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Lung and Diaphragm Ultrasound as a Predictor of Successful Weaning from Mechanical Ventilation: AProspective Observational Study of 100 ICU Patients

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Lung and Diaphragm Ultrasound as a Predictor of Successful Weaning from Mechanical Ventilation: ***A Prospective Observational Study of 100 ICU Patients***

ABSTRACT:

Background: Prediction of successful weaning is difficult in critically ill patients. We should take optimal time for extubation in intensive care unit for better outcome of the patients. Decision of weaning is taken on the basis of clinical improvement of patient.
Aims:Aim of the study was to assess the accuracy of lung and diaphragm ultrasound for predicting successful weaning outcome.
Material&Methods: We conducted prospective observational study in 100 patients who were consecutively admitted in intensive care unit of our hospital and who required support of mechanical ventilation. We did ultrasound of the patients and calculated modified Lung Ultrasound Score (m-LUS) and Diaphragm Thickness Index (DTI) and Diaphragmatic Excursion (DE). Data analysis was done in Microsoft excel.
Results: Out of 100 patients, 76 patients showed successful weaning. Diaphragm excursion, Diaphragm Thickness index and modified Lung Ultrasound Score showed high specificity in correlation with other parameters of weaning criteria. The cut-off value was 20.7mm for diaphragmatic excursion, 51.32 % for diaphragmatic thickness index and 8.14 for modified lung ultrasound score.
Conclusion: Lung and diaphragm ultrasound can be used as a new parameter for prediction ofweaning process outcome.
Key Words: Modified lung ultrasound score (m-LUS), Diaphragm thickness index (DTI) and Diaphragmatic excursion (DE), Weaning from mechanical ventilation.

1. INTRODUCTION
1.1 Background

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Primary function of mechanical ventilation is to provide respiratory support while treatingthe underlying processes that cause respiratory failure.[1] Widespread use of mechanical ventilation in intensive care unit saves hundreds of lives every day, but prolonged mechanical ventilation increases morbidity and mortality. Failure to wean is a common clinical problem in critically ill adult patients.[2]Multiple indices were used to assess patients before giving weaning trial.

Table 1: Weaning Criteria [3]

Clinical criteria	1. Resolution of acute phase of disease with cardiovascular and hemodynamic stability.[4] 2. Adequate cough and absence of excessive secretions.
Ventilator criteria	1. SBT- Tolerates for 20 to 30 minutes. 2. $PaCO_2$- <50 mmHg with normal pH. 3. F/VT- <100 breaths/min/L (Spontaneous tidal volume>5mL/kg, spontaneous frequency<35/minute). 4. Minute ventilation- <10 Litre with satisfactory arterial blood gas analysis.
Oxygenation criteria	1. PaO_2 without PEEP >60mmHg at FiO_2 up to 0.4. 2. PaO_2 with PEEP >100mmHg at FiO_2 up to 0.4. 3. SaO_2>90% at FiO_2up to 0.4. 4. PaO_2/FiO_2 (P/F) >150mmHg.
Pulmonary reserve	1. Vital capacity >10mL/kg. 2. Max inspiratory pressure >-30cmH_2O in 20second.
Pulmonary measurement	1. Static compliance >30 mL/cmH_2O. 2. Airway resistance – Stable or improving.

(SBT-spontaneous breathing trial, $PaCO_2$-partial pressure of carbon dioxide, PaO_2-partial pressure of oxygen, SaO_2-saturation of oxygen,FiO_2–fraction of inspired oxygen, PEEP-positive end expiratory pressure.)

The diaphragm is the main respiratory muscle for quiet breathing. Preserved diaphragmatic function is required for spontaneous breathing process. Diaphragm function can be assessed by ultrasonography,fluoroscopy, phrenic nerve conduction study andtrans-diaphragm pressure measurement.

1.2 Objectives of study

1. To access diaphragm and lung function via non-invasive method.
2. To compare various ultrasound parameter between successful and failed weaning groups.
3. To know accuracy of lung and diaphragm ultrasound in comparison with other weaning criteria in mechanically ventilated patients.

2. MATERIAL AND METHODS

This prospective, observational study was conducted in intensive care unit of emergency medicine department of a tertiary care hospital. After taking institutional ethical committee approval (IEC no: 35/2020) patients who required weaning from mechanical ventilation in intensive care unit were selected.

Inclusion criteria:

1. All intubated patients on mechanical ventilation who met weaning criteria
2. Male/female aged between 18 years to 70 yearsand whogave consent

Exclusion criteria:

1. Refusal to give consent
2. Age less than 18 years and more than70 years
3. Any patient with primary ultrasound revealing unilateral/bilateral absent diaphragmatic mobility
4. Patients with post-oesophageal and thoracic surgery and intra-operative diaphragm manipulation
5. SpinalcordinjuryhigherthanT8
6. Arrhythmias and hemodynamic instability
7. Pregnancy

Method

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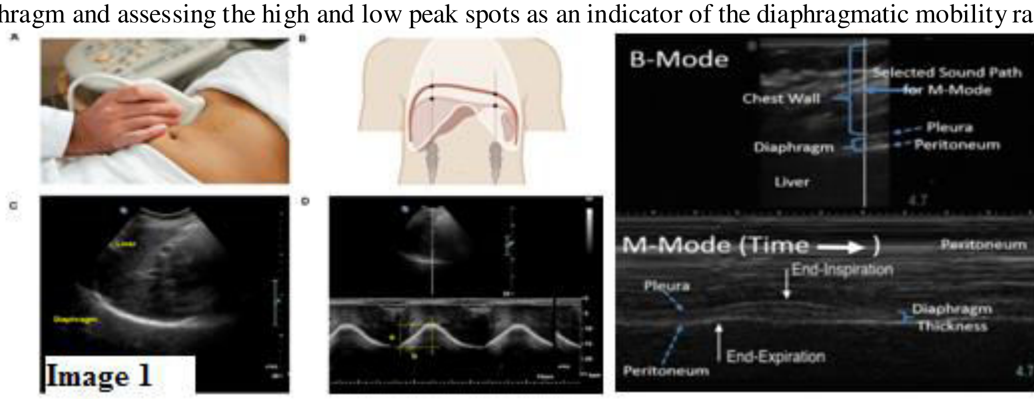
Patients were monitored on a daily basis to assess several weaning clinical indicators. The patients who were selected to start weaning according to the weaning criteria were disconnected from the ventilator to allow spontaneous breathing trial. We extubated the patients who completed the spontaneous breathing trial successfully.
The patients were divided into two groups according to their response to weaning trials with group A showed successful weaning (SW) and transferred to ward while group B showed failed weaning (FW) followed by re-intubation and mechanical ventilation after 48 hours.
Three different parameters were used:
1) Diaphragmatic excursion
2) Diaphragm thickness index
3) Modified lung ultrasound score

Ultrasound machine: Sonositemicromax ultrasound machine having 3.5-6.5 MHz convex probe and 9-11 MHz linear probe was used. Patient was placed in semi recumbent position.

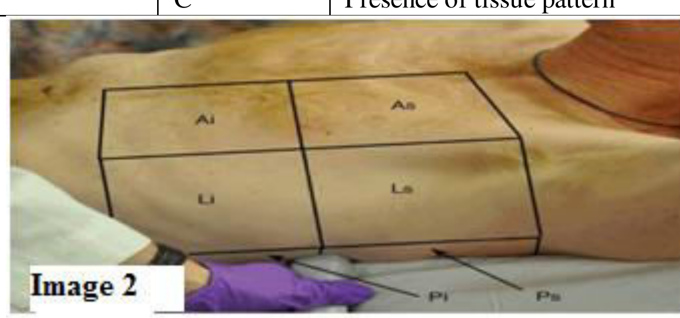
1) Diaphragmatic excursion - The convex probe is positioned subcostally, parallel to the intercostal space, to measure the range of diaphragmatic movement using the M-mode approach with the cursor traversing the diaphragm and assessing the high and low peak spots as an indicator of the diaphragmatic mobility range.



[Image 1 (a) Curvilinear transducer placement for the anterior sub-costal view in the mid-clavicular line showing diaphragmatic excursion in M and B mode, (b) image showing B mode and M mode view of diaphragm in ultrasound.]
2) Thickness index- Diaphragm thickness was measured from the middle of pleural line to the middle of peritoneal line. Thickness was measured during end of inspiration and during end of expiration.
Diaphragm thickness index = (thickness of end inspiration – thickness of end expiration)/thickness of end inspiration.
3) Modified lung ultrasound score- Each lung was divided into four zones and aeration of each lung zone was measured via ultrasonography. Modified lung ultrasound score is shown in table-2.

Table 2 - Modified lung ultrasonography score:

LUNGS	PROFILE	FINDING	SCORE
Normal aeration	N	Presence of lung sliding A line Fewer than two isolated b lines	0
Moderate loss of pulmonary function	B1	More than 2 well defined B-lines	1
Severe loss of pulmonary function	B2	Multiple coalescing B lines	2
Pulmonary consolidation	C	Presence of tissue pattern	3



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[Image 2 – Lung zones, each hemi thorax is divided into two zones: A- anterior and L –lateral, and each zone is divided into superior(s) and inferior (i) areas, so total four quadrants are there in modified lung ultrasound score.]
The diaphragmatic excursion, diaphragm thickness index and lung ultrasound measurements were collected for each group and correlated with some selected weaning criteria namely; arterial blood gas analysis, respiratory rate (RR) and rapid shallow breath index (RSBI). The data analysis was done using IBM SPSS (Statistical Program for Social Science version 24.0) and data were expressed as Mean ± SD for quantitative parametric measurements. The following tests were done:
1) Comparison between two independent mean groups for parametric data using Student t test.
2) Pearson correlation test to study the possible association between each two variables among each group for parametric data. The probability of error at 0.05 was considered significant, while at 0.01 and 0.001 were considered highly significant.
3) Diagnostic validity test: diagnostic sensitivity and specificity. Finally scoring system was put to use diaphragmatic excursion, diaphragm thickness index and lung ultrasound during the weaning process.

3. RESULTS:

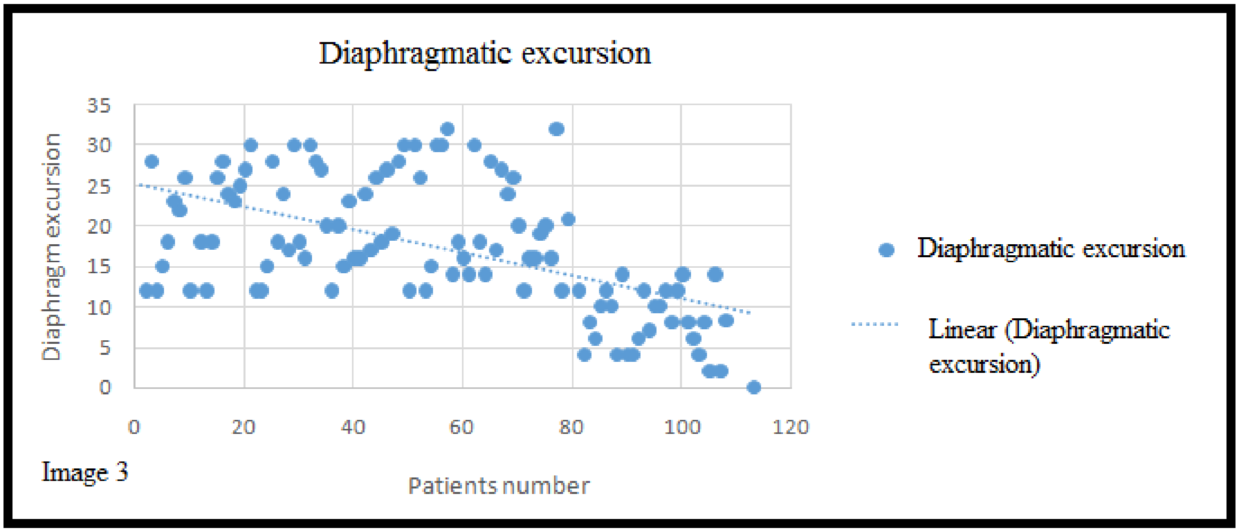
Out of 108 patients who fulfilled inclusion criteria of the study, a total of 100 patients were included in our study and 8 patients were excluded (6-patients were transferred to another hospital and 2-patients' ultrasound was not done due to non-functioning of ultrasound machine). 100 patients were given spontaneous breathing trial,out of which 6 patients failed in spontaneous breathing trial and 94 patients passed successfully.94 patients were extubated after successful spontaneous breathing trial, out of which 18 patients showed failed extubation (7 patients required non-invasive ventilator support, 8 patients requiredre-intubation and 3 patients were deceased). Their ages ranged between 26 to 72 years with a mean age of 62 years. A total of 76patients (76%)showed successful weaning process represented group A(SW) while 24 patients (24%) failed weaning andrepresented group B (FW). The results of the different ultrasound parameters, blood gases and respiratory mechanics mainly the mean value, t-value as well as the significance are illustrated in table-3.

Table 3: Ultrasound parameters of both study groups:

	Group A			**Group B**			**T test**
	Min	Max	Mean	Min	Max	Mean	
Diaphragmatic excursion(mm)	12	32	20.79	2	20	9.52	12.089
Diaphragm thickness index (%)	30	72	51.32	10	42	19.84	9.51
Modified lung ultrasound score	1	20	8.14	3	24	19.18	11.75
Respiratory rate	18	30	26	35	55	43	10.452
Maximum inspiratory pressure	-80	-98	-52	-14	-6	-10	12.545
Rapid shallow breathing index	48	98	70	106	124	114	10.212

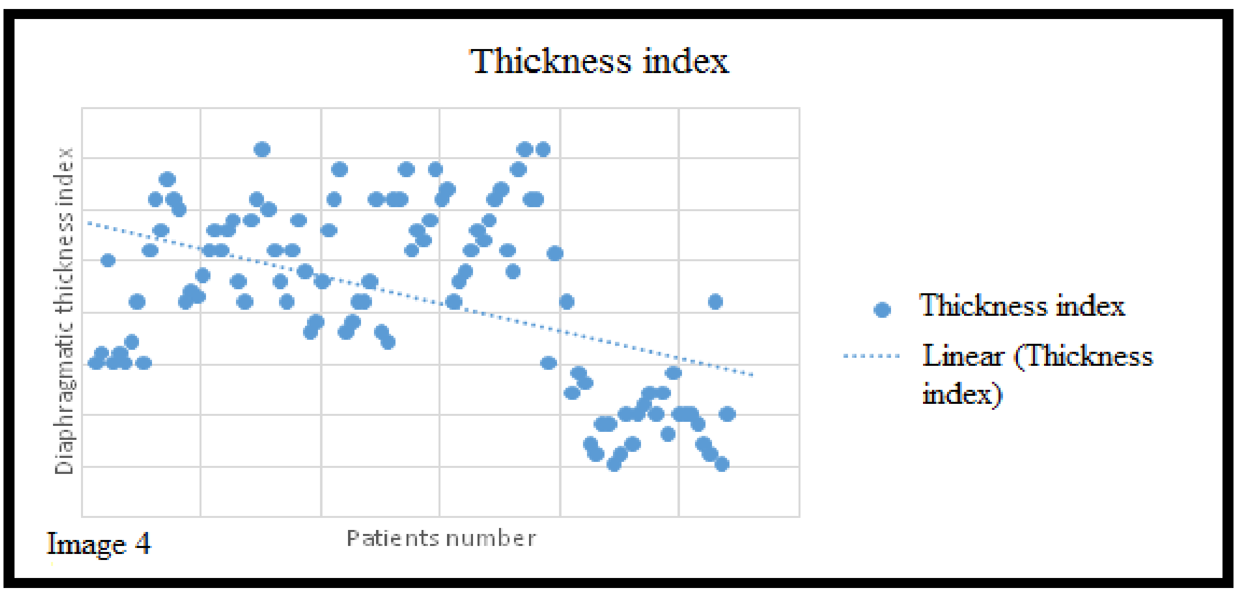
Diaphragmatic excursion: All patients from Group A and 3 patients from Group B had the values between 32 mm to 12 mm. The cut off value 20 mm had 92.6% sensitivity, 83.3% specificity, 71.4% negative predictive value and 96.2% positive predictive value. It showed 95.6% efficacy with significant correlation with other parameters mainly rapid shallow breathing index.

Image 3: Graph showing diaphragm excursion value of patients.



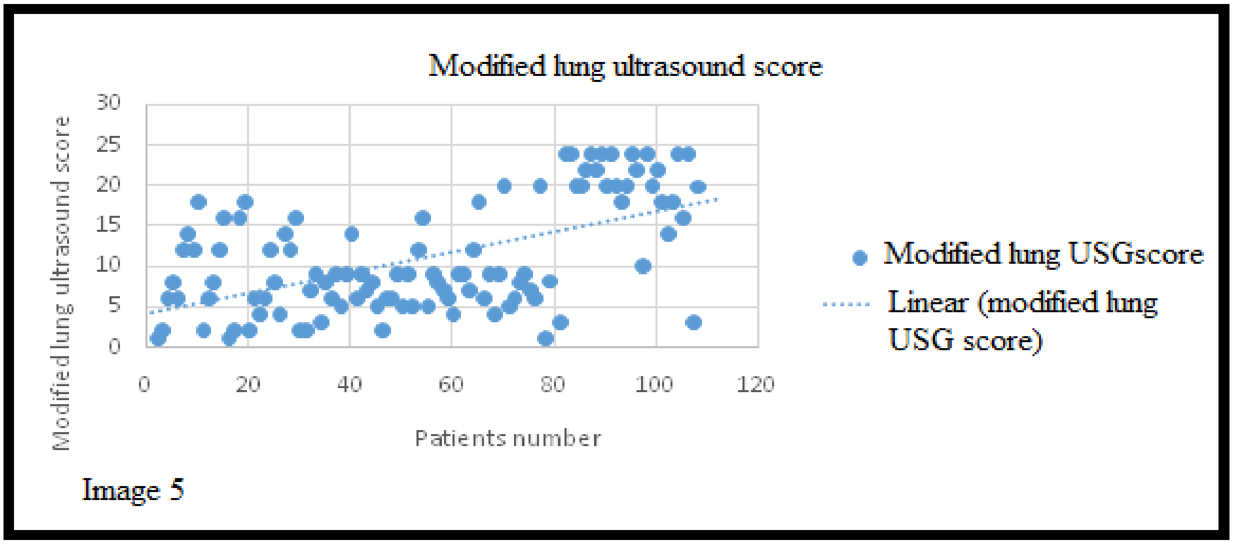
Diaphragmatic thickness index (DTI): All patients with DTI values above 72% showed successful weaning while all patients with DTI below 30% showed failed weaning. From the patients with DTI values between 72% and 30%, 7 patients showed successful weaning and 2 patients showed failed weaning. 51.32% cut off value showed 95.2% sensitivity, 81.2% specificity, 76.4% negative predictive value and 96% positive predictive value. It showed 97.1% efficacy with significant correlation with other parameters mainly the RSBI.

Image 4: Graph showing diaphragmatic thickness index value of patients.



Modified lung ultrasound score (m LUS): Value above 20 showed successful weaning, value below 1 show failed weaning.Cut off value 8.14 showed 89.7% sensitivity, 90.9% specificity, 71% negative predictive value and 97.2% positive predictive value. It showed 97.1% efficacy with highly significant correlation with the other parameters.

Image 5: Graph showing modified lung ultrasound score of patients.



According to the previous results; a score was put for the diaphragmatic excursion, diaphragm thickness index and modified lung ultrasound when used as weaning parameter.

4. DISCUSSION:

4.1. Clinical and research implication

The weaning process of intensive care unit patients is a complex process with an estimated 20% failure rate.

The choice to begin weaning is influenced by a number of indices and parameters, the most important of which are arterial blood gases and respiratory mechanics, with all measures indirectly indicating diaphragmatic function.Ultrasound which is widely available inside the intensive care unit provides direct, bedside and rapid visualization and assessment of the diaphragmatic mobility and diaphragmatic function which may be used as an indicator for the weaning outcome.

In our study we have used M mode of ultrasound to evaluate the diaphragm Excursion and to assess the degree of mobility as it was easier than the B mode during dealing with non-cooperative patients. M mode was also used by Umbrello et al [4] andBaesset al. [5], while Saeed et al. [6]studied the mobility using B mode.

Diaphragmatic thickness index, diaphragmatic excursion, and lung ultrasound showed high significant correlation with other parameters including arterial blood gas and RSBI similar to other previous trials [7]

Our results were correlated with many weaning parameters including blood gases and respiratory mechanics with rapid shallow breathing index was one of the most widely used parameter by the other authors for comparison. In the present study, therapid shallow breathing index was ranging between 48 and 98 breath/min/L in group A (SW) with 73 average values while ranging between 106and124 breath/min/Lin group B (FW) with 115 average values. Saeed et al. [6] found that average rapid shallow breathing index was 91 among patients with successful weaning and 123.6 among patients with failed weaning.Diaphragmatic thickness index (DTI), andlung ultrasound showedsignificanttohighsignificant correlation with the other parameters including the arterial blood gases as well as the respiratory mechanics mainly the rapid shallow breathing indexandmaximum inspiratory pressureandthisissimilartoBaess et al [5].

In the present study, 12 mm diaphragmatic excursionwas the cut off value with 92.6% sensitivity and 83.2% specificity. Saeedet al. [6] reported 86.4% sensitivity and 87.5% specificity while Bass et al. found 69.5% sensitivityand71.4%specificity. [5]

Regarding the DTI, the cut off value of 28% showed 88.9% sensitivity, and 100% specificity in our study. This is close to Baess et al. whoreported30% DTI cutoffvalueyetwithsensitivity about 69.57% and specificity of 71.43%,[5]. This is with contrast to Ferrari et al. who reported higher cut off value of 36% with 82% sensitivity and 88% specificity [10]. Umbrella et al. found lesser cut off value of 20% [4].

Although there are minor changes regarding the diagnostic validity results,diaphragmatic excursionand DTI are good indicators for weaning outcome. The DTIwas more reliable than diaphragmatic excursionwith higher sensitivity and higher efficacy and better AUC score consistent withUmbrello et al.[4]. Also, the findings of lung ultrasound were consistent withSoummeretal.[8].

Table4: Comparison of various weaning parameters of other studies

Study	N (sample size)	Sensitivity (%)	Specificity (%)
Ferrari DTI[9]	46	83	88
SoummermLUS[8]	86	68	86
Eva tenza DTI [10]	69	93	48
Eva tenzamLUS[10]	69	76	73
Osman DTI [11]	68	88	100

Table 5: Comparison of variousweaning parameters of our study

Parameters	Sensitivity (%)	Specificity (%)
Modified lung ultrasound score	89.7	90.9
Diaphragm thickness index	95.2	81.2
Diaphragm excursion	92.6	83.3

4.2 Limitation

Because of the small sample size, we had large variations in results with wide confidence ranges, particularly for thickness index. A larger sample size could have eliminated this limitation.

5. CONCLUSION:

Lung& diaphragm ultrasound provide rapid and non-invasive indices for weaning process outcome with highly accurate results. So, it can be used asa predictor of successful weaning from mechanical ventilation.

Research Quality and Ethics Statement:

The authors of this manuscript declare that this scientific work complies with reporting quality, formatting and reproducibility guidelines set forth by the EQUATOR Network. The authors also attest that this clinical investigation was determined to require Ethics Committee review, and the corresponding protocol/approval number is 35/2020. We also certify that we have not plagiarized the contents in this submission and have done a plagiarism check.

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