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## Effect of pressure support ventilation and positive end expiratory pressure on the rapid shallow breathing index in intensive care unit patients

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**Abstract Objective:** We compared rapid shallow breathing index (RSBI) values under various ventilatory support settings prior to extubation. **Design and setting:** Prospective study in the intensive care unit at a university hospital. **Patients:** Thirty six patients ready for extubation. **Interventions:** Patients were enrolled when receiving pressure support ventilation (PSV) of 5 cmH<sub>2</sub>O, PEEP of 5 cmH<sub>2</sub>O, and FIO<sub>2</sub> of 40% (PS). Subsequently each patient received a trial of PSV of 0 cmH<sub>2</sub>O, PEEP of 5 cmH<sub>2</sub>O, and FIO<sub>2</sub> of 40% (CPAP), a trial of PSV of 0 cmH<sub>2</sub>O, PEEP of 5 cmH<sub>2</sub>O and FIO<sub>2</sub> of 21% (CPAP-R/A), and a 1-minute spontaneously breathing room air trial off the ventilator (T-piece). Trials were carried out in random order. **Measurements and results:** Respiratory frequency (f) and tidal volume (V<sub>T</sub>) were measured during PS, CPAP, CPAP-R/A, and T-piece in all patients. RSBI (f/V<sub>T</sub>) was determined for each patient under all experimental conditions, and the

average RSBI was compared during PS, CPAP, CPAP-R/A, and T-piece. RSBI was significantly smaller during PS (46 ± 8bpm/l), CPAP (63 ± 13bpm/l) and CPAP-R/A (67 ± 14bpm/l) vs. T-piece (100 ± 23bpm/l). There was no significant difference in RSBI between CPAP and CPAP-R/A. RSBI during CPAP and CPAP-R/A were significantly smaller than RSBI during T-piece. In all patients RSBI values were less than 105 bpm/l during PS, CPAP, and CPAP-R/A. However, during T-piece the RSBI increased to greater than 105 bpm/l in 13 of 36 patients. **Conclusions:** In the same patient the use of PSV and/or PEEP as low as 5 cmH<sub>2</sub>O can influence the RSBI. In contrast, changes in FIO<sub>2</sub> may have no effect on the RSBI.

**Keywords** Mechanical ventilation · Rapid shallow breathing index · Pressure support ventilation · Positive end-expiratory pressure · Intensive care unit

### Introduction

Weaning from mechanical ventilation and extubation should be attempted as soon as the patient can sustain spontaneous breathing with effective gas exchange and clearance of airways secretions [1, 2]. The rapid shallow breathing index (RSBI) originally developed by Yang and Tobin [3] in 1991 remains the most widely used indicator for weaning and extubation outcome [4–11]. Yang and Tobin determined the RSBI as the ratio of respiratory

frequency to V<sub>T</sub> during the 1st min immediately after disconnection from ventilatory support while patients are still intubated and breathing spontaneously on room air. Also they reported that a threshold value of 105 bpm/l for the RSBI can best discriminate between successful and failure weaning outcome [3]. Several studies have used the 105 bpm/l threshold value for the RSBI even though their experimental designs were not comparable to that of Yang and Tobin [3]. In these studies V<sub>T</sub> and the respiratory rate were determined during either PSV [9, 12]

during high concentration of inspired oxygen fractions (FIO<sub>2</sub> 40%) [5, 7] and/or in the presence of positive-end expiratory pressure (PEEP) [6, 7, 10]. We have previously shown that the use of PEEP can significantly affect the RSBI in patients following cardiac surgery [13].

In the current study we hypothesized that the choice of ventilatory support settings influences the RSBI in patients receiving mechanical ventilation in the intensive care unit.

## Materials and methods

The study examined patients who were (a) not suffering from chronic obstructive pulmonary disease, (b) hemodynamically and clinically stable, (c) receiving mechanical ventilation in the intensive unit (ICU) for respiratory failure resulting from various medical conditions other than heart failure, and (d) judged ready to undergo an extubation trial by their ICU care team. The criteria for assessing readiness to undergo an extubation trial includes a PaO<sub>2</sub>/FIO<sub>2</sub> ratio of 200 or greater at an FIO<sub>2</sub> of 40%, PEEP of 5 cmH<sub>2</sub>O or lower, ability to cough when suctioned, afebrile status, and no administration of continuous vasopressor or sedative infusions. The study included 36 patients (21 men, 15 women), with mean age of 65 ± 4 years, weight 78 ± 5 kg, and height 171 ± 4 cm. The reason for intubation was pneumonia in 23, sepsis in 10, and pancreatitis in 3.

At the time of inclusion all patients were receiving mechanical ventilation (mean duration 8.7 ± 2.9 days) with a PB-840 ventilator (Tyco Healthcare, Pleasanton, Calif., USA) in the form of PSV with PSV 5 cmH<sub>2</sub>O, PEEP 5 cm H<sub>2</sub>O, and FIO<sub>2</sub> 40%. Prior to extubation attempts RSBI was determined under the initial PSV settings (PS) and with three additional experimental conditions [continuous positive airway pressure (CPAP), CPAP-room air (CPAP-R/A), and T-piece].

During CPAP the PSV was set to 0 cmH<sub>2</sub>O, PEEP was maintained at 5 cmH<sub>2</sub>O, and FIO<sub>2</sub> was maintained at 40%. During CPAP-R/A the PSV was set to 0 cmH<sub>2</sub>O, PEEP 5 cmH<sub>2</sub>O, and FIO<sub>2</sub> 21%. During T-piece the patients were disconnected from the ventilator for exactly 1 min during which they were spontaneously breathing room air. The experimental conditions CPAP and CPAP-R/A were applied for 10–15 min before collection of data which was carried out over a 1-min period while T-piece was maintained for exactly 1 min during which the data were collected. Experimental conditions CPAP, CPAP-R/A, and T-piece were applied in random order; however, following each experimental condition the patient was returned to the original PSV condition for 10–15 min. All patients were monitored with continuous electrocardiography, blood pressure, and pulse oximetry throughout study. The trial was interrupted anytime arterial saturation dropped more than 5% and/or heart rate increased/decreased more than 20–25% of baseline levels, or patient manifested clinical respiratory dis-

stress as reflected by diaphoresis, chest discomfort and pain, or shortness of breath. No significant deterioration was observed in any patient's heart rate, blood pressure, or oxygen saturation that required aborting any of the experimental trials.

V<sub>T</sub> and respiratory frequency during each experimental condition were continuously measured using a computerized pulmonary mechanics monitoring system (COSMO+, Novamatrix Medical Systems, Conn., USA) that incorporates an adult flow sensor which was placed between the endotracheal tube and the Y of the breathing circuit. RSBI was calculated by dividing the average respiratory rate by the average V<sub>T</sub>. Average values for RSBI in each of the four experimental conditions were then determined and compared. This study was approved by the institutional review board, and written consent was obtained prior to initiation of study.

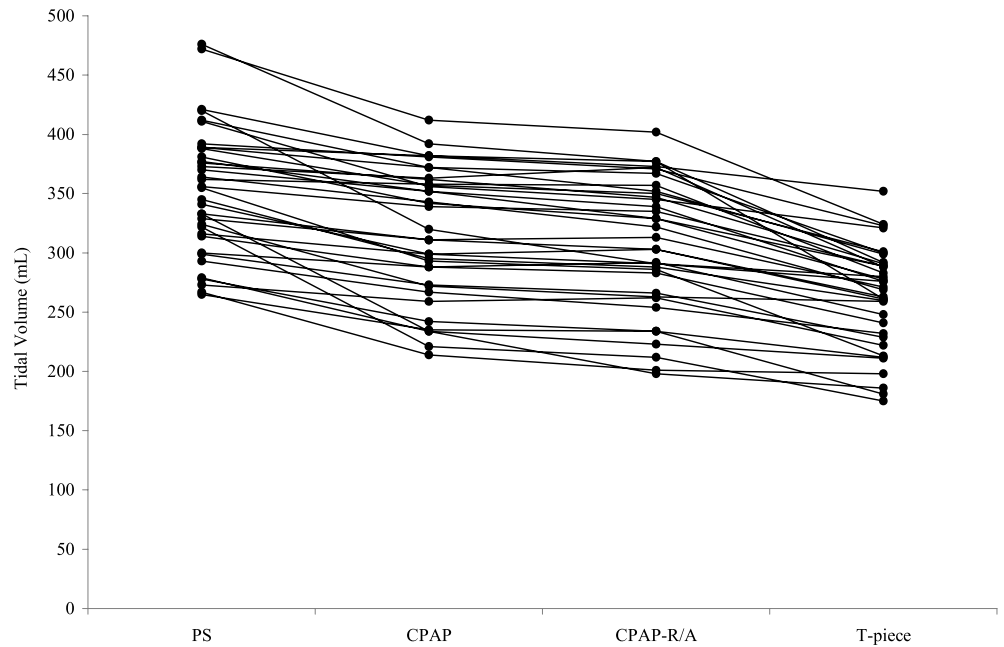
A power analysis was performed to determine the number of subjects needed for the study; for this analysis we considered a 20% change in the RSBI to be clinically significant. We also considered type I and type II errors of 5% and 10%, respectively. A previous pilot study showed that the standard deviation of RSBI is about 35%. Based on this the power analysis indicated that 36 subjects were needed for the study. The average values for RSBI under each of the experimental conditions were compared using analysis of variance for repeated measures, Scheffe's test for post-hoc analysis, and the nonparametric Mann–Whitney *U*-test. Regression analysis was performed to identify whether any of the patients' characteristics and in particular the patient underlying disease and duration of mechanical ventilation had any effect on the changes in the RSBI. Statistical significance was considered at  $p < 0.05$ .

## Results

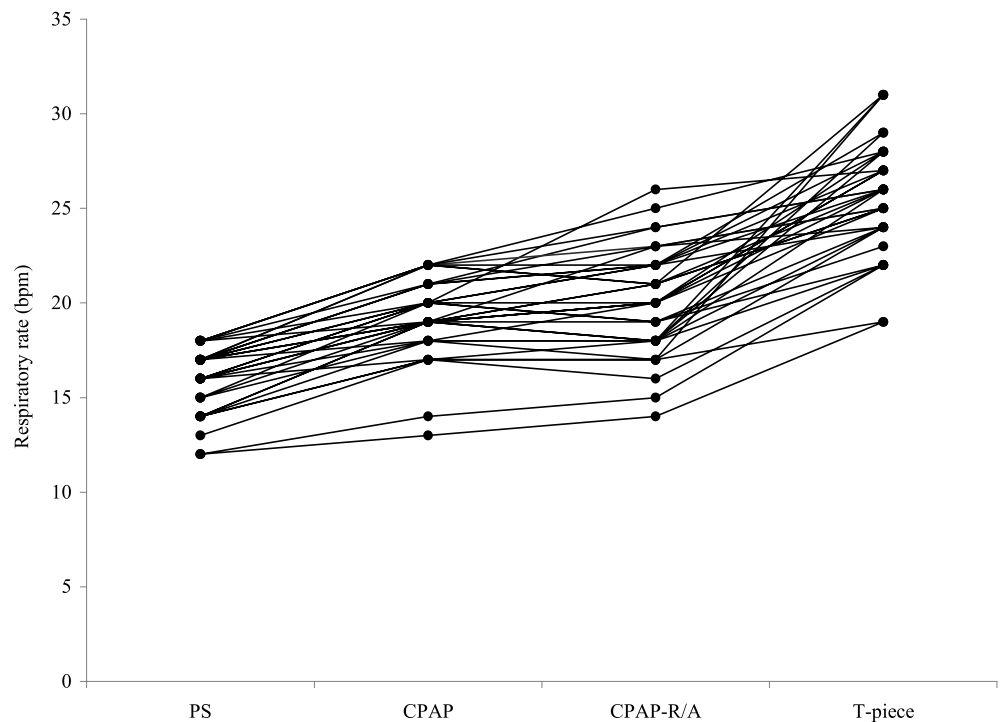
Average RSBI values were significantly lower during PS (46 ± 8bpm/l) than CPAP (63 ± 13bpm/l), CPAP-R/A (64 ± 14bpm/l), and T-piece (100 ± 23bpm/l). There was no significant difference in RSBI between CPAP and CPAP-R/A. However, the average RSBI during either CPAP or CPAP-R/A was significantly lower than that during T-piece. The changes in RSBI between PS, CPAP, CPAP-R/A, and T-piece were due to changes in both the V<sub>T</sub> and respiratory rate (Figs. 1, 2).

In all patients RSBI values were lower than 105 bpm/l during PS, CPAP, and CPAP-R/A (Fig. 3). However, during T-piece the RSBI increased to greater than 105 bpm/l in 13 of 36 patients, and the remaining 23 patients maintained a RSBI of smaller than 105 bpm/l (Fig. 3). All 23 patients who maintained a RSBI lower than 105 bpm/l during T-piece were successfully extubated (no reintubation or noninvasive ventilatory support within 72 h) at the end of the study. Of the 13 patients in whom the RSBI

**Fig. 1** Tidal volume for each patient under the four experimental conditions



**Fig. 2** Respiratory rate for each patient under the four experimental conditions



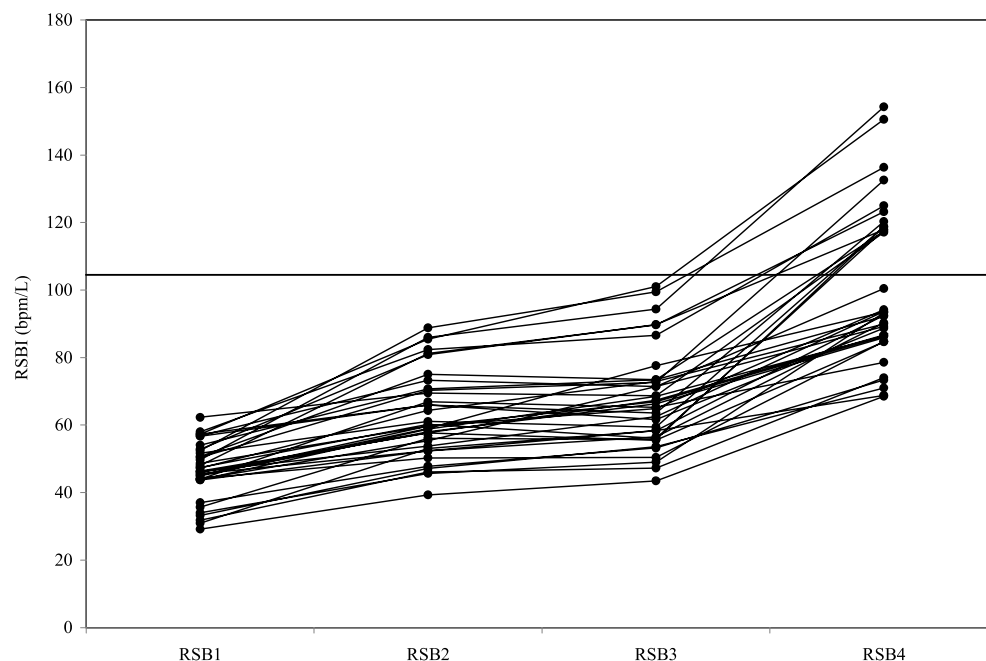
increased to greater than 105 bpm/l during T-piece 10 did not undergo an extubation trials as determined by their ICU medical team, and 3 who were extubated despite their RSBI of greater than 105 bpm/l were reintubated 1.5, 2.5, and 6.5 h after extubation.

Regression analyses showed no statistically significant correlations between the changes in the RSBI and any of the patients' characteristics.

## Discussion

The present study demonstrates that the ventilatory support settings of patients receiving mechanical ventilation in the ICU can significantly influence the RSBI. Values of RSBI significantly decreased during trials of PSV, of CPAP on 40% oxygen, and of CPAP trial on room air as compared to values with 1 min of spontaneously breathing

**Fig. 3** The rapid shallow breathing index for each patient under the four experimental conditions. *Horizontal line*, RSBI of 105 bpm/l



room air and off the ventilator. Also our data show that although all 36 patients had a RSBI lower than 105 bpm/l during trials of PSV and CPAP, values of RSBI increased to greater than 105 bpm/l in 13 of these 36 patients when it was determined under similar experimental conditions as originally described by Yang and Tobin [3] (i.e., during 1 min of spontaneous breathing off the ventilator and while breathing room air). Hence the use of a threshold value of 105 bpm/l for the RSBI during PSV or CPAP may mislead health care professionals into premature discontinuation of mechanical ventilation.

Similar to our current findings, previous studies have reported that the use of PSV [14, 15] or CPAP [16–18] increases the  $V_T$  with concomitant decrease in respiratory rate. These changes in  $V_T$  and respiratory frequency can lead to a significant decrease in the frequency to  $V_T$  ratio (i.e., the RSBI). None of our patients had clinical evidence of heart failure, and as such the increase in the RSBI following the removal of PEEP could not be attributed to a deterioration in the left ventricular function. Previous studies have indicated that the use of PEEP may not provide a significant and sustainable clinical advantage on the breathing pattern [19–21]. However, most of these studies were assessing the long-term effect of discontinuation of positive airway pressure. In the current study the effect of elimination of PSV and/or CPAP was assessed within 10–15 min of the intervention.

In our patients the decrease in  $FIO_2$  from 40% to 21% while maintaining PEEP at 5 cmH<sub>2</sub>O had no significant effect on RSBI. This is in contrast to previous studies [22, 23] that showed significant changes in the breathing pattern due to the step changes in the inspired

oxygen fraction. This may be due to the fact that in our patients the step change in the fraction of oxygen concentration was maintained for short period of time (10–15 min) and when the patients had recovered from the acute phase of their diseases and were deemed ready to undergo an extubation trial by their primary ICU care team.

Our data clearly show that the use of PSV and/or PEEP as low as 5 cmH<sub>2</sub>O resulted in a significant decrease in the RSBI. However, this study was not designed or intended to assess the weaning outcome and/or establish a new cutoff value for the RSBI at different ventilatory support modalities that can best discriminate between successful and failed extubation outcomes, although our current findings warrant future outcome studies to identify such cutoff values. However, this study shows that the use of PSV and/or PEEP can bring patients from the not-able-to-wean (i.e., RSBI > 105 bpm/l) range to the able-to-wean (i.e., RSBI < 105 bpm/l) range, as evidenced by the 13 patients in whom the RSBI changed from the able-to-wean range to the not-able-to-wean range when the PSV and PEEP were eliminated. The characteristics of patients with RSBI lower than 105 bpm/l did not differ significantly from those with RSBI higher than 105 bpm/l during 1-min T-piece breathing trial (Table 1), and regression analysis indicated that the observed changes in the RSBI could not be attributed to differences in the patients' age or to the reason for or duration of mechanical ventilation. Also, there was no significant difference in the fluid balance since our data were collected over a short period of time (2–3 h) on stable patients with similar clinical characteristics and normal cardiac and renal function. Therefore

**Table 1** Demographic data of patients by RSBI during 1-min T-piece breathing trial

	RSBI < 105 bpm/l (n = 23)	RSBI > 105 bpm/l (n = 13)
Age (years)	65 ± 4	64 ± 4
Gender: M/F	15/8	8/5
Weight (kg)	78 ± 4	78 ± 5
Height (cm)	171 ± 3	171 ± 4
Reason for intubation		
Pneumonia	15	8
Sepsis	6	4
Pancreatitis	2	1
Duration of mechanical ventilation prior to enrollment (days)	8.7 ± 2.6	8.5 ± 3.4

changes in the RSBI can only reflect the changes in the ventilatory support modalities.

In our study the use of a 1-min equilibration period during T-piece breathing in comparison to 10- to 15-min equilibration periods in PS, CPAP, and CPAP-R/A could not have affected the determination of the RSBI. During T-piece breathing we intended to use the same experimen-

tal conditions exactly as previously described by Young and Tobin [3]. However, with the other ventilatory modalities an equilibration period of 10–15 min was allowed in order for the patient to stabilize on each modality. Previous studies [10, 24] have reported that there were no statistically significant differences between RSBI values determined from data collections of 5 min compared with those of 10 and 15 min, with a coefficient of variation as low as 3%. A retrospective analysis of our data showed that there were no statistically significant differences in the RSBI at 1, 5, 10, and 15 min after initiation of each ventilatory modality.

## Conclusion

The current study shows that the choice of ventilator support settings in ICU patients has a significant effect on RSBI values. The predictive value of the RSBI reported by Yang and Tobin [3] should be adopted only if the index value is determined under similar experimental conditions to those applied by Yang and Tobin where patients were disconnected off the ventilator and spontaneously breathing room air for 1 min.

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