21		HS
DIAPHRAGMATIC THICKNESS TINS	Mean±SD	0.94±0.33	0.30±0.33	9.4	<0.001
	Range	0.1-1.8	0.1-1.9		HS
DIAPHRAGMATIC THICKNESS FRACTION TIN-TEX/TEX	Mean±SD	29.7±4.9	26.2±3.8	3.7	<0.001
	Range	3.5-38	20-37		HS
DIAPHRAGMATIC EXCURSION	Mean±SD	1.45±0.13	0.95±0.29	11.4	<0.001
	Range	1.21-1.74	0.22-1.41		HS

T:independent sample T-test. HS:p-value<0.001 is considered highly significant.

High statistically significant (p-value<0.001) decreased lung US score of patients with successful weaning (mean=10.2±2.9, range 6-21) when compared with patients of weaning failure (mean=15.4±3.1, range 8-21).

High statistically significant (p-value<0.001) increased diaphragmatic thickness of patients with successful weaning (mean=0.94±0.33, range=0.1-1.8) when compared with patients of weaning failure (mean=0.30±0.33, range=0.1-1.9).

High statistically significant (p-value<0.001) increased diaphragmatic thickness fraction of patients with successful weaning (mean=29.7±4.9, range=3.5-38) when compared with patients of weaning failure (mean=26.2±3.8, range=20-37).

High statistically significant (p-value<0.001) increased diaphragmatic excursion of patients with successful weaning (mean=1.45±0.13, range=1.2-1.74) when compared with patients of weaning failure (mean=0.95±0.29, range=0.22-1.41), (table 4; figures 4&5).

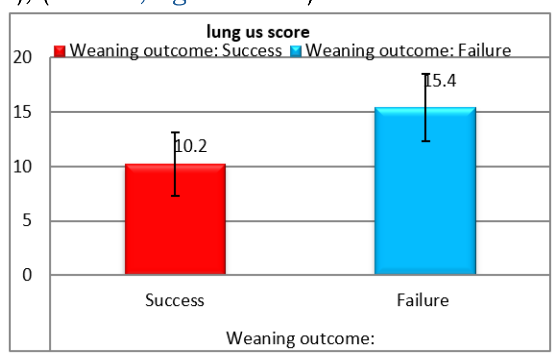

Figure 4. Correlation between weaning outcome and lung US score.

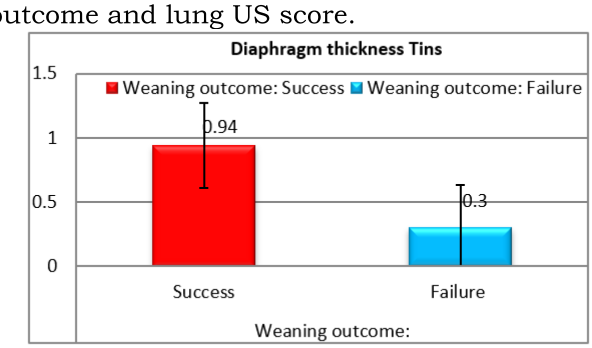

Figure 5. Correlation between weaning outcome and Diaphragmatic thickness.

Table 5. Correlation between weaning outcome and ECHO.

		WEANING OUTCOME		T	P-VALUE
		Success (N=60)	Failure (N=40)		
EF	Mean±SD	51.9±4.03	49.9±3.9	2.45	0.016 S
	Range	40-59	44-58		
E-A RATIO	Mean±SD	1.02±0.08	1.14 ± 0.18	4.3	<0.001 HS
	Range	0.87-1.21	0.9-1.54		
E-E RATIO	Mean±SD	8.57±1.69	12.4 ± 2.9	8.2	<0.001 HS
	Range	5.8-14.2	8.1-18.2		
LT ATRIAL PRESSURE	Mean±SD	12.6±1.9	16.4 ± 2.9	7.7	<0.001 HS
	Range	9.8-20.2	12.1-22.2		

S:p-value<0.05 is considered significant.
T:independent sample T-test. HS:p-

value<0.001 is considered highly significant.

Statistically significant (p-value=0.002) increased EF of patients with successful weaning (mean=51.9±4.03, range=40-59) when compared with patients of weaning failure (mean=49.9±3.9, range=44-58).

High statistically significant (p-value<0.001) decreased E-A ratio of patients with successful weaning (mean=1.02±0.08, range=0.87-1.21) when compared with patients of weaning failure (mean=1.14±0.18, range=0.9-1.54).

High statistically significant (p-value<0.001) decreased E-e ratio of patients with successful weaning (mean=8.57±1.69, range=5.8-14.2) when compared with patients of weaning failure (mean=12.4±2.9, range=8.1-18.2).

High statistically significant (p-value<0.001) decreased left atrial pressure of patients with successful weaning (mean=12.6±1.9, range=9.8-20.2) when compared with patients of weaning failure (mean=16.4±2.9, range=12.1-22.2), (table 5; figures 6&7).

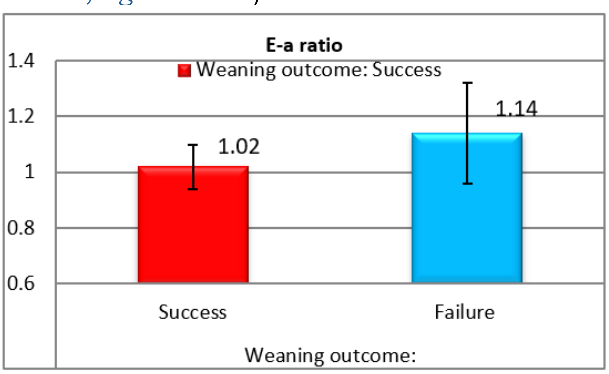

Figure 6. Correlation between weaning outcome and E-a ratio.

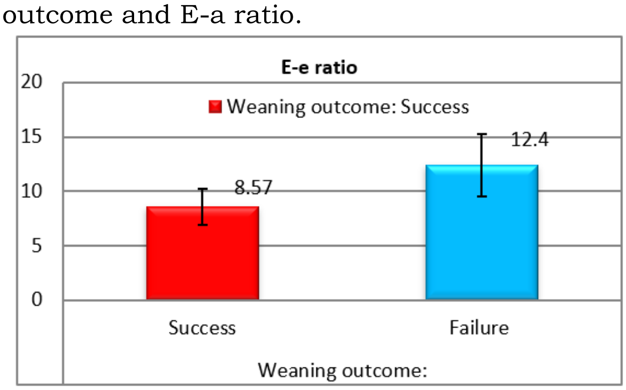

Figure 7. Correlation between weaning outcome and E-E ratio.

4. Discussion

In this study, weaning result and body mass index (BMI) of the patients were not significantly correlated (p=0.145). The average BMI of patients who were able to wean successfully was 25.5±1.6, with a range of 22-28. The mean BMI of patients whose weaning attempts failed was 26±1.6, with a range of 23-28.

A study conducted by found similar outcomes Xia Xu et al.,[9] Results showed no statistically significant relationship (p=0.504) between body mass index (BMI) and weaning outcome.

Regarding the causes of MV in this study, weaning results and causes of MV of the patients evaluated did not correlate statistically (p-value=0.952). Weaning patients with MV outcomes included 29 patients (48.3%), 26 patients (43.3%), four patients (6.7%), and one patient (1.7%). Among the patients who did not successfully wean, 21 (or 52.5% of the total) had MV as a result of chronic obstructive pulmonary disease (COPD), 16 (or 40% of the total) of them had pneumonia, 2 (or 5% of the total) reported ILD, and 1 (or 2.5% of the total) reported PE.

This result agreed with Silva et al.,[10] Using ultrasound data from 136 patients who were extubated after a pressure support ventilation experiment, researchers were able to predict post-extubation distress. However, they discovered no statistically significant association (p-value=0.924) between the reasons for mechanical ventilation and the results of weaning.

Those with effective weaning had a considerably shorter ICU stay (mean=9.6±2.2, range=7–17) than those with failure weaning (mean=13.8±1.7, range=10–16) in terms of the amount of time spent hospitalized. A p-value below 0.001 supported this conclusion.

Chung et al.,[11] There was a decrease in the length of time patients spent in the intensive care unit (ICU) after successful weaning (10.9±6.5 days) compared to patients whose weaning failed (14.7±8.7 days). This was based on a model that was developed using the predictive determinants of successful extubation, which comprised 169 patients (p-value=0.02).

There was a highly significant difference (p-value<0.001) in the mean duration of MV between patients with post extubation distress (mean=179.1±31.2, range=89-230) and patients with post extubation success (mean=123.1±24.9, range=90- 210) in this regard.

Consistent with previous research, Abdel Rahman et al.,[12] this study confirms that critically ill patients who require mechanical breathing for an extended period of time were more likely to die or have serious complications.

In agreement with this study, Soumer et al.,[13] in a study for the prediction of weaning outcome by lung ultrasound score and loss of lung aeration, found that lung ultrasound score was sensitive and specific for the prediction of weaning outcome and showed that long US>17 predicts post extubation distress and<12 predicts extubation success.

This result agrees with Demoule et al.,[14] who discovered that the three ultrasound measurements (DTF, DE, and DT) are positively correlated. The study involved 43 patients, split evenly between the two groups, and evaluated patient outcomes, including length of stay (LOS), intensive care unit mortality, and failure to wean off mechanical breathing (p-values of 0.035, 0.041, and 0.0211, respectively). One group had 23 patients (53% of the total) admitted with diaphragmatic dysfunction (DD), whereas the other group had 20 patients (47% of the total) admitted without DD.

This result didn't agree with Umbrello et al.,[15] to their research involving twenty-five surgical patients who were transferred to the intensive care unit. Together with a p-value of 0.981, we discovered no association between DE and the final result for the patients.with a p-value of 0.450, neither did DE and DT.

This result agreed with Ait-Oufella et al.,[16] In a study employing Doppler mitral flow and variations in circulating B-type and atrial natriuretic peptides (BNP, ANP), the cardiac consequences of a successful respiratory weaning were assessed in a group of 31 patients who were achieving spontaneous breathing on a T-tube.

Comparing patients whose weaning was successful (mean=8.57±1.69, range=5.8-14.2) to those whose weaning was unsuccessful (mean=12.4±2.9, range=8.1-18.2), this study found a highly significant (p-value<0.001) reduction in the E-e ratio.

A ROC curve analysis demonstrated that an E-e ratio can indicate MV weaning failure at a cut-off level of >10, with a specificity of 90%, a PPV of 82.9%, and an NPV of 83.1% (AUC=0.87 & p-value<0.001). These findings corroborated Moschietto et al.,[17]

The results demonstrated that at a cut-off level of >14, left atrial pressure may be utilized to forecast MV weaning failure using the ROC curve, with a sensitivity of 72.5%, specificity of 90%, PPV of 82.9%, and NPV of 83.1% (AUC=0.86&p-value<0.001).

This result was correlated with the study of Xia Xu et al.,[9] The researchers found that patients whose weaning went well had significantly lower left atrial pressures (p=0.017) compared to those whose weaning failed. They also demonstrated that the left ventricular diastolic function could be accurately predicted using the estimated LAP as a ratio of E/e', and that LAP was a significant independent factor in the development of weaning failure. Patients with elevated LAP may be at a higher risk of developing pulmonary venous congestion due to the increased hemodynamic stress that comes with weaning.

With a sensitivity of 67.5%, specificity of 68.3%, PPV of 58.7%, and NPV of 75.9% (AUC=0.66&p-value=0.005), the ROC curve demonstrated that EF may be employed to forecast MV weaning failure at a cut-off level of ≤51.

This result was correlated with the study of Xia Xu et al.,[9] significant statistical findings were reported (p-value=0.061), increased EF of patients with successful weaning(58.93±8.83) when compared with patients of weaning failure(54.93±9.94).

4. Conclusion

Weaning failure in critical care unit patients on mechanical ventilation was linked to left ventricular dysfunction, both systolic and diastolic. To help determine whether patients were at risk of not making it through the weaning phase, it is helpful to measure their diaphragmatic and left ventricular systolic and diastolic functions in addition to their lung aeration.

Disclosure

The authors have no financial interest to declare in relation to the content of this article.

Authorship

All authors have a substantial contribution to the article

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Conflicts of interest

There are no conflicts of interest.

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