Original Article

Sonographic assessment of diaphragmatic thickening and excursion as predictors of weaning success in the intensive care unit: A prospective observational study

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ABSTRACT

Background and Aims: Ultrasonographic assessment of diaphragmatic function can be a useful bedside tool in the weaning and extubation of mechanically ventilated patients, especially in patients with difficult weaning, in whom diaphragmatic weakness is suspected. Thus, this study was planned to assess the role of bedside sonographic assessment of diaphragmatic indices such as diaphragmatic thickening fraction (DT*f*) and diaphragmatic excursion (DE) in predicting successful extubation or extubation failure in weaning eligible patients by comparing the measurements with outcome. **Methods:** This prospective observational study was conducted on 50 mechanically ventilated, weaning-ready patients during the spontaneous breathing trial (SBT). The DE and DT*f* of patients were noted along with conventional parameters of weaning. Probability value <0.05 was considered statistically significant. Receiver operating characteristic (ROC) curves were used for analysis. Area under the curve (AUC) was measured, and sensitivity and specificity for different cut-off values were estimated. **Results:** Out of 50 patients, 15 (30%) had SBT failure and 4 had extubation failure. The group with SBT failure had significantly higher rapid shallow breathing index (RSBI) and airway occlusion pressure (P0.1s), whereas DE and DT*f* were lower compared to the SBT successful group. Strong correlation existed between RSBI, DT*f*, DE and P0.1s. DT*f* of nearly 24% (sensitivity 93.5%, specificity 94.7%) and DE of 1.10 cm (84% sensitivity, 89.5% specificity) were associated with best outcome. **Conclusion:** Along with conventional parameters of weaning, sonographic assessment of diaphragmatic parameters can be useful in predicting the success of SBT and in avoiding unnecessary extubation failures and thereby help in achieving a successful weaning outcome.

Key words: Diaphragm, ultrasonography, weaning

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INTRODUCTION

Weaning from mechanical ventilation in critically ill patients is one of the major challenges faced by intensive care physicians. Several indices that have been used to predict successful weaning include minute ventilation (MV), vital capacity, negative inspiratory force (NIF), rapid shallow breathing index (RSBI), airway occlusion pressure (P0.1s)), etc., during the spontaneous breathing trial (SBT) in weaning-ready patients.[1] Failed weaning in critically

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ill patients could be due to multiple causes such as sepsis, electrolyte disturbances, unresolved cardiac or respiratory pathologies, and neuromuscular weakness including critical illness polyneuropathy/myopathy, etc.[2] Diaphragmatic weakness starts from the time the patient is put on mechanical ventilation and though weaning is successful in most of the eligible patients, it could be difficult for 20%–30% of them.[3] Prevalence of diaphragmatic dysfunction (DD) in mechanically ventilated patients ranges from 33% to 95%.[2] Mode of ventilation has also been identified as a key factor influencing ventilator-induced diaphragmatic dysfunction (VIDD). Among controlled and assisted modes, assisted modes are preferred so as to sensitise the respiratory muscles to prevent atrophy and thinning due to unloading because of non-use.[3] Development of diaphragm atrophy was also associated with prolonged mechanical ventilation, increased intensive care unit (ICU) length of stay, and increased morbidity.[4]

The overall reintubation rate is nearly 10%–20% which is a cause of concern as it poses further challenges in the weaning of patients.[5] Moreover, ultrasound allows real-time assessment of diaphragmatic function by estimating the diaphragmatic thickness (DT) and diaphragmatic excursion (DE) which in turn helps in diagnosing diaphragmatic weakness and predicts successful weaning/extubation.[6] Diaphragmatic thickening fraction (DT*f)* in percentage reflects the magnitude of diaphragmatic effort, and DE measures adequate movement of the diaphragm during quiet breathing or deep inspiration.[7] Studies have shown that assessment of ultrasound-derived indices may predict successful weaning, but sensitivity, specificity, and negative predictive values of these indices are highly variable.[1–7]

However, ultrasound-guided weaning parameters are still not commonly used probably due to uncertainty about its efficacy and cut-off values to predict weaning from mechanical ventilation. Thus, this study was planned to assess the DT*f* and DE using bedside ultrasound in selected weaning-eligible patients. Our primary objective was to assess the role of diaphragmatic indices in predicting successful extubation or extubation failure by comparing the measurements with outcome. We also planned to correlate these findings with other conventional weaning parameters such as NIF, RSBI, and tracheal P0.1s and SBT outcome.

METHODS

This prospective observational study was conducted in the ICU of a tertiary care hospital from May 2021 to January 2022, after receiving approval from the institutional ethics committee (IEC no: 2021-626 dated March 6, 2021). The study was conducted on mechanically ventilated and weaning-ready patients after obtaining written and informed consent from the relatives.

Assuming 15% (10%–20%) to have the factor of interest (extubation failure)[5], 80% of power with 95% confidence interval (CI) and margin of error as 10%, the sample size was estimated to be 49. We included 50 patients by convenience sampling from the ICUs.

The study participants were mechanically ventilated patients selected for weaning by the treating physician's or intensivist's team and who had already tolerated pressure support ventilation (PSV) and were considered fit for weaning. Selection of patients for SBT was based on the well-established weaning criteria (fraction of inspired oxygen [FiO_2] <0.5, positive end-expiratory pressure [PEEP] ≤ 5 cmH_2O, partial pressure of arterial oxygen [PaO_2]/FiO_2 >200, respiratory rate <30 breaths per minute, absence of fever, alert and cooperative state, and haemodynamic stability without vasoactive support). Patients having RSBI <105, NIF >-20 cmH_2O, and P0.1s <3.5 cmH_2O were considered eligible for SBT. Patients who were less than 18 years old and more than 80 years old, patients with primary diaphragmatic disease or trauma, patients who underwent oesophageal and thoracic surgeries, pregnant women, patients with electrolyte derangements and other correctable disorders, unstable haemodynamics, and low consciousness level were excluded from the study.

RSBI is measured as ratio between the respiratory rate (breaths/min) and tidal volume (TV) in litres. Literature supports that RSBI <105 has been associated with better weaning outcomes.[8]

P0.1s is the negative pressure generated at the airway opening, 100 millisecond after initiation of an inspiratory effort against an occluded airway; for mechanically ventilated patients, values of >3 cmH_2O are associated with increased effort.[9]

NIF is the maximum inspiratory pressure that can be generated against an occluded airway after a maximum expiration. Studies support that NIF of -20 cmH_2O is adequate to initiate weaning and that of −25 cmH_2O is associated with successful weaning.[10]

DT was measured by bedside transthoracic ultrasonography (Sonosite machine from FUJIFILM SonoSite, Inc.; Bothell, WA 98021 USA) by an intensivist experienced in the performance of diaphragmatic ultrasound (DUS). A high-frequency (10 Mega Hertz [MHz]) linear probe was placed in cranio-caudal direction in the ninth or tenth intercostal space near the mid-axillary line and angled perpendicular to the chest wall. The diaphragm was identified as a three-layered muscular layer bounded by the membranes of the diaphragmatic pleura and peritoneum [Figure 1a].

Diaphragmatic thickness difference (DTD) is the difference of thickness measured at both end-inspiration and end-expiration in a patient on SBT during tidal breathing.[8]

$DTf = TI - TE/TE \times 100$

(Where TI is thickness at end inspiration and TE is the thickness at end expiration).

To measure DE during tidal and deep breathing, a curvilinear low-frequency probe (3–5 MHz) was used. The probe was placed subcostally parallel to the intercostal space between the mid-clavicular and the mid-axillary lines with the beam directed medially, cephalad, and dorsally to measure the range of the movement in supine position.[8] Excursion was measured both during tidal and deep breathing in M-mode, with the M-line placed perpendicular to the direction of motion to get the high and low waves which indicate diaphragmatic mobility [Figure 1b].

Though the definition of DD is variable, we considered a cut-off of thickening fraction of <20% and/or tidal excursion of <10 mm during tidal breathing as DD based on the existing literature.[11,12]

Figure 1: (a) Diaphragmatic thickness, (b) Diaphragmatic excursion

Cut-off values for weaning success in this study were RSBI <105, NIF > −20 cmH_2O, P0.1s <3.5 cmH_2O, DE (tidal) >1.0 cm, DE (deep breathing) > 3.0 cm, and DT*f* >20% based on previous studies.[9–12]

Criteria for failure of SBT were change in mental status, diaphoresis, increased respiratory rate, haemodynamic instability, and signs of increased work of breathing.

Extubation failure was defined as inability to sustain spontaneous breathing after removal of an endotracheal tube or tracheostomy tube within 48 hours, with the need for re-intubation.

A proforma was constructed based on existing literature and data regarding basic demographic information, comorbidities, clinical diagnosis, weaning readiness, pre-extubation arterial blood gases, respiratory rate, MV, RSBI, NIF, P0.1s, and DUS based diaphragmatic parameters along with weaning outcome were noted.[2,11]

To mitigate interobserver variability, a single trained operator with approximately five years of experience in ultrasound-guided procedures and assessment was involved in taking measurements of all the patients. The average of three readings was taken to mitigate the effect of intra-observer variability. The investigator was not involved in the actual treatment or weaning of the patients and the treating team of the patient was blinded to ultrasound measurements.

Normal distribution of data was determined via the Kolmogorov–Smirnov test. Comparison of quantitative variables between the study groups was done using Mann–Whitney *U* test for independent non-parametric data. For comparing categorical data, chi-square (χ^2) test was performed, and Fisher's exact test was used when the expected frequency was less than 5. Receiver operating characteristic (ROC) curves were plotted and criterion values were estimated depending on specificity and sensitivity. Area under the curve (AUC) was measured. A probability value (*P*) less than 0.05 was considered statistically significant. All statistical calculations were done using the Statistical Package for the Social Sciences (SPSS) version 21 (SPSS Inc., Chicago, Illinois, United States of America) for Windows.

RESULTS

Among the 50 mechanically ventilated, weaning-ready patients, 31 (62%) were successfully extubated, 15 (30%) had SBT failure and 4 (8%) had extubation failure and required re-intubation. Out of these 19 patients, 15 (30%) were transitioned back to controlled (volume/pressure) mode or PSV. Age, gender, comorbidities, and speciality of admission did not have significant relationship with extubation success. Patients with extubation success and SBT failure had comparable haemodynamic and arterial blood gas values [Table 1].

The mean NIF during the SBT was significantly higher (−22.13 ± 1.43) in the extubation success than the failure (SBT and extubation failure) group (−17.68 ± 0.89) with $P < 0.001$. The RSBI was significantly lower in the patients who could be extubated successfully (46.61 ± 18.19 versus 105.63 ± 7.93, $P = 0.001$) [Table 1]. Similarly, P0.1s was significantly lower (3.76 ± 1.32 versus 6.63 ± 1.35) in patients where extubation was successful. On comparing the diaphragmatic parameters measured with bedside ultrasonography, it was observed that the mean DT during inspiration, expiration, and DT*f* was significantly lower in the failure group than in the successful extubation group. Thickness difference of right and left hemidiaphragm were comparable in all the study subjects. Mean tidal excursion on tidal breathing was lower in patients with SBT and extubation failure group (0.83 ± 0.32) than patients who were extubated after SBT (1.48 ± 0.42). Similarly, the mean DE on deep breathing was also lower in the failure group than in the successful extubation group (2.12 ± 0.67 versus 3.75 ± 0.90). There was a strong correlation and statistically significant relation between diaphragmatic parameters and weaning/SBT outcome. The DD was found in 44% (22 out of 50) of patients on the basis of tidal DE and 32% (16 out of 50) based on DT*f*. Among the patients with low tidal excursion (22 patients), 17 patients (77%) had subsequently either SBT failure or extubation failure ($\chi^2 = 25.718$, $P = 0.001$), whereas among patients with low excursion on deep breathing (22 patients), 19 patients (86%) had failure ($\chi^2 = 36.08$, $P = 0.001$). Among 16 patients who had low DT*f*, 14 (87.5%) had SBT failure ($\chi^2 = 25.471$. $P = 0.001$).

Maximum AUC was seen in RSBI, followed by NIF, DT*f*, and P0.1s [Figures 2 and 3]. Least AUC was observed in tidal DE.

Correlation coefficients of 0.40–0.59, 0.60–0.79, and 0.80–1.00 were considered to indicate moderate, strong, and very strong correlations, respectively. Strong correlation existed between RSBI and NIF,

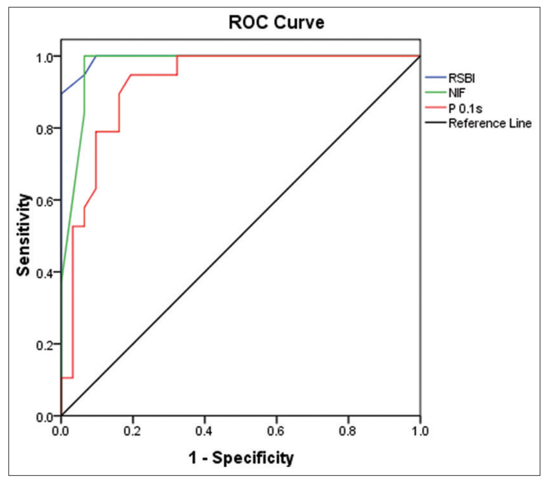

Figure 2: Receiver operating characteristic (ROC) curve of weaning parameters. (RSBI: Rapid shallow breathing index; NI: negative inspiratory force; P0.1s: Airway occlusion pressure at 100 milliseconds)

Table 1: Relation of extubation success with haemodynamic, arterial blood gases, and weaning parameters

Extubation success	No		Yes		*P*
	Mean	Standard Deviation (SD)	Mean	Standard Deviation (SD)	
Mean arterial pressure (mmHg)	98.68	10.65	97.37	9.63	0.447
pH	7.44	0.10	7.46	0.06	0.703
PCO_2 (mmHg)	32.00	4.55	35.06	5.89	0.060
PO_2 (mmHg)	157.79	75.76	195.42	94.14	0.114
SpO_2 (%)	97.32	1.45	98.19	1.01	0.005
Lactate (mmol/L)	1.44	0.65	1.14	0.45	0.151
RSBI (breaths/min/L)	105.63	7.93	46.61	18.19	0.001
RR (breaths/min)	20.84	2.75	14.35	2.01	0.001
Mean NIF in cmH_2O	−17.68	0.89	−22.13	1.43	0.001
Mean P0.1s in cmH_2O	6.63	1.35	3.76	1.32	0.001
Diaphragmatic thickening fraction (%)	19.26	3.49	36.57	8.22	0.001
Mean tidal excursion in cm	0.83	0.32	1.48	0.42	0.001
Mean diaphragmatic excursion on deep breathing in cm	2.12	0.67	3.75	0.90	0.001

(PCO_2: Partial pressure of carbon dioxide; PO_2: Partial pressure of O_2; SpO_2: Peripheral oxygen saturation; RSBI: Rapid shallow breathing index; RR: Respiratory rate; NIF: Negative inspiratory force; P0.1s: Airway occlusion pressure at 100 milliseconds)

DT*f*, excursion, and P0.1s [Table 2]. Mean NIF on the other hand had moderate correlation with mean tidal excursion, and strong correlation with DT*f*. DT*f* had strong correlation with excursion on deep breathing.

We observed that all the weaning parameters in this study had a significant relationship with SBT outcome, in which DT*f*, excursion, and NIF were lower, and RSBI and P0.1s were higher in patients with SBT failure indicating DD [Table 1]. Accuracy of the different cut-off values with sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) to predict SBT success/failure or extubation success/failure were calculated [Table 3].

RSBI of 80 had a sensitivity of 100%, specificity of 90%, PPV of 86.35, and accuracy of 94%, whereas RSBI of 85 had a sensitivity of 94.7%. A NIF of −20 cmH_2O provides good accuracy with 100% sensitivity and good PPV and NPV. Among the three

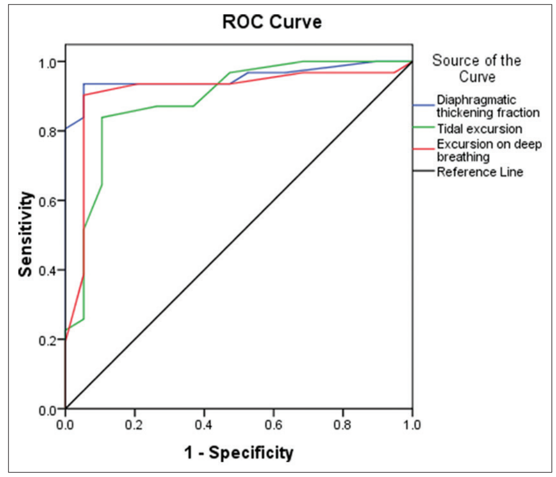

Figure 3: Receiver operating characteristic (ROC) curve of diaphragmatic measurements

Table 2: Correlation table of weaning parameters measured during spontaneous breathing trial						
Correlations	**Spearman's Rho**	**Mean NIF**	**Diaphragmatic Thickening Fraction**	**Mean Tidal Excursion (cm)**	**Mean Excursion During Deep Breath (cm)**	**Mean P0.1s (cmH_2O)**
RSBI (breaths/min/L)	Correlation coefficient	0.762	−0.764	−0.651	−0.759	0.711
	P	0.001	0.001	0.001	0.001	0.001
Mean NIF (cmH_2O)	Correlation coefficient		−0.712	−0.570	−0.775	0.648
	P		0.001	0.001	0.001	0.001
DTf (%)	Correlation coefficient			0.574	0.711	−0.615
	P			0.001	0.001	0.001
Mean tidal excursion in cm	Correlation coefficient				0.826	−0.454
	P				0.001	0.001
Mean excursion during deep breath in cm	Correlation coefficient					−0.595
	P					0.001

RSBI: Rapid shallow breathing index; NIF: Negative inspiratory force; DT*f*: Diaphragmatic thickening fraction; P0.1s: Airway occlusion pressure at 100 milliseconds

Table 3: Sensitivity and specificity of weaning parameters with respect to cut-off values						
Variable	**Measurements (cut-off values)**	**Sensitivity**	**Specificity**	**PPV (%)**	**NPV (%)**	**Accuracy (%)**
RSBI	76.00	1.000	0.871	82.61	100	92
	80.00	1.000	0.903	86.36	100	94
	85.00	0.947	0.935	90	96.67	94
NIF (cmH_2O)	−21.50	1.000	0.774	73	100	86
	−20.00	1.000	0.935	90.48	100	96
	−18.50	0.842	0.935	88.89	90.62	90
DT*f*	22.250	0.935	0.895	93.55	89.47	92
	23.750	0.935	0.947	96.67	90	94
	26.000	0.903	0.947	96.55	85.71	92
Diaphragmatic excursion in tidal breathing (cm)	0.95	0.871	0.737	84.38	77.78	82
	1.10	0.839	0.895	92.86	77.27	86
	1.25	0.742	0.895	92	68	80
Diaphragmatic excursion during deep breathing (cm)	2.75	0.935	0.789	87.88	88.24	88
	3.05	0.903	0.947	96.55	85.71	92
	3.15	0.839	0.947	96.3	78.26	88
P0.1s (cmH_2O)	4.6	0.947	0.774	72	96	84
	4.7	0.947	0.806	75	96.2	86
	4.8	0.895	0.839	77.3	92.86	86

(PPV: Positive predictive value; NPV: Negative predictive value; RSBI: Rapid shallow breathing index; NIF: Negative inspiratory force; P0.1s: Airway occlusion pressure at 100 milliseconds; DT*f*: Diaphragmatic thickening fraction)

DT*f* values checked, a fraction of nearly 24% was associated with the best outcome (sensitivity 93.5%, specificity 94.7%, PPV 96.7%, accuracy 94%). DE cut-off of 1.10 cm showed 84% sensitivity, 89.5% specificity, and a PPV of 93%. DE value of 3.0 cm on deep breathing provided 90.3% sensitivity, 94.7% specificity, and PPV of 96.5%.

DISCUSSION

Studies have suggested that bedside DUS could be of great help in predicting extubation failure, but this modality is still not much used in practice.[11,12] Many studies have analysed the role of assessment of DE as well as DT*f* and observed that weaning failure can be predicted with these measurements, but cut-off values given in these studies are variable and range from <1.0 to 1.5 cm excursion in normal tidal breathing and from <20% to 36% in thickening fraction.[13–15] Conventionally, DD has been defined as a thickening fraction of less than 20% or a tidal excursion of less than 10 mm.[11] In our study, the DD threshold taken was a thickening fraction of ≤20% or a tidal excursion of ≤10 mm based on existing literature.

Thickness differences of right and left hemidiaphragm were comparable at functional residual capacity level and met the criteria given by Boon *et al*.[16] and hence, only values from the right hemidiaphragm were considered for analysis. We also observed that 62% of patients were successfully extubated after SBT whereas 38% had weaning failure, out of which four patients had to be re-intubated (8%). Low DE on tidal breathing (≤1.0 cm) was found in 44% of patients and out of these, 77% patients had SBT failure. On the other hand, 32% of patients had low DT*f* (≤20%), out of which 87.5% had SBT failure. The prevalence of DD in our study (32%–44%) is comparable to that in other studies which showed the prevalence of DD to be 31%[2] and 29%.[14] In another study, it was observed that DE >25 mm increased the likelihood of success of SBT and a DT*f* >30%–36% during SBT increased the likelihood of success of SBT.[17]

We observed that the patients with successful extubation had significantly higher NIF, lower RSBI, and lower airway occlusion pressure (P0.1s) than the SBT failure group. On ultrasound-guided assessment, mean DT difference, DT*f*, and excursion on tidal and deep breathing was found to be significantly lower in the SBT failure group. Other studies have also shown that combined approach of RSBI and DUS in the pre-extubation time was associated with successful extubation.[14–16] Nevertheless, the combination of RSBI with DT*f* >26% was a more accurate predictor of successful weaning from mechanical ventilation than RSBI alone in another study.[18,19] In our study, DT*f* in patients with SBT failure was 19.26% ± 3.49% compared to 36.57% ± 8.22% in patients with successful extubation.

In a study done by Alam *et al*.[20] in extubation-ready ICU patients, it was observed that DUS (DE and DT*f*) was a better tool to predict successful extubation compared to RSBI. The authors also reported that DE was a better predictor of successful extubation than DT*f*.

During quiet breathing, the excursions were measured by most authors as between 10 mm and 25 mm on both sides.[21–23] While looking into the cut-off values, we observed that RSBI of 80 and NIF of − 20 cmH_2O had a 100% sensitivity and high accuracy of 94%. DT*f* of 24%, DE cut-off of 1.10 cm at tidal breathing, and DE of 3.0 cm on deep breathing provided high sensitivity, specificity, and PPV.

The main limitation of this study was that as we had enroled medical, surgical, and neurological patients together, we could not extrapolate the results to specific subgroup of patients. The study also did not explore the role of other variables such as duration of ventilation, mode of ventilation in unsuccessful weaning, or extubation.

CONCLUSION

Sonographic assessment of DT*f* and excursion tells us the functional status of the diaphragm and can be used along with conventional parameters of weaning during SBT to detect patients at risk of experiencing difficult weaning and to predict weaning outcome and successful extubation.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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