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Original Research Article

A Comparative Study Assessing Diagnostic Accuracy of Diaphragmatic Rapid Shallow Breathing Index (D-RSBI) as a Predictor of Weaning Outcomes in Comparison to Rapid Shallow Breathing Index

Santosh Kumar[1], Avinash Kumar[2]

[1]Fellow & SR Trauma Anaesthesia, Institute of Medical Sciences, Banaras Hindu University in Varanasi, Uttar Pradesh, India

[2]Senior Resident, Department of Anaesthesia, Darbhanga Medical College and Hospital, Darbhanga, Bihar, India

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Corresponding author: Dr. Avinash Kumar

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Abstract

Aim: The aim of the present study was to evaluate to study the diagnostic accuracy of diaphragmatic rapid shallow breathing index (D-RSBI) as a predictor of weaning outcomes in comparison to rapid shallow breathing index.

Methods: The current study was a prospective observational study carried out for a period of 12 months, on consecutively admitted critically ill patients in the ICU at Institute of Medical Sciences, Banaras Hindu University in Varanasi, Uttar Pradesh, India . 60 patients were included in the study.

Results: There were 60% male in the study with at least one medical comorbid illness present majority being diabetes mellitus (40%). The primary indication for ventilation in 36 patients (60%) was a hypercapnic respiratory failure arising in an acute exacerbation of chronic obstructive pulmonary disease, followed by acute respiratory distress syndrome (ARDS) in 12 patients; four hypoxemic respiratory failures due to multilobar pneumonia; three pulmonary edema due to cardiac origin; two massive hemoptysis; two depressed sensorium, and one pulmonary edema due to fluid overload secondary to renal insufficiency. The baseline clinical characteristics of age, APACHE II, and SAPS II score on the day of ICU admission, the total number of days of ICU stay, and the total duration of mechanical ventilation before the first SBT were not significantly different in the two outcomes groups. The MIP, RSBI, DD, DTF, and D-RSBI were compared in the outcome groups, and the difference between the groups was statistically significant. At a cut-off of 1.740 breath/minute/millimetre, D-RSBI had a sensitivity, specificity, PPV, and NPV of 100%, 90.2%, 100%, and 68.20%, respectively

Conclusion: Diaphragmatic rapid shallow breathing index is a novel, ultrasonography-based, noninvasive, and simple bedside predictive tool for weaning guiding intensivists during weaning from mechanical ventilation.

Keywords: Critical Care, Diaphragm, Ultrasonography, Ventilator Weaning.

Introduction

Minimizing the duration of mechanical ventilation (MV) is of a paramount importance for all critical care physicians. Therefore, deciding the appropriate time of weaning from MV is crucial as delayed weaning and extubation is associated with longer intensive care unit (ICU) stay, inappropriate utilization of health care resources, and greater morbidity and mortality. [1-3] Although rates of weaning and extubation failure differ considerably among ICUs, Approximately 15% of patients in whom mechanical ventilation is discontinued require reintubation within 48 h.

Consequently, it is fundamental for critical care physicians to differentiate between readiness for discontinuation of ventilation and successful spontaneous breathing trials. [4] The rapid shallow breathing index (RSBI), calculated from respiratory rate divided by tidal volume (RR/VT), is a well-known weaning index and one of the most clinical indices used to predict weaning outcome. However, it has some limitations in predicting weaning outcomes. [5] Several previous studies have defined different sensitivities and specificities for RSBI less than 105 to predict weaning success which may lead to errors in predicting successful weaning. [6-8]

Currently, many indices and parameters have been developed to assess a patient’s ability to breathe spontaneously. Rapid shallow breathing index (RSBI), which is calculated by dividing respiratory rate (RR) by tidal volume (VT), is the most commonly measured index [9] to predict weaning outcome. During a weaning attempt, RSBI measures the balance between the mechanical load on the inspiratory muscles and the inspiratory muscles' ability to respond to this load. [10] Nonetheless, its low specificity and positive predictive value (PPV) can still lead to errors in weaning assessment. [11] The diaphragm is the principal respiratory muscle and plays a crucial role in generating VT in healthy subjects. [12] From previous studies, diaphragmatic dysfunction (DD) is a common occurrence and has likely been underestimated in critically ill patients. [13-16] On the other hand, weaning failure is likely to occur if there is an imbalance between the load on the inspiratory muscles and their neuromuscular capacity, the imbalance between the mechanical load imposed on the diaphragm which is the major muscle of inspiration and its ability to cope with it. Therefore, evaluating the function of diaphragm before any weaning trial could be useful in predicting weaning outcome. [17] Bedside ultrasonography is an easy, fast, noninvasive, and accurate maneuver for evaluating diaphragmatic function. Diaphragmatic displacement (DD) reflecting the ability of diaphragm to produce force and subsequently tidal volume during inspiration and defined as displacement of less than 10mm has been found to be a predictor of weaning failure among patients in medical ICUs. [18]

The aim of the present study was to evaluate to study the diagnostic accuracy of diaphragmatic rapid shallow breathing index (D-RSBI) as a predictor of weaning outcomes in comparison to rapid shallow breathing index.

Materials and Methods

The current study was a prospective observational study carried out for a period of 12 months, on consecutively admitted critically ill patients in the ICU at Institute of Medical Sciences, Banaras Hindu University in Varanasi, Uttar Pradesh, India. 60 patients were included in the study.

Patients who were intubated and mechanically ventilated for more than 48 hours and who were ready for the first SBT as per the weaning criteria used in the intensive care unit were enrolled for the study. The weaning criteria included: (a) Resolution of acute phase of the disease; (b) Adequate mentation; (c) Systolic blood pressure of 90–160 mm Hg (no or minimal vasopressor); (d) Absence of excessive trachea-bronchial secretion; (e) Stable metabolic status;

(f) pH >7.30; (g) PaO_2 >60 mm Hg on PEEP <8 cm and FiO_2 <0.5;

(h) Stable oxygenation: PEEP/FiO_2 not increased from last day;

(i) Consistent patient triggered breath; (j) Withheld feeding for 2–4 hours; and (k, h) Richmond Agitation and Sedation Scale score measuring between –1 and +1.

The exclusion criteria included: (a) Use of any paralyzing agents in 24 hours before the study; (b) Diagnosis of diaphragm paralysis or paradoxical movement of hemidiaphragm detected on ultrasound; (c) Pregnant patients; (d) Ascites; (e) Age <18 years; (f) Post-thoracotomy; (g) Presence of pneumothorax; (h) Large pleural effusion, subcutaneous emphysema, flail chest, or rib fractures on the right side; and (i) Neuromuscular diseases.1

The clinical data regarding age of patients, acute physiologic and chronic health evaluation II (APACHE II) score, and simplified acute physiologic score (SAPS 2) score on the day of admission to the intensive care unit, total stay in ICU, and duration of mechanical ventilation were recorded. The decision to carry out the SBT, extubate the patient, or consider reinstitution of mechanical ventilation at the end or during the SBT was carried out by the treating physician.

The primary endpoint was the weaning outcome. Successful weaning is defined as when patients could be extubated and were clinically stable for more than 48 hours without any assisted ventilation. Weaning failure is determined if the patient's required restoration of mechanical ventilation under the following circumstances: (a) At the end or during the SBT; (b) Reintubation, or (c) NIV use within 48 hours of extubating.

Study Design

Spontaneous breathing trial was started with the patient in the 30–45° semi-recumbent position using pressure support after ventilation (PSV) mode, set an inspiratory pressure of 5 cm H_2O and PEEP of 5 cm H_2O. Ultrasonographic scanning of the right hemidiaphragm was carried out in the same posture after a time period of 30 minutes from the beginning of the SBT. Ultrasound scanning was performed earlier than 30 minutes if the patient showed any signs of SBT failure. Signs of SBT failure included the following: (a) Respiratory rate >35/minute; (b) Signs of intolerance – sweating or agitation; (c) Frequent periods of apnea for >15 seconds;

(d) SpO_2 <90% for >5 minutes; (e) Increase in $PaCO_2$ >10 mm Hg from baseline; (f) pH <7.30; (g) Acute deterioration of mental status; and (h) Features of raised intracranial tension.

Diaphragmatic ultrasonography was performed by a single operator who was adequately trained in the procedure of intensive care ultrasonography. The curvilinear ultrasound probe of 3.5 MHz frequency was used for visualizing the diaphragm and then measuring the diaphragmatic displacement using both B and M modes. Additionally, the high-resolution linear probe of 10 MHz frequency was used for measuring the diaphragmatic thickness during both inspiration and expiration for calculating the diaphragmatic thickness fraction (DTF). The diaphragm could be seen thickening during inspiration due to muscle contraction.

The transducer was placed on the right side of the chest at the anterior subcostal location between the midclavicular line and anterior axillary line. The ultrasound beam would reach the posterior part of the diaphragm at an angle of not less than 70°. The displacement of the diaphragm was visualized when the diaphragm contracts and approaches anteriorly and inferiorly toward the ultrasound probe. This excursion or displacement of the right hemi-diaphragm was measured using the M mode scanning as an upward motion. Five such measurements were recorded and averaged, and DD was recorded in millimeters. All measurements were recorded at 6–12 mL/kg during tidal breathing, excluding smaller or deeper breaths.

The following parameters were calculated during the SBT:

(a) Rapid shallow breathing index – RSBI; (b) Diaphragmatic displacement – DD; (c) Diaphragmatic thickness during inspiration and expiration; (d) Diaphragmatic thickness fraction – DTF;

(e) Diaphragmatic rapid shallow breathing index – D-RSBI; and

(f) Maximum inspiratory pressure – MIP.

The DTF was calculated as: [(Thickness of the diaphragm at end inspiration – Thickness at end-expiration) / Thickness of diaphragm at end expiration] × 100. The ventilatory parameters like TV, minute ventilation, RR, and maximum inspiratory pressure (MIP) were noted from the ventilator display and were recorded. RSBI was calculated as RR/TV (in liters). Diaphragmatic RSBI was calculated as RR/diaphragmatic displacement (in millimeters) and expressed as breath/minute/millimeter.

Patients who developed signs of SBT failure were immediately reconnected to the ventilator. Those who tolerated the SBT got extubated and liberated from a mechanical ventilator. These patients were then monitored closely for the next 48 hours in the ICU for any features of extubation failure.

Statistical Analysis

The statistical analysis was done using GraphPad Prism 8 (GraphPad Software, CA, USA). The Kolmogorov–Smirnov test was used to identify variables with a normal distribution. Data were reported as the mean ± standard deviation (SD) or median along with interquartile range (IQR) for continuous variables. Percentages in the form of frequencies (%) were used for categorical variables. Unpaired Student's t-tests or Mann–Whitney U tests were used as appropriate to compare the various continuous variables in the successful and unsuccessful weaning groups. Chi-square test or the Fisher exact test were used to asses differences in categorized variables. The correlation analysis was calculated using Pearson correlations (Pearson's R2 and p values).

The diagnostic accuracy of D-RSBI and RSBI was evaluated using ROC curves. The positive and negative predictive value (PPV and NPV, respectively), sensitivity, specificity, optimal cut-off point, and the accuracy were calculated for each ROC curve. For all statistical analyses, two-tailed tests were utilized, and p-values equal to or less than 0.05 were taken as statistically significant.

Results

Table 1: Patient details

Gender	**N%**
Male	36 (60)
Female	24 (40)
Co-morbidities	
Diabetes	24 (40)
Hypertension	18 (30)
Indications of ventilation	
Hypercapnic respiratory failure	36 (60)
ARDS	12 (20)
Hypoxemic respiratory failures	4 (6.66)
Pulmonary edema due to cardiac origin	3 (5)
Massive hemoptysis	2 (3.33)
Depressed sensorium	2 (3.33)
Pulmonary edema due to fluid overload	1 (1.66)

There were 60% male in the study with at least one medical comorbid illness present majority being diabetes mellitus (40%). The primary indication for ventilation in 36 patients (60%) was a hypercapnic respiratory failure arising in an acute exacerbation of chronic obstructive pulmonary disease, followed by acute respiratory distress syndrome (ARDS) in 12 patients; four hypoxemic respiratory failures due to multilobar pneumonia; three pulmonary edema due to cardiac origin; two massive hemoptysis; two depressed sensorium, and one pulmonary edema due to fluid overload secondary to renal insufficiency.

Table 2: Baseline characteristics of the patients in the outcome groups

Variable	Success group	Failure group	p-value
Age (years)	49.4 ± 16.4	52.8 ± 13.7	0.767
APACHE II	16.2 ± 4.8	17.3 ± 2.36	0.314
SAPS	34.6 ± 10	28.2 ± 5.35	0.150
Total number of days in ICU	5.02 ± 2.4	6.34 ± 8.4	0.822
Total days of mechanical ventilation	5.25 ± 3.16	6.44 ± 8.22	0.518

The baseline clinical characteristics of age, APACHE II, and SAPS II score on the day of ICU admission, the total number of days of ICU stay, and the total duration of mechanical ventilation before the first SBT were not significantly different in the two outcomes groups.

Table 3: Comparison of various weaning parameters measured in the outcome groups

Variable	Success group	Failure group	p-value
MIP (cm H2O)	34.8 ± 4.8	23.7 ± 6.4	<0.001
RSBI	53.15 ± 16.8	70.04 ± 24.3	0.05
DD (mm)	15.1 ± 3.5	7.3 ± 1.04	<0.001
D-RSBI	1.25 ± 0.36	2.78 ± 0.96	<0.001
DTF	42.8 ± 4.6	27.43 ± 4.36	<0.001

The MIP, RSBI, DD, DTF, and D-RSBI were compared in the outcome groups, and the difference between the groups was statistically significant.

Table 4: Comparison of diagnostic accuracy of RSBI and D-RSBI

	RSBI	D-RSBI
Threshold	43.67	1.740
Sensitivity (95% confidence interval)	40.5 (0.2–0.5)	90.2 (0.7–0.9)
Specificity (95% confidence interval)	100 (0.7–1)	100 (0.7–1)
PPV	100	100
NPV	26.4	68.2
AUR (95% confidence interval)	0.7 (0.5–0.8)	0.97 (0.94–1)
p-value	0.05	<0.001

At a cut-off of 1.740 breath/minute/millimeter, D-RSBI had a sensitivity, specificity, PPV, and NPV of 100%, 90.2%, 100%, and 68.20%, respectively.

Discussion

The current weaning guidelines endorse applying SBT as a tool to predict outcomes. Lately, indices and weaning predictors have been introduced; however, none has shown high prognostic accuracy. [19] Weaning failure is determined as either a failure of SBT or clinical worsening needing a re-intubation within 48 hours following extubation.2 Respiratory and cardiac failure are common reasons for weaning failure, while psychological, nutritional-related, or ventilator-related issues can also be contributory. Studies have shown that weaning failure has a prevalence of 20%, but it may vary with the type of patient population being taken care of (e.g., postsurgical versus nonsurgical). [20] Diaphragmatic dysfunction has been increasingly documented to play a major role in ventilator dependency and failure of weaning. The diaphragmatic strength evaluation is based on calculating the maximal trans-diaphragm pressure generated by the diaphragm when phrenic nerve stimulation is carried out. The technique is invasive, primarily research-based, and difficult to emulate in daily ICU settings. [21]

There were 60% male in the study with at least one medical comorbid illness present majority being diabetes mellitus (40%). The primary indication for ventilation in 36 patients (60%) was a hypercapnic respiratory failure arising in an acute exacerbation of chronic obstructive pulmonary disease, followed by acute respiratory distress syndrome (ARDS) in 12 patients; four hypoxemic respiratory failures due to multilobar pneumonia; three pulmonary edema due to cardiac origin; two massive hemoptysis; two depressed sensorium, and one pulmonary edema due to fluid overload secondary to renal insufficiency. Maximal inspiratory pressure refers to the maximum pressure the patient can generate against an obstructed airway and it is a marker of inspiratory muscle strength; directly assesses the ability of the respiratory pump to generate and maintain adequate TV to sustain alveolar ventilation. Hence, MIP is one of the main factors of weaning success. Bien et al [22] reported the diagnostic accuracy of MIP in comparison to RSBI, sensitivity of 0.93, specificity of 0.95, positive predictive value of 0.98, negative predictive value of 0.79, and the diagnostic accuracy of 20.85. The current study did not perform comparison between MIP and any other weaning index. Diaphragmatic displacement is the measure of diaphragmatic movement or excursion during inspiration measured by ultrasound. Traditionally diaphragmatic excursion is measured on T-piece, however, a recent RCT has demonstrated that it can be accurately measured with low levels of pressure support as was done in the current study. [23] Various cut-off values are described in the literature for the normal DD. Theerawit et al. observed that the cut-off value of 12.85 mm for diaphragmatic inspiratory excursion provided a specificity of 55% and a sensitivity of 83% for predicting re-intubation within 48 hours (120). The NPV and PPV of a diaphragmatic inspiratory excursion <12.85 mm were 97 and 17%, respectively. Llamas-Álvarez et al [24] in a systematic review of 19 studies and 1071 patients, reported diaphragmatic excursion, pooled sensitivity, and specificity of 75%. In the present study, all the patients who had weaning failure had a DD of less than 10 mm.

The baseline clinical characteristics of age, APACHE II, and SAPS II score on the day of ICU admission, the total number of days of ICU stay, and the total duration of mechanical ventilation before the first SBT were not significantly different in the two outcomes groups. The MIP, RSBI, DD, DTF, and D-RSBI were compared in the outcome groups, and the difference between the groups was statistically significant. At a cut-off of 1.740 breath/minute/millimetre, D-RSBI had a sensitivity, specificity, PPV, and NPV of 100%, 90.2%, 100%, and 68.20%, respectively. Pirompanich and Romsaiyut[8] observed that at a cut-off value of DTF of more than or equal to 26%, had the highest sensitivity of 96.0%, specificity of 67.7%, PPV of 88.9%, NPV of 85.7%, and an accuracy of 88.2%. The combination of RSBI and right diaphragm thickening fraction significantly increased the accuracy for weaning success than RSBI alone. Pirompanich and Romsaiyut[8] reported for diaphragm thickening fraction, the AUC was 0.87, and diagnostic odds ratio (DOR) was 21 (95% CI, 11–40). The present study also documented significant differences in DTF values among the success and failure groups. Vivier et al [25] in an observational prospective multicentric study studied 191 at-risk of reintubation patients for over a 20-month period. Among these 191 patients, 33 (17%) were labelled as extubation failures. The proportion of patients who had diaphragmatic dysfunction using diaphragm excursion was similar between successful extubation (46%) and those in whom extubation failed (51%) (p = 0.55). For DTF also, there was no significant difference (71% vs 68%; p = 0.73). Spadaro et al. [26]

Conclusion

Diaphragmatic rapid shallow breathing index is a novel, ultrasonography-based, noninvasive, and simple bedside predictive tool for weaning guiding intensivists during weaning from mechanical ventilation.

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