The impact of heart, lung and diaphragmatic ultrasound on prediction of failed extubation from mechanical ventilation in critically ill patients.

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Abstract

Background: Weaning failure is defined as failing spontaneous breathing trial or developing post-extubation respiratory distress that requires re-intubation or non-invasive ventilation within 48 h following extubation. Identification of reliable predictors of weaning failure may represent potential avenues of treatment that could reduce the incidence of weaning failure. Known predictors of weaning failure include chronic obstructive airway disease, cardiac failure, positive fluid balance and diaphragmatic dysfunction. Aim: To assess the usefulness of heart, lung & diaphragmatic ultrasound in prediction of weaning failure in critically ill patient and to compare it with conventional predictors of weaning. Patients and Methods: A prospective observational study conducted on 40 critically ill ventilated patients and admitted to the critical care department where heart, lung & diaphragmatic ultrasound were done for adult patients who were intubated and mechanically ventilated for at least 48 hours and ready for weaning according to the readiness criteria. Results: According to weaning outcome in the initial SBT, patients were divided into 2 groups: Successful weaning group (Group A): included 18 patients who had successful weaning during SBT. Failed weaning group (Group B): included 22 patients. The failing group had higher B-line score (2.5±0.7 vs. 1.6±0.6), P = 0.002. Successful group had higher diaphragmatic excursion (2±0.4 vs. 1.2±0.5 cm, P <0.001). Diastolic dysfunction more
than grade I, could predict weaning failure with sensitivity 100%, specificity 66%, PPV 78% and NPV 100% with an AUC 0.955(0.837-0.995). **Conclusion**: Failed weaning in mechanically ventilated patients is more prevalent if markers of LV dysfunction (systolic and diastolic), B line score and reduced diaphragmatic excursion are present. Prediction of weaning failure could be significantly assisted by an integrative, dynamic, and fully bedside ultrasonographic concomitant assessment of the heart and lungs before the start of the weaning process or during SBT.

**Keywords**: B-lines, diaphragmatic ultrasound, diastolic dysfunction, weaning failure

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1. **Introduction:**

Mechanical ventilation is a life-saving intervention to any sort of respiratory failure. Complications resulting from mechanical ventilation increase with the duration of ventilator support; thus, early weaning is a cornerstone in prevention of these complications. [1]

Identifying the ideal time to wean a mechanically ventilated patient is a crucial issue, as both premature and delayed weaning prolong the duration of mechanical ventilation, length of ICU stay and increased morbidity and mortality. [2, 3] Consequently, accurate prediction of post extubation distress and the early diagnosis of the causes responsible for failure of weaning are of a great importance in improving the outcome of ventilated [4-6].

Identification of reliable predictors of weaning failure could reduce the incidence of weaning failure and its associated morbidity. Unfortunately, the pathophysiology of weaning failure is complex and is incompletely understood.

Known risk factors of weaning failure have considerable crossover, especially those related to the heart, lungs and diaphragm [4,6,7].

Known predictors of weaning failure include chronic obstructive airway disease [1], cardiac failure [6,7] positive fluid balance [8], pneumonia [8] and diaphragmatic dysfunction [9]. Rapid shallow breathing index (RSBI) is a clinical predictor of failure of weaning from mechanical ventilation and it is widely used in clinical research and in practice [10]. Therefore, a combined

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structured transthoracic echocardiogram (TTE), lung and diaphragm ultrasound examination added to conventional clinical predictors could be a useful tool to increase the accuracy in predicting weaning outcome and extubation failure [9].

Cardiac dysfunction is a leading cause of weaning failure [1]. The abrupt cessation of positive pressure ventilation increases venous return and left ventricular (LV) afterload [11], decreases LV compliance [12], and may even induce cardiac ischemia [4]. All these factors tend to increase LV filling pressure and may subsequently result in cardiogenic pulmonary edema [13]. Lung ultrasound is increasingly becoming a diagnostic tool in the critical care setting. The B-line is an artifact that correlates with interstitial edema. Decreases in intrathoracic pressure during a spontaneous breathing trial (SBT) will augment venous return and impede left ventricular ejection, increasing intrathoracic blood volume [14]. LUS score for calculating lung aeration patterns in patients with ventilator-associated pneumonia [15]. This score is used to predict weaning outcome with promising results [16,18].

Ultrasound assessment of diaphragmatic dysfunction in weaning process: The effects of atrophy of the diaphragm secondary to mechanical ventilation have been recently described. The development of diaphragm atrophy was associated with prolonged duration of mechanical ventilation, increased ICU length of stay, and a higher rate of complications [19]. Therefore, ultrasound is an effective method for the early detection and evaluation of acquired weakness in the intensive care unit [20]. Diaphragmatic ultrasound may identify patients at risk of weaning failure. Diaphragmatic dysfunction has been found to be a predictor of weaning failure in ICU patients [21].

The aim of the current study was to evaluate prediction of weaning failure using ultrasonography. B-line score was used to evaluate lung water, echocardiography was used to evaluate diastolic and systolic function. Diaphragmatic function was evaluated by measuring diaphragmatic excursion.

2. Patients and Methods:
This study is a prospective, single center, observational study conducted on 40 critically ill ventilated patients, admitted to the critical care department, Beni-Suef
university hospital in the period from February 2019 to February 2020. The study protocol was approved by the ethical committee of Beni-Suef University. Written informed consent was obtained from patients or their close relatives.

Inclusion criteria: Adult patients who were intubated and mechanically ventilated for at least 48 hours and ready for weaning according to the readiness criteria including: [11] Resolution or improvement in the disease that led to mechanical ventilation; Cardiovascular stability with no or minimal doses of vasopressors; (HR≤120 /min, systolic blood pressure ≥ 90 mmHg and ≤180 mmHg, FiO2 ≤ 40%; Pressure support ≤ 10 cmH2O; PEEP ≤ 5 cmH2O; Tidal volume ≥ 5 ml/kg; Respiratory rate < 24 breaths/min., RSBI<105 breath/min/l. Patients younger than 18 years were excluded, inappropriate acoustic windows or presence of chest wall lesions that impair imaging of the heart and lungs e.g. burn or open wound, atrial fibrillation, interstitial pulmonary fibrosis, previous pneumonectomy or extensive bronchiectasis, traumatic lung injury or pneumothorax were also excluded. Patient diagnosed as brain death Patients ventilated through tracheostomy, diaphragmatic paralysis, neuromuscular disorders as: Gullian Barrie Syndrome and Myasthenia gravis were also excluded.

Methods: All patients were subjected to full history, clinical examination and laboratory investigations. All patients were intubated and mechanically ventilated, observed till improvement of their conditions and became eligible to enter the SBT for weaning. 

Hemodynamic monitoring: Heart rate, rhythm and blood pressure were recorded before and after the SBT. Patients were put on PS/CPAP trial (pressure support 8 cm H2O, CPAP 5 cm H2O for one hour and extubated once they have succeeded in the trial. Failure of the weaning process was defined as a failed SBT or the need for reintubation within 48 hours following extubation. [11]. Trans-thoracic Doppler echocardiographic examination was done 30 minutes after the start of the SBT using TOSHIBA ACUSON X 300, 3.5 MHZ. Echocardiographic examination, including M-mode, two-dimensional (2D), color flow mapping and Doppler measurements were recorded. LV systolic function assessment of the
ejection fraction by M-Mode in the long axis or short axis parasternal view. LV diastolic function assessment of velocity mitral inflow signal by application of PW Doppler at the mitral inflow and calculation of the \([E/A]\) ratio. Lung ultrasound was performed on all participants in a semi-recumbent position at 30°–50° using the six-zone method of each lung. An aeration score was assigned to each zone based on the presence and degree of aeration loss [23]. Score 1: represents a normally aerated zone with the absence of/fewer than three B-lines. Score 2: represents moderately aerated zone with three or more discrete B-lines. Score 3: represents severe loss of aeration with multiple and fused B-lines. Score 4: represents consolidation. Score 5: represents consolidation with pleural effusion.

**Diaphragmatic ultrasound**

The lateral approach was used to image the diaphragm, with the participants in a supine and head-up position at 30°–50°. The same landmarks and techniques are to be applied on the right and left hemidiaphragm. Diaphragmatic movement of greater than 1.3 cm was considered normal function [25]. Unilateral dysfunction is defined when a unilateral hemidiaphragm movement is less than 1.3 cm; bilateral dysfunction is defined as movement of less than 1.3 cm in both hemidiaphragms.

**3. Results:**

According to weaning outcome in the initial SBT, patients were divided into 2 groups: Successful weaning group (Group A): included 18 patients who had successful weaning during SBT. Failed weaning group (Group B): included 22 patients who failed weaning. This group was sub-divided into 2 subgroups according to the timing of weaning failure. 14 Patients who failed the SBT and were brought back to assist ventilation and 8 patients required reintubation or non-invasive ventilation within 48 hours of extubation. The study included 19 (47.5%) males and 21 (52.5%) females with ages ranging from 22 to 80 years (64.2±15.6 years). Mean heart rate was 120±36 bpm. There were 30% of study population with diastolic dysfunction grade I, 30% grade II, 37.5% grade III and one case with grade IV. Mean RSBI, tidal volume, diaphragmatic excursion, and B line score were 86.7±40, 347±110.9, 1.5±0.6 and 2.1±0.8, respectively. Patients with successful weaning had significantly lower grades of
diastolic dysfunction. Their heart rate and respiratory rate were significantly lower than failed patients and their ejection fraction was significantly higher (P < 0.05). There was a significant association between 1st trial of weaning success and RSBI, tidal volume, diaphragmatic excursion and B-line score. B-line score more than 2, could predict weaning failure with sensitivity 94.4%, specificity 86.4%, PPV 77.3% and NPV 95%. At diaphragmatic excursion less than or equal to 1.3 cm, could predict the failure of weaning with sensitivity 94.5%, specificity 59.1%, PPV % 65.4% and NPV 92.9%. Diastolic dysfunction more than grade I, could predict the failure of weaning with sensitivity 85%, specificity 66 %, PPV 78% and NPV 90%

4. Discussion:
A great majority of intensive care unit patients are composed of that receiving mechanical ventilation therapy due to respiratory failure. Early termination or unnecessary delays in weaning lead to various negative consequences [28]. The existence of serious consequences such as ventilator-associated pneumonia, ventilator-induced diaphragmatic atrophy, and resumption of mechanical ventilator therapy indicates the importance of correct timing of weaning decisions [24].
The patient is considered to be weaned as evaluated primarily under clinical parameters. Besides, there are also some measured parameters utilized by each clinician. The oldest and most widespread of such parameters is the rapid shallow breathing index (RSBI) [28]. However, since the breathing process is carried out by the diaphragm and auxiliary respiratory muscles, RSBI can be at desired values due to the auxiliary respiratory muscles, even if the diaphragmatic function is insufficient, meaning that RSBI values will be misleading in making the weaning decision [28]. After placing a patient on mechanical ventilation, the main goal is to define the best time to begin the weaning process. Weaning is considered successful when a patient can stay off mechanical ventilation for more than 48 h [28]. The greatest difficulty in the weaning process is the absence of one or more variables (mechanical, hemodynamic, neurological or exchange gas) and/or an adequate index for accurately predicting successful weaning. Performing the transition process empirically prolongs the duration of
mechanical ventilation, with consequent increases in treatment costs and the risk of death [26]. This work aimed to study the usefulness of heart, lung & diaphragmatic ultrasound in prediction of weaning failure in critically ill patients and to compare it with conventional predictors of weaning. Regarding lung ultrasound, the failing group had higher B-line score (2.5±0.7 vs. 1.6±0.6), \( P = 0.002 \). ROC curve analysis was used to detect the ability of B-line score to predict weaning failure. A cut-off value > 2, could predict weaning failure with a sensitivity 94.4%, specificity 86.4%, NPV 95%, PPV 77.3%, AUC 0.895, confidence interval (0.757-0.970) (\( P < 0.001 \)).

Similar to our result was Bouhemad B. et al 2020, a study conducted on 40 elderly patients. They prospectively performed lung ultrasound (LUS) and transthoracic echocardiography (TTE) before and at the end of spontaneous breathing trials (SBT). Extubation was decided by an independent operator. LUS included global and anterolateral LUS score. SBT LUS scores for prediction of weaning outcome and for the diagnosis of weaning induced pulmonary edema were studied. Weaning or extubation failure was observed in 45% (95% CI 28-61) of patients. ROC analysis for ability of global SBT LUS to predict weaning failure and extubation failure found AUC of 0.80 and 0.81, respectively. AUC for anterolateral SBT LUS to predict weaning failure and extubation failure was 0.79 and 0.81, respectively [27].

Also, Osman et al 2017, found that LUS during SBT (<12) has high probability for success, (12-17) intermediate probability for success and (>17) high probability for failure (19). Again, Shoaeir et al. 2016, found that ROC curve for LUS score 30 minutes from SBT at a cut-off value of (19) could predict re-intubation with 100% positive predictive value, 100% specificity. Moreover, a score of less than (10) showed high accuracy in excluding weaning failure with 100% negative predictive value.

On the contrary, Antonio et al; 2018 (2014) performed a prospective observational study including ventilated subjects who met eligibility criteria for ventilation liberation. Lung ultrasound was performed immediately before SBT. The inability to tolerate a T-piece trial within 30–120 min, and the failure to extubate subjects represented the outcome of the study. B line
predominance was a weak predictor for SBT outcome, showing (47% sensitivity, 64% specificity, 25% PPV and 82% NPV) [17].

Regarding diaphragmatic excursion in the current study, we found that successful group had higher measurements of diaphragmatic excursion (2±0.4 vs. 1.2±0.5 cm, P <0.001). A cut-off value of diaphragmatic excursion ≤ 1.3 cm, could predict the failure of weaning with sensitivity 94.5%, specificity 59.1%, PPV 65.4% and NPV 92.9% with an AUC 0.828 (0.676-0.929).

Similar results were found by Arshad Hayat et al 2017. They conducted a study on 100 mechanically ventilated patients. Out of 100 cases, 76 patients had a successful weaning while 24 had failing weaning. At a diaphragmatic excursion of 1.2 cm and more, out of 67 cases, 60 had a successful weaning (89.55%) while 7 cases (10.45%) had weaning failure. At an excursion of less than 1.2 cm, 17 out of 33 cases (51.5%) had successful weaning while 16 (48.48%) had weaning failure.

Shigang Li et al. 2021 a prospective study included 101 consecutive elderly patients undergoing a trial of extubation. Patients were divided into the successful weaning group (n = 69) and the failed weaning group (n = 32). Measurements of diaphragmatic excursion (DE), diaphragmatic thickening fraction (DTF) and LUS were made using ultrasound within 24 h before extubation. Median DE was greater in patients with extubation success than in those with extubation failure (1.64 cm vs. 0.78 cm, P = 0.001).

Regarding echocardiographic measurements, in the current study we have found that diastolic dysfunction more than grade I, could predict the failure of weaning with sensitivity 100%, specificity 66%, PPV 78% and NPV 100% with an AUC 0.955(0.837-0.995).

Similar results were found by Elhefny et al 2020, a study included 30 patients with difficult weaning who underwent spontaneous breathing trial (SBT). Echocardiography was done and sampling of N-BNP at start of MV and at SBT. TTE showed diastolic dysfunction grade II in 70% and grade I in 30%. There was significant increase in N-BNP from start of MV than SBT (15275±6667.7 vs 1599.7±1448.7 ng/L) [27].

Similar findings were observed in Sasidharan Sachin et al 2021, a study explored the trend of changes with
integrated lung and cardiac ultrasonography in predicting success of weaning in neurosurgical patients. Lung ultrasound and cardiac ultrasound was performed before and after 30 min and 120 min of SBT. E/E' was measured to assess left ventricular filling pressure. Twenty seven patients underwent SBT, among these 22 had success and five had failure of SBT. The SBT failure group had higher baseline LUS and progressively higher LUS during SBT compared to the success group, suggesting significant lung de-recruitment.

Similar to our results regarding LV diastolic dysfunction, Beshir et al. 2021, found significant differences in E/A ratio: (1.08 ± 0.2) in patients with SBT success and (1.6 ± 0.1) in patients with SBT failure (p-value < 0.001) [33].

In contrary, Bouhemad B. et al. 2020, TTE included measurement of E/A and E/Ea ratios to determine LV filling pressures. Increased LV filling pressure during SBT was observed without increase of anterolateral LUS score. Inversely, increase of anterolateral LUS was observed without increased filling pressure and was associated with extubation failure.

In the present study; patients in successful weaning were significantly younger age, most of them were males. Patients with successful weaning had significantly lower grades of diastolic dysfunction, their heart rate and respiratory rate were significantly lower than failed patients and their ejection fraction was significantly higher (P-value<0.05).

There was a significant association between 1st trial of weaning and diaphragmatic excursion and B line score.

The results of this study can be further tested by a larger prospective study in a high-risk population with different risk factors and clinical scenarios.

5. Conclusion:
Failed weaning in mechanically ventilated patients is more prevalent if markers of LV dysfunction (systolic and diastolic), B line score and reduced diaphragmatic excursion are present. Prediction of weaning failure could be significantly assisted by an integrative, dynamic, and fully bedside ultrasonographic concomitant assessment of the heart and lungs before the start of the weaning process or during SBT.

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6. References:
4. Kite-Powell DM: Rapid shallow breathing index and weaning outcome in cardiovascular surgery patients requiring mechanical ventilation for 24 hours or longer: Texas Woman's University; 2008.
13. Barker JE: Physiological and clinical effects of diurnal noninvasive ventilation in hypercapnic COPDDiaz O, Begin P.


https://jicem.journals.ekb.eg/


33. Sassoon CSH, Caiozzo VJ, Manka A, Sieck GC: Altered diaphragm contractile

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