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Research Article

Value of diaphragmatic ultrasound in predicting failure of weaning from mechanical ventilation

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Abstract
Background: Background: Diaphragmatic dysfunction was reported in most of mechanically ventilated patients and is considered one of the contributing factors of difficult weaning. Several parameters such as respiratory rate (RR), Tidal volume (TV), and rapid shallow breathing index (RSBI), are used as predictors of liberation failure from mechanical ventilation. The aim of the study was to investigate diaphragmatic dysfunction as an index of failure of liberation from mechanical ventilation and compare it with other conventional predictors of failure of weaning. **Methods:** 56 patients on invasive mechanical ventilation, admitted to our respiratory intensive care unit from November 2021 to May 2023, were included. Bedside chest ultrasound was done 30 minutes after starting spontaneous breathing trial. We recorded chest ultrasound indices; diaphragmatic excursion (DE) at inspiration (DE-insp) and forced inspiration (DE-forced-insp) and diaphragmatic thickness at inspiration (Tdi-insp) and expiration (Tdi-exp) and diaphragmatic thickening fraction (DTF). We compared these indices with predictors of weaning as TV, RR, RSBI, PaO2, PaO2/FiO2 ratio, and Total leucocytic count (TLC). **Results:** liberation failure from mechanical ventilation was detected in thirty cases (53.57 %). Also, those who failed weaning had significantly lower PaO2, pH, TV and significantly higher RSBI, RR, and TLC. As regard chest Ultrasound findings, patients with weaning failure had significantly lower DTF, Tdi-insp, and Tdi-exp. The sensitivity, specificity, negative predictive value, and positive predictive value of the diaphragmatic indices were all recorded and shown in tables. **Conclusion:** diaphragmatic dysfunction is considered an obstacle to weaning. Ultrasound diaphragmatic thickness is a better predictor of weaning failure than diaphragmatic excursion.

Key words: Diaphragmatic thickening fraction, mechanical ventilation, weaning failure, chest ultrasound, diaphragmatic excursion.

Introduction

The Optimal liberation time from mechanical ventilation and avoidance of premature weaning is very important to reduce morbidity, mortality, and hospital cost **[1-4]**.

Attributable factors of weaning failure from mechanical ventilation include malnutrition, infection, acquired weakness, cardiac insufficiency, nervous system disease, and other diseases **[5-7]**.

Several parameters are traditionally used as predictors of weaning failure from mechanical ventilation. One of the widely approved predictors is the Rapid Shallow Breathing Index (RSBI) due to its simplicity **[8]**. The main limitation of using RSBI in predicting successful weaning is that it disregards the diaphragm's contribution **[9]**.

Other common predictors of weaning are vital capacity (VC), tidal volume (TV), Respiratory rate (RR), and CROP (compliance, rate, oxygenation, and maximum inspiratory pressure) index. These parameters, however, also do not necessarily anticipate diaphragmatic function, and the specificity%, sensitivity%, negative predictive value (NPV), positive predictive value (PPV), and cut-off values of these parameters vary greatly across studies.

Sedation and muscle paralysis diminish respiratory rate, while pain, distress, and acidosis raise it. Also, vital capacity cannot be assessed effectively in many instances as reduced patient consciousness. The main disadvantage of maximum inspiratory pressure is the different methods of measurement that give different values **[8]**.

Diaphragmatic dysfunction that was reported in most mechanically ventilated patients is considered as one of the contributing factors of difficult weaning **[10-14]** and is mostly related to myopathy and critical illness polyneuropathy **[15]**.

Data from physiological and histological studies state that mechanical ventilation causes diaphragm structural alterations such as myofibrillar disruption, small abnormal mitochondria, oxidative stress, increased lipid vacuoles in the sarcoplasm, and remodeling of muscle fibers of diaphragmatic **[16, 17]**.

With the progress of critical care ultrasonography, intensivists use chest ultrasonography to detect different etiologies of respiratory failure and the difficulty to wean through bedside diaphragmatic excursion and thickness assessment, and its changes during inspiration **[12]**. There are two indices used as predictors of weaning failure: DTF and DE.

The current study was conducted to investigate diaphragmatic dysfunction as an index of failure of liberation from mechanical ventilation and compare it with other conventional predictors of failure of weaning.

Patients and methods:

The present research is observational and prospective study that was held at RICU, Minia cardiothoracic university hospital, during the period from November 2021 to May 2023. The Minia University Hospital research ethics board approved the research (Approval No.102:9/2021).

56 cases, involved in our study, were admitted to our RICU. Patients were admitted after signing a consent form.

Inclusion criteria:

1- Age above 16 years old.
2- Both genders.
3- Mechanically ventilated patients who fulfill all weaning criteria.

Exclusion criteria:

1- Age below 16 years old.
2- Pregnant females.
3- Cases with tuberculosis.

Patients were subjected to the following:

- Complete medical history.
- Thorough clinical examination, both local and general examination.
- Routine lab tests including CBC, liver enzymes, serum albumin, renal function tests, INR & PC) to estimate the patient's general condition.
- Plain chest radiography and computed tomography (CT) of the chest.
- Chest ultrasound to determine diaphragmatic motion and thickening.

Criteria for weaning from IMV

- Patients were evaluated to see if they were ready for a low-level PS weaning trial or an SB trial after being intubated and ventilated for more than 48 hours. SBT is spontaneous ventilation using a T-tube with the same FiO2 setting as during receiving IMV.
- If a patient exhibited all of the following, they could be considered weaning-ready; The following criteria must be met: 1) improvement of the cause of acute respiratory failure; 2) intact cough reflex; 3) absence of excessive tracheobronchial secretion or discharge; 4) hemodynamic stability (systolic BP 90–160 mmHg; heart rate < 120 beats/min; and no vasopressor use); 5) normal levels of electrolytes and blood sugar, hemoglobin $\geq$ 8–10 g/dL, temperature < 38°C); 6) adequate oxygenation (SaO2 > 92% with FiO_2 < 50 % with PEEP $\leq$ 8 cmH2O and PaO2/FiO2 > 200); 7) adequate respiratory rate (RR $\leq$ 30 breaths/min with VT $\geq$ 5 mL/kg IBW, RSBI < 105, and no significant respiratory acidosis) **(18).**

Criteria for the failure of weaning from IMV

- Failure criteria include altered mental status, the onset of diaphoresis, discomfort, Tachypnea (RR greater than 35 breaths per minute), and hemodynamic instability. **(19)**.

Chest Ultrasound:

- Bedside CUS was used to assess diaphragmatic function indices (DE and diaphragmatic thickening). All cases had bedside Ultrasound done using (Philips© ClearVue 350, Netherlands 2015 Ultrasound Machine). We used the linear probe of high frequency (5–12 MHz) and the convex transducer of low frequency (3–7 MHz). The probe was directed in a craniocaudal direction with the patient lying supine.

Ultrasound Measurements:

Diaphragm thickness (Tdi) was evaluated by a 7 – 12 MHz direct probe in B mode. The right diaphragm was shown at the diaphragmatic apposition zone in the midaxillary line (MAL) between the 8th and 10th intercostal spaces. The zone of apposition is where the contents of the abdomen reach the lower part of the cage. The diaphragm is viewed in this section as a muscular layer with an echoic middle layer framed by two hyper-echoic layers, the peritoneum, and the diaphragmatic pleurae. The diaphragmatic thickness can be estimated during quiet inspiration & expiration. By the M mode, we can calculate the thickening fraction (TF). (TF = thickness at end-inspiration-thickness at end-expiration/ thickness at end-expiration) **(20).** All cases were investigated with elevation of the head of the bed between 20 degrees and 40 degrees. The tdi was assessed at end-expiration and end-inspiration.

Diaphragmatic excursion (motion) was estimated using a 2- 5 MHz convex probe. All measurements were attained with cases in the supine position. A low anterior subcostal, a coronal intercostal approach, or both were performed. The best approach was determined by the two-dimensional (2D). Liver facilitates finding a window for diaphragmatic identification on the right. The probe is positioned medially, cephalad, and dorsally, below the right costal margin, so that the ultrasound waves are directed perpendicularly at the posterior 1/3 of the hemi-diaphragm. The M- mode can also show the diaphragmatic excursion (motion). Cases were examined at the long axis of the intercostal spaces, via the liver window to the right. When breathing normally, the diaphragm moves caudally during inspiration towards the probe and cranially during expiration away from the probe. The diaphragmatic motion can be measured in the M mode. N.B. numerous ICU cases may have pleural effusions, or collapse, which, in discrepancy to what is anticipated, show the hemi-diaphragm better.

Statistical analysis:

Data were processed using the SPSS statistical package version 20. The mean and standard deviation were used to show continuous variables, and the number (percentage) was used to show categorical variables. Pearson's chi-square test was used to compare the percentages of category variables. Receiver operating characteristic (ROC) curve analysis was for identification of best cutoff values of DD-inspiratory, DD-forced inspiratory, DTF, tdi-insp, tdi-exp, PaO2, MV, TV, RR, and RSBI with greatest sensitivity and specificity for weaning failure evaluation. The AUROC was estimated as well, with the following characteristics of qualification: 0.90-1 = excellent, 0.80-0.90 = good, 0.70-0.80 = fair, 0.60-0.70 = poor, and 0.50-0.60 = fail. The point of maximum accuracy was chosen to be the ideal cut-off point.

All of the tests were two-sided. For all tests p value < 0.05 was considered significant.

Results:

The present study involved 56 MV cases and fulfilled the traditional criteria of weaning. The mean age of the patients was 66.21±11.59 (43-85) and the mean BMI was 26.96±2.95. Males represented 60.7 % and smokers represented 57.1 %. One or more comorbidities were seen in 67.9 % of patients and hypertension and DM were the most common comorbidities seen as shown in table 1.

In the present study, 30 patients (53.57 %) failed to wean from MV. As shown in Table 2, it was found that Patients who experience weaning failure have a higher mortality rate. Also, cases with weaning failure had significantly lower PaO2, pH, and TV and significantly higher RSBI, RR, and TLC. As regard chest US findings, patients who experienced failure of weaning had significantly lower DTF, Tdi-inspiratory, and Tdi-expiratory.

As shown in Table 3 and Figure 1, regarding the assessment of the accuracy of ultrasound diaphragmatic parameters in predicting weaning failure, the AUC test was used. A cutoff value of Tdi-inspiratory < 1.9 mm, AUC 0.77 was associated with weaning failure with 92.3 % sensitivity, 46.7 % specificity, 87.5 % PPV, 60 % NPV, and 76.8 % accuracy. A cutoff value of Tdi-expiratory < 1.6 mm, AUC 0.67 was associated with weaning failure with 84.6 % sensitivity, 33.3 % specificity, 71.4 % PPV, 52.4 % NPV, and 57.1 % accuracy. A cutoff value of DTF > 19.94, AUC 0.75 was associated with weaning failure with 84.6 % sensitivity, 66.7 % specificity, 83.3 % PPV, 68.8 % NPV, and 75 % accuracy. A cutoff value of DE-inspiratory < 1.7 cm, AUC 0.71 was associated with weaning failure with 84.6 % sensitivity, 73.3 % specificity, 84.6 % PPV, 73.3 % NPV, and 78.5 % accuracy. A cutoff value of DE-expiratory < 2.19 cm, AUC 0.60 was associated with weaning failure with 84.6 % sensitivity, 60 % specificity, 81.8 % PPV, 64.7 % NPV, and 71.4 % accuracy. A cutoff value of RR > 27.5 beat/min, AUC 0.74 was associated with weaning failure with 80 % sensitivity, 53.8 % specificity, 70 % PPV, 66.7 % NPV and 67.8 % accuracy. A cutoff value of expiratory tidal volume < 329.5 ml, AUC 0.69 was associated with weaning failure with 82.3 % sensitivity, 46.7 % specificity, 87.5 % PPV, 60 % NPV and 67.8 % accuracy. A cutoff value of RSBI inspiratory > 67.3 breaths/min/mm, AUC 0.73 was associated with weaning failure with 86.7 % sensitivity, 30.8 % specificity, 66.7 % PPV, 59.1 % NPV and 60.7 % accuracy. A cutoff value of Duration of MV > 5.5 days, AUC 0.74 was associated with weaning failure with 73.1 % sensitivity, 40 % specificity, 63.2 % PPV, 51.4 % NPV and 55.3 % accuracy.

Table 1: Demographic data, comorbidities of cases, and other weaning indices:

Variables	
Age (years) ** Range	66.21±11.59 (43-85)
Sex ***	
Male	34 (60.7%)
Female	22 (39.3%)
Body mass index (kg/m^2) **	26.96±2.95
Smoking	
Non-smokers	24 (42.9 %)
Smokers	32 (57.1 %)
Comorbidities ***	
No Comorbidities	18 (32.1%)
Diabetes Mellitus	20 (35.7%)
Hypertension	28 (50%)
Cardiac diseases	6 (10.7%)
Chronic renal diseases	12 (21.4%)
Cerebrovascular diseases	2 (3.6%)
Chronic liver diseases	3 (7.1%)
Malignancy	0 (0%)
Rheumatological diseases	0 (0%)
Duration of Mechanical ventilation (days) ** Range	7.64±3.66 (2-19)
Tidal volume (ml)**	362.93±56.89
Minute ventilation (L) **	10.26±1.63
Rapid shallow breathing index (breaths/min/mm) **	80.66±18.51
Vital signs	
Pulse (beat/min) **	96.18±12.71
Systolic Blood Pressure (mmHg) **	119.29±25.8
Diastolic Blood Pressure (mmHg) **	73.57±11.93
Respiratory Rate (breath/min) **	28.36±2.50
Temperature (C) **	37.54±0.4
ABG	
P/F ratio	250.39±53.94
PaO2 (mmHg) **	58.61±10.97
PH	7.35±0.07

PaCO2 (mmHg) **	54.96±12.28
HCO3 (mmHg) **	28 6.57
CBC	
Hemoglobin (g/dl) **	12.63±1.98
TLC (cell/cm^3) **	11.54±6.64
Platelets (cell/cm^3) **	271.64±81.7
Ultrasound findings	
DE-inspiratory (cm) **	1.85±0.84
DE-forced inspiration (cm) **	2.49±0.87
DTF (%) **	34.18±31.57
Tdi-inspiratory (mm) **	2.69±1.35
Tdi-expiratory (mm) **	1.99±0.83

** data presented by **mean ±SD** *** data presented by **n (%)** **ABG:** Arterial blood gas, **P/F ratio:** ratio of the partial pressure of arterial oxygen to the fraction of inspired oxygen, **PaO2:** partial pressure of arterial oxygen**, PH:** Potential of hydrogen**, PaCO2**: partial pressure of carbon dioxide**, HCO3:** bicarbonates**, CBC:** complete blood count**, TLC:** total leucocytic count**, DE- inspiratory:** diaphragmatic excursion at end of inspiration**, DE-forced inspiration:** diaphragmatic excursion at end of forced inspiration**, DTF:** Diaphragmatic thickening fraction**, Tdi-inspiratory:** diaphragmatic thickening at end of inspiration, **Tdi-expiratory:** diaphragmatic thickening at end of expiration**.**

Table 2: Comparison between patients with weaning success and weaning failure

		Weaning success (n= 26)	Weaning failure (n=30)	P value
Age (years) **		64.77±8.76	67.47±13.78	0.54
Sex ***	Male	16 (61.5%)	18 (60%)	0.93
	Female	10 (38.5%)	12 (40%)	
Pulse (beat/min) **		94.92±8.49	97.27±15.72	0.64
Respiratory Rate (breath/min) **		27.38±1.98	29.20±2.63	0.006 *
Tidal volume (ml) **		380.46±44.48	347.36±62.37	0.03 *
RSBI (breaths/min/mm) **		72.99±10.07	87.30±21.54	0.003 *
Minute ventilation (L) **		10.03±1.06	10.47±2.04	0.49
Duration of MV (days) **		6.00±1.79	9.07±4.26	0.02 *
Length of hospital stay (days) **		10.85±3.60	9.40±4.14	0.34
Mortality ***		1 (7.7%)	13 (86.7%)	0.001*
ABG				
P/F ratio		265.23±42.53	237.53±60.66	0.18
PaO2 (mmHg) **		64.54±6.41	53.47±11.65	0.005*
PH **		7.38±0.05	7.33±0.07	0.04*
PaCO2 (mmHg) **		52.69±12.56	56.93±12.1	0.37
HCO3 (mEq/L) **		30.15±5.43	26.13±7.07	0.11
CBC				
Hemoglobin (g/dl) **		12.92±1.32	12.37±2.43	0.47
TLC (cells/cm^3) **		8.02±2.65	14.60±7.59	0.006*
Platelets (cells/cm^3) **		295.69±85.28	250.8±75.08	0.15
Ultrasound findings				
DE inspiratory (cm) **		2.54±0.47	2.31±1.15	0.49
DE forced inspiration (cm) **		2.57± 0.49	2.42±1.1	0.64
DTF (%)		46.24±32.69	23.73±26.94	0.007 *
Tdi-inspiratory (mm) **		3.26±1.38	2.19±11.37	0.02*
Tdi-expiratory **		2.25±0.81	1.76±0.78	0.002*

* significant ** data presented by **mean ±SD** *** data presented by **n (%)**

Table 3: Diagnostic accuracy of diaphragmatic ultrasound finding and traditional methods of weaning

	Cut off value	AUC	Sensitivity	Specificity	PPV	NPV	Accuracy
DE-inspiratory (cm) **	1.7	0.71 CI=0.50-0.92	84.6%	73.3%	84.6%	73.3%	78.57%
DE forced inspiration (cm)**	2.19	0.60 CI=0.36-0.83	84.6%	60%	81.8%	64.7%	71.43%
DTF (%) **	19.94	0.75 CI=0.63-0.88	84.6%	66.7%	83.3%	68.8%	75%
TDI-inspiratory (mm) **	0.19	0.77 CI=0.65-0.89	92.3%	46.7%	87.5%	60%	76.88%
TDI-expiratory (cm) **	0.16	0.67 CI=0.53-0.81	84.6%	33.3%	71.4%	52.4%	57.14%
RR (breath/min) **	27.5	0.74 CI=0.6 – 0.87	80%	53.8%	70%	66.7%	67.86%
TLC (cells/cm^3) **	7.45	0.90 CI=0.79-1	93.3%	38.5%	83.3%	63.6%	67.86%
P/F ratio	215	0.78 CI=0.36-0.80	92.3%	33.3%	83.3%	54.5%	60.71%
PaO2 (mmHg) **	53	0.83 CI=0.67-0.99	92.3%	46.7%	87.5%	60%	67.86%
PaCO2 (mmHg) **	51	0.59 CI=0.37-0.81	80%	46.2%	63.2%	66.7%	64.29%
Tidal volume (ml) **	329.5	0.69 CI=0.55-0.83	82.3%	46.7%	87.5%	60%	67.86%
RSBI (breaths/min/mm) **	67.26	0.73 CI= 0.60-0.87	86.7%	30.8%	66.7%	59.1%	60.7%
Minute volume (L) **	9.13	0.54 CI=0.32-0.77	86.7%	23.1%	56.5%	60%	57.14%
Duration of MV (days) **	5.5	0.74 CI=0.56-0.93	73.1%	40%	63.2%	51.4%	55.36%

* significant ** data presented by **mean ±SD**

AUC: Area under the ROC curve, **PPV**: positive predictive value, **NPV**: negative predictive value, **RR**: Respiratory rate

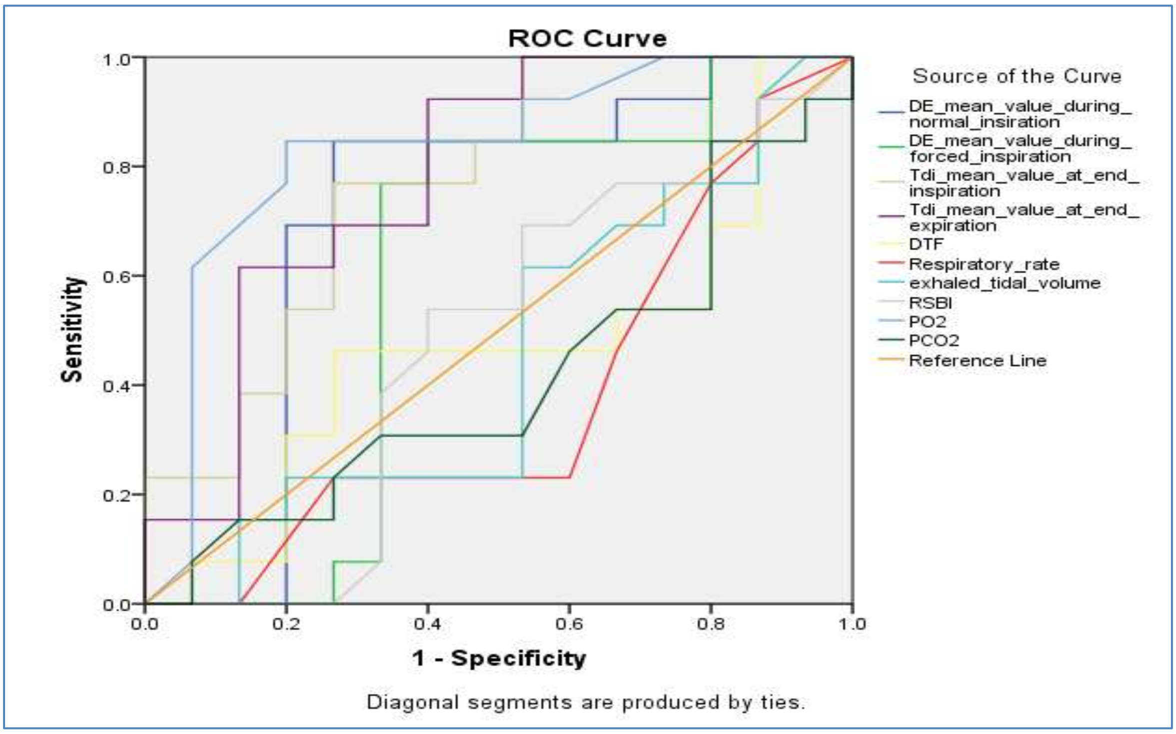

Figure (1): AUROC for predictors of weaning from IMV

Discussion

Nowadays, ultrasound has a great role in the detection of diaphragmatic dysfunction in mechanically ventilated patients and to evaluate different diaphragmatic parameters as predictors of failure of weaning during spontaneous weaning trials.

The current study demonstrated that 56 patients underwent weaning from invasive mechanical ventilation. 26 patients experienced successful weaning (46.4 %), while 15 patients experienced failed weaning (53.6%). Similar results were reported by previous studies that reported successful weaning in 46.7 % **(21)** and 48.8 % **(22).** Different results were noticed by several previous studies that reported successful weaning in 51.7 % **(23)**, 56.6 % **(24)**, 58.1 % **(1)**, 63.3 % **(25)**, 68.9 % **(26)**, 74 % **(27)**, 75 % **(28)**, and 82.3 % **(29)**.

As regards traditional weaning parameters, our study reported that RSBI was significantly higher in the failure group (p 0.003). RSBI was also significantly higher in the failure group in most of the previous trials **(24, 25, 26, 30, 31)**. In contrast, several previous studies found that RSBI was significantly lower in the failure group **(28, 32, 33).**

These differences in results can be explained by the variety of mechanical ventilation causes and the variable duration of mechanical ventilation which may have an impact on the outcome of the weaning process.

The 1st study to use RSBI as weaning criteria was performed by **Yang and Tobin** who settled that RSBI can be used as a predictor of weaning outcomes and it exhibits the best performance compared with other parameters. They demonstrated that a cutoff value < 105 was the best threshold to predict liberation success **(34).** Several previous studies have found a wide variety of cutoff values for RSBI, which may reflect differences in methods, research demographics, and outcome classification **(35, 36).**

The current study shows that RSBI was a poor predictor of weaning success as the RSBI cutoff of 71.5 was 80 % sensitive and 23 % specific for weaning failure.

Similar to our results several previous studies reported that the RSBI is not recommended to predict extubation success **(9, 37, 38)** The current study shows that RSBI was a poor predictor of weaning success as the RSBI cutoff of 71.5 was 80 % sensitive and 23 % specific for weaning failure.

Similar to our results several previous studies reported that the RSBI is not recommended to predict extubation success **(39-42).**

Khan and colleagues found RSBI cutoff of 59 is of 79% sensitivity and 64% specificity for successful extubation **(26).** Abbas and colleagues found that AUROC for RSBI > 70 was 69.2 % specific, 61.2 % sensitive, 39.1 % PPV, 85.2 % NPV, and 63.3% accuracy **(27).** Also, Theerawit and colleagues found that AUROC for RSBI > 100 was 96.1 % specific, 45.5 % sensitive, 89.1 % PPV, 71.4 % NPV **(30).** Elgazzar and colleagues found that for RSBI at cutoff < 103 were 100 % specific, 82 % sensitive, 90.5 PPV, and 100% NPV, respectively **(25).** Farghaly and Hasan found that RSBI < 105 is of 90% sensitivity and 18.7% specificity in anticipation of successful extubation **(32).** A recent study by Pirompanich and Romsaiyut found that RSBI up to 105 has a sensitivity of 96.0%, specificity of 44.4%, PPV of 82.8%, NPV of 80.0%, and accuracy of 82.4% **(33).** In contrast, Baess et al. reported that RSBI is considered a more accurate and reliable tool for anticipating successful weaning and is highly recommended to be used in every weaning trial **(43).**

In the present study, PaO2, pH, and expiratory TV were significantly lower in the failure group, while RR, WBCs, and duration of MV were higher in the failure group. Similar results were reported by previous studies, which reported that RR was significantly higher in patients who failed to wean from MV **(24, 25, 27, 28, 44).** Also, previous studies reported that exhaled TV was significantly higher in the failure group **(25, 45).** Mohamed and colleagues reported that PaO2/FiO2 and RSBI were significantly lower in the failure group, while RR and MV were significantly higher in the failure group **(28).** Previous studies found that the duration of ventilator treatment was significantly higher in the failure **(23, 44, 45)**, while Farghaly and Hasan, found no significant differences between failure and success groups as regard the duration of mechanical ventilation **(32).**

The present study shows that at cutoff point for RR in the prediction of weaning failure > 27.5, AUC was 0.74, with 80 % sensitivity, 53.8 % specificity, 70 % PPV, 66.7 % NPV, and 67.8 % accuracy. Abbas et al. found that AUROC for RR > 19 was 100 % specific, 29.7 % sensitive, 33.3 % PPV, 100 % NPV, and 48 accuracy **(27).**

There is a previous study held at a general ICU on 93 mechanically ventilated patients due to pulmonary disease. They discovered that none of the weaning predictors, such as minute volume, RSBI, or TV, is strong enough to predict success; as a result, the systematic application of these weaning "indices" is of little clinical value. **(46).**

Li C et al. a meta-analysis showed that diaphragmatic ultrasound is a useful tool with high diagnostic accuracy for anticipating when patients will be able to be weaned from mechanical ventilation. **(47).**

As regard chest ultrasound parameters, patients with weaning failure in the present study had significantly lower DTF, tdi-inspiratory, and tdi-expiratory, and no significant differences between both groups were found as regard DE either at the end of inspiration or at the end of forced inspiration.

Similarly, Algazzar and colleagues reported that the weaning failure group has significantly lower DTF, and no significant differences between both groups were found as regard diaphragm thickness at total lung capacity and DE **(25).** Also, Xue and colleagues reported no significant differences between weaning failure and success groups as regards diaphragmatic thickening and DE and only TDF was significantly lower in the weaning failure group **(48).**

Previous studies found significantly lower both diaphragmatic thickness and diaphragmatic excursion indices in failure groups **(1, 24, 28, 49)**.

Theerawit found no significant difference between weaning failure and success groups as regards both DTF and DE **(30).**

AUROC curve was used to assess the accuracy of diaphragmatic parameters in predicting weaning failure. The present study shows that at cutoff point for DTF in the prediction of weaning failure < 19.94 %, AUC was 0.75, had 84.6% sensitivity, 66.7% specificity, 83.3% PPV, 68.8% NPV, and 75% accuracy. Farghaly and Hasan found that DTF% of at least 34.2% had 90% sensitivity and 64.3% specificity in predicting successful extubation **(32).**

Alam and colleagues revealed that the DTF values showed good properties with AUC of 0.706; cut-off value, 19.77 %; sensitivity, 58.8%; specificity, 77.8%; PPV, 83.3%; and NPV, 50.0% **(1).**

Elgazzar and colleagues found that at cutoff value for DTF > 0.33 %, there were 94 % sensitivity, 100 % specificity, 100 % PPV, and

91.7 NPV **(25).** Also, Osman and Hashim, found AUROC for DTF > 28% cut-off value showed 88.9% sensitivity, 100% specificity, 96.2% NPV, and 100% PPV **(50).** Ali and Mohamed showed that the cutoff value for DTF > 30% has a sensitivity of 97.3%, specificity of 85.2%, PPV of 94.4%, NPV of 90.6%, and accuracy of 91.9% **(13).**

In the present study, AUROC for tdi-inspiratory < 3.1 mm was 92.3 % specific, 46.7% sensitive, 87.5% PPV, 60% NPV, and 67.86 % accurate. AUROC for tdi-expiratory < 2.1 mm was 92.3 % specific, 60 % sensitive, 90 % PPV, 66.7 % NPV, and 75 % accurate.

It was stated that DE is more precise and better than the traditional weaning parameters, such as tidal volume and RSBI in predicting weaning failure or success **(51).** In the present study DE either at the end of inspiration or at the end of forced inspiration were non-significantly lower in patients with weaning failure.

That was in agreement with a previous study that found no benefit of maximal DE over conventional clinical testing for predicting weaning failure in patients undergoing their first spontaneous breathing trial **(52).** Also, Theerawit and colleagues 2018 found no significant difference between weaning failure and success groups as regard DE **(30).** In contrast to our study, there was a previous study that demonstrate that patients in the failure group had significantly lower DE compared with the success group **(53).**

The present study shows that at cutoff point for DE-inspiratory in the prediction of weaning failure < 1.7 cm, AUC was 0.71, with 84.6% sensitivity, 73.3 % specificity, 84.6 % PPV, 73.3 % NPV and 78.57 % accuracy. DE predicted successful weaning in the present study is matched with several studies. Hayat and colleagues reported that at DE of <1.2 cm, 51.5% had successful weaning while 48.5 % had a weaning failure. At this 1.2 cut-off point, the sensitivity for successful weaning was 78.95% and the specificity was 70.83% **(54).** Similarly, in a study done by Jiang and colleagues using a cutoff value of 1.1 cm of spleen and liver displacement, the sensitivity to predict successful extubation was 84.4% and the specificity was 82.6% **(55).** This emphasizes that ultrasonography of the diaphragm may be useful in predicting weaning failures **(10).**

Osman and Hashim found a cut-off value of 1.0 cm; sensitivity, 83.3%; specificity, 100%; NPV, 94.3%; and PPV, 100% **(50).**

Ali and Mohamed reported that the cutoff value for DE > 30% has a sensitivity of 88.7%, specificity of 84.3%, PPV of 92.6%, NPV of 81.3%, and accuracy of 87.9% **(13).**

Elgazzar and colleagues found that DE at cutoff value > 0.91 cm were 84 % specific, 37 % sensitive, 69.6 % PPV, and 57.1 % NPV **(25).** Alam and colleagues found that the AUC for DE was 0.83, and the cut-off value was 1.14 cm, with 77.8% sensitivity, 84.6% specificity, 87.5% PPV and 73.3% NPV **(1).** Also, Spadaro and colleagues found similar results with a cut-off value of ≤ 1.4 cm, AUC 0.82, sensitivity 88.2%, specificity 61.8%, PPV 53.6%, and NPV 91.3% **(18).** Farghaly and Hasan found that when the cut-off value of DE was ≥1.05 cm, AUC was 0.879 with 87.5% sensitivity and 71.2% specificity **(32).**

The present study's small number of extubation failures and the different demographic characteristics of the subjects under investigation may be the cause of the higher cutoff values compared to the majority of other earlier studies.

Collectively, our results revealed that the accuracy of DE is lower compared to DTF and tdi, and RSBI. This is in concordance with the results of the systemic review and meta-analysis done to evaluate and compare the accuracy of the diaphragmatic indices obtained by chest ultrasound including DTF, DE, and the RSBI **(56).**

Conclusion: The present study concluded that ultrasound thickness is a better index than excursion in anticipation of weaning failure. And it can be used besides conventional weaning criteria to predict weaning failure in mechanically ventilated cases.

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