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ORIGINAL RESEARCH ARTICLE

Predicting Weaning Outcome in Mechanically Ventilated ICU Patients Using the Rapid Shallow Breathing Index, Ultrasound-Guided Diaphragm Thickening Fraction, and Their Combination: A Prospective Cohort Study

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ABSTRACT

Background: Timely liberation from mechanical ventilation is a central goal in intensive care, as both premature and delayed extubation carry avoidable risk. The rapid shallow breathing index (RSBI) is widely used but limited by low specificity, while diaphragm ultrasound offers a bedside measure of respiratory muscle performance. We compared RSBI, the diaphragm thickening fraction index (DTFI), and their combination for predicting weaning outcome.

Methods: This single-centre prospective observational study enrolled 157 adults ventilated for at least 24 hours in a mixed medical–surgical ICU who were ready for their first spontaneous breathing trial (SBT). After tolerating an SBT, RSBI was recorded and the diaphragm thickening fraction was measured with ultrasound in the zone of apposition. Weaning success was defined as unassisted breathing sustained for 48 hours. Diagnostic performance was assessed using receiver operating characteristic (ROC) curves.

Results: Weaning failed in 21 patients (13.4%). Age, BMI, duration of ventilation, ICU stay, haemodynamics and gas-exchange variables did not differ between groups. RSBI was similar in patients who failed and succeeded (69.94 vs 67.35 breaths/min/L; $p = 0.369$), whereas DTFI was markedly lower in the failure group (24.98% vs 39.02%; $p < 0.001$). Areas under the curve were 0.423 for RSBI, 0.750 for DTFI and 0.765 for the combination. At RSBI $\leq$ 105, sensitivity was 100% but specificity only 5%; at DTFI $\geq$ 26%, sensitivity was 83% and specificity 57%. Combining the two did not improve on DTFI alone.

Conclusion: DTFI predicted weaning outcome substantially better than RSBI and performed comparably to the combined index. Diaphragm ultrasound is a simple, reproducible bedside adjunct that can strengthen the assessment of weaning readiness in critically ill patients.

Keywords: Weaning; Mechanical ventilation; Rapid shallow breathing index; Diaphragm thickening fraction; Diaphragm ultrasound; Spontaneous breathing trial.

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INTRODUCTION

Invasive mechanical ventilation supports gas exchange in critically ill patients while the underlying illness is treated, but it is not without cost. Prolonged ventilation is associated with ventilator-associated pneumonia, diaphragm injury and higher mortality, so ventilation should be withdrawn as soon as the patient can breathe unaided.[1] Weaning, however, accounts for a large share of total ventilation time, and misjudging readiness in either direction is harmful: premature extubation leads to reintubation, while unnecessary delay prolongs exposure to the ventilator. A structured spontaneous breathing trial remains the reference method for judging when a patient is ready to breathe on their own.[2]

Several parameters have been proposed to guide this decision, including minute ventilation, maximum inspiratory pressure and the CROP index. Of these the rapid shallow breathing index (RSBI) — the ratio of respiratory

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frequency to tidal volume — is the most widely used because it is quick and needs no additional equipment. In the original description by Yang and Tobin, an RSBI below 105 breaths/min/L predicted successful weaning with high sensitivity but modest specificity. A later systematic review confirmed its value for predicting extubation while noting the same trade-off. That limited specificity remains its main weakness and can lead to failed extubation when RSBI is used in isolation, and its prognostic value is weaker still in patients requiring prolonged ventilation.[3,6,12, 13]

Diaphragmatic dysfunction is a common and under-recognised contributor to weaning failure, and it worsens with the duration of controlled ventilation.[7] The diaphragm is the principal muscle of inspiration, and its contractile function can now be assessed at the bedside with ultrasound. The diaphragm thickening fraction (DTF), calculated from diaphragm thickness at end-inspiration and end-expiration, reflects active contraction and correlates with the work of breathing.[4,5] Because ultrasound is safe, non-invasive, radiation-free and repeatable, it is an attractive complement to conventional indices.[9] Standardised approaches to measuring diaphragm ultrasound parameters have since been defined by expert consensus, improving their reproducibility at the bedside.[19] We therefore studied whether DTF, expressed as the diaphragm thickening fraction index (DTFI), and its combination with RSBI could improve prediction of weaning outcome compared with RSBI alone.

Aim and Objectives

Aim to assess the efficacy of the rapid shallow breathing index, the diaphragm thickening fraction index, and their combination for predicting successful weaning from mechanical ventilation in ICU patients.

Primary objective

To determine the sensitivity and specificity of RSBI, DTFI and the combined index for predicting weaning outcome.

Secondary objectives

To evaluate the positive and negative predictive values of each index, and to compare their overall accuracy for predicting weaning outcome.

MATERIALS AND METHODS

Study design and setting

We conducted a hospital-based, single-centre, prospective observational study in the 40-bedded medical and surgical ICU of Marengo QRG Hospital, Faridabad, over 18 months. The study was approved by the Institutional Ethics Committee and the Scientific Research Committee, and written informed consent was obtained from every participant or their attendant.

Participants

Adults older than 18 years who had been mechanically ventilated for at least 24 hours and were ready for their first spontaneous breathing trial were eligible. Patients with neuromuscular disease, spinal cord injury, recent oesophageal or thoracic surgery, or in whom ultrasound was not feasible (for example a chest tube at the site), those with absent unilateral or bilateral diaphragmatic mobility, and those with decompensated cardiac failure were excluded to limit confounding.

Weaning protocol

Readiness was judged on standard subjective and objective criteria, including adequate cough, resolution of the precipitating cause, haemodynamic stability and satisfactory oxygenation. The spontaneous breathing trial was delivered with low pressure support (5–8 cmH_2O) and PEEP of 5–6 cmH_2O and lasted between 30 and 120 minutes.

Measurements

In patients who tolerated the trial for more than 60 minutes, RSBI was recorded and the diaphragm was imaged in B-mode with a high-frequency ($\geq$ 10 MHz) linear probe in the zone of apposition at the mid-axillary line, between roughly the 8th and 11th ribs. Diaphragm thickness was measured at maximal inspiration and expiration, and the thickening fraction was calculated as (thickness at end-inspiration − thickness at end-expiration) / thickness at end-expiration, expressed as a percentage.[5]

Outcome

Weaning success was defined as the ability to maintain spontaneous breathing for at least 48 hours without ventilatory support and without features of respiratory distress. Failure was defined as an inability to sustain spontaneous breathing over the same period, or the appearance of a change in mental status, respiratory rate above 35 breaths/min, haemodynamic instability, or signs of increased work of breathing.

Sample size and statistics

Assuming a weaning-failure proportion of 52.09% from an earlier cohort, with 95% confidence, 5% absolute precision and 80% power, a minimum of 157 patients was required (Epi Info v3.0). Continuous variables are summarised as mean ± standard deviation and categorical variables as counts and percentages. Groups were compared with the Student t test, the chi-squared test or the Fisher exact test as appropriate. Predictive performance was assessed from ROC curves, with the area under the curve (AUC) and the Youden index used to define cut-offs; AUCs were compared using the DeLong test. A two-sided p value below 0.05 was considered significant.[11]

RESULTS

A total of 157 patients were enrolled. Weaning failed in 21 (13.4%) and succeeded in 136 (86.6%). The mean age was 49.81 ± 13.15 years and the mean BMI 22.04 ± 2.03 kg/m². Neither age (53.24 vs 49.28 years; p = 0.231) nor BMI (22.40 vs 21.99 kg/m²; p = 0.384) differed between patients who failed and succeeded (Table 1). The duration of mechanical ventilation and length of ICU stay were also comparable, as were heart rate, respiratory rate and mean arterial pressure.

Gas-exchange and ventilatory settings at the time of the trial did not distinguish the two groups. PaO_2, $PaCO_2$, the PaO_2/FiO_2 ratio, pressure support, PEEP and tidal volume were all similar, although tidal volume showed a borderline trend (392.76 vs 370.51 mL; p = 0.051) (Table 2).

The key difference between groups lay in diaphragm function. RSBI was similar in patients who failed and succeeded (69.94 vs 67.35 breaths/min/L; p = 0.369), and diaphragm thickness at maximal inspiration and expiration did not differ. By contrast, the diaphragm thickening fraction index was substantially lower in patients who failed to wean (24.98% vs 39.02%; p < 0.001) (Table 3).

RSBI, rapid shallow breathing index; DTFI, diaphragm thickening fraction index. Values are mean ± SD.

Receiver operating characteristic curves were constructed for RSBI, DTFI and the combined index (Figure 1). The area under the curve was 0.423 for RSBI,

Table 1: Baseline and clinical characteristics by weaning outcome

Variable	Failure (n = 21)	Success (n = 136)	Total (n = 157)	p
Age (years)	53.24 ± 14.75	49.28 ± 12.86	49.81 ± 13.15	0.231
BMI (kg/m²)	22.40 ± 3.19	21.99 ± 1.80	22.04 ± 2.03	0.384
Length of MV (days)	3.10 ± 1.70	3.14 ± 4.54	3.13 ± 4.27	0.965
Length of ICU stay (days)	4.71 ± 2.12	4.61 ± 2.64	4.62 ± 2.57	0.864
Heart rate (/min)	77.05 ± 11.72	76.44 ± 9.50	76.52 ± 9.79	0.792
Respiratory rate (/min)	26.76 ± 3.55	24.94 ± 3.54	25.18 ± 3.59	0.321
MAP (mmHg)	127.95 ± 7.03	127.46 ± 7.16	127.53 ± 7.12	0.771

MV, mechanical ventilation; MAP, mean arterial pressure. Values are mean ± SD.

Table 2: Ventilatory and gas-exchange parameters by weaning outcome

Parameter	*Failure (n = 21)*	*Success (n = 136)*	*p*
PaO_2 (mmHg)	73.14 ± 6.62	72.35 ± 6.78	0.619
$PaCO_2$ (mmHg)	38.95 ± 4.84	40.12 ± 5.15	0.332
PaO_2/FiO_2	246.86 ± 12.86	243.57 ± 9.38	0.158
Pressure support (cmH_2O)	7.00 ± 1.22	6.23 ± 1.24	0.328
PEEP (cmH_2O)	4.76 ± 0.77	5.00 ± 0.83	0.217
Tidal volume (mL)	392.76 ± 63.89	370.51 ± 44.11	0.051

PEEP, positive end-expiratory pressure. Values are mean ± SD.

Table 3:RSBI and diaphragm ultrasound parameters by weaning outcome

Parameter	*Failure (n = 21)*	*Success (n = 136)*	*p*
RSBI (breaths/min/L)	69.94 ± 14.98	67.35 ± 11.82	0.369
Thickness, max inspiration (cm)	0.26 ± 0.08	0.26 ± 0.07	0.909
Thickness, max expiration (cm)	0.21 ± 0.06	0.19 ± 0.08	0.468
DTFI (%)	24.98 ± 13.48	39.02 ± 14.52	<0.001

Table 4: Diagnostic performance of RSBI, DTFI and the combined index for predicting successful weaning

Measure	*RSBI ≤ 105*	*DTFI ≥ 26%*	*RSBI ≤ 105 + DTFI ≥ 26%*
Area under the curve	0.423	0.750	0.765
Sensitivity	100%	83%	83%
Specificity	5%	57%	57%
Positive predictive value	87%	93%	93%
Negative predictive value	100%	34%	34%
Accuracy	87%	80%	80%

0.750 for DTFI and 0.765 for RSBI combined with DTFI, indicating good discrimination for the diaphragm-based measures and poor discrimination for RSBI in this cohort. At the conventional cut-off of RSBI ≤ 105 breaths/min/L, sensitivity was 100% but specificity only 5%. A DTFI threshold of ≥ 26% gave a sensitivity of 83%, specificity of 57%, positive predictive value of 93% and negative predictive value of 34%. Combining RSBI ≤ 105 with DTFI ≥ 26% produced results identical to DTFI alone (Table 4).

RSBI, rapid shallow breathing index; DTFI, diaphragm thickening fraction index.

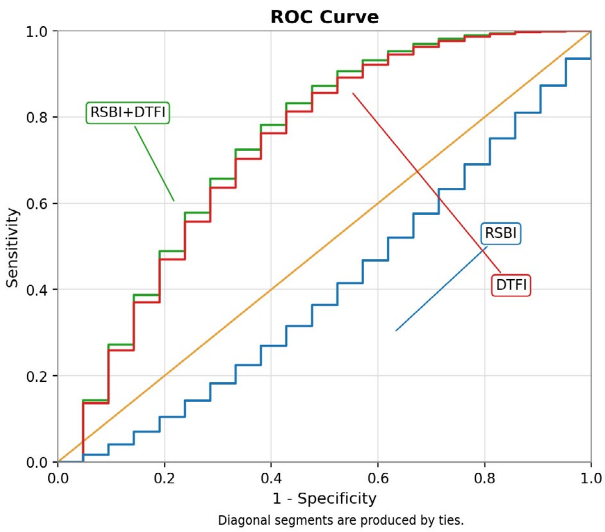

Figure 1: ROC curves for RSBI, DTFI and their combination for predicting weaning outcome (AUC 0.423, 0.750 and 0.765, respectively)

DISCUSSION

In this prospective cohort of mechanically ventilated ICU patients, the diaphragm thickening fraction discriminated between successful and failed weaning far better than RSBI, and combining the two indices offered no advantage over DTFI on its own. RSBI, despite its perfect sensitivity at the standard threshold, had a specificity of only 5% and an AUC below chance, whereas DTFI achieved an AUC of 0.750 with a more balanced sensitivity and specificity. These findings support the growing view that a purely respiratory-pattern index cannot, by itself, capture the physiology that determines whether a patient will tolerate extubation.

RSBI reflects the balance between inspiratory muscle load and capacity and is attractive for its simplicity, but its low specificity is well documented and can generate false reassurance.[3,6] Part of the variability arises from how and where it is measured: ventilator settings, the mode used during the trial, and even the device used to obtain the value all influence the result, and ventilators tend to overestimate RSBI relative to a Wright spirometer.[6,15] In our patients, measured on low-level pressure support, RSBI failed to separate the two groups, which is consistent with reports of weak or inverted discrimination when the index is applied outside its original conditions. To address these limitations, diaphragm-based modifications of the index have been proposed for use during pressure-support trials.[14]

The diaphragm is the principal inspiratory muscle, and diaphragmatic dysfunction is both common and easily missed in the critically ill.[7] Ultrasound assessment of the thickening fraction reflects active contraction rather than passive displacement, and it is less affected by the confounders that limit diaphragmatic excursion.[8] Our results are in keeping with earlier work: Pirompanich and Romsaiyut reported an AUC of 0.951 for right DTF with a cut-off of ≥ 26% (sensitivity 96%, specificity 68%), and found that adding RSBI ≤ 105 raised specificity slightly at the expense of sensitivity.[10] Other single-centre studies using DTF thresholds around 26–29% report comparable discrimination.[16] Meta-analyses have likewise identified DTF as one of the more reliable ultrasound predictors of weaning outcome, with pooled specificity consistently above 0.80.[9,18].Spadaro and colleagues took a related approach, replacing tidal volume with diaphragmatic excursion to build a diaphragmatic RSBI that outperformed the traditional index.[8,20]

Our combined index did not improve on DTFI alone, which mirrors the modest and sometimes opposing effects of combining indices reported elsewhere. This is not surprising: weaning failure is multifactorial, driven by respiratory-centre dysfunction, muscle weakness or overload, cardiovascular strain during the trial, and difficulty clearing secretions. When the airway and lung mechanics are favourable and the primary illness is controlled, adequate ventilation can be sustained despite relatively little diaphragmatic thickening, which may explain the lower specificity and occasional false-negative results we observed. No single index is likely to be ideal, and broader evaluations of non-invasive muscle assessment reach the same conclusion, that no one measure captures every mechanism of weaning failure.[17] DTFI is best viewed as a strong, physiologically grounded complement to clinical judgement rather than a replacement for it.

Length of ICU stay did not differ between groups in our cohort. This is expected, since stay is driven mainly by illness severity and comorbidity: roughly a third of our patients had neurological problems prolonging their stay, and others required post-extubation non-invasive support or had poorly controlled diabetes or hypertension, all of which dilute any weaning-related difference.

CONCLUSION

The diaphragm thickening fraction index was a considerably better predictor of weaning outcome than the rapid shallow breathing index and performed as well as the two indices combined. DTFI was significantly lower in patients who failed to wean, and diaphragm ultrasound proved feasible and reproducible even in a resource-limited setting. Point-of-care diaphragm assessment has a learning curve but is readily achievable, and incorporating DTFI into the evaluation of weaning readiness is a simple, low-cost way to support safer liberation of critically ill patients from mechanical ventilation.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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