

Determining the Best Threshold of Rapid Shallow Breathing Index in a Therapist-Implemented Patient-Specific Weaning Protocol

David C Chao MD and David J Scheinhorn MD

BACKGROUND: For weaning patients from prolonged mechanical ventilation, we previously designed a respiratory-therapist-implemented weaning protocol that decreased median weaning time from 29 days to 17 days. An acceleration step at the start of the protocol allowed patients with a rapid shallow breathing index (RSBI) of ≤ 80 to advance directly to spontaneous breathing trials (SBTs). **METHODS:** We prospectively evaluated whether calibrating the RSBI threshold allowed more patients to safely accelerate to the 1-hour SBT in the protocol, and whether that correlated with weaning duration and outcome. If the patient passed the clinical stability screening, the respiratory therapist calculated the RSBI and then attempted a 1-hour SBT. If the pre-SBT RSBI was > 80 , the SBT was attended by an investigator, with continuous electrocardiography and pulse oximetry. This SBT was followed by continued weaning efforts, as dictated by the weaning protocol. The data were analyzed using receiver operating characteristic curves and univariate and multivariate analyses. **RESULTS:** One hundred ninety-one patients (with a wide range of RSBIs [10 to 1,248]) underwent 1-hour SBT, of whom 26 failed weaning and 165 succeeded. RSBI correlated with 1-hour SBT outcome; the area under the receiver operating characteristic curve was 0.844. Plotting the sensitivity and specificity together against RSBI allowed calibration of the RSBI threshold to the desired level of false positives and false negatives. Accuracy was maximized (81.7%) at an RSBI of 97. Tolerance of a 1-hour SBT, using the new RSBI threshold, correlated with duration of weaning and weaning outcome. **CONCLUSIONS:** The conservative RSBI threshold of ≤ 80 can be raised for patients weaned with our respiratory-therapist-implemented weaning protocol. The optimal RSBI threshold was 97, where accuracy was maximal. RSBI was a good predictor of 1-hour SBT tolerance in this cohort of tracheotomized patients weaning from prolonged mechanical ventilation. *Key words: prolonged mechanical ventilation, ventilator weaning, respiratory therapist, protocol, long term, spontaneous breathing trial.* [Respir Care 2007;52(2):159–165. © 2007 Daedalus Enterprises]

Introduction

Barlow Respiratory Hospital is a long-term acute care facility in Los Angeles, California, that functions as a regional

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David J Scheinhorn MD presented a version of this report at the 97th International Conference of the American Thoracic Society, held May 18–23, 2001, in San Francisco, California.

The authors report no conflicts of interest related to the content of this paper.

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weaning center that accepts patients who have had prolonged mechanical ventilation and failed to wean in the intensive care unit (ICU), from a referral base of more than 50 hospitals in Southern California. In 1998 we began using a respiratory-therapist-implemented patient-specific ventilator weaning protocol. This protocol is ordered by the pulmonologist and managed by the respiratory therapist (RT) as our standard of practice for weaning from prolonged mechanical ventilation. We found that our protocol significantly hastened the weaning process and reduced its variability.¹

In our RT-implemented weaning protocol, the weaning process is divided into 19 steps, one step daily (Fig. 1), and objective assessments dictate the patient's progression through the protocol. There are 3 acceleration steps in the protocol that may allow the patient to progress more rapidly than the standard 19 days. One of these acceleration steps is to mea-

<p style="text-align: center;"><u>Therapist-Implemented Ventilator Weaning Protocol</u></p> <p><u>Initial Ventilator Setting</u> For initial flow/volume setting, see footnote A.</p> <p>For patient admitted on SIMV/PS: If SIMV > 10 breaths/min or PSV ≥ 20 cm H₂O → change to assist-control ventilation. If SIMV ≤ 10 breaths/min and PSV ≤ 20 cm H₂O → no change, but begin weaning steps with footnote B or C.</p> <p><u>Daily Evaluation</u> Do NOT wean if any ONE is present:</p> <ol style="list-style-type: none"> 1. Hemodynamic instability: <ul style="list-style-type: none"> • Any pressor infusion • Systolic blood pressure < 90 mm Hg • Pulse < 50 beats/min or > 130 beats/min 2. Temperature > 100.4°F 3. F_{IO₂} > 0.5 or PEEP > 8 cm H₂O 4. Other (record reason) <p><u>Weaning Assessment</u> Do NOT wean if any ONE is present:</p> <ol style="list-style-type: none"> 1. Respiratory rate > 35 breaths/min 2. Spontaneous V_T < 0.3 L 3. Oxygen saturation < 90% 4. Pulse > 130 beats/min or > 20 beats/min increase from baseline 5. Prominent accessory muscle use <p>Measure RSBI after first successful daily evaluation and weaning assessment. If RSBI ≤ 100, start weaning at Step 10.</p> <p><u>Weaning</u></p> <ol style="list-style-type: none"> 1. Chart baseline weaning assessment, then advance to weaning steps. 2. Chart weaning assessment 5 min after weaning step. 3. If patient fails a weaning step, chart weaning assessment and record time. Reverse steps until tolerated by patient. Notify attending physician if patient moved back ≥ 3 steps. 4. If patient fails next step for 3 consecutive days, report to attending physician. 	<p><u>Weaning Steps</u></p> <p>Reduction of SIMV (breaths/min)</p> <ol style="list-style-type: none"> 1. SIMV 10 / PS 20 (footnote C) 2. SIMV 8 / PS 20 3. SIMV 6 / PS 20 4. SIMV 4 / PS 20 <p>Reduction of PSV (cm H₂O)</p> <ol style="list-style-type: none"> 5. SIMV 4 / PS 18 6. SIMV 4 / PS 16 7. SIMV 4 / PS 14 8. SIMV 4 / PS 12 9. SIMV 4 / PS 10 <p>SBT duration (footnotes D and E) (all with provision of cool aerosol)</p> <ol style="list-style-type: none"> 10. 1 hour (footnote F) 11. 2 hours (draw ABG, result to attending physician) 12. 4 hours 13. 6 hours 14. 8 hours 15. 10 hours 16. 12 hours 17. 16 hours 18. 20 hours 19. 24 hours <p><u>Footnotes</u></p> <p>A. Set flow between 70 and 100 L/min, decelerating flow. Set V_T to 9 mL/kg, up to 900 mL. If plateau pressure > 35 cm H₂O, titrate V_T down to 7 mL/kg.</p> <p>B. If PSV breaths are < 9 mL/kg, increase PSV to 20 cm H₂O, then footnote C.</p> <p>C. If PSV breaths are > 9 mL/kg, change SIMV to 4 breaths/min in one step. Reduce PSV until spontaneous breaths approximate 8–9 mL/kg.</p> <p>D. Return to SIMV 4 breaths/min, PSV 10 cm H₂O at end of SBT.</p> <p>E. If at the end of SBT the patient is comfortable and wishes to continue, the SBT may be continued 1 more step.</p> <p>F. Add electrocardiogram telemetry and pulse oximetry at the start of SBTs.</p>
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Fig. 1. Our current respiratory-therapist-implemented ventilator weaning protocol (updated from Reference 1), with footnotes that encompass the acceleration steps, and details of the daily weaning-readiness screening. The measurement of rapid shallow breathing index (RSBI) is performed only the first time the daily evaluation and weaning assessment are passed, which skips from step 1 to step 10. Because each weaning step corresponds to 1 day, skipping to step 10 can save as much as 10 days of weaning time. SIMV= synchronized intermittent mandatory ventilation. PS= pressure support. F_{IO₂}= fraction of inspired oxygen. PEEP= positive end-expiratory pressure. V_T= tidal volume. ABG= arterial blood gas sample. PSV = pressure-support ventilation. SBT = spontaneous breathing trial.

sure the rapid shallow breathing index (RSBI) when the patient first passes the weaning readiness screening. Patients with an RSBI lower than the protocol-dictated threshold RSBI value directly advance to protocol step 10, which is the first 1-hour spontaneous breathing trial (SBT). Because there was no precedent for using the RSBI with patients suffering prolonged mechanical ventilation, we decided, for patient safety, to adopt a conservative RSBI threshold of 80, from an evidence-based recalculation of Yang and Tobin's RSBI data.^{2,3}

This was a prospective study to determine the “best” threshold RSBI value for advancing patients to SBT. We hypothesized that a threshold RSBI higher than 80 in our weaning protocol would allow more patients to successfully and safely advance to 1-hour SBT and therefore progress more quickly through the protocol.

Methods

This was a prospective cohort study approved by the institutional review board of Barlow Respiratory Hospital.

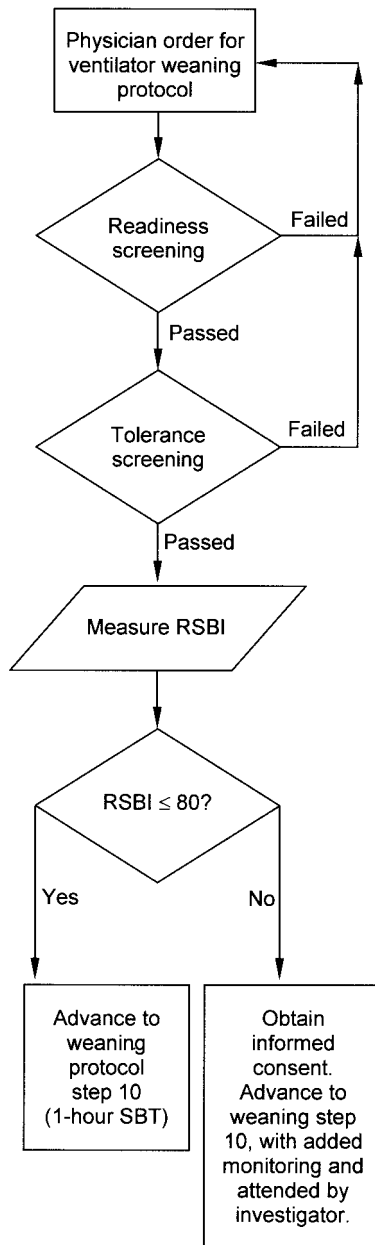


Fig. 2. Protocol flow diagram.

All tracheotomized, ventilator-dependent patients with an order for the RT-implemented weaning protocol were eligible for enrollment. Informed consent was obtained from the patient or surrogate. Figure 2 summarizes the study algorithm in a flow diagram. If the patient passed the baseline clinical stability and tolerance screening, per the weaning protocol (see Fig. 1), RSBI was then measured while the patient was connected to the ventilator (7200ae, Mallinckrodt Puritan-Bennett, Nellcor, Carlsbad, California), which was set for “flow-by” (option 50) with a base flow of 12 L/min and a flow sensitivity of 1 L/min. The ventilator alarm was silenced, and positive end-expiratory

pressure was turned off. The ventilation mode was changed to continuous positive airway pressure of zero, and pressure support was turned off. This setting was maintained for 75 s (a 15-s “run-in,” followed by a 60-s measurement) while the patient was observed for distress. At the end of that 75-s period, we recorded the respiratory rate (f) and the minute volume (\dot{V}_E) from the ventilator’s readout. RSBI was calculated as:

$$f^2/\dot{V}_E$$

which is an algebraic rearrangement of the ratio usually used to calculate RSBI (f/V_T).

The protocol dictated that patients with $RSBI \leq 80$ proceed to 1-hour SBT (weaning step 10). The SBTs are conducted with a T-piece and are monitored by the RT. In this study, patients with $RSBI > 80$ also underwent 1-hour SBT, but attended by a physician investigator (DCC) and monitored with electrocardiography and continuous pulse oximetry. If the patient tolerated the SBT, the duration of SBT was increased thereafter, per the protocol. If the patient failed the 1-hour SBT, we resumed the prior ventilatory support. SBT success/failure was based on the following objective criteria: respiratory distress, with oximetry-measured desaturation to $< 90\%$, heart-rate increase of > 30 beats/min above baseline, or development of a new cardiac arrhythmia. Failure was also defined as the patient’s insistence on resuming ventilatory support, due to marked dyspnea not alleviated by bronchodilator treatment, airway suctioning, body repositioning, and/or reassurance. The SBT was terminated under those conditions, and ventilatory support was resumed at the patient’s initial weaning protocol step. Transient abnormalities were not acted upon, at the discretion of the investigator, who was very familiar with this population.

The patients were followed until discharge from Barlow Respiratory Hospital. Ventilator weaning progress was recorded daily. Outcome (weaned, failed to wean, died) was scored at discharge, and weaning duration was determined for all weaned patients. Weaning success was defined as a live discharge without mechanical ventilation. Time to wean was defined as the duration of stay at Barlow Respiratory Hospital, up to and including the last day of mechanical ventilation.

Statistical Analysis

Univariate. We compared the distribution of the log of RSBI, age, sex, and tracheostomy tube size in those who did versus those who did not tolerate SBT. We used the log of RSBI instead of RBSI because the distribution of RSBI was well approximated by a normal (Gaussian) distribution, only on the log scale. We used the parametric t

test for comparing means and the nonparametric Wilcoxon rank sum test for comparing medians for log RSBI, age, and tracheostomy tube size. Fisher's exact test was used for comparing the differences between the sexes. For continuous variables that were significantly different, we computed the receiver operating characteristic curve for 1-hour SBT tolerance/nontolerance. This included computing the area under the receiver operating characteristic curve and plotting sensitivity and specificity versus the variable values to determine the best threshold value. We determined both the best threshold for sensitivity equal to specificity, and the threshold for maximum (unweighted) accuracy (sensitivity plus specificity).

We also examined the relationship of 1-hour SBT tolerance to weaning outcome and time to wean. We used the chi-square test to compare the proportion that were weaned, failed weaning, or died between those who tolerated the 1-hour SBT versus those who did not. We used the Wilcoxon rank sum test to compute the p value for comparing the distribution of weaning times in those with successful versus unsuccessful SBT.

Multivariate. We carried out a backwards (step-down) logistic regression, using all 4 variables as potential predictors, to determine which combination of variables best predicted 1-hour SBT success. Only those variables significant using a liberal $p < 0.15$ screening criterion were retained in the model.

Results

From February 2000 to August 2002, 517 patients were screened for study eligibility. Many patients and their surrogates, after a stormy ICU illness, were not inclined to participate in research studies. Informed consents were obtained from 135 patients. The protocol dictated conducting an SBT if RSBI is ≤ 80 , so we did not need consent from patients whose RSBI was ≤ 80 , and there were 56 such patients during the study period, whom we included to appropriately power the data analysis. Table 1 shows selected demographics, admission measurements, and outcomes. These values were similar to all patients admitted for weaning.

Among the 191 patients who underwent 1-hour SBT, there were 26 failures and 165 successes. There were no adverse events during the SBTs with these patients. Figure 3 shows the usual receiver operating characteristic plot of sensitivity versus 1 minus specificity for RSBI in predicting the success of a 1-hour SBT. The area under the receiver operating characteristic curve is 0.844.

Figure 4 shows a re-plot of the receiver operating characteristic, with sensitivity and specificity plotted separately against the log of RSBI. Figure 5 shows the plot of accuracy versus the log of RSBI.

Table 1. Selected Demographics, Measurements on Hospital Admission, and Outcome Data Scored at Discharge*

Age (mean \pm SD y)	70.2 \pm 13.0
Percent female	49.5
Days on ventilator prior to transfer (median and range d)	29 (5–136)
Days with tracheostomy prior to transfer (median and range d)	17 (0–132)
Patients with history of tobacco use (percent and mean \pm SD pack years)	72.6 (53.0 \pm 37.0)
RSBI (median and range)	76 (10–1248)
APACHE III acute physiology score (mean \pm SD)	36.3 \pm 17.5
Outcome (%)	
Weaned	54
Ventilator-dependent (not weaned)	20
Died	26
Time to wean (median and range d)	13.5 (3–83)

*n = 191
 RSBI = rapid shallow breathing index
 APACHE = Acute Physiology and Chronic Health Evaluation

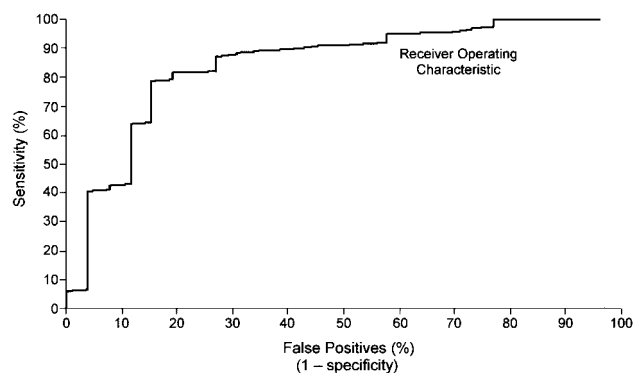


Fig. 3. Receiver operating characteristic plot of sensitivity versus 1 minus specificity for rapid shallow breathing index in predicting the success/failure of the 1-hour spontaneous breathing trail. The area under the receiver operating characteristic curve is 0.844.

Plotting in the manner of Figures 3 and 4 is a convenient way of choosing the “best” RSBI threshold values, by calibrating the desired combination of sensitivity and specificity.

Table 2 summarizes the effects of age, sex, and tracheostomy tube size on the outcome of 1-hour SBT. No significant effect was found. The female patients had significantly higher RSBI (120 ± 142) than did the male patients (81 ± 61) (t statistic = 3.80, $p < 0.001$), and 15 of the 94 female patients (15.9%) failed 1-hour SBT, compared to 11 of the 97 male patients (11.3%) ($p = 0.35$). In multivariate analysis, controlling for log RSBI, the p value for the 1-hour SBT outcome between the sexes was 0.49. Of the whole group, 54% were weaned on discharge, with a median time to wean of 16 days. Tolerance of 1-hour SBT

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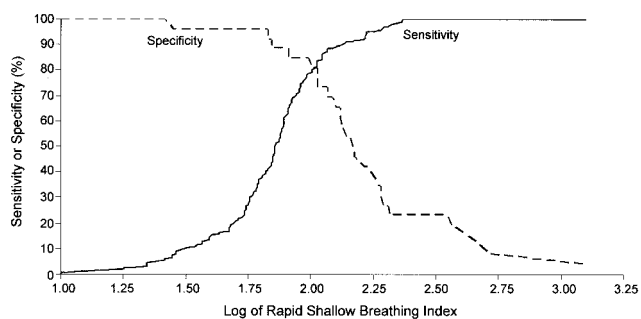


Fig. 4. Receiver operating characteristic curve with sensitivity and specificity plotted separately against the log of the rapid shallow breathing index.

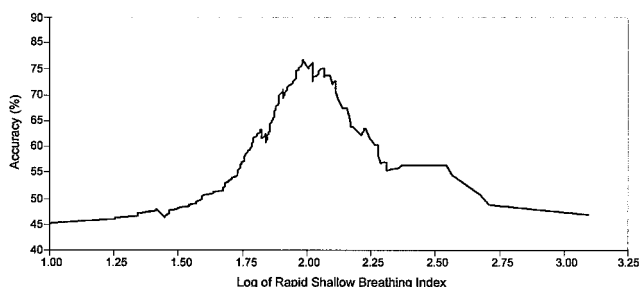


Fig. 5. Accuracy versus the log of the rapid shallow breathing index.

Table 2. Effect of RSBI, Age, Sex, and Tracheostomy Tube Size on the Outcome of 1-hour SBT

	Passed SBT	Failed SBT	p
Log of RSBI (median)	1.86	2.16	< 0.001
Log of RSBI (mean)	1.84	2.21	< 0.001
Median age (y)	72	75	0.54
Mean age (y)	70.0	71.1	0.67
Tracheostomy tube size (mean mm inner diameter)	7.47	7.67	0.39
Percent female	48	58	0.35

RSBI = rapid shallow breathing index
SBT = spontaneous breathing trial

correlated well with weaning outcome and time to wean (Table 3).

Discussion

After we determined the best RSBI threshold for use in our RT-implemented weaning protocol, an additional 20% of the patients could proceed directly to protocol step 10 (the half-way mark in the protocol) and attempt the further screening of a 1-hour SBT.

Table 3. Tolerance of 1-Hour SBT and Weaning Outcome

	Passed 1-Hour SBT	Failed 1-Hour SBT	p
Outcome			0.028*
Weaned (<i>n</i> and %)	96 (58.2)	9 (34.6)	
Failed to wean (<i>n</i> and %)	32 (19.4)	5 (19.2)	
Died (<i>n</i> and %)	37 (22.4)	12 (46.2)	
Median time to wean (d)	8	22	0.008†
Mean time to wean (mean ± SD)	16.5 ± 16.9	44.8 ± 52.9	

*Via chi-square test

†Via Mann-Whitney test

SBT = spontaneous breathing trial

Clinical protocols are designed and implemented based on available evidence, to reduce practice variability while achieving desired quality and cost-effectiveness. A robust protocol can accommodate heterogeneity in the target population. However, protocols should by no means be static; rather, they should undergo periodic re-evaluation, based on outcomes and new evidence.

In 1991, with the publication of Yang and Tobin's seminal paper³ in which the RSBI bested all other indices of readiness for extubation in the ICU, the stage was set for expanded use of RSBI, including as the screening test to precede SBT.^{4,5} Either extubation per protocol, or weaning from short- or long-term ventilation per protocol usually follows, with variable success.¹⁻¹¹ As opposed to subjecting every patient to a 1-hour SBT, for patient safety the RSBI was incorporated in our RT-implemented weaning protocol. It seemed unlikely that a patient who adopted a rapid shallow breathing pattern within 1 min would be able to accomplish a 1-hour SBT. With patients now located in medical-surgical wards, staffing at less than ICU levels precludes RT attendance during each 1-hour SBT, and a T-piece trial without mechanical ventilator alarms would be hazardous.

In our prior studies of RSBI in patients undergoing prolonged mechanical ventilation, we tested the correlation with weaning outcome, and we found that the predictive accuracy of Yang and Tobin's ICU RSBI threshold of 105 was only 59%.¹² In our RT-implemented weaning protocol we chose a low RSBI threshold of 80 for advancing the patient to 1-hour SBT. This conservative threshold, chosen to minimize false positives (patients below threshold RSBI but who fail to tolerate 1-h SBT), was from a published evidence-based recalculation of Yang and Tobin's data for the ICU population.² We found that this threshold value allowed 28% of patients to start SBTs earlier, and 89% of these patients tolerated the SBT.¹ The present study prospectively determined an appropriate RSBI threshold specifically for protocol weaning from prolonged mechanical ventilation.

The manner in which we measured RSBI merits comment, since methodological differences affect the RSBI value.¹³ Yang and Tobin detached their patients from the ventilator and measured exhaled volume manually with a calibrated respirometer, while timing the patient for 1 min. In a large-scale implementation of an extubation protocol, Ely et al measured RSBI with the patient connected to the ventilator, with continuous positive airway pressure set at 5 cm H₂O.⁹ This method resulted in a significantly lower RSBI.¹⁴ For clinical utility, we also performed the measurement with the patient connected to the ventilator, using the flow-by/continuous-flow setting to minimize the latency for inspiratory air-flow. The 7200ae ventilator's display for respiratory rate shows a running average of the preceding 10 breaths, and the displayed minute volume is an 8-breath projected average. We thought this was a good measure of the "rapid shallow breathing pattern" at the 1-min mark, while it also reduced the sampling error of single-breath measurement due to breath-to-breath variability.

In addition to the consideration of overall accuracy, both false positive and false negative predictions of successful 1-hour SBT based on RSBI are problematic. Minimizing false negatives (allowing patients with higher RSBI to advance) increases false positives, with a higher incidence of failed 1-hour SBT. A failed SBT may increase risks, including re-institution of mechanical ventilation, respiratory muscle fatigue, and potential cardiopulmonary arrest. Continued use of the lower RSBI threshold 80 (not advancing patients who could have advanced) may increase weaning time, ventilator-associated morbidity, and cost. It should be noted that in our tracheotomized population, re-institution of mechanical ventilation entails less cost than reintubation in patients who are orally or nasally intubated.¹⁵

RSBI correlated well in this study with the patients' ability to tolerate 1-hour SBT (area under the receiver operating characteristic curve 0.844). We calculated that an RSBI threshold of 80 had a sensitivity of 62.4% and specificity of 88.5%. We found that by re-plotting the sensitivity and specificity separately against the log of RSBI we were able to calibrate a threshold RSBI to the desired combination of sensitivity and specificity. Increasing the RSBI threshold to 97 increased the sensitivity by 15% while sacrificing specificity by 4%. Tolerance of the consequent SBT correlated with decreased time to wean, whereas intolerance of the SBT correlated with decreased survival (see Table 3).

The women had significantly higher RSBI than the men. They also had a higher tendency to fail the 1-hour SBT, but this difference was not statistically significant. In multivariate analysis we did not find a need to calibrate RSBI separately for men and women. A larger study may help answer whether differences in frame size and body mass explain the difference between the sexes in RSBI.

Yang and Tobin rounded off their RSBI from 105 to 100 for their short-term-ventilated cohort of ICU patients.³ For ease of use, in patients who have undergone prolonged mechanical ventilation and are ready for the RT-implemented weaning protocol, the RSBI may be rounded off to 100 with little loss of specificity or sensitivity.

Conclusions

A robust clinical weaning protocol, while capable of accommodating variability in the target population, should undergo continued refinement as new evidence emerges, as in the present study. We used a convenient method of calibrating the threshold RSBI value to optimize weaning advance for prolonged mechanical ventilation patients. We found RSBI to be a good predictor of 1-hour SBT tolerance, and decided that our RSBI threshold of 80 was unnecessarily conservative. The RSBI threshold did not need to be calibrated for difference between the sexes in this population. Determining the optimal threshold requires consideration of the advantages of the true-positive/true-negative ratio, as well as the risks and cost of false positives and false negatives. For maximum accuracy, we now use an RSBI threshold of 97 (or, for convenience, 100) for determining whether to accelerate weaning by conducting the 1-hour SBT earlier in our RT-implemented weaning protocol.

ACKNOWLEDGMENT

We gratefully acknowledge the invaluable biostatistics assistance of Jeffery A Gornbein DrPH, Department of Biomathematics, University of California, Los Angeles, California.

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A nurse and two corpsmen attending to a poliomyelitis patient in an iron lung
US Army, 1949
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