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Original Article

Evaluating Diaphragmatic Rapid Shallow Breathing Index for Predicting Weaning Outcome of Ready to Wean Mechanically Ventilated Patients: A Prospective Cohort Study in A Tertiary Care Intensive Care Unit of Bangladesh

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Abstract:

Background: *Weaning failure is a common problem in mechanically ventilated ICU patient. There are many weaning predictors to reduce weaning failure, among them Rapid shallow breathing index (RSBI) is widely used. But several studies showed various specificity and sensitivity of RSBI. Diaphragmatic dysfunction is found to be a vital cause of weaning failure. Taking Diaphragmatic dysfunction in consideration, the diaphragmatic rapid shallow breathing index(D-RSBI) is a new and promising tool to predict weaning outcome. Its accuracy in predicting weaning outcome of our mixed ICU population need to be evaluated.*

Procedure: *This prospective cohort study was carried out at the Department of Anesthesia, Analgesia and Intensive Care Medicine, Bangladesh Medical University, Dhaka, Bangladesh for a period of 12 months. A total of 32 patients requiring mechanical ventilation for more than 48 h who were ready to perform a spontaneous breathing trail (SBT) were included in this study. At 30min of SBT, Respiratory rate, tidal volume and diaphragm displacement (DD) are measured with diaphragm ultrasonography. Then the weaning outcome was recorded. Receiver operating characteristic (ROC) curves were used to evaluate the diagnostic accuracy of D-RSBI and RSBI.*

Result: *Among the total 32 enrolled subject, 14 (44%) were successfully liberated from mechanical ventilation. The 18 (56%) patients who failed weaning, 9 (50%) failed the SBT and reconnected to the ventilator, 5 (28%) were reintubated within 48 h of extubation and 4 (22%) required NIV support within 48 h of extubation. Receiver operating characteristic (ROC) analysis showed that DRSBI with the best diagnostic accuracy for predicting weaning failure (AUROC = 0.929; p value 0.00) with a cutoff of DRSBI >1.7 breaths/min/mm at 30 min of SBT, On other hand RSBI showed best sensitivity and specificity with a cut off value >63 breaths/min/liter (AUROC = 0.796; p value 0.005).*

Conclusion: *Diaphragmatic rapid shallow breathing index is a good and superior weaning predictor to RSBI.*

Key wards: *Diaphragmatic rapid shallow breathing index, Diaphragm ultrasonography, Intensive care unit, Rapid shallow breathing index, Weaning predictor.*

Introduction

Mechanical ventilation is often lifesaving in case of respiratory failure. But it only becomes lifesaving when we successfully withdraw the ventilator support. The process of abruptly or gradually withdrawing ventilatory support can be defined as weaning. Weaning from mechanical ventilation usually implies two separate but closely related aspects of care, discontinuation of mechanical ventilation and removal of any artificial airway. Artificial airway can be removed if the patient has an adequate sensorium with intact airway protection mechanism and without excessive secretions[1]. But the problem for the clinician is to determine when a patient is ready to resume ventilation on his or her own. Determining the optimal timing of weaning from mechanical ventilation is highly expected to intensivist because both early and delayed weaning is associated with a lot of complication[2]. But weaning outcome may be affected by several factors such as hemodynamic stability, muscle weakness, electrolyte imbalances, pulmonary function, and the ability of the patient to generate a good cough and expectorate endotracheal secretions[3].

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An ideal predictive index should reflect all pathophysiological pathways that may lead to weaning failure, including excessive mechanical workload imposed on the respiratory muscles, impaired diaphragmatic function, weaning-induced cardiac failure, and a reduced ability to keep the airways opened and to clear secretions. Most of these pathways lead to rapid shallow breathing, which explains the rationale of taking into account the ratio between respiratory rate (RR) and tidal volume (VT) in the study by Yang and Tobin[4].

Imbalance between mechanical load imposed on inspiratory muscles and their ability to bear it, is the main reason of weaning failure. Tidal volume exerted by all inspiratory muscle takes into account in rapid shallow breathing index (RSBI). In case of diaphragmatic dysfunction other inspiratory muscles become active and hide the fact by generating adequate tidal volume until they become fatigued, so delayed weaning failure occur[5].

So the drawback of RSBI is they did not take into account diaphragmatic dysfunction and delayed weaning failure. Several previous studies have reported different sensitivities and specificities for RSBI of <105 to predict weaning success[6].

Many studies have shown that diaphragmatic dysfunction could lead to weaning failure. Thus, an early diagnosis of diaphragmatic dysfunction is compulsory to avoid weaning failure. Diaphragmatic ultrasound is a safe bed-side tool for assessing diaphragmatic excursion and thickening fraction that could reflect diaphragmatic function and predict weaning outcome[7].

Bedside ultrasonography is a noninvasive, easy, safe and accurate maneuver for evaluating diaphragm function. Diaphragm displacement (DD) and diaphragmatic thickening fraction (DTF) could reflect diaphragmatic function and predict weaning outcome[7]. Diaphragm displacement is more accurate then DTF in predicting extubation success[8]. The predictive accuracy of DD is greatly enhanced if DD is combined with respiratory rate as in Diaphragmatic rapid shallow breathing index (D-RSBI). Along with diaphragm function D-RSBI reflects rapid shallow breathing as a sign of imbalance between respiratory load and ability to cope up[9].

Spadaro et al (2016) proposed this new index called Diaphragmatic rapid shallow breathing index (D-RSBI) combining RSBI and DD. He calculated D-RSBI by substituting the tidal volume from RSBI with DD which solely reflect the diaphragmatic contribution in tidal volume. Spadaro et al (2016) showed that DRSBI is more accurate then RSBI in predicting weaning failure, when the threshold value of D-RSBI >1.3 breath/min/mm.

Later Mowafy and Abdelgalel (2018) conduct another study, this time they measure the diaphragm displacement at 30min of starting spontaneous breathing trail along with at 1st minute. They also include traumatic brain injury patient whose Glasgow Coma Scale (GCS) level more than 10. They compare DRSBI at 1st minute with DRSBI at 30 minute for predicting weaning outcome and showed that DRSBI at 30 min with the best diagnostic accuracy for predicting weaning success with a cutoff of DRSBI < 1.6 breaths/min/mm. Yielded 97.3% sensitivity, 93.9% specificity, 97.1% positive predictive value (PPV), 93.9% negative predictive value (NPV) and 96.2% accuracy[10].

DRSBI is new and superior tool in predicting weaning outcome in Chronic obstructive pulmonary disease (COPD) patient with acute exacerbation. In case of COPD patient the cutoff value >1.9 breath/min/mm for weaning failure [11].

The aim of present study is to evaluate the accuracy of the new index D-RSBI and compared its accuracy to traditional RSBI for predicting successful weaning in ready to wean patient in our tertiary care mixed ICU patient population.

Most of above studies regarding DRSBI represent population of first world countries and some studies are population specific. But in resource limited settings like Bangladesh, ICU patient population becomes heterogeneous. Most of the patient of Bangladesh Medical University (BMU) ICU are transferred cases from the ICUs of another hospital and are already receiving mechanical ventilatory support for a variable duration. So it needs to evaluate the accuracy of DRSBI as a weaning predictor in the unique characteristics of these ICU population of BMU.

Patients admitted in BMU ICU often have a poor socioeconomic background and resources are limited. In that case diaphragmatic ultrasound can provide a quick idea about weaning readiness and reduce the need for further investigations such as chest CT scans or repeated chest radiographs and can be used in conjunction with other predictors of weaning.

Methodology

This prospective cohort study was carried out at the Department of Anesthesia, Analgesia and Intensive Care Medicine, Bangladesh Medical University, Dhaka, Bangladesh from July, 2019 to June, 2020 for a period of one year. Patients were enrolled after the date of institutional review board (IRB) clearance. Prior to the commencement of this study, the thesis protocol was approved by the IRB, BMU. Informed written consent was obtained from the patient's authorized guardians after explaining every ethical issue regarding the study.

Patients underwent mechanical ventilation for more than 48 hours with the age of more than 18 years and who fulfill weaning criteria were included in this study. Patients with chest injury such as chest trauma, pulmonary contusions, rib fractures, chest wounds, patients having thoracotomy, pneumothorax or pneumomediastinum, patients with neuromuscular disease, paralyzed hemi diaphragm were excluded from this study. Standard weaning criteria was considered as a) Clinical improvement of the underlying acute cause of respiratory failure; b) Adequate cough reflex; c) Absence of excessive or purulent tracheobronchial secretion; d) Stable cardiovascular status (ie, heart rate <120 beats/min; systolic blood pressure, 90–160 mmHg; and no vasopressor use); e) Stable metabolic status (ie, electrolytes and blood sugar within normal range, temperature 37-38°C, hemoglobin ≥10 g/dL); f) Adequate oxygenation (ie, arterial oxygen saturation (SaO_2) >92% with inspiratory oxygen fraction (FiO_2) ≤0.5 with positive end expiratory pressure (PEEP) ≤8 cmH_2O) and g) Adequate pulmonary function (ie, RR ≤30 breaths/min with VT ≥5 mL/kg ideal body weight (IBW) and no significant respiratory acidosis[12].

All patient who was included in this study was subjected to the following investigations:

1. Plain x-ray chest
2. Routine laboratory investigations
   a. Complete Blood count
   b. SGPT and serum bilirubin
   c. Serum creatinine
   d. Serum Electrolytes
3. Arterial blood gas analysis

Time of starting and continuing spontaneous breathing trial in ready to wean patient depends on the decision of controlling physician and local protocol. Patient underwent Spontaneous breathing trial (SBT) with Pressure support ventilation at the following setup: FiO_2 0.40, PEEP 5, Pressure support 8 for all size of endotracheal tube. At 30 min of SBT or before than if patient develop criteria of SBT failure, Respiratory rate, tidal volume was noted from ventilator monitor and Diaphragm displacement (DD) is measured with diaphragm ultrasonography. After taking the reading patient was put on T-tube circuit for further SBT who pass SBT for 30min. D-RSBI (RR/ DD in mm) and RSBI (RR/ VT in liter) is calculated. Patient was reinstituted to ventilator support who develop sign of SBT failure. Sign of SBT failure include, **Clinical assessment and subjective indices**: agitation and anxiety, depressed mental status, diaphoresis, cyanosis, evidence of increasing effort, increased accessory muscle activity, facial signs of distress, dyspnea and **Objective measurements:** $PaCO_2$ ≥50 mmHg or an increase in $PaCO_2$ >8 mmHg**,** pH <7.32 or a decrease in pH ≥0.07 pH units**,** f/VT >105 breaths/min/L**,** f >35 breaths/min or increased by > 50%**,** HR >140 beats/min or increased by > 20%**,** Systolic BP >180 mmHg or increased by > 20%**,** Systolic BP <90 mmHg**,** Cardiac arrhythmias**,** PaO_2 ≤60 mmHg on FIO_2 ≥0.5 or SaO_2 <90%. Patient who successfully completed total 2 hours of SBT, were extubated. After extubation patients were observed for 48 hours. Weaning success was defined as extubation and the absence of ventilatory support 48 h following the extubation. Weaning failure is defined as one of the following: 1) failed SBT; 2) Reintubation and/or resumption of ventilator support within 48 hr of extubation ; or 3) death within 48 h following extubation[12].

Diaphragmatic Displacement (DD) measurement: Ultrasonography for DD performed in the semi-sitting position with The head of the bed elevated at an angle 30°-45° with a sonoscape ultrasound machine (sonoscape, P/N: 2100.00138, SN: 00124.16389(c09.1), sonoscape Co.Ltd,4/F, YizHe building,Yuquan Road,Nanshan,Shenzhen 518051, P.R.China).Ultrasound probe will be placed immediately below the right or left coastal margin in the mid-clavicular line in longitudinal scanning plan with the angle in cephalad direction to make the ultrasound beam perpendicular to the posterior third of the corresponding hemi diaphragm. Then the 2 dimensional mode can be initially used to select the best approach and then the M mode is used to display the diaphragm along the selected line. Then the diaphragmatic displacement (excursion) was measured on right side during quiet breathing, and the highest 3 values was recorded. The average of three values was used for D-RSBI calculation.

DD is the difference between the maximum downward displacement during inspiration and the maximum upward displacement during expiration. Diaphragmatic excursion values was taken as normal if they are at least 1 cm for males and 0.9 cm for females during quiet breathing. These values were previously obtained after a study was done on diaphragmatic motion by M mode USG[13].

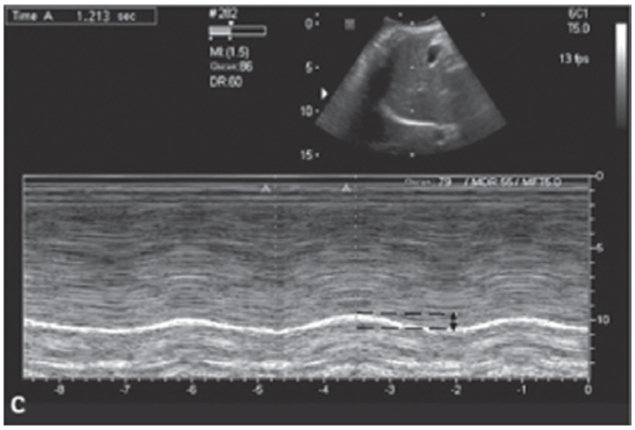

Fig. 1 The above image shows the distance of the diaphragmatic excursion

Data Analysis

Following collection of the data, all data was edited and encoded into a statistical software named 'Statistical Package for Social Science' (SPSS) version 22.0 ('IBM **SPSS** Statistics for Windows, version 22 (IBM Corp., Armonk, N.Y., USA)'). Data was entered into the software (termed as variable) according to the prior analysis plan. In this study, normally distributed continuous data was displayed as mean ± standard deviation, non-normally distributed data was displayed as median (interquartile range) and the categorical variables was expressed as number (percentage). Continuous variables were checked for normality by using the Shapiro–Wilk test. Independent samples student's t-tests was used to compare between two groups of normally distributed variables. Man Whitney U test is used to compare median. Percent of categorical variable was compared using Pearson's chi-square test or fisher's exact test as appropriate. The accuracy of DRSBI and RSBI for predicting weaning outcome was studied using receiver operator characteristic (ROC) curves. For each ROC curve, the accuracy, sensitivity, specificity, positive and negative predictive values were calculated as well as the optimal cut-off point of DRSBI and RSBI with maximal sensitivity and specificity for predicting weaning success. In whole study, significance level was set p<.05 in all cases.

Result

After exclusion, 32 patients were included and analyzed. Among them, 14 (44%) were successfully liberated from mechanical ventilation. The 18 (56%) patients who failed weaning, 9 (50%) failed the SBT and reconnected to the ventilator, 5 (28%) were reintubated within 48 h of extubation and 4 (22%) required non-invasive ventilation (NIV) support within 48 h of extubation.

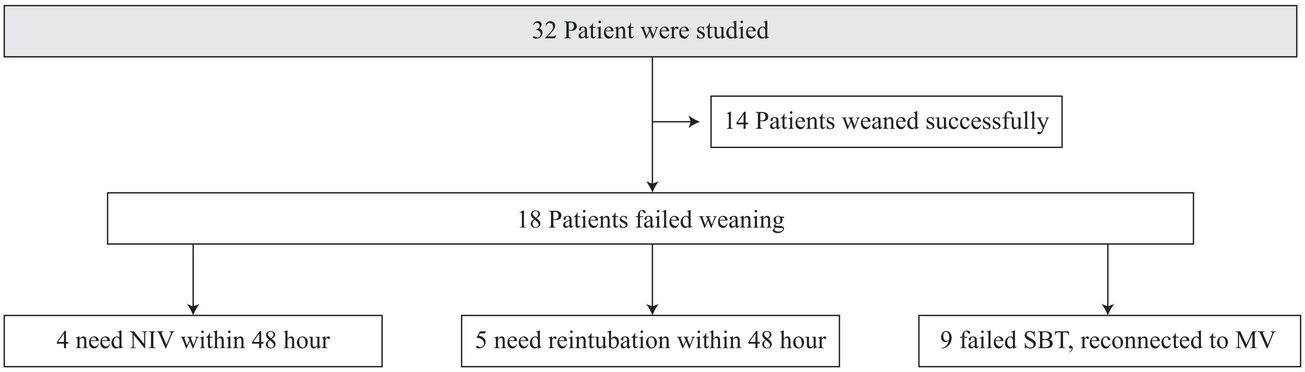

Fig. 2 Flow chart of the study population.

Abbreviations: MV: mechanical ventilation; NIV: non-invasive ventilation; SBT: spontaneous breathing trial.

The demographic and clinical characteristics of the studied patients are presented in Table I. The mean age in weaning failure group is significantly higher (p=0.017). Smoker patients showed higher weaning failure (p value 0.000). Common ICU population in this setting are Traumatic head injury, Stroke, Sepsis and Respiratory failure, 16%, 16%, 13%, and 13% respectively. Stroke, sepsis, heart failure and the patients admitted for metabolic causes showed significantly higher weaning failure. On the other hand post-surgical, traumatic head injury patients showed significantly higher weaning success (p value 0.024). No other demographic and clinical characteristics of the studied patients shows statistically significant differences between weaning success and weaning failure group.

Table I: Demographic and clinical characteristics of all studied patients

Characteristic	**All (N = 32)**	**Weaning success (n = 14)**	**Weaning failure (n = 18)**	**P value***
Age	48.38±**13.44**	41.07±**11.53**	54.06±**12.23**	0.00*
Sex				
Male	18 (56)	7(38.9)	11 (61.1)	0.53#
Female	14 (44)	7 (50)	7 (50)	
Smokers	14(43.8)	1(7.1)	13(92.9)	0.000*
Comorbidities				
Diabetes	7(21.9)	4(80)	3(20)	0.864##
Hypertension	7(21.9)	3	4(100)	
Ischaemic heart disease	1(3.1)	0	1(100)	
Chronic pulmonary disease	2(6.3)	0	2(100)	
Obesity	4(12.5)	2(50)	2(50)	
Primary Diagnosis				
Stroke	5(16)	1(20)	4(80)	0.024##
Traumatic brain injury	5(16)	4(80)	1(20)	
Meningoencephalities	2(6)	1(50)	1(50)	
Respiratory failure due to respiratory cause	4(13)	2(50)	2(50)	
Heart failure	2(6)	0	2(100)	
Sepsis	4(13)	0	4(100)	
Post surgical	3(9)..	3(100)	0	
Gynecological	2(6)	2(100)	0	
Metabolic	4(12)	1(25)	3(75)	

Notes: *Independent samples Student's *t*-test; #Chi-square test; ## Fisher exact test. *P*<0.05 is significant. Continuous variables are expressed as mean ± standard deviation; categorical variables are expressed as number (percentage).

Table II shows RR, DD, RSBI and D-RSBI differed significantly between patients who were successfully weaned and those who failed the weaning trial (P value 0.000, 0.000, 0.005 and 0.000 respectively). ICU length of stay is significantly higher in weaning failure group (p value 0.008).

Table II: Clinical, and first SBT ventilatory parameters of the overall population and of successfully and unsuccessfully weaned patients (N = 32)

Characteristic	All	Weaning success (n = 14)	Weaning failure (n = 18)	P value*
Respiratory rate (/min)	24.5±3	22.5±2.7	26.06 ± 2.4	0.000*
PaO_2/F_IO_2 ratio	236.3±12.97	238.2 ± 14.7	234.9 ± 11.7	0.480*
$PaCO_2$	38.87±2.66	38.7 ± 2.0	39.1 ± 3.1	0.578*
pH	7.39±.03	7.40 ± 0.04	7.40 ± 0.03	0.597*
DD (mm)	13.91±3.43	16.36±2.5	12.00±2.7	0.000*
D-RSBI (breaths/min/mm)	1.89±0.61	1.41±0.32	2.26±0.51	0.000*
RSBI (breaths/min/L)	67.53±16.47	57.9±14.5	75.00±14.08	0.005*
Length of MV until SBT (h)	120(48-280)	66(48-280)	120(48-216)	0.092#
ICU length of stay (days)	10(3-20)	7.5(3-15)	12(5-20)	0.008#

Notes: *Independent samples Student's *t*-test; #Mann-Whitney U test; $P<0.05$ is significant. Normally distributed data are shown as mean ± standard deviation; not normally distributed data as median (interquartile range);Continuous variables are expressed as mean ± standard deviation.

Abbreviations Diaphragmatic displacement (DD), Diaphragmatic rapid shallow breathing index(D-RSBI), Rapid shallow breathing index (RR/tidal volume)-(RSBI),Intensive care unit (ICU)

Table III and Figure 3 reported the overall results of the Receiver operating characteristic (ROC) analysis of RSBI and DRSBI for predicting weaning outcome. Which showed that DRSBI with the best diagnostic accuracy for predicting weaning failure (AUROC = 0.929; p value 0.00). With a cutoff of DRSBI >1.7 breaths/min/mm at 30 min of SBT, yielded 92.86% sensitivity, a specificity of 88.89%, 86.67% positive predictive value (PPV), 94.12% negative predictive value (NPV) and 90.63% accuracy. On other hand RSBI showed best sensitivity and specificity with a cut off value > 63 breaths/min/liter (AUROC = 0.796; p value 0.005).

Table III: Accuracy of D-RSBI and RSBI in predicting weaning failure

Cutoff values	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV% (95% CI)	NPV% (95% CI)	Accuracy (95% CI)	AUROC (95% CI)	*p*-value
D-RSBI >1.7	92.86	88.89	86.67	94.12	90.63	0.929 (0.840–1.000)	0.000
RSBI >63	64.28	77.7	69.2	73.7	71.9	0.796 (.639-.953)	0.005

Note: $p<0.05$ is significant.

Abbreviations: Positive predictive value (PPV); Negative predictive value (NPV); Area under receiver operating characteristic curve (AUROC); Confidence interval (CI); Diaphragmatic rapid shallow breathing index (D-RSBI); Rapid shallow breathing index (RSBI)

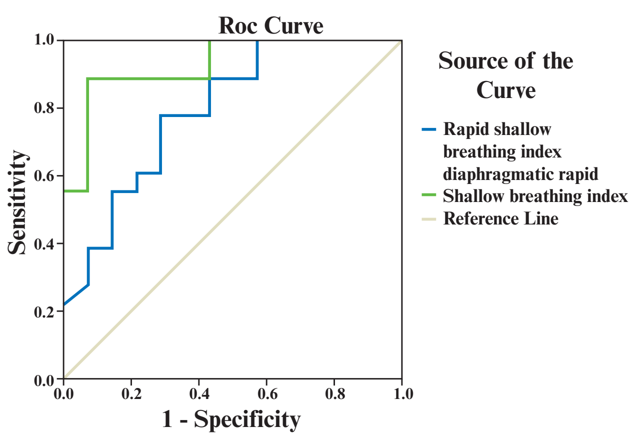

Fig. 3 Receiver operating characteristic (ROC) curve for diaphragmatic rapid shallow breathing index (D-RSBI) and traditional rapid shallow breathing index (RSBI).

Discussion

Weaning failure is a common problem in mechanically ventilated ICU patients. An ideal weaning predictor is highly desirable to intensivist for combating the problem. An ideal predictive index should reflect all pathophysiological pathways that causes weaning failure. Most of these pathophysiological pathways lead to rapid shallow breathing. That's why Rapid shallow breathing index (RSBI) which is the ratio of respiratory rate to tidal volume, is widely used. But in RSBI tidal volume exerted by all inspiratory muscle is taking into account where diaphragm is the main muscle of inspiration. In case of diaphragmatic dysfunction other inspiratory muscle exert their highest function and mask the incident. But after a certain period of time when other inspiratory muscles become fatigued tidal volume is reduced and delayed weaning failure occurs. So Diaphragmatic dysfunction is very important cause of weaning failure.

Combining the respiratory rate with diaphragm displacement as a feature of diaphragm dysfunction, Spadaro at el (2016) proposed the new index diaphragmatic rapid shallow breathing index which is the ratio of respiratory rate to diaphragmatic displacement[9]. DRSBI is new and promising tool with high sensitivity and specificity to predict weaning outcome. But all study regarding DRSBI as weaning predictor, represent population of first world country and some studies are population specific. Evaluation of DRSBI as a weaning predictor is the main moto of present study, in resource limited setting like BMU ICU, where patient population is heterogeneous.

Results of our study found that the D-RSBI was significantly higher in patients' group who failed weaning compared to those who succeeded to wean (3.27±0.84 versus 1.43±0.32, respectively). The new index DRSBI is superior to traditional RSBI in predicting weaning outcome with a cutoff of DRSBI <1.7 breaths/min/mm monitored at 30 min. with the best diagnostic accuracy for predicting weaning success. Although, the cutoff value for the DRSBI reported by Spadaro et al was lower (1.3)[9]. The cutoff value seen in the study of Mowafy and Abdelgalel was lower (1.6) and the cutoff value reported by Abbas et al was higher (1.9) [10,11].This may be due to the difference in the study population, Spadaro et al study was carried out on mixed medical and surgical ICU patients, while Mowafy and Abdelgalel study carried out with surgical intensive care unit patient and Abbas et al study included only chronic obstructive pulmonary disease (COPD)[9–11].

RSBI showed best sensitivity and specificity with a cut off value > 63 breaths/min/liter for predicting weaning failure which is lower than the cutoff value of 105 originally described by Yang and Tobin. There are several other studies who have documented a wide range of predictive values for RSBI, which could reflect differences in methodology, classification of outcomes, and study populations[14,15]

Additional finding in present study is the mean age in weaning failure group was significantly higher (p=0.017). This may be due to one of most common ICU population in this setting was traumatic head injury (16%) which group also exhibit significantly higher weaning success and they are mostly from younger age group. Smoker patients showed higher weaning failure (p value 0.000), which is similar with that of other studies. RR and DD differed significantly between patients who were successfully weaned and those who failed the weaning trial (P value 0.000 and 0.000 respectively). This finding is synergistic to our result. ICU length of stay was significantly higher in weaning failure group (p value 0.008), which is also similar with other studies. From above result we can say that DRSBI is a very much sensitive and specific weaning predictor where its accuracy may change depending on the time of calculation and on group of patient population.

Limitation of the present study is diaphragmatic rapid shallow breathing index is not reevaluated in weaning failure group. Such information could be helpful in determining whether weaning failure has its roots in diaphragmatic dysfunction or has a cardiac or a respiratory origin.

Finally, many experts consider that clinical judgment, based upon careful inspection, is superior to and more accurate than available predictors of weaning outcome[16–18]. However, integrating this clinical judgment with a relatively easy to do bedside index like the D-RSBI may at least help intensivists in their decision to extubate [9].

Conclusion

D-RSBI (RR/DD) is a new and promising tool that is superior to the traditional RSBI (RR/VT) in predicting weaning outcome in mixed ICU at tertiary care hospital. A cutoff value of 1.7 is associated with the best diagnostic accuracy. Further large prospective randomized controlled studies are warranted to assess if these findings hold true in a larger number of patients with different disease pathologies.

Conflict of interest

There is no conflict of interest

Reference

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