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Rapid Shallow Breathing Index and Its Predictive Accuracy Measured under Five Different Ventilatory Strategies in the Same Patient Group

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Abstract

The rapid shallow breathing index (RSBI) is commonly used clinically for predicting the outcome of weaning from mechanical ventilation. We compared the RSBI and its predictive accuracies measured under 5 ventilatory strategies before weaning trials. Ninety-eight patients were included and divided into successful (n = 71) and failed (n = 27) groups based on their weaning outcomes. The RSBI was randomly measured when patients spontaneously breathed 21% O_2 with no ventilator support (the control strategy) or were connected to ventilator breathing with 21% or 40% O_2 and 0 or 5 cmH_2O of continuous positive airway pressure (CPAP). We found that the RSBI values did not exhibit significant differences among the 4 ventilator strategies, but all were higher than that of the control; this remained valid in the non-chronic obstructive pulmonary disease (COPD) subgroup, but not in the COPD subgroup. Values of the area under the receiver operating characteristic curve of the RSBI for the 5 strategies were 0.51~0.62 with no significant difference between any 2 strategies. The incidences of adverse reactions (respiratory rate ≥ 35 breaths/min or oxygen saturation ≤ 89% for ≥ 1 min) were relatively high for the 21% O_2-0 and 5 cmH_2O CPAP groups (20 patients each) and low for the 40% O_2-5 cmH_2O CPAP group (2 patients). We concluded that RSBI values increased with the use of a ventilator, but not with additional applications of 40% O_2 and/or 5 cmH_2O CPAP. Their accuracies for predicting weaning outcome were unaltered by any of these interventions, but the incidence of adverse reactions increased with the use of the ventilator and decreased with additional 40% O_2 supplementation.

Key Words: mechanical ventilation, ventilator weaning, rapid shallow breathing index, continuous positive airway pressure, receiver operating characteristic curve

Introduction

Various weaning predictors have been developed for deciding the time to wean patients off a ventilator (31, 39). Among them, the rapid shallow breathing index (RSBI) is superior to others for predicting weaning

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success (8, 18, 35, 39). Originally, the RSBI measurement was performed immediately after discontinuation of ventilatory support while patients were still intubated and had spontaneously breathed room air for 1 min (39). A threshold RSBI of 105 breaths/min/l was suggested to have good predictive accuracy (39). To avoid patient distress and discomfort, the RSBI measurement was modified to obtain values when patients were still connected to the ventilator with various strategies such as supplementation with different fractions of inspired oxygen (FiO_2) and application of continuous positive airway pressure (CPAP). These modified methods of the RSBI measurement are widely used (9, 13, 15, 22, 24, 27, 30, 32, 35).

That differences in ventilatory strategies, such as the use of a ventilator with O_2 supplementation and application of CPAP, may influence RSBI values is a generally accepted concept (13, 22, 40), but this remains to be verified. This concept evolved from observations reported by different studies with dissimilar patient populations and measurement methods, all of which may themselves have affected the threshold values of RSBI for predicting weaning outcomes (3, 7, 11, 20, 21, 24, 27, 30, 35, 39). Therefore, the extent the RSBI and its predictive accuracy are influenced by O_2 supplementation and CPAP is still unknown. Conceivably, comparison of the RSBI and its predictive accuracies measured under different ventilatory strategies in the same group of patients would directly resolve this uncertainty, yet so far no such studies have been carried out.

The purpose of this study was to compare the RSBI values, the incidence of adverse reactions, and the predictive accuracy measured under 5 different ventilatory strategies before weaning trials in the same patient group. The strategies used in this study were: spontaneously breathing room air with no ventilator, the original method used by Yang and Tobin (39) (used in this study as the control strategy), and breathing 21% or 40% O_2 combined with 0 or 5 cmH_2O CPAP when patients were still connected to the ventilator. If a difference was found among these 5 ventilatory strategies, a simulated test lung model was used to measure the breathing load through the circuits of these 5 strategies.

Materials and Methods

Subjects

Ninety-eight consecutive and intubated medical patients were included when they met the criteria for assessing a readiness to wean which included reversal or improvement of the underlying cause of respiratory failure, an afebrile status, stable cardiovascular and metabolic functions, a PaO_2/FiO_2 ratio of ≥ 200 at an FiO_2 of 40% and a positive end-expiratory pressure (PEEP) of ≤ 5 cmH_2O, and no administration of continuous vasopressor or sedatives (23, 31). They were divided into successful (n = 71) and failed (n = 27) groups based on their weaning outcomes. No patients presented ongoing lung or neuromuscular disease or signs of increased intracranial pressure although 28 patients had a chronic post-stroke status, 2 patients had a post-traumatic head injury status, and 3 patients had Parkinson's disease. Their Glasgow coma scale scores were all ≥ 8. On inclusion, they were mechanically ventilated with a T-Bird ventilator (Bird Product, Palm Springs, CA, USA) connecting to a standard-length circuit. The ventilator settings were: assist-controlled, pressure support (PS), or synchronized intermittent mandatory ventilation plus PS mode, an FiO_2 of ≤ 40%, a PEEP of ≤ 5 cmH_2O, and a flow-triggering sensitivity setting of 1 l/min. The decision to discontinue or reinstitute the mechanical ventilator was made by the primary physicians who were blinded to the study design. Patients were continuously monitored by electrocardiography, a blood pressure gauge, and a pulse oximeter during the study. The study was approved by the Institutional Review Board of the Taipei Veterans General Hospital (approval no.: VGHIRB 93-09-02A). All patients or their next of kin gave written consent before enrolment into the study.

Experimental Protocols

Before the study, routine measurements of maximal inspiratory pressure (Pimax) and maximal expiratory pressure (Pemax) were performed using previously reported methods (25, 37). Ten minutes or more later, if the patient's Pimax was ≤ -20 cmH_2O, the spontaneous minute ventilation and respiratory frequency were randomly measured with a Haloscale Wright spirometer (Ferraris Medical, London, UK) immediately after discontinuation of the ventilatory support while patients were still intubated and had spontaneously breathed room air for 1 min (39) (the control strategy) and 4 other different ventilator settings with a CPAP of 0 or 5 cmH_2O plus an FiO_2 of 21% or 40% with no mandatory breathing or pressure support. During each of the 4 ventilator strategies, at least a 2-min period of stabilization was allowed when patients presented a stable breathing pattern with the least deviation in the respiratory parameters appearing in the ventilator's display window. The minute ventilation and respiratory rate (RR) at the end of the next minute were recorded from the ventilator's display window. At least 10 min was allowed to elapse between any 2 strategies to allow clinical and physiological conditions of the patients to return to the baseline (RR: ± 5/min, pulse rate:

± 10 no./min, oxygen saturation measured by the pulse oximeter (SpO_2): ± 2%). At that time, the patient was reconnected to the ventilator with the original ventilator settings. Only patients with an RR of ≤ 38 breaths/min under the control strategy were included and proceeded to the weaning trial of PS ventilation at 5 (normal lung) or 10 cmH_2O (COPD lung) for 60 min. Successful weaning was defined as patients who were free from the ventilator for over 48 h after extubation. A weaning failure was defined as weaning trial failure or reinstitution of ventilator support either by non-invasive or invasive mechanical ventilation within 48 h of extubation based on the situation and previously reported criteria (5). For reinstitution of ventilatory support, noninvasive mechanical ventilation was the first choice unless the patients had contraindications to its use or presented severe cardiopulmonary distress immediately after extubation. Patients on whom non-invasive mechanical ventilation was used but whose symptoms of cardiopulmonary distress did not improve within 60 min (2, 28) were re-intubated.

Measurement of Breathing Load Using a Test Lung

A 2-chamber test lung (TTL Dual Adult Pneuview® System Model 5600i, Michigan Instruments, Grand Rapids, MI, USA) was used to compare the external resistive loads imposed by the 5 ventilatory strategies used in this study. The left-side chamber (the driving chamber) was connected to a Breath Simulation Model (BSM, Michigan Instruments), and the right-side chamber (the experimental chamber) was connected to a T-Bird ventilator with the standard-length circuit or a Haloscale Wright spirometer. Compliance and resistance settings of both test lungs were 0.10 l/cmH_2O and an Rp of 20 cmH_2O/l/sec, respectively, as suggested by the manufacturer. The inspiratory time setting was 1 s in the BSM, and the breathing rate (24 breaths/min) and tidal volume were adjusted to match the mean values measured under these 5 ventilatory strategies. A pulmonary mechanical monitoring system (CO_2SMO+ Model 8100, Respironics Novametrix, Wallingford, CT, USA) was used to record the pressure, volume, and flow signals for 10 min for each of the 5 test conditions.

Data Analysis

In each test condition, data of the RR, minute ventilation, calculated tidal volume, and RSBI values were averaged in 98 patients. The RR, mean arterial blood pressure, pulse rate, and SpO_2 were also recorded before and after each test condition. The number of patients experiencing adverse reactions (RR ≥ 35 breaths/min or SpO_2 ≤ 89% for ≥ 1 min) was counted. The accuracy of the RSBI as a weaning predictor using a cutoff value of 105 breaths/min/l was reflected by its sensitivity, specificity, positive and negative predictive values, and diagnostic accuracy. Mean values of the respiratory parameters for 10 min of data of the 5 simulated conditions using the test lung were also calculated.

Statistical Analysis

A power analysis was performed to determine the number of subjects needed for the study; for this purpose, we considered a 20% change in the RSBI to be clinically significant. We also considered type I and II errors of 5% and 10%, respectively. Our previous study (5) showed that the coefficient of variation of RSBI is about 49%. The power analysis indicated that 78 subjects were needed for the study. Categorical variables were analyzed by Chi-squared or Fisher's exact test. Friedman repeated-measures analysis of variance on ranks and Dunn's method were used to compare the RSBI values measured under the 5 strategies. Wilcoxon's signed-rank test was applied to compare the physiological parameters before and after measurement. The predictive performance of the RSBI measured under the 5 strategies and their pair-wise comparison with a cutoff value of 105 breaths/min/l for each strategy were assessed by analysis with the receiver operating characteristic (ROC) curve. Data obtained from the study of the test lung were analyzed by one-way analysis of variance (ANOVA) followed by Bonferroni's test for *post-hoc* comparisons. All data are presented as the means ± SD except for data of the area under the ROC curve which are presented as the means ± SEM. A value of $P < 0.05$ was considered statistically significant.

Results

Patient Characteristics

All patients successfully completed the RSBI measurement under the 5 ventilatory strategies but 2 of them presented signs of weaning failure during the weaning trials and were not extubated. Another 25 patients completed the weaning trials but presented signs of weaning failure after extubation. Among these 27 patients who failed to wean, 21 were treated with non-invasive positive-pressure ventilation *via* a face mask, and 4 were reintubated and reconnected to the ventilator. The physical and clinical characteristics of the successful, failed, and total patient groups are listed in Table 1. As shown, chronic obstructive pulmonary disease (COPD) was the most-frequent admission diagnosis (43.9%) of these patients. Five patients in the failed group were intubated through

Table 1. Physical and clinical characteristics of patients

Variable	Total (n = 98)	Successful (n = 71)	Failed (n = 27)
Age (years)	76 ± 10	77 ± 9	76 ± 11
Gender (n of male/female)	68/30	50/21	18/9
Glasgow coma scale (EVM)	4T5	4T5	4T5
APACHE II on admission to ICU	17 ± 4	17 ± 4	16 ± 4
MV duration (day)	11 ± 10	11 ± 11	9 ± 7
Type of ETT (n in oral/nasal)	93/5	71/0	22/5*
Internal diameter of ETT (n at 7.0/7.5 mm)	12/86	7/64	5/22
Reasons for need of mechanical ventilation: n (%)			
Acute exacerbation of COPD	43 (44)	28 (39)	15 (56)
Pneumonia	20 (21)	16 (23)	4 (15)
Heart failure	10 (10)	8 (11)	2 (7)
Neurological diseases	10 (10)	7 (10)	3 (11)
Sepsis	3 (3)	2 (3)	1 (4)
Others	12 (12)	10 (14)	2 (7)
Past history (n): Respiratory disease	64	47 17	
Cardiovascular disease	45	33	12
Neuromuscular disease	33	24	9
Ventilator settings prior to measurement:			
Mode: ACMV/SIMV+PS/PS (n of patients)	7/2/89	5/1/65	2/1/24
Fraction of inspired oxygen	0.29 ± 0.06	0.29 ± 0.05	0.31 ± 0.07
Positive end-expiratory pressure (cmH_2O)	5 ± 1	5 ± 2	5 ± 1
Pimax (cmH_2O)	-39 ± 10	-39 ± 10	-38 ± 10
Pemax (cmH_2O)	53 ± 31	54 ± 31	48 ± 33

Values are the means ± SD. EMV, eyes open, motor response, and verbal response; APACHE II, Acute Physiologic and Chronic Health Evaluation II; ICU, intensive care unit; MV, mechanical ventilation; ETT, endotracheal tube; COPD, chronic obstructive pulmonary disease; ACMV, assist-controlled mechanical ventilation; SIMV, synchronized intermittent mandatory ventilation; PS, pressure support.
*$P < 0.05$ *vs*. the successful group.

the nasal cavity whereas all patients in the successful group were intubated through the oral cavity. Other characteristics including age, gender, Glasgow coma scale, APACH II score, number of days on mechanical ventilation, types and size of endotracheal tube, reasons for the need for mechanical ventilation, with or without history of respiratory, cardiovascular or neuromuscular disease, ventilator settings prior to measurement, and values of Pimax and Pemax showed no significant difference between the successful and failed groups. The post-weaning-trial $PaCO_2$ significantly increased (41.30 ± 10.72 mmHg; $P < 0.05$; n = 98) and pH significantly decreased (7.46 ± 0.06; $P < 0.05$; n = 98) compared to values measured before the measurement of the 5 strategies ($PaCO_2$ = 38.07 ± 10.02 mmHg; pH = 7.49 ± 0.07) in the total group. These changes, however, were within clinically acceptable ranges. Comparison of other parameters including PaO_2 (before, 97.34 ± 27.74 *vs*. after, 96.22 ± 26.04 mmHg; n = 98) and HCO_3^- (before, 29.67 ± 7.84 *vs*. after, 29.06 ± 8.28 mEq/l; n = 98) showed no statistical significance in the total group.

Rapid Shallow Breathing Index (RSBI)

Fig. 1 shows that RSBI values measured under the 4 ventilator strategies were all higher than that of the control; the higher RSBI values were due to lower tidal volumes, not a lower respiratory rate. Additionally, RSBI values did not significantly vary among these 4 ventilator strategies regardless of whether 40% O_2 supplementation or 5 cmH_2O CPAP was used. Since acute exacerbation of COPD was the most frequent admission diagnosis, we sub-grouped patients with and without this etiology. The finding that patients had higher RSBI values measured under 4 ventilator strategies remained valid in the non-COPD subgroup but not the COPD subgroup (Fig. 2).

Adverse Reactions

Table 2 shows that the mean arterial blood

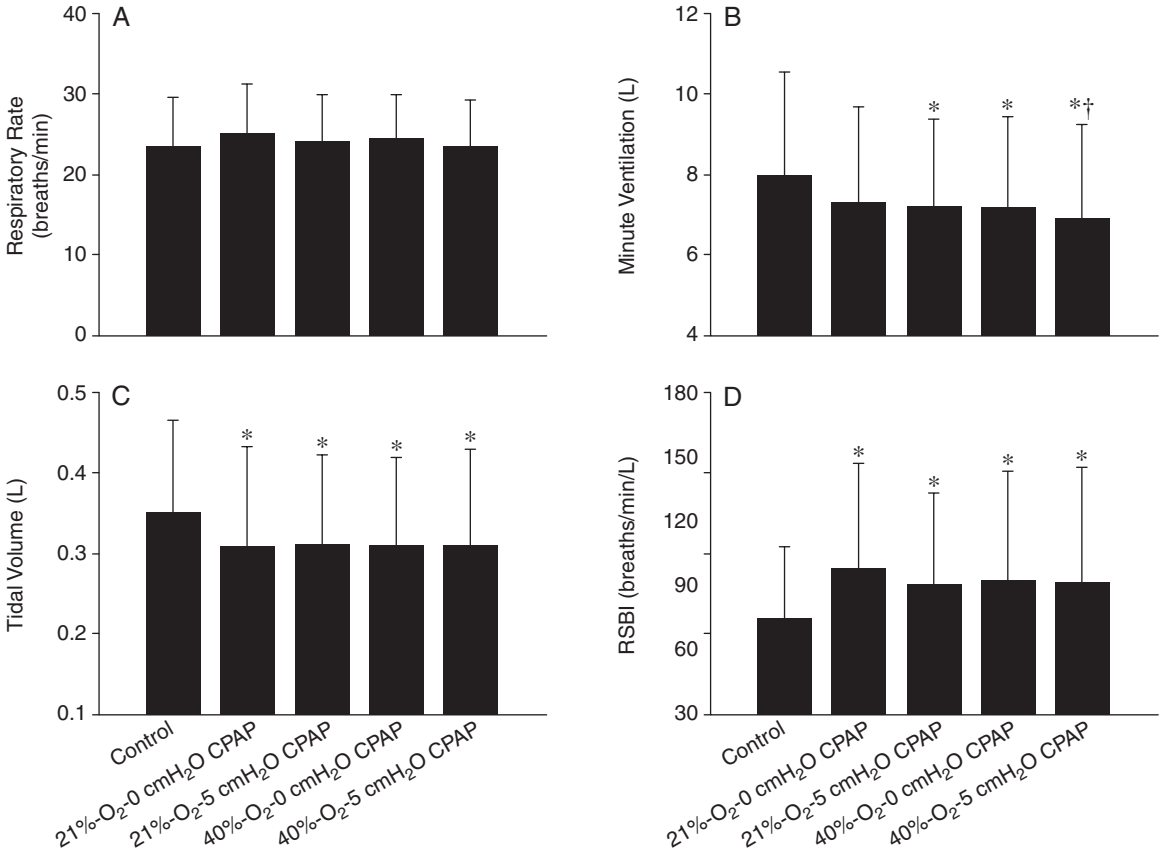

Fig. 1. Average values of (A) the respiratory rate, (B) minute ventilation, (C) tidal volume, and (D) rapid shallow breathing index (RSBI) measured in 98 patients when disconnected from the ventilator and breathing room air (the control strategy), breathing spontaneously through the ventilator with settings of the fraction of inspired oxygen of 21% or 40% combined with a continuous positive airway pressure (CPAP) of 0 or 5 cmH_2O (21% O_2-0 cmH_2O CPAP, 21% O_2-5 cmH_2O CPAP, 40% O_2-0 cmH_2O CPAP, and 40% O_2-5 cmH_2O CPAP, respectively) for 1 min. Data are the means ± SD. Note that the RSBI values measured under the 4 ventilator settings were higher than that of the control strategy. $P < 0.05$ *vs.* * the control or *vs.* †21% O_2-0 cmH_2O CPAP.

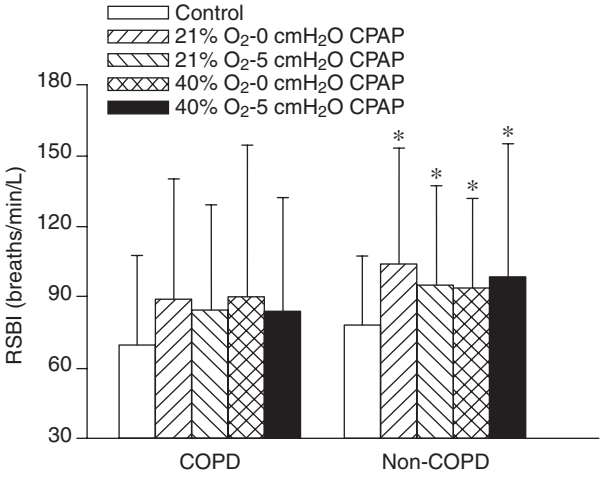

Fig. 2. Average values of the rapid shallow breathing index (RSBI) in patients with or without acute exacerbation of chronic obstructive pulmonary disease (COPD) (n = 43 and 55, respectively) measured under 5 ventilatory strategies as described in Fig. 1. Data are the means ± SD. Note that the RSBI values measured under the 4 ventilator settings were significantly higher than that of the control strategy in the non-COPD subgroup but did not reach a significant level in the COPD subgroup. *$P < 0.05$ *vs.* the control.

Table 2. Respiratory rate, mean arterial blood pressure, pulse rate, and oxygen saturation measured before and after weaning parameter measurements under 5 ventilatory strategies in all patients (n = 98)

	Respiratory rate (breaths/min)	Mean arterial blood pressure (mmHg)	Pulse rate (no./min)	SpO_2 (%)
Control strategy				
Before	18 ± 4	80 ± 12	88 ± 15	97 ± 2
After	22 ± 5*	82 ± 14	90 ± 15*	94 ± 4*
21% O_2-0 cmH_2O CPAP				
Before	18 ± 4	80 ± 13	88 ± 16	97 ± 3
After	23 ± 5*	81 ± 13	90 ± 16*	93 ± 5*
21% O_2-5 cmH_2O CPAP				
Before	18 ± 4	81 ± 15	88 ± 15	97 ± 3
After	22 ± 5*	82 ± 13	90 ± 16*	93 ± 4*
40% O_2-0 cmH_2O CPAP				
Before	18 ± 4	80 ± 12	87 ± 16	96 ± 3
After	22 ± 5*	83 ± 13	89 ± 16*	96 ± 4
40% O_2-5 cmH_2O CPAP				
Before	17 ± 4	80 ± 14	88 ± 16	96 ± 3
After	22 ± 5*	82 ± 13	87 ± 17	97 ± 3

Values are the means ± SD. Control strategy, patients were disconnected from the ventilator and breathed room air; 21% O_2-0 cmH_2O CPAP and 21% O_2-5 cmH_2O CPAP, patients breathed spontaneously through the ventilator with settings of the fraction of inspired oxygen (FiO_2) of 21% and continuous positive airway pressure (CPAP) of 0 or 5 cmH_2O; 40% O_2-0 cmH_2O CPAP and 40% O_2-5 cm H_2O CPAP, patients breathed spontaneously through the ventilator with settings of FiO_2 of 40% and CPAP of 0 or 5 cmH_2O; SpO_2, oxygen saturation measured by a pulse oximeter.
*$P < 0.05$ *vs*. the value before the measurement for the same parameter.

Table 3. Accuracy of the rapid shallow breathing index in predicting weaning success with a cutoff value of 105 breaths/min/l

Index	Sensitivity	Specificity	Positive predictive value	Negative predictive value	Diagnostic accuracy
Control strategy	0.86	0.11	0.72	0.23	0.65
21% O_2-0 cmH_2O CPAP	0.62	0.30	0.70	0.23	0.53
21% O_2-5 cmH_2O CPAP	0.68	0.33	0.73	0.28	0.58
40% O_2-0 cmH_2O CPAP	0.73	0.30	0.73	0.30	0.61
40% O_2-5 cmH_2O CPAP	0.76	0.33	0.75	0.35	0.64

Values shown were derived from 71 successfully weaned patients and 27 patients in whom weaning failed. Abbreviations are defined in the footnotes to Table 2.

pressure did not change and the respiratory rate significantly increased after each test of the 5 strategies. The pulse rate significantly increased after the test in the control, 21% O_2-0 cmH_2O CPAP, 21% O_2-5 cmH_2O CPAP, and 40% O_2-0 cmH_2O CPAP groups, whereas SpO_2 significantly decreased after the test in the control and 21% O_2-0 or 5 cmH_2O CPAP groups. The numbers of patients displaying adverse reactions after the tests in the control, 21% O_2-0 or 5 cmH_2O CPAP, and 40% O_2-0 or 5 cmH_2O CPAP groups were 16, 20, 20, 4 and 2, respectively.

Predictive Accuracy of the RSBI

Areas under the ROC curve of RSBI measured in the control, 21% O_2-0 or 5 cmH_2O CPAP, and 40% O_2-0 or 5 cmH_2O CPAP groups were 0.62 ± 0.07, 0.51 ± 0.07, 0.57 ± 0.07, 0.55 ± 0.07, and 0.56 ± 0.07, respectively, and no significant difference was found between any 2 strategies. We further used a threshold value of the RSBI of ≤ 105 breaths/min/l to analyze the accuracies of predicting weaning success. As shown in Table 3, the RSBI measured under each

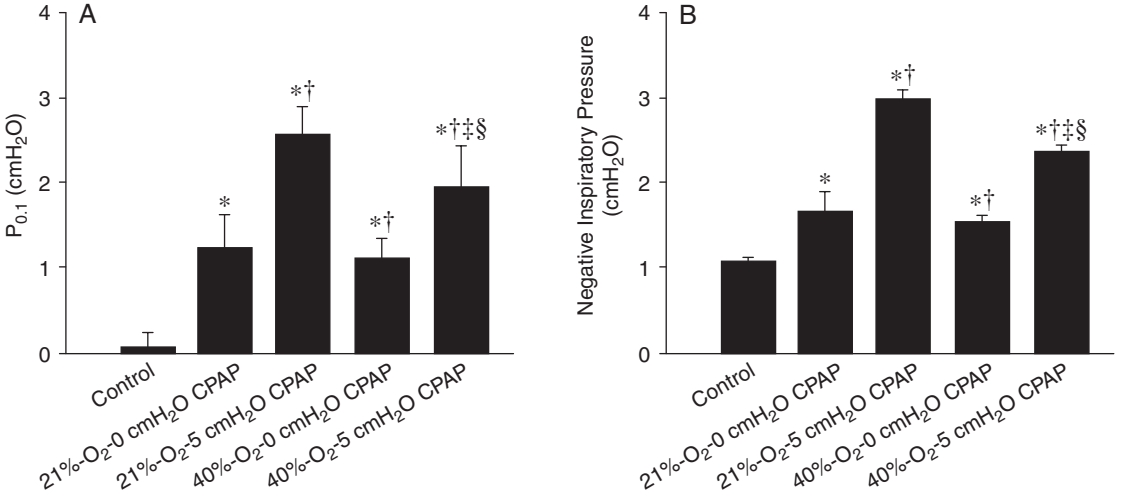

Fig. 3. Average absolute values of (A) airway occlusion pressure at 0.1 s ($P_{0.1}$) and (B) negative inspiratory pressure measured under the control strategy with the Haloscale and 4 ventilator strategies with a T-bird in a simulated lung model for 10 min. Under a similar respiratory rate (24 breaths/min) and tidal volume in each of 5 test conditions as described in Fig. 1, the control strategy had the lowest $P_{0.1}$ and negative inspiratory pressure. Application of 5 cmH_2O continuous positive airway pressure (CPAP) produced a higher $P_{0.1}$ and negative inspiratory pressure, compared to strategies with no CPAP. $P < 0.05$ *vs.* * the control, *vs.* †21% O_2-0 cmH_2O CPAP, *vs.* ‡21% O_2-5 cmH_2O CPAP, or *vs.* §40% O_2-0 cmH_2O CPAP.

strategy had high sensitivity and positive predictive values and low specificity and negative predictive values as reported previously (8, 11, 15, 18, 21, 27, 30, 35, 39).

Breathing Load Measurement Using the Simulated Test Lung

Fig. 3 shows the data obtained from 240 breaths during breathing load measurements using the simulated test lung. As shown, the 4 ventilator strategies imposed higher external resistive loads as revealed by a higher airway occlusion pressure at 0.1 s ($P_{0.1}$) and negative inspiratory pressure recorded by the CO_2SMO+ monitoring system compared to the control. Additionally, application of 5 cmH_2O CPAP produced a higher external resistive load compared to strategies with no CPAP.

Discussion

Our results demonstrate that the use of a ventilator increased RSBI values in our patients, whereas additional applications of 40% O_2 and/or 5 cmH_2O CPAP did not further influence RSBI values. This increase in RSBI values, however, was only observed in the non-COPD subgroup but not the COPD subgroup. Furthermore, the increase in RSBI values was within a range that did not result in a loss of predictive accuracy of the RSBI for weaning outcomes. When we set the cutoff RSBI value at 105 breaths/min/l, the control strategy or 40% O_2-5 cmH_2O CPAP seemed to have the best diagnostic accuracy of predicting weaning success. Moreover, the incidence of adverse reactions was high under 21% O_2-0 and 5 cmH_2O CPAP, but greatly decreased by additional 40% O_2 supplementation. It appears that using a strategy of 40% O_2-5 cmH_2O CPAP to measure RSBI values in our patient group was superior to the others because it produced less risk of cardiorespiratory distress in patients during the RSBI measurement.

The lower RSBI values measured under the control strategy may have been due to a less-resistive load for the breathing circuit. It is known that spontaneous breathing through modern ventilators and circuits imposes a burden of increased work (4) which affects RSBI values (19). Spontaneous breathing through T-bird series ventilators with the standard circuit used in this study was demonstrated to significantly increase inspiratory and expiratory trigger pressure and delay time in a simulated lung model study (33). Thus, these ventilator strategies would significantly elevate the resistive load to respiration compared to the scenario of the Haloscale Wright respirometer[a]. We found the lowest $P_{0.1}$ and negative inspiratory pressure in the control which may represent the least work which was done, and those 4 ventilator strategies imposed higher external resistive loads

[a] Haloscale Wright Respirometer Operating Instructions. Londan, UK: FdE Ferraris Medical Limited, 1985.

compared to the control. Curiously, our simulated tests showed that the additional application of 5 cmH_2O CPAP produced a higher external resistive load compared to strategies with no CPAP, yet it did not further increase the RSBI values measured in patients. This was possibly due to the fact that the influence of resistive load on RSBI values imposed by the ventilator had already reached its maximal effect. Thus, although 2 of the ventilatory strategies tested in this study had 5 cmH_2O CPAP, their influences of resistive load on RSBI values were similar to those produced by the other 2 ventilator strategies without 5 cmH_2O CPAP. Additionally, we found that significant increases in the RSBI value produced by the use of the ventilator were only noted in the non-COPD subgroup, not in the COPD subgroup. COPD is known to result in complex changes in the control of breathing as well as the internal restrictive elastic mechanical properties of the respiratory pump (26). It is possible that our COPD patients had already developed some compensatory mechanism (26) resulting in a reduced responsiveness of the central controller and respiratory muscles to the external resistive load imposed by the ventilator. Alternatively, COPD patients might not respond positively or establish certain compensatory mechanisms to an unnecessary imposed load. The other intriguing finding in our simulated tests is that both $P_{0.1}$ and negative inspiratory pressure measured in the 21% O_2-5 cmH_2O group were slightly greater than those measured in the 40% O_2-5 cmH_2O group. The circuit was the same for these 2 conditions, and the only difference was the FiO_2. The exact reason for these slight differences in $P_{0.1}$ and negative inspiratory pressure in the simulated tests between these 2 strategies remains unknown.

Yang and Tobin reported that O_2 supplementation can lower minute ventilation (40). However, this O_2 effect was observed when patients were undergoing spontaneous breathing trials (40). Our findings are consistent with those reported by El-Khatib *et al*. who demonstrated no influence of applying 40% O_2 on RSBI values in coronary artery bypass graft patients or intensive care unit patients on ventilatory support (13, 14). On the other hand, our finding regarding no CPAP effect on RSBI values differs from those reported by El-Khatib *et al*. who found a reduction in RSBI values when applying 5 cmH_2O of CPAP (13, 14). This discrepancy may have been due to the fact that in their patients, the presence of PEEP may have improved alveolar recruitment and arterial-alveolar oxygen gradients (12, 17, 38). Our patients had a broad variety of medical problems, and 64.3% of patients needed mechanical ventilation due to acute exacerbation of COPD and pneumonia. No oxygenation problems were noted before the measurement. Positive end-expiratory pressure may change the mechanics differently in post-cardiac surgery patients than COPD patients. Additionally, T-Bird ventilators, which were used in our study, may impose a greater amount of work to breathe for patients than do PB 7200 and 840 ventilators used in Khatib *et al.*'s study, which may have affected RSBI values. Although both studies used the same breathing circuits (4, 6, 16, 33), El-Khatib *et al*. applied CPAP for 15 min before collecting the data (13, 14), whereas we applied CPAP for only 3 min. Our analysis of the area under the ROC curve showed that the predictive accuracies of the RSBI measured under these 5 strategies were lower than those reported previously (8, 9, 18, 21, 35, 39). Similarly, using a cutoff RSBI value of 105 breaths/min/l, the diagnostic accuracies of predicting weaning success measured under these 5 strategies were also lower than those reported previously (8, 18, 21, 37). A heterogeneous population with a high percentage of acutely exacerbated COPD patients in our patients may have contributed to these results (1, 10, 29).

Use of the RSBI alone to predict weaning outcome is still controversial (23, 34, 36). The RSBI has been reported not to be a reliable weaning predictor based on a meta-analysis of likelihood ratios, and clinicians were recommended to bypass its measurement and begin the weaning process with a trial of spontaneous breathing (23). Including the RSBI as a weaning predictor in a protocol was reported to prolong weaning time (34). Therefore, clinicians were suggested not to use the RSBI routinely in weaning decision-making (34). However, for the purpose of selecting cases with a certain condition at the earliest possible time, the RSBI constitutes a reliable screening test (26). In this study, we did not focus on this issue, but the predictive accuracy of the RSBI under each condition did not show satisfactory values.

In summary, RSBI values increased with the use of a ventilator but not by additional applications of 40% O_2 and/or 5 cmH_2O CPAP. The predictive accuracy of the RSBI for weaning outcomes was unaltered by any of these interventions. While the incidence of adverse reactions increased with the use of the ventilator, it decreased with additional 40% O_2 supplementation. The findings of this study can benefit clinicians when choosing an appropriate method to measure the RSBI and determining how to use its value for clinical decision-making.

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