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The rapid shallow breathing index as a predictor of successful mechanical ventilation weaning: clinical utility when calculated from ventilator data

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ABSTRACT

Objective: The use of the rapid shallow breathing index (RSBI) is recommended in ICUs, where it is used as a predictor of mechanical ventilation (MV) weaning success. The aim of this study was to compare the performance of the RSBI calculated by the traditional method (described in 1991) with that of the RSBI calculated directly from MV parameters. **Methods:** This was a prospective observational study involving patients who had been on MV for more than 24 h and were candidates for weaning. The RSBI was obtained by the same examiner using the two different methods (employing a spirometer and the parameters from the ventilator display) at random. In comparing the values obtained with the two methods, we used the Mann-Whitney test, Pearson's linear correlation test, and Bland-Altman plots. The performance of the methods was compared by evaluation of the areas under the ROC curves. **Results:** Of the 109 selected patients (60 males; mean age, 62 ± 20 years), 65 were successfully weaned, and 36 died. There were statistically significant differences between the two methods for respiratory rate, tidal volume, and RSBI ($p < 0.001$ for all). However, when the two methods were compared, the concordance and the intra-observer variation coefficient were 0.94 (0.92-0.96) and 11.16%, respectively. The area under the ROC curve was similar for both methods (0.81 ± 0.04 vs. 0.82 ± 0.04; $p = 0.935$), which is relevant in the context of this study. **Conclusions:** The satisfactory performance of the RSBI as a predictor of weaning success, regardless of the method employed, demonstrates the utility of the method using the mechanical ventilator.

Keywords: Respiration, artificial; Ventilator weaning; Spirometry.

INTRODUCTION

The use of indices predicting weaning outcomes can reduce the risk of weaning failure and complications posing potential morbidity, such as reintubation.[1,2] Weaning indices are used in order to evaluate lung mechanics and can provide information regarding the causes of mechanical ventilation (MV) dependence.[3,4] It is currently recommended that weaning indices be used only in cases in which it is difficult to make a decision; the decision to perform a spontaneous breathing trial (SBT) should not be based on any one weaning index.[5,6]

The rapid shallow breathing index (RSBI), which is also referred to as the ratio of respiratory rate to tidal volume (f/V_T), is the most widely used predictor of weaning success because it is easy to use and interpret.[1,4,7-13] The 2007 international consensus guidelines for weaning from MV, the 2007 Brazilian consensus guidelines for weaning from MV, and the 2013 Brazilian guidelines for MV underscore the clinical utility of the RSBI and recommend its use.[5,8,9]

First described by Yang & Tobin in 1991,[3] the RSBI allows assessment of respiratory mechanics by f/V_T. The RSBI was designed to be measured during spontaneous breathing for 60 s with a spirometer connected to the artificial airway before an SBT. An RSBI of less than 105 breaths/L predicts successful weaning from MV.[3,11,14]

It has been proposed that the RSBI be calculated directly from ventilator data during spontaneous ventilation; however, because of the study design, the small number of patients enrolled, and the limitations of the statistical tests used, the results were inconclusive.[14-17]

The major limitations of the RSBI appear to be related to neurological and neuromuscular diseases, as well as to prolonged ventilation. In such cases, the performance of the RSBI is far worse than that of other predictors, such as the Glasgow Coma Scale score and the recently described timed inspiratory effort (TIE) index.[4,12,13,18,19]

The primary hypothesis of the present study was that the RSBI calculated directly from ventilator data is comparable with the RSBI calculated by the traditional method in terms of their accuracy in predicting successful weaning from MV.

METHODS

The present study evaluated data from a database developed for a previous study of predictors of weaning

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success and was approved by the Research Ethics Committee of the Fluminense Federal University (Protocol no. 259/09). At the time, patients (or their legal guardians) gave written informed consent.

The inclusion criteria were as follows: being over 18 years of age; having been on MV for more than 24 h; and being a candidate for weaning from MV. The study participants also met the following criteria: resolution of the acute phase of the disease that led to their being placed on MV; a preserved cough reflex or absence of excessive tracheobronchial secretion; cardiovascular stability (heart rate ≤ 120 bpm and systolic blood pressure = 90-160 mmHg, with minimal or no use of vasopressors); stable metabolic state; adequate oxygenation (SaO_2 > 90% with an FiO_2 ≤ 0.4 or PaO_2/FiO_2 ≥ 200 mmHg with a positive end-expiratory pressure ≤ 8 cmH_2O); adequate respiratory rate (≤ 35 breaths/min); pressure support ≤ 20 cmH_2O; absence of significant respiratory acidosis (pH > 7.30); and, for endotracheally intubated patients, adequate mental status (a Glasgow Coma Scale score > 10).

The exclusion criteria were as follows: tracheal stenosis; intracranial pressure > 20 mmHg; sedation; severe heart failure or hemodynamic instability; and signs of systemic infection/reinfection during the weaning process.

The following mechanical ventilators were used: eXtend (Air Liquide, Paris, France), Servo-s (Maquet, Rastatt, Germany), and Puritan Bennett™ 840 (Covidien Nellcor, Boulder, CO, USA). Before measurement of MV parameters on the ventilator display, all mechanical ventilators and their circuits were calibrated in order to prevent measurement bias.

Procedures

The RSBI was calculated after the aforementioned weaning criteria were met and before an SBT was performed. For all study participants, the RSBI was calculated by the traditional method (i.e., employing a spirometer) and directly from MV parameters (i.e., employing the parameters from the ventilator display). The choice of which method should be used first was made by random sampling. All patients were on pressure support ventilation (PSV) at 12-20 cmH_2O, without sedation, and with the head of the bed at 45°, having been preoxygenated with an FiO_2 of 1.0 for 2 min and their airways having previously been aspirated.[20,21] After the RSBI was calculated by the two different methods, patients underwent an SBT with a T-piece and an FiO_2 of 0.4 for 30 min, without the influence of previous test results. All patients were continuously monitored by pulse oximetry and electrocardiography, under the supervision of a respiratory physiotherapist.[20,21]

In order to calculate the RSBI by the traditional method, the spirometer (Wright MK20; Ferraris Medical Ltd., Hertford, England) was connected to the artificial airway and left in place for 1 min. Spontaneous V_T was calculated by dividing minute ventilation by respiratory rate, and the RSBI was calculated by dividing respiratory rate by V_T in liters.[3,4]

In order to calculate the RSBI directly from ventilator data, respiratory rate and minute ventilation were obtained from the parameters from the ventilator display, with patients on PSV at 5 cmH_2O and continuous positive airway pressure of 5 cmH_2O. The RSBI was calculated after 5 min of ventilation as described above, and V_T was calculated by dividing minute ventilation by respiratory rate.

The decision to place patients on MV again was made by a respiratory physiotherapist, the attending physician, or both (who were blinded to the RSBIs obtained), being based on signs of poor tolerance (described below). Weaning from MV was considered successful if patients were able to breathe spontaneously after the SBT.[2,4,8,9,16,22,23]

In order to be extubated, patients had to pass the SBT and meet the following criteria: an adequate level of consciousness; an effective cough; and a patent airway. Extubation was considered successful if patients were not reintubated within 48 h after extubation. In tracheostomized patients, extubation was considered successful if, after passing the SBT, patients were able to breathe spontaneously after ventilator disconnection, without the need for reconnection within 48 h after disconnection.[5]

The SBT was interrupted if patients met at least one of the following criteria: SaO_2 < 90%; respiratory rate > 35 breaths/min; heart rate > 140 bpm, a sustained increase in heart rate, or a reduction in heart rate of more than 20%; mean arterial pressure > 130 mmHg or < 70 mmHg; or the presence of agitation, excessive sweating, disorientation, or depressed mental status. Patients who showed any of the aforementioned signs during the SBT or within 48 h after discontinuation of MV were considered to be cases of weaning failure, extubation failure, or both and were again placed on ventilatory support.[2,4,5,8,9,16,22,23]

Statistical analysis

Variables with normal distribution were expressed as means and standard deviations, whereas variables with non-normal distribution were expressed as medians and interquartile ranges. Categorical data were expressed as absolute and relative frequencies. The nonparametric Mann-Whitney test was used, and values of $p < 0.05$ were considered significant.

The performance of the RSBI calculated by the traditional method and that of the RSBI calculated directly from ventilator data in predicting weaning outcomes were evaluated by the following quality indicators: sensitivity; specificity; positive predictive value (PPV); negative predictive value (NPV); positive likelihood ratio (PLR); and negative likelihood ratio (NLR). They were also evaluated by calculating the area under the ROC curve (AUC). The AUCs were compared by the method proposed by Hanley & McNeil, and the cut-off points were calculated by the Youden index.[23]

All statistical analyses were performed with MedCalc, version 11.4.2.0 (MedCalc Software, Mariakerke, Belgium).

RESULTS

Of the 109 patients who participated in the study, 60 were male, and the mean age was 62 ± 20 years (Table 1). Sixty-five (59.6%) were successfully weaned from MV, and 36 (33%) died, 8 of whom had been successfully weaned from MV. The reintubation rate was 10.7%.

Table 2 shows the medians and interquartile ranges of the parameters used in order to calculate the RSBI, together with a comparison between the two different methods used in order to calculate f/V_T. All variables showed statistically significant differences, with values of $p < 0.001$, the exception being minute ventilation ($p = 0.132$).

Quality indicators (sensitivity, specificity, PPV, NPV, PLR, and NLR) and the cut-off points for the RSBIs calculated by the two different methods are shown in Table 3.

Table 1. General characteristics of the patients studied (N = 109).[a]

Variable	Result
Male gender	60 (55)
Non-White	53 (49)
Intubated patients	62 (57)
Tracheostomized patients	47 (43)
Age, years	62 ± 20
Mechanical ventilation, days	14.2 ± 12.9
APACHE II score	17.9 ± 5.6
Conditions leading to ICU admission	
Sepsis	23 (21.1)
Pulmonary sepsis	22 (20.3)
Stroke	21 (19.3)
COPD	18 (16.5)
Acute myopathy	10 (9.2)
Abdominal surgery	8 (7.3)
Heart failure	5 (4.6)
Acute respiratory distress syndrome	2 (1.8)

APACHE II: Acute Physiology and Chronic Health Evaluation II. [a]Values expressed as n (%) or as mean ± SD.

Table 2. Medians and interquartile ranges of the study parameters.

Variable	Rapid shallow breathing index calculated with the use of		p*
	A spirometer	Pressure support ventilation	
f	29 (26-33)	27.0 (23.7-31.3)	< 0.001
V_E	9.6 (8.3-11.3)	9.6 (8.3-11.4)	0.132
V_T	0.34 (0.30-0.40)	0.36 (0.31-0.42)	< 0.001
f/V_T	86.3 (68.1-106.1)	75.9 (58.2-98.3)	< 0.001

f: respiratory rate; V_E: minute volume; and V_T: tidal volume. *Mann-Whitney test.

As can be seen in Figure 1, there were no statistically significant differences between the AUCs for the RSBIs calculated by the two different methods (0.81 ± 0.04 vs. 0.82 ± 0.04; p = 0.947). As can be seen in Figure 2, Pearson's linear correlation between the two methods was 0.94 (0.92-0.96). As can be seen in Figure 3, the intra-observer variation coefficient was 11.16%.

DISCUSSION

The use of the RSBI as a predictor of weaning success has been widely studied in the intensive care setting.[24] The performance of the RSBI has been shown to range from moderate to good (AUC, 0.72-0.89).[3,4,11,25,26] This variation might be due to the heterogeneity of the study samples, given that the proportions of patients with neurological disease, neuromuscular disease, or prolonged ventilation vary across studies.[4,11-13] The use of different study designs, weaning protocols, measurements, and cut-off points also contributes to this variation.[4,6,15,26-29]

The RSBI and maximal inspiratory pressure (MIP) have historically been recommended by the *American Thoracic Society/European Respiratory Society* and are among the most widely used predictors of weaning outcome in clinical practice.[5,8] The superiority of f/V_T and MIP over other predictors has been reported in two different studies, in which the AUCs for f/V_T and MIP were 0.89[3] and 0.80,[20] respectively. Promising new weaning indices include the integrative weaning index, the AUC for which was found to be 0.96 in a study from which neurological patients were excluded,[11] and the TIE index, the AUC for which was found to be 0.90 for a mixed population of intubated patients and 0.96 for patients with neurological or neuromuscular disease.[4,13]

In our sample of 109 patients, weaning failure occurred in approximately 40%, a proportion that is larger than that reported in the literature (i.e., 30%).[8] This can be explained by advanced age (mean age, 62 ± 20 years), a high prevalence of patients with prolonged ventilation (mean duration of MV, 14.2 days), a high proportion of tracheostomized patients (43%), and high Acute Physiology and Chronic Health Evaluation II scores.[9,17]

The performance of the RSBI calculated by the traditional method and that of the RSBI calculated directly from ventilator data were comparable with the RSBI performance reported in other studies.[4,11,20] It is of note that, regardless of how it was calculated, the RSBI was found to have low accuracy in identifying positive/negative cases (of patients who pass the SBT but cannot be weaned), as evidenced by its relatively low specificity, NPV, and NLR.

Technological advances in patient monitoring and ventilation have made it easy to obtain real-time data that allow determination of the clinical status of patients on ventilatory support. This led to studies comparing the RSBI calculated by the traditional method with the RSBI calculated directly from ventilator data, significant

Table 3. Indicators of the accuracy of the rapid shallow breathing index (calculated with the use of a spirometer and directly from ventilator data) in predicting weaning outcomes.

Index	CP	Sensitivity	Specificity	PPV	NPV	PLR	NLR
f/V_T (spirometer)	88.5	0.82	0.62	78.3	70.6	3.91	0.25
f/V_T (PSV)	80.1	0.80	0.65	76.9	71.2	4.40	0.24

CP: cut-off point for weaning outcome (as determined by the ROC curve); PPV: positive predictive value; NPV: negative predictive value; PLR: positive likelihood ratio; NLR: negative likelihood ratio; f/V_T: ratio of respiratory rate to tidal volume (the rapid shallow breathing index); and PSV: pressure support ventilation.

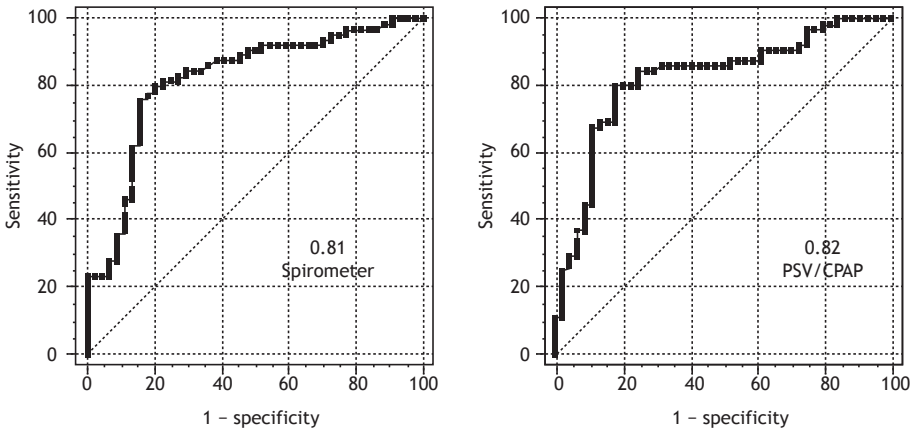

Figure 1. Areas under the ROC curves for the rapid shallow breathing index (f/V_T) calculated with the use of a spirometer and directly from ventilator data, showing no significant difference between the two in terms of their accuracy in predicting successful weaning from mechanical ventilation (p = 0.935; Hanley & McNeil test for pairwise comparisons). PSV: pressure support ventilation; and CPAP: continuous positive airway pressure.

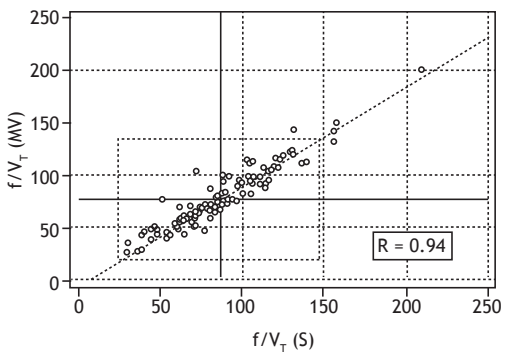

Figure 2. Pearson's linear correlation between f/V_T calculated with the use of a spirometer (S) and f/V_T calculated from the parameters from the mechanical ventilator (MV) display. f: respiratory rate; and V_T: tidal volume.

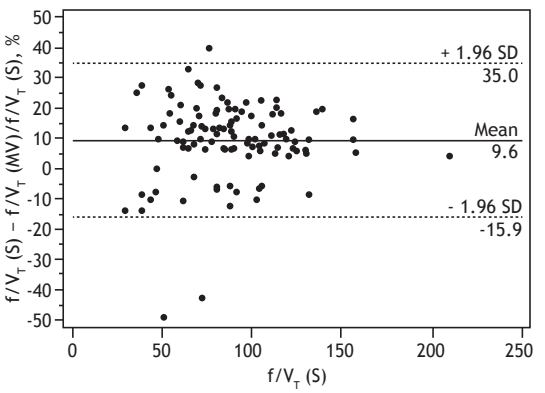

Figure 3. Bland-Altman plots. Intra-observer variation coefficient (11.16%) for f/V_T calculated with the use of a spirometer (S) and f/V_T calculated from the parameters from the mechanical ventilator (MV) display. f: respiratory rate; and V_T: tidal volume.

differences being found between the two.[14,17,22,28-30] However, none of the aforementioned studies evaluated the performance of the RSBI (as calculated by each method) in predicting weaning success.

Unlike the aforementioned studies, the present study was aimed at comparing the RSBI calculated by the traditional method with the RSBI calculated directly from ventilator data in terms of their accuracy in predicting weaning outcome. As in previous studies, the two methods for calculating the RSBI were found to be significantly different in terms of median respiratory rate, V_T, and f/V_T. However, our most important finding was that the performance of the RSBI calculated by the traditional method was statistically similar to that of the RSBI calculated directly from ventilator data, as evaluated by the AUCs (0.81 vs. 0.82; p = 0.19). In addition, the concordance—0.94 (0.92-0.96)—and the intra-observer variation coefficient (11.16%) were all within the recommended range for tests that are reproducible and reliable.

In the present study, the cut-off point for the RSBI calculated with the use of a spirometer was 88.5 breaths/L (as determined by the ROC curve), whereas in the original study it was 105 breaths/L.[3] The cut-off point for the RSBI calculated directly from ventilator data in the present study was even lower (i.e., 80.1 breaths/L). Although we cannot offer a definitive

explanation for these differences, they might be partly due to the characteristics of the study samples.

It is of note that the accuracy of the SBT, which is considered the gold standard for determining the success of weaning from MV and extubation, is approximately 85%.[2,23,25,31] Therefore, the use of predictors such as f/V_T, MIP, the integrative weaning index, and the recently described TIE index can make the outcome of weaning from MV safer, especially in difficult-to-wean patients.[4,11,13,24]

One limitation of the present study is that we did not determine interobserver reproducibility or f/V_T after the SBT. However, the primary objective of the present study was to compare AUCs in terms of their accuracy in predicting weaning success. Therefore, we believe that the aforementioned limitation had little impact on the final result.

In conclusion, the RSBI calculated directly from ventilator data can be easily incorporated into clinical practice, having no negative impact on the RSBI accuracy in predicting weaning outcome. However, our study shows that the cut-off point for the RSBI calculated directly from ventilator data should be approximately 80 breaths/L, which is lower than that for the RSBI calculated by the traditional method.

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