

# Evaluation of a New Method for Measurement of Minute Ventilation Recovery Time

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**PURPOSE:** To determine if the measurement of minute ventilation recovery time ( $\dot{V}_E$ RT), a recently proposed predictor of extubation outcome, can be reproduced using a more practical, simpler method. **METHODS:** A case series with convenience sampling was performed in the surgical intensive care unit of a tertiary-care hospital. Nineteen patients were enrolled during weaning from mechanical ventilation, prior to the initial extubation attempt. Within-subject comparisons of  $\dot{V}_E$ RT were performed, using 2 alternative methods for measuring baseline  $\dot{V}_E$  and one alternative method for determining the threshold for recovery of  $\dot{V}_E$  during the final spontaneous breathing trial prior to extubation. Comparison methods for baseline  $\dot{V}_E$  included an 8-hour average and the last  $\dot{V}_E$  measurement prior to the spontaneous breathing trial. The alternative threshold for defining recovery of  $\dot{V}_E$  was 100% of the baseline value (vs 110% in the original method). **RESULTS:** The study subjects were primarily cardiac surgery patients (63%) and were ventilated for a median of 5 days prior to extubation.  $\dot{V}_E$ RT calculated using the 8-hour average or the last  $\dot{V}_E$  measurement prior to the spontaneous breathing trial as baseline, and a threshold of 100% of baseline  $\dot{V}_E$  to define recovery most closely approximated  $\dot{V}_E$ RT obtained by the original method and similarly classified patients at high risk for reintubation (kappa statistic =  $0.78 \pm 0.2$ ). **CONCLUSIONS:**  $\dot{V}_E$ RT can be determined using a simpler method for measuring both baseline  $\dot{V}_E$  and the recovery threshold. These methodological modifications may increase the feasibility of measuring  $\dot{V}_E$ RT, while reproducing the results obtained by the original method. *Key words:* minute ventilation recovery time, extubation, mechanical ventilation, weaning, spontaneous breathing trial. [Respir Care 2006;51(2):133–139. © 2006 Daedalus Enterprises]

## Introduction

Extubation failure, defined as the inability to sustain spontaneous breathing after removal of an endotracheal

tube, is associated with poor intensive care unit (ICU) and hospital outcomes.<sup>1</sup> It is not known whether reintubation causes adverse outcomes or is simply a marker of disease severity. Given the potential adverse impact on patient outcomes, there is increased interest in developing better predictors of extubation outcome. Based on several cohort studies that demonstrated an association between extubation failure and several clinical variables, decisions regarding the timing of extubation are based on qualitative or semi-quantitative assessments of the patient's capacity to protect the upper airway,<sup>2</sup> the quantity of respiratory-tract secretions,<sup>3</sup> and cough strength.<sup>4,5</sup> However, there is no single, objective test available to predict extubation outcome, and the decision to extubate typically involves a judgment call that considers these as well as other clinical variables.

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Minute ventilation recovery time ( $\dot{V}_{E\text{RT}}$ ), which is the time required for minute ventilation ( $\dot{V}_E$ ) to return to baseline following a successful spontaneous breathing trial (SBT), is a relatively newly identified variable that may predict extubation outcome.<sup>6</sup> Performed in a community hospital, the initial study demonstrated that an elevated  $\dot{V}_{E\text{RT}}$  was independently associated with extubation failure, with a greater predictive accuracy than other traditional respiratory variables.<sup>6</sup> The method used to measure  $\dot{V}_{E\text{RT}}$  involved a 2-step process: (1) define a baseline  $\dot{V}_E$  on ventilator settings used prior to the SBT, and (2) measure the time required for  $\dot{V}_E$  to recover back to 110% of the baseline  $\dot{V}_E$  after the SBT while being “rested” on pre-SBT ventilator settings for 15 min.  $\dot{V}_{E\text{RT}}$  is hypothesized to reflect patients’ respiratory reserve as they convalesce from respiratory failure, and it is unlikely to identify patients reintubated for airway compromise.

Though  $\dot{V}_{E\text{RT}}$  may provide a novel approach to the clinical assessment of respiratory reserve prior to extubation,<sup>7</sup> the published method has several practical limitations that limit the feasibility of more widespread  $\dot{V}_{E\text{RT}}$  testing. First, the determination of baseline  $\dot{V}_E$  (step 1), although recently shown to be reproducible,<sup>8</sup> is tedious as well as subjective, requiring visual inspection of many hours of trended  $\dot{V}_E$  data to determine the nadir value. Recording devices (eg, Tram-Net Interface, Marquette Electronics) that are not readily available in most ICUs are also needed to acquire the  $\dot{V}_E$  measurements prior to the start of the SBT. Second, the threshold  $\dot{V}_E$  value that defines the recovery time after the SBT (step 2), requires an additional calculation ( $110\% \times$  baseline  $\dot{V}_E$ ).

Rather than validate the original method in a large population of patients, our objective was to find a surrogate measure of  $\dot{V}_{E\text{RT}}$  that would give results similar to those of the original method but be more feasible to perform. The current study determines if the original  $\dot{V}_{E\text{RT}}$  method is reproducible after simplifying the measurement of both baseline  $\dot{V}_E$  and the threshold that defines recovery.

## Methods

This research protocol was approved by the Investigational Review Board of the Hospital of the University of Pennsylvania, with the requirement for written informed consent from all study patients or their surrogate decision-makers.

### Study Design

We conducted a case series with convenience sampling to measure baseline  $\dot{V}_E$  and  $\dot{V}_{E\text{RT}}$  in all patients at the time of their last SBT prior to extubation.

### Patients

Mechanically ventilated patients were prospectively screened in the surgical ICUs (trauma, cardiac, general) of the Hospital of the University of Pennsylvania over a 3-month period during weekday surgical critical-care-service rounds. Patients were included if they were older than 18 years of age and received mechanical ventilation via endotracheal tube for more than 24 hours postoperatively. Patients were excluded if they had preexisting tracheostomy, were receiving noninvasive mechanical ventilation, or were undergoing non-protocol weaning. Patients were followed until the final successfully passed SBT prior to extubation, after which  $\dot{V}_{E\text{RT}}$  was measured. Initial weaning trials were performed on continuous positive airway pressure with pressure support of 7 cm H<sub>2</sub>O; if repeated SBTs were unsuccessful, patients were weaned subsequently via pressure support, to a minimum value of 7 cm H<sub>2</sub>O.

### Primary Comparisons

For each patient enrolled,  $\dot{V}_E$  was recorded continuously, in a blinded fashion, for 8 hours prior to, during, and after (15-min recovery period) the final SBT prior to extubation. Five alternative ways of calculating  $\dot{V}_{E\text{RT}}$  were compared to the previously published method.<sup>6</sup> As shown in Figure 1, baseline  $\dot{V}_E$  was measured by (1) the original method (the lowest, stable  $\dot{V}_E$  nadir that lasted 15–30 min), visually determined from 8 hours of trended  $\dot{V}_E$  data prior to the final SBT<sup>6</sup>; (2) the mean  $\dot{V}_E$  over the 8 hours prior to the start of the SBT, and (3) the last  $\dot{V}_E$  measured within 15 min prior to the start of the SBT. Recovery of  $\dot{V}_E$  was defined in 2 ways: using the original threshold of 110% of baseline  $\dot{V}_E$ , and using a threshold of 100% of baseline. Each of the 3 methods of determining baseline  $\dot{V}_E$  (original plus 2 new methods) were combined with each of the 2 recovery thresholds (110% of baseline [original method] and 100% of baseline), which produced 6 methods of measuring  $\dot{V}_{E\text{RT}}$ .

### Data Collection

Data were collected using a device-interfacing module (VueLink, Philips Medical Systems, The Netherlands), which interfaced the ventilator (model 7200, Puritan Bennett, Pleasanton, California) to the bedside cardiac monitor (Hewlett Packard, Houston, Texas), which allowed continuous recording of  $\dot{V}_E$ . One-minute averages were calculated by the VueLink module, derived from ventilator data sampled every 12 s. At the conclusion of a successful SBT, the patient was placed back on the ventilator, with settings identical to those used immediately prior to the SBT. During this recovery period,  $\dot{V}_{E\text{RT}}$  was calculated from consecutive  $\dot{V}_E$  measurements made every minute

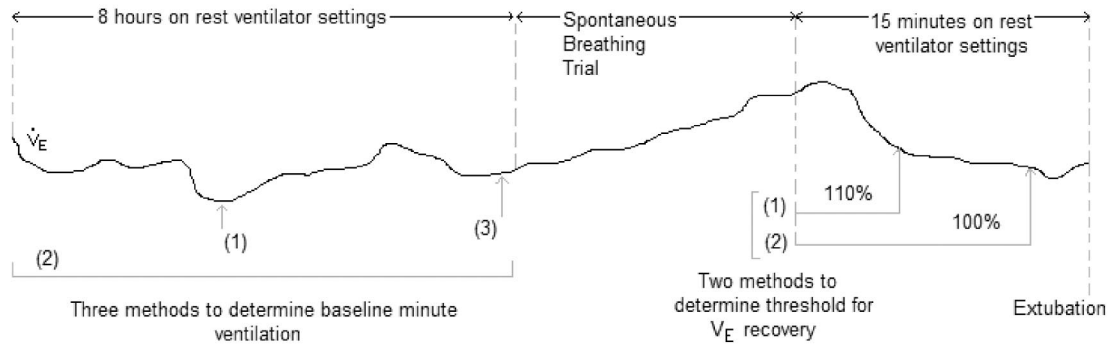


Fig. 1. Measurement of baseline minute ventilation ( $\dot{V}_E$ ) for calculation of minute ventilation recovery time ( $\dot{V}_{ERT}$ ). The 3 methods for determining baseline  $\dot{V}_E$  are: (1) the subjective  $\dot{V}_E$  nadir (original method), (2) the 8-hour  $\dot{V}_E$  average, and (3) the last  $\dot{V}_E$  measurement prior to the spontaneous breathing trial.  $\dot{V}_{ERT}$  is the time when  $\dot{V}_E$  recovers to either 100% or 110% of the baseline value. Figure not drawn to scale.

for 15 min. Baseline  $\dot{V}_E$  was established from measurements of  $\dot{V}_E$  recorded prior to the successful SBT. Ventilator settings were not standardized during this period. In order to limit false elevations of  $\dot{V}_E$  during the baseline rest period, we minimized airway suctioning and interventions by respiratory therapists and nurses to reduce the likelihood of patient distress or agitation. All extubating physicians, respiratory therapists, and nursing staff were blinded to study data, and study personnel were not present at the patient bedside until the conclusion of the protocol. Demographic data collected included age, gender, Acute Physiology and Chronic Health Evaluation (APACHE) II score, surgery service, and comorbidities, and days on the ventilator prior to weaning.

**Measurement of  $\dot{V}_{ERT}$  Using Comparison Methods**

Baseline  $\dot{V}_E$  was established by 3 methods: (1) the original method for determining baseline  $\dot{V}_E$  (the subjectively-determined nadir) was performed blindly by one investigator,<sup>6</sup> (2) the 8-hour average method was computed by downloading  $\dot{V}_E$  data from the bedside monitor every 15 min, with manual entry into a spreadsheet (Excel, Microsoft, Redmond, Washington) and calculation of mean  $\dot{V}_E$  by the spreadsheet, and (3) the most proximate 15-min data point recorded by the Vuelink module prior to the start of the SBT.  $\dot{V}_{ERT}$  was defined as the time required for  $\dot{V}_E$  to return back to the  $\dot{V}_E$  baseline value following the completion of the SBT.  $\dot{V}_{ERT}$  was calculated using both the previously published threshold value of 110% of baseline  $\dot{V}_E$ <sup>6</sup> and 100% of baseline  $\dot{V}_E$ . Each data point represents measurements of  $\dot{V}_E$  baseline and  $\dot{V}_{ERT}$  obtained from a different patient; each patient contributed data from only one SBT.

For all  $\dot{V}_{ERT}$  methods studied, if  $\dot{V}_E$  failed to increase above baseline during the SBT,  $\dot{V}_{ERT}$  was designated as 1 min. In addition, if  $\dot{V}_E$  failed to recover to the baseline

value,  $\dot{V}_{ERT}$  was designated as 15 min.<sup>6</sup> Furthermore, categorization of  $\dot{V}_{ERT}$  as prolonged versus non-prolonged was assessed using the mean  $\dot{V}_{ERT}$  of failed extubations in the study by Martinez et al (4 min).<sup>6</sup>

**Statistical Analysis**

All methods for measuring baseline  $\dot{V}_E$  (subjective nadir, 8-h average, and last  $\dot{V}_E$  measured) were compared using intraclass correlation. Alternative methods for measuring baseline  $\dot{V}_E$  and  $\dot{V}_{ERT}$  were compared using the Bland-Altman analysis,<sup>9</sup> with an assessment of mean difference [95% confidence intervals] and upper and lower limits of agreement. Statistical significance for the difference in variance was determined by the Pitman’s test. A p value < 0.05 was considered statistically significant. For each method,  $\dot{V}_{ERT}$  was also categorized using a cutoff of  $\geq 4$  min, and these arrays of nominal data points were compared to the categorization by the original method, using the kappa statistic. Analyses were performed using statistical software (NCSS version 2000 Kaysville, Utah; STATA version 8.0, STATA Datacorp, College Station, Texas).

**Results**

**Patients**

During 3 months of prospective evaluation, informed consent was obtained from 32 of 50 study-eligible patients (Fig. 2). Of these, 4 patients required tracheostomy, 2 patients died prior to extubation, and one self-extubated, which prevented  $\dot{V}_{ERT}$  measurement. In 6 additional patients, a full 8 hours of  $\dot{V}_E$  was not recorded prior to the final weaning trial before extubation. Demographic data for the 19 study patients are presented in Table 1. Patients were primarily status post-cardiac-surgery, had congestive

heart failure and coronary artery disease as primary comorbidities, and were weaned early in the postoperative period (1.5 d), although median time on the ventilator was 5 days. Patients were more likely to be on pressure support (84%) than on volume-controlled ventilation at the time  $\dot{V}_{E}RT$  was measured.

**Baseline  $\dot{V}_E$**

Baseline  $\dot{V}_E$  measured with both the last  $\dot{V}_E$  measurement prior to the SBT and the average  $\dot{V}_E$  of the prior 8 hours was higher than when measured with the subjective nadir method. As detailed in Table 2, intraclass correlation showed good agreement between the methods. As shown in Table 2 and plotted in Figure 3, Bland-Altman analysis revealed a mean difference and limits of agreement that were closer with baseline  $\dot{V}_E$  measured with the 8-hour average than with the last- $\dot{V}_E$ -measurement, although both alternative methods had a nonsignificant difference in variance, by Pitman’s test ( $p > 0.1$ ).

**Minute Ventilation Recovery Time**

As shown in Table 3, 5 comparison methods for measuring  $\dot{V}_{E}RT$  were evaluated against the original method. Use of either of the 2 comparison methods for baseline  $\dot{V}_E$  in combination with the 100% threshold value yielded median  $\dot{V}_{E}RT$  values that were most similar to the original

Table 1. Demographic Data\*

Number of patients	19
Median age (25–75 IQR)	68 (54–79)
Male sex ( <i>n</i> and %)	4 (21)
APACHE II score (mean ± SE)	19 ± 4.4
Co-morbidities ( <i>n</i> and %)	
Chronic obstructive pulmonary disease	2 (11)
Coronary artery disease	6 (32)
Congestive heart failure	7 (37)
Surgery Service ( <i>n</i> and %)	
Cardiac	12 (63)
Trauma	3 (16)
Vascular	2 (11)
General	2 (11)
Median length of stay prior to weaning (d and 25–75 IQR)	1.5 (0.8–2.5)
Median duration of mechanical ventilation prior to extubation (d and 25–75 IQR)	5 (2–8)
Time on minimal settings prior to measurement of $\dot{V}_{E}RT$ (h and 25–75 IQR)	3 (2.5–4)
Pressure-support mode during recovery ( <i>n</i> and %)	16 (84)

IQR = interquartile range  
 $\dot{V}_{E}RT$  = minute ventilation recovery time

method. When  $\dot{V}_{E}RT$  was classified as above or below a cutoff value of 4 minutes,<sup>6</sup> 2 comparison techniques (8-h average and last  $\dot{V}_E$  measured) for  $\dot{V}_E$  baseline were in close agreement with the original method, particularly with the 100% threshold ( $\kappa > 0.78$ ,  $p < 0.01$  for all).

Despite the small sample size, Bland-Altman analysis (Fig. 4) confirmed that the methods that use the 100% threshold had smaller mean differences than methods that use the 110% threshold; of the 100% methods, the 8-hour-average  $\dot{V}_E$  baseline method had the narrowest range for limits of agreement.

**Discussion**

This study demonstrates that the original technique for measuring  $\dot{V}_{E}RT$  can be reproduced using alternative methods that are much simpler to perform. When baseline  $\dot{V}_E$  is calculated with either an 8-hour average or the last recorded  $\dot{V}_E$  value and the recovery threshold for  $\dot{V}_E$  of 100% of baseline,  $\dot{V}_{E}RT$  closely approximates values obtained with the original method.

Martinez and colleagues recently introduced  $\dot{V}_{E}RT$  as a new index that may predict extubation outcome.<sup>6</sup> They hypothesized that the inability to tolerate discontinuation of mechanical ventilation is indicative of poor respiratory reserve and would be reflected by a prolonged increase in  $\dot{V}_E$  (ie, increased  $\dot{V}_{E}RT$ ) following the “challenge” of an

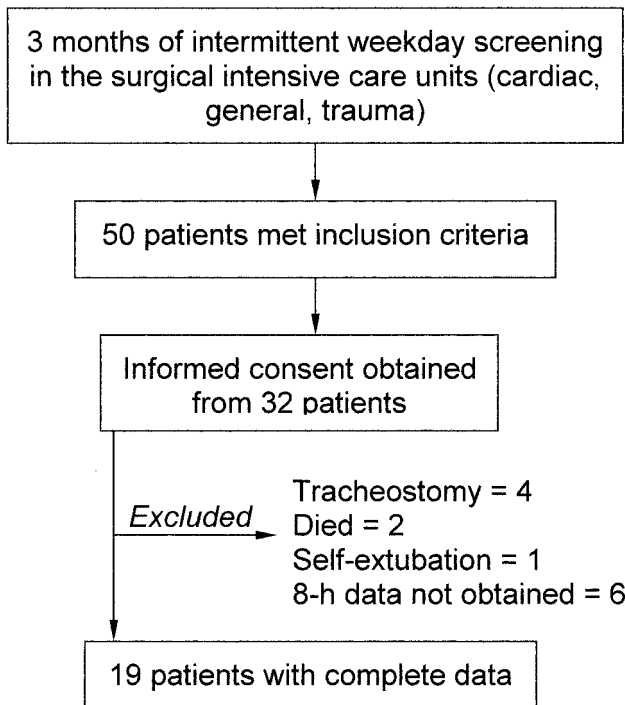


Fig. 2. Patient enrollment in the present study.

Table 2. Comparison of Methods for Calculating Baseline Minute Ventilation

$\dot{V}_E$ Baseline Method	$\dot{V}_E$ (mean $\pm$ SD L)	Intraclass Correlation (mean and 95% CI)	Bland-Altman Analysis With Comparison to Subjective Nadir Method		
			Mean Difference (mean and 95% CI) (L)	Limits of Agreement (L)	Pitman's Test of Difference in Variance
Subjective nadir*	8.3 $\pm$ 2.3*	*	*	*	*
8-h average	9.3 $\pm$ 2.6	0.86 (0.73 to 0.98)	1.05 (0.63 to 1.46)	-0.67 to 2.77	r = 0.29, p = 0.22
Last $\dot{V}_E$ measurement	9.6 $\pm$ 2.8	0.67 (0.4 to 0.92)	-1.33 (-2.19 to -0.47)	-4.89 to 2.23	r = -0.3, p = 0.25

\* Original method  
 $\dot{V}_E$  = minute ventilation  
 CI = confidence interval

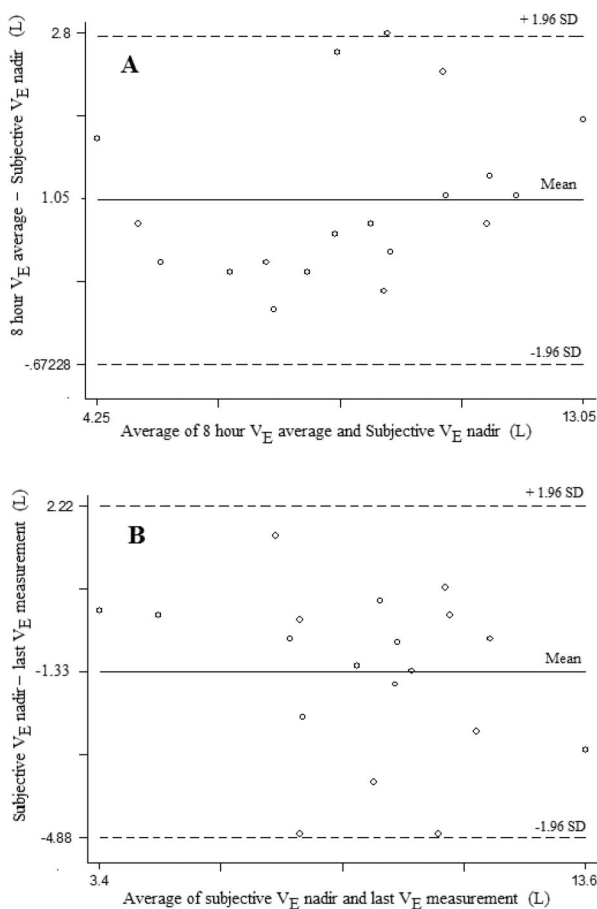


Fig. 3. Bland-Altman plots comparing methods for determining baseline minute ventilation ( $\dot{V}_E$ ). A: 8-hour  $\dot{V}_E$  average versus subjective  $\dot{V}_E$  nadir. B: Subjective  $\dot{V}_E$  nadir versus last  $\dot{V}_E$  measurement.

SBT. The original technique for measuring  $\dot{V}_{ERT}$  has several methodological issues that may limit its widespread use and potential clinical application. Accurate and precise measurement of  $\dot{V}_{ERT}$  requires a standardized and reproducible method for determining both the baseline  $\dot{V}_E$  and the  $\dot{V}_{ERT}$ . Thus, before a large-scale validation study of

$\dot{V}_{ERT}$  is done, it is important to simplify the measurement and eliminate the subjectivity.

In the current investigation, defining the  $\dot{V}_E$  baseline as either an 8-hour average or the last  $\dot{V}_E$  measurement resulted in higher values than the reference method. This finding is not surprising, given that the original method for baseline  $\dot{V}_E$  uses the lowest consistent nadir prior to the final SBT. We did not control for the effect of different ventilator settings, patient agitation, or nursing interventions during the 8 hours prior to the SBT, which may explain part of the variability between the baseline values obtained using the comparison methodologies. However, ventilator settings during the baseline period were not standardized in previous studies of  $\dot{V}_{ERT}$ .<sup>6</sup>

The comparison techniques resulted in baseline  $\dot{V}_E$  values that were similar to those obtained using the original method, when compared via intraclass correlation as well as Bland-Altman analysis. The decision as to which method should be employed in future studies depends not only on the test reproducibility but also on test applicability. The last- $\dot{V}_E$ -measurement method is the simplest method currently and is therefore most appealing for future clinical application. On the other hand, the 8-hour-average method most closely approximated the original method and could easily be measured routinely, by incorporating an automated calculation into the ventilator software. Importantly, in contrast to the original method, in the comparison techniques the baseline  $\dot{V}_E$  is determined objectively, eliminating physician subjectivity and the time required to visually review all the trended baseline data.

$\dot{V}_{ERT}$  was originally defined using recovery to 110% of baseline<sup>6</sup>; however, the use of a fractional threshold for  $\dot{V}_E$  recovery adds additional calculations for the bedside practitioner. We hypothesized that a recovery threshold of 100% of baseline would simplify the test for clinical use, without significantly altering  $\dot{V}_{ERT}$  values. As expected, we found that recovery to 110% of baseline occurred sooner than did recovery to 100%; however, when the alternative methods for determining baseline  $\dot{V}_E$  were used in combination



## NEW METHOD FOR MEASURING MINUTE VENTILATION RECOVERY TIME

Table 3. Comparison of Methods for Calculating Minute Ventilation Recovery Time

$\dot{V}_{E\text{RT}}$ Method		$\dot{V}_{E\text{RT}}$ (median and 25–75 IQR min)	Kappa Statistic*	Bland-Altman Analysis of Comparison to Subjective Nadir Method, 110%		
Baseline	Percent Recovery			Mean Difference (mean and 95% CI) (min)	Limits of Agreement (min)	Pitman's Test of Difference in Variance (p)
Subjective nadir†	110	4 (1–15)†	†	†	†	†
8-h average		1 (1–5)	0.79 ± 0.14	–2.3 (–4 to –0.6)	–4 to –0.6	0.15
Last $\dot{V}_E$ measurement		2 (1–4)	0.48 ± 0.17	–2.1 (–4 to –0.4)	–9 to 5.1	0.27
Subjective nadir*	100	8 (1–15)	0.78 ± 0.22	2 (0.2 to 3.4)	–5.1 to 9.1	0.79
8-h average		4 (1–10)	0.79 ± 0.14	–0.16 (–1.5 to 1.2)	–5.9 to 5.6	0.84
Last $\dot{V}_E$ measurement		4 (1–10)	0.79 ± 0.14	–0.53 (–2.4 to 1.4)	–8 to 7.6	0.54

\* Kappa statistic represents comparison to the original method for  $\dot{V}_{E\text{RT}}$  (baseline = subjective nadir, percent recovery = 110%), with categorization around a cutoff of 4 minutes.

† Original method

$\dot{V}_{E\text{RT}}$  = minute ventilation recovery time

CI = confidence interval

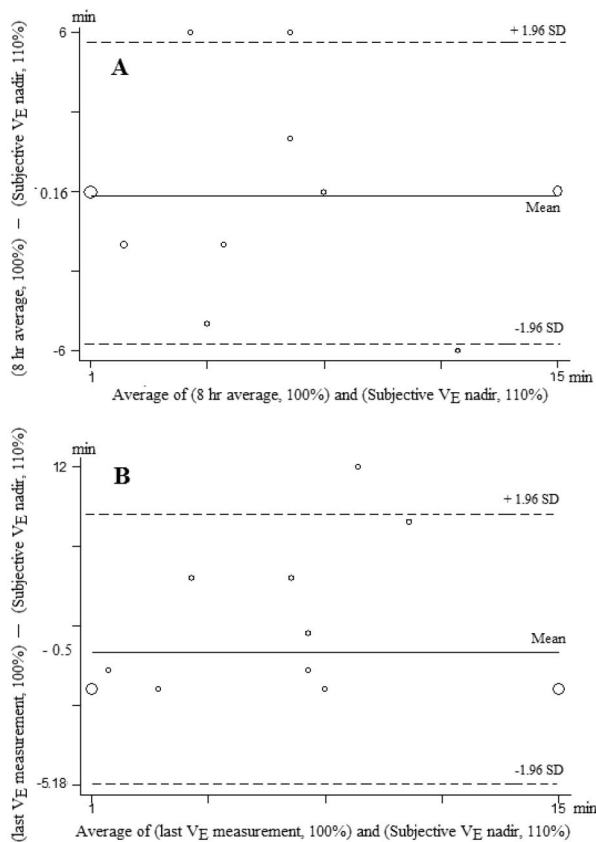


Fig. 4. Bland-Altman plots comparing methods for determining minute ventilation recovery time ( $\dot{V}_{E\text{RT}}$ ). A: 8-hour  $\dot{V}_E$  average with 100% of  $\dot{V}_E$  threshold versus subjective  $\dot{V}_E$  nadir with 110% of  $\dot{V}_E$  threshold. B: Last  $\dot{V}_E$  measurement with 100% of  $\dot{V}_E$  threshold versus subjective  $\dot{V}_E$  nadir with 110% of  $\dot{V}_E$  threshold.

with the 100% recovery threshold,  $\dot{V}_{E\text{RT}}$  values were

closely approximated (see Table 3). We believe the additional time spent at the bedside measuring  $\dot{V}_{E\text{RT}}$  with the 100% recovery threshold (approximately 4 min) will not be clinically important. In addition, full recovery of  $\dot{V}_E$  to 100% of baseline with any of the comparison techniques for  $\dot{V}_E$  baseline did not change the interquartile range of  $\dot{V}_{E\text{RT}}$  values, and provided values comparable to those published by Martinez and colleagues.<sup>6</sup>

When the comparison techniques were compared to the original technique in their ability to categorize patients using a threshold of  $\geq 4$  min, the measurement of  $\dot{V}_{E\text{RT}}$  using comparison baseline methods in conjunction with the 100% recovery threshold gave equivalent classification of patients by the kappa reliability statistic (see Table 3). For alternative methods of baseline  $\dot{V}_E$  using the 100% recovery threshold, the mean difference, when compared to the original method, was within 1 min, which is a clinically acceptable discrepancy. The limits of agreement obtained via Bland-Altman analysis were large, which was probably a consequence of the small sample size. Because we altered both the method of determining  $\dot{V}_E$  baseline and  $\dot{V}_E$  recovery concurrently, the equivalence of the alternative methods in this study may reflect a balance of the inaccuracies in both variables. This limitation can be overcome by demonstrating that these alternative  $\dot{V}_{E\text{RT}}$  methods similarly predict extubation outcome, which is the focus of a current investigation. If the predictive accuracy of this new methodology is subsequently validated, these modifications will make it more feasible to measure  $\dot{V}_{E\text{RT}}$  and allow automated  $\dot{V}_{E\text{RT}}$  measurement.

The major limitation of this study is the small sample size. However, the definitive method for measuring  $\dot{V}_{E\text{RT}}$  has not been established, since this variable has yet to be validated in a large-scale study or corroborated by another

investigator. At this early stage in the study of  $\dot{V}_{E}RT$ , our investigation was designed primarily to find a satisfactory alternative method for measuring  $\dot{V}_{E}RT$  that would be objective and simpler to perform. Ultimately, it will be important to demonstrate that these simpler methods can predict extubation outcome, and the findings from the present study must be interpreted with caution in different patient groups. Preliminary data obtained via one of these simplified methods (baseline = last  $\dot{V}_{E}$  measured, recovery = 100% of baseline) demonstrates that extubation outcome is successfully predicted in a cohort of surgical patients.<sup>10</sup>

Although this study advances our knowledge of the  $\dot{V}_{E}RT$  variable,  $\dot{V}_{E}RT$  should not yet be used in clinical decisions regarding extubation for several reasons. First, we studied  $\dot{V}_{E}RT$  with recording devices (the Vuelink module and Tram-net interface) that are not readily available in most ICUs. Second, bedside measurement of  $\dot{V}_{E}RT$  by respiratory therapists has not yet been studied. Third, a reliable  $\dot{V}_{E}RT$  threshold or likelihood ratio for reintubation has not been firmly established to assist in bedside clinical decision making, nor has a randomized, implementation study of  $\dot{V}_{E}RT$  been performed in a larger population of difficult-to-wean patients.

### Conclusions

We have demonstrated that the original method for determining  $\dot{V}_{E}RT$  can be reproduced using a method that is more objective and more feasible to perform. The introduction of an objective and automated method for deter-

mining baseline  $\dot{V}_{E}$ , using either an 8-hour average or the last  $\dot{V}_{E}$  measurement and changing the  $\dot{V}_{E}$  recovery threshold to 100% of baseline, may simplify future investigation of  $\dot{V}_{E}RT$  and facilitate both wider testing and integration of this index into clinical practice.

### REFERENCES

1. Epstein SK, Ciubotaru RL, Wong JB. Effect of failed extubation on the outcome of mechanical ventilation. *Chest* 1997;112(1):186–192.
2. Epstein SK. Decision to extubate. *Intensive Care Med* 2002;28(5):535–546.
3. Khamiees M, Raju P, DeGirolamo A, Amoateng-Adjepong Y, Manthous CA. Predictors of extubation outcome in patients who have successfully completed a spontaneous breathing trial. *Chest* 2001;120(4):1262–1270.
4. Coplin WM, Pierson DJ, Cooley KD, Newell DW, Rubenfeld GD. Implications of extubation delay in brain-injured patients meeting standard weaning criteria. *Am J Respir Crit Care Med* 2000;161(5):1530–1536.
5. Smina M, Salam A, Khamiees M, Gada P, Amoateng-Adjepong Y, Manthous CA. Cough peak flows and extubation outcomes. *Chest* 2003;124(1):262–268.
6. Martinez A, Seymour C, Nam M. Minute ventilation recovery time: a predictor of extubation outcome. *Chest* 2003;123(4):1214–1221.
7. Truitt JD. Viewpoints to liberation from mechanical ventilation (editorial). *Chest* 2003;123(6):1779–1780.
8. Seymour CW, Christie JD, Gaughan C, Fuchs BD. Measurement of a baseline minute ventilation for the calculation of minute ventilation recovery time: is a subjective method reliable? *Respir Care* 2005;50(4):468–472.
9. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;1(8476):307–310.
10. Seymour CW, Hanson CW, Fuchs BD. Minute ventilation recovery time ( $\dot{V}_{E}RT$ ) can predict extubation outcome in surgical patients (abstract). *Am J Respir Crit Care Med* 2002;A687.