

Variation in the Rapid Shallow Breathing Index Associated With Common Measurement Techniques and Conditions

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BACKGROUND: The rapid-shallow-breathing index (RSBI) is widely used to evaluate mechanically ventilated patients for weaning and extubation, but it is determined in different clinical centers in a variety of ways, under conditions that are not always comparable. We hypothesized that the value of RSBI may be significantly influenced by common variations in measurement conditions and technique. **METHODS:** Sixty patients eligible for a weaning evaluation after ≥ 72 hours of mechanical ventilation were studied over 15 months in a medical intensive care unit. RSBI was measured while the patients were on 2 different levels of ventilator support: 5 cm H₂O continuous positive airway pressure (CPAP) versus T-piece. RSBI was also calculated in 2 different ways: using the values of minute ventilation and respiratory rate provided by the digital output of the ventilator, versus values obtained manually with a Wright spirometer. Finally, RSBI was measured at 2 different times of the day. **RESULTS:** RSBI was significantly less when measured on 5 cm H₂O CPAP, compared to T-piece: the medians and interquartile ranges were 71 (52–88) breaths/min/L versus 90 (59–137) breaths/min/L, respectively ($P < .001$). There were no significant differences in the value of RSBI obtained using ventilator-derived versus manual measures of the breathing pattern. RSBI was also not significantly different in the morning versus evening measurements. **CONCLUSIONS:** RSBI can be significantly affected by the level of ventilator support, but is relatively unaffected by both the technique used to determine the breathing pattern and the time of day at which it is measured. *Key words:* mechanical ventilation, weaning, minute ventilation, rapid shallow breathing index. [Respir Care 2009;54(11):1462–1466. © 2009 Daedalus Enterprises]

Introduction

Determining when patients with respiratory failure can be liberated from mechanical ventilation is critical. A de-

lay in removal from the ventilator increases the risk of hospital-acquired pneumonia¹ and other complications. On the other hand, premature removal from the ventilator is an independent risk factor for prolonged intensive care unit (ICU) stay and death.²

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Of the various predictors of weaning outcome that have been used, the rapid-shallow-breathing index (RSBI), defined as the ratio of respiratory rate (breaths/min) to tidal volume (V_T), has been shown to be the best.³ At many institutions, decisions about whether to proceed with trials of spontaneous breathing and/or extubation are often influenced by, and sometimes based exclusively on, RSBI, which is typically measured once a day.⁴ However, clinicians have questioned the sensitivity, specificity, and positive and negative predictive value of RSBI.⁵⁻⁷ These questions arise in part because RSBI is measured in different clinical practices using different techniques and modes of

Table 1. Patient Characteristics

Variable	Airway Pressure Protocol (<i>n</i> = 47)	Measurement Technique Protocol (<i>n</i> = 48)	Time of Day Protocol (<i>n</i> = 44)
Age (mean ± SD y)	64 ± 15	63 ± 15	64 ± 14
Male (<i>n</i> , %)	20 (43)	18 (38)	18 (41)
Days on ventilator (mean ± SD d)	8 ± 4	8 ± 4	8 ± 5
ALI/ARDS (<i>n</i> , %)	10 (21)	10 (21)	10 (23)
Obstructive lung disease (<i>n</i> , %)	3 (6)	2 (4)	1 (2)
Pneumonia (<i>n</i> , %)	6 (13)	8 (14)	7 (16)
Congestive heart failure (<i>n</i> , %)	7 (15)	8 (14)	6 (13)
Neuromuscular disease (<i>n</i> , %)	6 (13)	5 (10)	4 (9)

ALI = acute lung injury
ARDS = acute respiratory distress syndrome

ventilation. This raises the possibility that some RSBI measurements may differ from the values that would be obtained by measuring the pattern of spontaneous breathing with a hand-held spirometer, the technique originally described by Yang and Tobin.³ In particular, it has been suggested that RSBI values may differ if measured during unsupported spontaneous breathing versus continuous positive airway pressure (CPAP).⁵

Furthermore, it also seems reasonable to suspect that RSBI might be affected by the technique used to measure the parameters of the breathing pattern that are required for its calculation,⁸ and by other factors that potentially affect the control of breathing, such as circadian rhythm.

Understanding the sources of variability and bias in the measurement of RSBI is crucial to maximizing its usefulness as a widespread tool for predicting the outcome of weaning trials and extubation. The goal of the present study was therefore to investigate the extent to which RSBI may be significantly influenced by common variations in measurement conditions and technique, by conducting a prospective study of patients receiving mechanical ventilation in a medical ICU.

Methods

Subjects

We recruited 60 mechanically ventilated patients as a convenience sample of subjects with acute respiratory failure who met the pre-selected criteria of age ≥ 18 years, mechanical ventilation for ≥ 72 hours and ≥ 8 hours/d (volume controlled continuous mandatory ventilation or volume controlled intermittent mandatory ventilation ≥ 6 breaths/min), $P_{O_2} \geq 60$ mm Hg and/or oxygen saturation via pulse oximeter $\geq 90\%$ while on fraction of inspired oxygen $\leq 50\%$, positive end-expiratory pressure (PEEP) ≤ 5 cm H₂O (while on a mechanical ventilator) or

PEEP ≤ 8 cm H₂O (while on a pressure-support trial), and hemodynamically stable (eg, heart rate ≤ 120 beats/min, mean arterial pressure ≥ 60 mm Hg). Subjects were excluded if they had a tracheostomy or needed vasopressors. Patient characteristics and primary causes of respiratory failure are listed in Table 1.

Informed consent was obtained either from the patients themselves or from their authorized patient surrogates if they did not have capacity for informed consent. The study was approved by the Institutional Review Board for Human Research at the University of Vermont College of Medicine.

Study Design

Each patient was enrolled in 3 protocols, each of which addressed one of the interventions of the study and involved making 2 different RSBI measurements. The 2 RSBI measurements that were made using different methods within each protocol were made by different investigators, each of whom was blinded to the results obtained by the other investigator. The protocols were performed in random order and performed sequentially on consecutive days. The order of the 2 RSBI measurements was also randomized within each protocol. All patients received 50% inspired oxygen during all RSBI measurements made in this study, and their oxygen saturations remained adequate throughout.

Airway Pressure Protocol. RSBI was evaluated both while patients breathed through the ventilator circuit with 5 cm H₂O CPAP, and while they breathed on a T-piece. Each measurement period lasted 60 s, during which minute ventilation (\dot{V}_E) was measured with a Wright spirometer and the respiratory rate was counted manually. The order of the 2 measurement periods was randomized, and they were separated by > 15 min, because of the necessity of

disconnecting the patient from the ventilator in order to make the spirometric measurements. For the CPAP measurements the Wright spirometer was attached to the expiratory port of the ventilator circuit. For the T-piece measurements the spirometer was attached to the T-piece device.

Measurement Technique Protocol. RSBI was evaluated from measurements of \dot{V}_E and respiratory rate obtained in 2 different ways. One set of measurements was provided by the computer in the ventilator (Evita 4 or Evita XL, Dräger, Telford, Pennsylvania), which updates the \dot{V}_E every second, using data from the previous approximately 35 s, and displays it in increments of 0.1 L. The other set of measurements was obtained using the Wright spirometer attached to the expiratory port of the ventilator circuit. Spirometer measurements were made after a 1–2 min equilibration period was allowed to elapse after stopping the ventilator. Each measurement period lasted 60 s. For both sets of measurements the ventilator was set to “flow-by” mode (CPAP and pressure support both zero). The order of the 2 measurements was randomized, and they were separated by > 15 min.

Time of Day Protocol. RSBI was evaluated in patients breathing on a T-piece at 2 different times during the day, between 7:00 AM and 5:00 PM, separated by ≥ 4 hours of mechanical ventilation. Measurements of breathing frequency and \dot{V}_E were made over 60-s periods, using a Wright spirometer connected to the T-piece device.

Calculations. The V_T (L) was calculated as \dot{V}_E (L/min) divided by respiratory frequency (f , breaths/min). RSBI was calculated as the ratio f/V_T .

Statistical Analysis

The measurements of RSBI obtained under each experimental condition were not normally distributed about the mean. Therefore, hypothesis testing was performed using the nonparametric Wilcoxon signed-rank test to compare the values of RSBI obtained within each protocol. Statistical significance was taken as $P < .05$. All analyses were 2-tailed. To detect a difference in mean RSBI of 10% with a standard deviation in RSBI of 30%, we determined that we needed 36 patients within each protocol. Statistical software (Stata version 9.0, StataCorp, College Station, Texas) was used for analysis.

Results

Ninety-one patients, screened from August 2004 to October 2006, were judged eligible to enroll in the study. Thirty-one patients or patient surrogates declined to par-

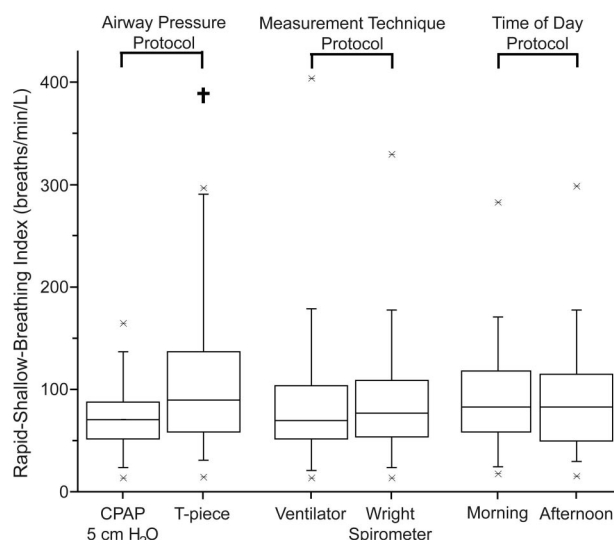


Fig. 1. Box plot of rapid-shallow-breathing index median and interquartile ranges in all 3 protocols. The upper and low ends of each box represent the 25th and 75th percentiles in the data, while the horizontal lines inside the boxes represent the medians. The upper and lower error bars encompass 95% of the data, while the asterisks represent the extremes of the data. The dagger symbol represents statistical significance.

ticipate. Six additional patients withdrew or were unable to complete any one of the 3 protocols, due to a further decline in clinical condition or a new failure to meet criteria for weaning after enrollment.

Thirty-nine patients completed all 3 protocols. Forty-seven patients completed the airway pressure protocol, 48 completed the measurement technique protocol, and 44 completed the time of day protocol. Reasons for completing only one or two of the 3 protocols included early tracheostomy, extubation, and/or worsening clinical condition.

The RSBI measurements obtained in each of the 3 protocols are shown in Figure 1. The airway pressure protocol yielded a significant decrease in RSBI when measured on 5 cm H₂O CPAP versus T-piece: median and interquartile range of 71 (52–88) breaths/min/L versus 90 (59–137) breaths/min/L, respectively ($P < .001$). There was no significant difference between the 2 RBSI measurements obtained in the measurement technique protocol when the ventilator and the Wright spirometer were used to measure the breathing pattern. The median and interquartile range were 75 (53–106) breaths/min/L and 78 (56–110) breaths/min/L, respectively ($P = .9$). There were also no significant differences between the 2 RSBI measurements obtained in the time of day protocol. RSBI values in the morning and evening: median and interquartile range were 83 (59–118) breaths/min/L and 83 (50–115) breaths/min/L, respectively ($P = .8$).

Discussion

We have prospectively evaluated how the measurement of RSBI in mechanically ventilated patients in a medical ICU is affected by the use of CPAP versus T-piece, by the method by which breathing pattern parameters are obtained, and by the time of day at which the measurements of RSBI are made. Only the airway pressure protocol showed a significant intervention effect; RSBI measured on 5 cm H₂O CPAP was found to be significantly lower than RSBI measured on T-piece (see Fig. 1). Our finding is consistent with the results of El-Khatib et al,⁵ who studied patients after coronary-artery-bypass grafting. They found that CPAP of 5 cm H₂O reduced RSBI by 49%, compared to a spontaneous breathing trial. This influence of CPAP on RSBI is not surprising. Reissmann et al⁹ found that application of CPAP during the weaning of patients with chronic obstructive pulmonary disease facilitates carbon dioxide elimination by improving the pattern of breathing. Similarly, Sydow et al¹⁰ found that, by lowering the inspiratory threshold presented by intrinsic PEEP, CPAP can reduce the work of breathing. Intrinsic PEEP may occur in a variety of patient groups during mechanical ventilation if expiratory duration is insufficiently long, so this explanation for the effect of CPAP on RSBI may extend to pathologies other than chronic obstructive pulmonary disease.

The effect of CPAP on RSBI has important clinical implications because the critical value of RSBI for weaning, promoted by the original RSBI study,³ is still in general use. An RSBI value ≤ 105 breaths/min/L predicts successful wean attempt, while RSBI > 105 breaths/min/L predicts unsuccessful weaning. Applying this critical RSBI value to the patients in the present study, we find that 35% of the patients were above the critical value while on T-piece, yet only 11% were above it on CPAP. Our subjects were not undergoing a weaning trial during our study of RSBI. However, if they had been and we had used a critical RSBI value of 100 breaths/min/L (chosen because it is a convenient round number close to the Yang and Tobin value), we would predict a difference in rate of weaning success of nearly 25% between the patients on T-piece versus those on CPAP. This strongly suggests that the critical RSBI value should be different for patients on CPAP versus T-piece. Indeed, when the patients in the present study were on T-piece, they were ventilated with 50% oxygen instead of room air, as used in the original study by Yang and Tobin,³ raising questions about the suitability of a critical RSBI value of 105 breaths/min/L, even for these patients. Furthermore, it seems likely that the critical RSBI value would depend on the level of CPAP.

In contrast, RSBI measurement was not significantly affected when it was calculated using data provided by the ventilator, versus manual determinations of respiratory rate

and \dot{V}_E obtained with a Wright spirometer. RSBI was also not significantly affected by the time of day at which it was measured (see Fig. 1). These 2 comparisons suggest that RSBI is relatively immune to some of the variability currently involved in its calculation in the typical ICU. Such robustness is essential to the usefulness of a widely used clinical variable. Indeed, substantial variability in RSBI due to variation in measurement technique between centers would limit its usefulness in predicting the outcome of weaning trials and extubation. Previous studies have shown that other weaning indexes such as maximal inspiratory pressure, measured in the same individual on the same day by different investigators, can have a coefficient of variation of as much as 32%.¹¹ By contrast, Yang¹² found that when the same individual using the same technique repeated RSBI measurements on 3 trials over a 15-min period, the coefficient of variation was only 9.5%. Petrini et al¹³ reported that breath-by-breath calculations of RSBI during a 15-min period in 8 patients resulted in a mean coefficient of variation of 15%. These findings suggest that the intra-operator variability in RSBI calculation is substantially less than inter-operator variability, pointing to the need to identify the source of such variability. On the other hand, one also expects biological variability in RSBI itself within a given patient, so comparing measurements over a period of time is important for validating RSBI.⁶

Weaning patients from mechanical ventilation is an important part of decision making in the ICU. Indeed, patient morbidity and mortality are significantly affected by prolongation of intubation and by failed extubation, and both are associated with significant increases in the costs incurred due to prolonged hospital stay. Even so, the utility of RSBI to predict readiness to wean from mechanical ventilation has been questioned,^{14,15} despite the fact that RSBI continues to be widely used among a variety of patients in multiple types of ICUs. Yang¹² observed that the reliability of weaning data is confounded by factors that include patient cooperation, physiologic instability, and lack of standardized measurement techniques. A key factor that may have limited the predictive power of RSBI in some studies may thus be variations in the conditions under which RSBI was measured. In particular, our results suggest that RSBI measurements may not be reliable or consistent unless they are obtained under standardized conditions of ventilator support.

The present study has a number of limitations. For example, it took place in a single institution and involved only a limited number of medical ICU patients. This led to the apparently abnormally elevated upper percentile in the T-piece group from the airway pressure protocol (see Fig. 1). Nevertheless, by having each patient group serve as its own control within each of the 3 protocols, we still had sufficient power to generate a statistically significant

difference in the case of the airway pressure protocol. Our sample size was also limited by the fact that patients with tracheostomy were excluded because we do not routinely use RSBI to assess this patient group for weaning at our institution. Consequently, our sample size did not allow us to determine if the differences we found in RSBI measured on CPAP versus T-piece would persist across ICU patients with different causes of respiratory failure, such as chronic obstructive pulmonary disease, pneumonia, neuromuscular disorders, or acute lung injury. Also, the patients we studied represented a convenience sample. Accordingly, we must be cautious about generalizing the results of our study to all potentially weanable patients, especially as other sources of error, such as test-referral bias,¹⁶ may influence the performance of RSBI as a predictor of weaning. Another limitation is that, with only 2 investigators collecting the data in this study, we were not able to properly assess inter-observer variability. Additionally, our study has the potential for selection bias because the investigators were not blinded to the study hypotheses. Finally, we did not examine the impact of RSBI measurement on clinician decision to attempt weaning and extubation, so we do not know how variations in RSBI affect patient outcomes. This may be an important direction for future research.

Conclusions

In conclusion, in a medical ICU population eligible for weaning from mechanical ventilation, we have demonstrated that RSBI is significantly affected by the level of ventilator support that a patient receives. This variability could alter the sensitivity and negative predictive value originally reported for RSBI by Yang and Tobin.³ On the other hand, RSBI seems to be relatively insensitive to the method used to obtain the breathing pattern parameters required for its calculation, or by the time of day at which it is measured. These factors need to be taken into account when using RSBI to predict the success of spontaneous breathing trials for weaning.

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