ORIGINAL ARTICLE

The prognostic value of rapid shallow breathing index and physiologic dead space for weaning success in intensive care unit patients under mechanical ventilation

Farzin Ghiasi, Keivan Gohari Moghadam[1], Babak Alikiaii[2], Sara Sadrzadeh, Ziba Farajzadegan[3]
Alzahra Hospital Pulmonary Department, Isfahan University of Medical Sciences, Isfahan, Iran, [1]Shariati Hospital Pulmonary Department, Tehran University of Medical Sciences, Tehran, Iran, [2]Anesthesiology and Critical Care Research Center, Isfahan University of Medical Sciences, Isfahan, Iran, [3]Department of Community and Preventive Medicine, Faculty of Medicine, Isfahan University of Medical Sciences, Isfahan, Iran

Background: Mechanical ventilation (MV) is a life-saving intervention that should be considered for patients with respiratory failure. This study was conducted to evaluate the predictive value of physiologic dead space for weaning success and compare it with rapid shallow breathing index (RSBI). **Materials and Methods:** This cross-sectional study was conducted on 80 intensive care unit (ICU) patients who were under MV and candidate for weaning; among them, 68 patients experienced weaning success. RSBI was measured by dividing the respiratory rate by tidal volume. End-tidal CO_2 ($PETCO_2$) was obtained using caponometry, then dead-space was calculated as ($VD/VT = (PaCO_2 – PETCO_2)/PaCO_2$). $PaCO_2$ was also obtained from arterial blood gas recorded chart. **Results:** Age, $PaCO_2$, $PETCO_2$, and RSBI were significantly different between those patients with and without weaning success ($P < 0.05$). RSBI ≤ 98 could predict the success of weaning with sensitivity 91.7%; specificity 76.5% and (AUC) area under the ROC curve (AUC = 0.87; 95% confidence interval [CI]: 0.78–0.94; $P < 0.001$). Dead space was not statistically significant prognostic index (AUC = 0.50; 95% CI: 0.31–0.69; $P = 0.09$). **Conclusion:** In our study, RSBI was an effective predictive index for weaning success in ICU patients under MV, but dead space did not show significant predictive value. Further studies with larger sample sizes for providing more evidence are recommended.

Keywords: Intensive care unit, mechanical ventilation, physiologic dead-space, rapid shallow breathing index, weaning

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INTRODUCTION

Mechanical ventilation (MV) is a life-saving intervention that is considered for patients with respiratory failure. Acute respiratory failure may occur due to respiratory diseases, neuromuscular disorders, shock and major surgeries. Approximately half of the intensive care unit (ICU) patients require MV. This fact imposes heavy burden on health care systemand reflects the importance of avoiding unnecessary ventilatory support. Change or decrease in ventilator settings with the goal of discontinuation of respiratory support is called weaning. Weaning success depends on patients' respiratory function, acid-base balance, neurologic status and patients' psychological readiness.[1]

Any delay in weaning may cause side effects such as ventilator acquired pneumonia. On the other hand, early weaning may result in re-requirement of MV, longer ICU admission, higher rate of death, and high costs on the health system.[2-4]

Many indices have been presented as determinants for successful weaning including: acute physiology and chronic health evaluation II score, creatinine level, skin

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Address for correspondence: Dr. Sara Sadrzadeh, Isfahan University of Medical Sciences, Isfahan, Iran. E-mail: sr.sadrzadeh@gmail.com
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integrity, albumin level within 1 week of admission to the ICU and ejection fraction, respiratory parameters, including: static lung compliance (Cst) and the rapid shallow breathing index (RSBI).[5]

RSBI is a factor presented for MV weaning potential. This index is achieved through respiratory rate (RR) divided by tidal volume (TV) and could be measured when a patient is under MV and had no respiratory support.[4,6]

Less invasive techniques are preferred for prediction of weaning success. Physiologic dead space is the sum of anatomic and alveolar dead spaces.[7] It has been considered as a possible predictor of successful weaning, but the results of studies are controversial and limited.[8-10]

In this study, we evaluated the predictive value of dead space using capnometry as an available tool for measuring end-tidal carbon dioxide pressure ($PETCO_2$) and RSBI as a validated predictor of weaning success[11] and best cut of values for both indices was determined compared their results.

MATERIALS AND METHODS

Study design and participants

In this cross-sectional study, 80 adult patients admitted at ICU (AL Zahra Hospital affiliated to Isfahan University of Medical Sciences) between January 2016 and January 2017 were enrolled. These patients were under MV because of cardiopulmonary diseases such as chronic obstructive pulmonary disease (COPD), massive pulmonary thromboembolism, and candidate for weaning.

Inclusion criteria were as hemodynamic stability, absence of potentially lethal dysrhythmias, lack of need for neuromuscular blockade or continuous sedatives, needs minimal ventilator supports: fraction of inspired oxygen (FiO_2) <60%, positive end-expiratory pressure of 5 cm H2O or less, and pressure support 8 cmH_2O or less. Patients with previous weaning failure and post cardiopulmonary resuscitation patients not included in the study. The study protocol was approved by bioethics committee of the Isfahan University of Medical Sciences with project number: 395830.

Procedures and measured variables

Rapid shallow breathing index measurement

The RSBI is a tool that is used in the weaning of MV on intensive care units. The RSBI is defined as the ratio of respiratory frequency to tidal volume (RR/VT).

During daily visits, we tried to check the potential of weaning success in our patients. We used spontaneous breathing trail, progressive decreases in the level of pressure support during pressure support ventilation (PSV), and progressive decreases in the frequency of ventilator-assisted breaths during intermittent mandatory ventilation. The items that we looked for were: hemodynamic stability, oxygenation condition ($pao2/FiO_2 > 200$), no fever, no respiratory distress, better clinically, and radiological conditions.

For measuring RSBI, the least ventilatory support (continuous positive airway pressure [cpap] ≤5 cmH_2O, PSV ≤8 cmH_2O) were considered for 30 min in our weaning candidates, if there was no evidence of weaning failure after this time, we check out the number of RSBI that our ventilators (Hamilton c2) calculated (Hamilton Medical). Objective criteria that we considered as weaning failure include tachypnea, respiratory distress (use of accessory muscles, thoracoabdominal paradox and diaphoresis), hemodynamic changes (tachycardia, hypertension), and changes in mental status (somnolence and agitation).[12]

End tidal CO_2 measurements

For measuring end-tidal CO2 pressure, we used Hamilton C2 ventilator possibility for monitoring CO2 via a mainstream CO2 sensor. The mainstream CO2 sensor is a solid-state infrared sensor, which is attached to an airway adapter that connects to an endotracheal tube or other airway and measures bases flowing through these breathing circuit components. The sensor generates infrared light and beams it through the airway adapter or sample cell to a detector on the opposite side. The Hamilton C2 determines the CO2 concentration in the breathing gases by measuring the amount of light absorbed by gases flowing through the airway or sample cell.[13]

Physiologic dead space calculation

Samples were immediately analyzed for partial pressure of carbon dioxide (PaCO2) using a blood gas analyzer and the arterial to end-tidal CO2 gradient was determined. Subsequently, alveolar dead space was calculated for each patient using the following formula:

$$\text{Physiologic dead space fraction } VD/VT = (PaCO_2 - PETCO_2)/PaCO_2$$

where PeCO2 is the partial pressure of carbon dioxide in mixed expired gas and is equal to the mean expired carbon dioxide fraction multiplied by the difference between the atmospheric pressure and the water–vapor pressure. PaCO2 is the arterial CO2 tension obtained through ABG.[7]

The decision for reinstitution of MV (trial failure) was made based on the following criteria: respiratory rate >35 breaths/min, PaO_2 <55 mmHg while the patient was on O2 therapy through T tube using venturi tube 40%,

SpO_2 <90% on 50% inspired oxygen; subjective distress or diaphoresis, heart rate increment >20 beats/min, systolic blood pressure decrement >20 mmHg and arrhythmia (an increase in premature ventricular beats >4/min or new onset of sustained supraventricular rhythm).

Statistical analysis

Quantitative and categorical data were presented as mean (standard deviation) and frequency (percentage). Normality of quantitative data was evaluated using Kolmogorov–Smirnov and Q-Q plot. Student's *t*-test was used for comparing normally distributed data between two groups. Chi-square test was used for comparing categorical data between study groups.

Receiver operating characteristic (ROC) curve was constructed to evaluate the diagnostic value of RSBI and physiologic dead space indices. The ROC curve was also used to determine the best cut-off values of the studied indices with highest predictive values. Areas under the ROC curve (AUCs) for two indices were computed and compared using DeLong test.

Univariate and multivariable binary logistic regression was also used for evaluating the predictive values of RSBI and physiologic dead space indices for weaning success in the presence of confounding variables. The results of logistic regression was presented as odds ratio (OR) and 95% confidence interval for OR (95% confidence interval [CI] for OR). All statistical analyses were performed using SPSS version 20 (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.) and STATA version 11 (StataCorp. 2009. Stata Statistical Software: Release 11. College Station, TX: Stata Corp LP.)

RESULTS

Eighty patients with mean age of 55.11 ± 21.48 years were included in this study. Table 1 presents the measured characteristics of total sample and patients with and without weaning success. as can be seen the age, PaCO2, PETCO2 and RSBI were significantly different between two groups ($P < 0.05$).

Table 1: Basic and clinical characteristics of study participants

Variables	Total sample (*n*=80)	Success group (*n*=68)	Failure group (*n*=12)	P^a
Age (years)	55.11±21.48	46.75±20.17	69.17±19.23	0.001
pH	7.395±0.047	7.396±0.049	7.395±0.047	0.622
PCO_2	41.47±3.87	40.75±3.52	45.58±3.18	<0.001
HCO_3	22.76±2.54	22.66±2.67	23.33±1.67	0.4
$PETCO_2$	35.24±3.94	34.69±3.82	38.33±3.17	0.003
RSBI	91.29±10.83	89.12±9.76	103.58±8.18	<0.001
Physiologic dead space	0.15±0.09	0.15±0.09	0.15±0.08	0.946
Sex (%)				
Male		42 (85.7)	7 (14.3)	0.82
Female		26 (83.9)	5 (16.1)	

[a]Resulted from independent samples *t*-test for continuous data and Chi-square test for categorical data. RSBI=Rapid shallow breathing index

Table 2 presents the predictive values of RSBI and physiologic dead space for weaning success. As can be seen RSBI with optimum cut of value 98 is a significant predictive index with highest sensitivity and specificity and correct classification rate 78.9%; however, the physiologic dead space with AUC = 0.50 has predictive value same as the chance. DeLong test resulted significant difference between two AUCs, indicating significantly higher AUC (higher predative value) for RSBI than physiologic dead space ($P = 0.0001$). Figure 1 depicts the AUCs for both study indices.

Table 2: The predictive values of rapid shallow breathing index and physiologic dead space for weaning success

Variables	Cut of value	Sensitivity (%)	Specificity (%)	AUC (95%CI)	*P*
RSBI	98	91.7	76.5	0.87 (0.78-0.94)	<0.001
Physiologic dead space	0.18	58.3	54.4	0.50 (0.31-0.69)	0.09

RSBI=Rapid shallow breathing index; AUC=Area under the curve; CI=Confidence interval

Fitting binary logistic regression showed that the RSBI index is a significant predictor for weaning success (OR = 1.25; 95%CI: 1.10–1.42; $P = 0.001$) and after adjusting the confounding effect of age, it was remained statistically significant (OR = 1.25; 95% CI: 1.08–1.44; $P = 0.002$); however, we did not reach an interpretable regression model for physiologic dead space index.

DISCUSSION

In current study, we evaluated the predictive value of dead space and RSBI as a validated predictor of weaning success and the best cut of values for both indices. Our results led to RSBI with optimum cut of value 98 with highest sensitivity and specificity and correct classification rate 78.9%; however, the physiologic dead space with cut of value 0.18 has predictive value same as the chance.

In general, two steps should be considered for the management of patients under MV. The first step is assessment of underlying cause of respiratory failure and the second is to select suitable candidates for weaning, as most of clinicians tend to underestimate patients' capacity of weaning.[14]

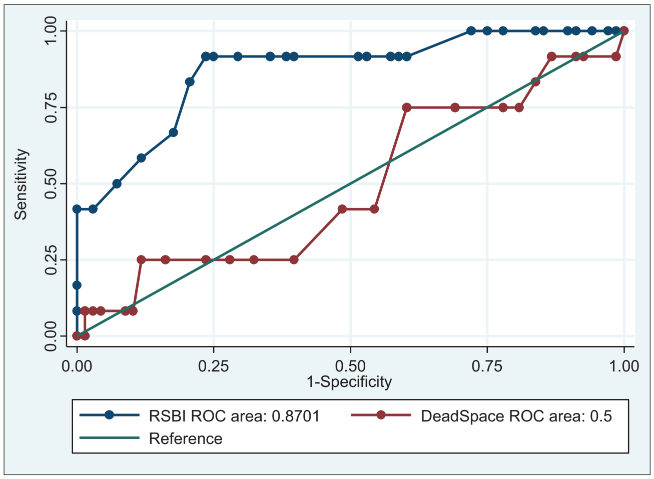

Figure 1: The AUC of the rapid shallow breathing index and physiologic dead space for predicting weaning success

Following 24-h MV, patients should be assessed about their ability for weaning. Readiness tests are used for weaning; however, there is no consensus about the most appropriate approach with least MV liberation failure.[15-17] Variety of weaning predictors RSBI, oxygenation, minute ventilation, maximal inspiratory pressure, compliance, work of breathing, gastric mucosal acidosis, and oxygen cost of breathing have been noted but none of them is merely enough for prediction of weaning success; thus integrative indices have been recommended.[18-20]

One of the tests that were assessed to find patient's readiness is measurement of arterial Carbone dioxide (PaCO2) which is obtained through arterial blood gas sampling. This procedure is time-consuming and painful and reflects patients' respiratory status at the time of sampling and the results may be affected by hyperventilation induced by this painful procedure.[21] As PaCO2 reflcts ventilation and PETCO2 reflects lung perfusion degree, therefore, indirectly cardiac output and dead space, respectively, those were assumed to be a useful weaning predictor.

Yang and Tobin presented a new method for making decision of MV weaning based on RSBI.[11] Although this method is easy to use, measured tidal volume may be overestimated because of pressure support given by ventilator. Aboussouan *et al*. mentioned a cut-off of <105 for RSBI as an appropriate index for the patient's weaning.[5] In another study, Fadaii *et al*. confirmed the cut-off of 105 again; however, they mentioned that the use of RSBI merely can mislead the physician. They did not present another index and sufficed to present that patients' duration of hospitalization, underlying disease and general status at the time of weaning should be considered as well.[4] In the current study, we found that RSBI ≤98 is an appropriate cut-off for weaning with sensitivity of 91.7% and specificity of 76.5%. In addition, each unit increase in RSBI was in association with 25% of weaning failure, which shows the importance of considering more precise predictors of weaning.

Further studies should be considered as by this lower cutoff may larger number of patients be weaned successfully in comparison to cutoff 105 in previous studies. Ahmed *et al*. tried ultrasonography of diaphragm and lung as predictor factors of weaning. In their study, similar to our findings, they mentioned similar RSBI cutoff of <100 for ICU patients.[22] Findings of Sun *et al*. about an appropriate cutoff for RSBI were even less than us, as they presented RSBI < 86.5 as an appropriate cutoff with sensitivity of 81.8% but specificity of 52.9%.[23]

Previous studies have mentioned that RSBI is inappropriate factor for weaning prediction among patients with neuromuscular and neurological disorders. In addition, they have presented RSBI limitation for prediction of weaning success among patients under ventilation for a long time.[24] In our study, we have assessed dead space as a novel predictor of successful weaning in adult.

Respiratory failure may be accompanied with lung blood flow disruption and microcirculation damage. If the blood flow disrupts in some parts of the lungs while ventilation is normal; physiologic dead space would increase. This increase in dead space means disturbance of Carbone dioxide disposal. This process had been mentioned in some studies during acute respiratory distress.[25] Thus, we have hypothesized that dead-space may be an appropriate index for prediction of weaning success. However, in the current study, dead space of 0.18 showed sensitivity of 58.3% and specificity 54.4%, indicating low ability for predicting weaning success.

In a study conducted by Christopher *et al*. on intubated pediatrics, they presented that dead-space of ≤50 is an appropriate cutoff for successful extubation. They went on that dead-space greater than 0.65 is significantly accompanied with extubation failure.[26] These results may be different from ours due to age of studied population and the fact that the goal of their study was extubation not just successful weaning as in ours.

These findings were consistent with the presentations of Agmy *et al*. that assessed THE rate of weaning success among patients' undergone MV due to obstructive pulmonary disorders including asthma and COPD. They found that dead-space fraction was not statistically in association with survival and weaning success.[8] These results were inconsistent with findings of Helmy *et al*. that presented inverse association of alveolar dead-space with weaning success among patients under MV due to COPD.[10]

CONCLUSION

In our study, RSBI was an effective predictive index for weaning success in ICU patients under MV but dead space did not show significant predictive value. Low prognostic value of dead-space may reflect diverse acute disorders among studied patients which may lead to MV requirement for them. Accordingly, we recommend further studies in which different underlying etiologies for patients' MV requirement would be assessed separately or to use a more comprehensive index which integrates many physiopathologies variables like general status of the patient such as body mass index, concomitant diseases and duration of stay at ICU should be considered for evaluating successful weaning Further studies are needed to evaluate the effects of these variables on the predictive values of RSBI and physiologically dead space in ICU patients. In addition, we suggest to conduct further studies with larger sample size.

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Conflicts of interest

There are no conflicts of interest.

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