Minute Ventilation: It Takes Time to Get It Right

The search for ideal predictors of successful extubation or "liberation" from mechanical ventilation has been a subject of constant investigation for over half a century. Initial investigations were spurred by the need to determine adequate reversal of paralytic agents after general anesthesia, sufficient to allow sustained spontaneous ventilation and permit extubation.[1,2] It is notable that these and other investigators felt that restoration of adequate minute ventilation ($\dot{V}_E$), in and of itself, was not sufficient to allow safe extubation. They sought another measurement of ventilatory reserve, which led to measurement of the peak inspiratory pressure (P_{Imax}, or negative inspiratory pressure against an occluded airway). They found that the amount of negative pressure generated increased with the duration of time the airway was occluded and as the paralytic effect dissipated or was reversed. A threshold value of -20 cm H_2O identified suitability for extubation.

However, there remained uncertainty about extubation in patients requiring mechanical ventilation for respiratory failure or conditions other than general anesthesia. Discontinuation of mechanical ventilation was considered an "arbitrary clinical decision based on judgment and experience."[3] Other criteria were available, but none were utilized in a systematic fashion. This led to an investigation in which a P_{Imax} (or peak negative pressure on maximal inspiration) of -30 cm H_2O, a $\dot{V}_E < 10$ L/min, and the ability to double $\dot{V}_E$ were identified as accurate predictors of successful extubation.[3] These parameters quickly became part of a constellation of measurements collectively referred to as "weaning parameters." This is a bit of a misnomer, since the criteria are really used to determine suitability for extubation and not weaning, but the terminology has become part of medical jargon.

Since that initial investigation, over 50 other measurements have been included in this category of "weaning parameters," with more being developed annually.[4] This is a telling statistic and a reflection of the relatively modest performance of these measures in predicting successful extubation. It is unlikely that there exists a single best parameter, because this decision requires integration of multiple aspects of patient performance, including strength, endurance, upper-airway control and clearance, as well as nonpulmonary issues (eg, cardiac, mental status, medications) that can contribute to extubation failure. No single parameter can encompass all of these issues. Patients may also be too heterogeneous to permit general categorization, meaning that this decision to extubate also requires some judgment and experience, and remains as much of an art as it is a science.[5]

On the other hand, if weaning parameters are used in the decision to extubate, it is imperative that the measurements are accurate and reproducible, and therefore reflective of the parameter they are designed to measure. It follows that uniform or standardized methods are a crucial element to ensure reliable measures. This would seem to be an obvious tenet of practice.

Unfortunately, the technique used in measuring of weaning parameters is widely variable. For example, a survey of 25 hospitals on the measurement of $\dot{V}_E$ revealed 5 different methods of measurement: obtained with and without oxygen, on or off the ventilator, with different measurement devices.[6] Not surprisingly, differences in technique produced statistically different values of $\dot{V}_E$ in the same patient. In our survey of over 100 respiratory therapists, even greater variation was reported for individual weaning parameters, most notably the P_{Imax}.[7] The reported occlusion time ranged from < 1 second to $16-20$ seconds, with only 10% meeting the recommended time of at least 12 seconds. There was not only great variation noted *between* hospitals; there was also variation noted by therapists in the *same* hospital. It also follows that standardizing techniques leads to consistent and reproducible values.[8] This issue has been well recognized, as has the need for proper standardization of measurement.[9] This experience also raises the disconcerting possibility that another reason for the inconsistent performance of weaning parameters is not the parameter, but the technique used to make these measurements. These variations would result in values that may misclassify patients and lead to incorrect decisions in management.

The variable track record of weaning parameters has not discouraged their investigation. The $\dot{V}_E$ recovery time is another predictor of extubation that may provide better discrimination than currently used measures.[10] Its methodology consists of a 2-part process, with the first part identifying a patient's baseline nadir $\dot{V}_E$, based on data obtained from the ventilator. The second part involves measure of recovery time to 110% of baseline during a rest

period, after completion of a spontaneous breathing trial. A longer recovery time was felt to represent decreased respiratory reserve and inability to maintain unsupported breathing. A longer recovery time was a better predictor of extubation failure than were commonly used parameters such as the frequency/tidal volume ratio. Using automatically collected data with an electronic interface attached to the ventilator has another advantage over other weaning parameters, as it eliminates, to a large extent, the human element in data collection. The information is derived from the ventilator and monitored electronically, minimizing variations in technique and, therefore, errors. However, the determination of the baseline $\dot{V}_E$ is still subject to human interpretation.

Determining the baseline $\dot{V}_E$ as described had not been subject to rigorous evaluation. The index study used only one observer to make that determination, defined as the lowest, stable nadir $\dot{V}_E$ lasting 15–30 min.[10] In this issue of RESPIRATORY CARE, Seymour et al report on how they sought to validate the methodology used to establish the baseline $\dot{V}_E$, since it represented the greatest potential source of error in this measure.[11] Errors in the baseline measurement would translate into errors in the $\dot{V}_E$ recovery time. Three blinded physician readers trained in the methodology reviewed the data in 19 patients. This was a straightforward study and inter-rater reliability and agreement between readers, defined as baseline $\dot{V}_E$ within 1 L/min, was excellent, as demonstrated by several measures, including scatter plots. The readers agreed in almost 80% of those studies.[11] However, a closer review is warranted.

$\dot{V}_E$ has always seemed to be a fairly straightforward measurement. It requires measurement of only 2 variables for a total of 1 min. It should even be easier if one uses the ventilator to acquire and record the data. This is based on an assumption that the data acquired by the ventilator are accurate. After all, in the computer age, electronically acquired data are often considered infallible, but one must recognize that data acquisition is based on algorithms that are written by human programmers. A review of the ventilator manual can be enlightening. In that manual, $\dot{V}_E$ measurement is described at a *projected* (my emphasis) 8-breath running average *or* a 1-min sample, whichever occurs first.[12] This means the volumes from 8 breaths are used to calculate the $\dot{V}_E$, making an assumption that the 8 breaths are representative of ventilation over a minute. In some series, 10 breaths were used, but the main point is that the value represents an estimate based on breathing that occurs for the most part in less than a minute, unless of course the patient's respiratory rate was 8 breaths/min. Few patients have a respiratory rate of ≤ 8 breaths/min and, therefore, this suggests that the $\dot{V}_E$ data generated are not 1-min measurements, but projections or estimates for 1 min. Can this be correct? In a review of the same ven-

dor's manual for their newest ventilator, the description of exhaled $\dot{V}_E$ is more extensive but the methodology seems the same, albeit with frequent updates occurring with each breath or at least every 10 seconds.[13] The values are not 1-min measurements, but rather projections for 1 min. The obvious question is whether this is of clinical importance. After all, the practice of medicine is full of shortcuts that have no clinical consequences. Routine vital signs usually represent 15 seconds of observation. When was the last time someone measured a heart rate for 60 seconds? The quick response to this question is that the 8-breath projection should make no difference, but let's examine this further.

$\dot{V}_E$ data were collected from the ventilator's measurement of $\dot{V}_E$ at 15-min intervals. This was not an average of 15 min of breathing, but the average of the 1 min at the minute of sampling. Even that value may not represent a patient's $\dot{V}_E$. For anyone who has ever spent time observing patients with this ventilator, it will become apparent that this value is constantly changing. In the stable patient, this is unlikely to be of any importance, as there will be little overall change. But tachypnea can produce a marked increase in displayed $\dot{V}_E$, and an unstable breathing pattern will produce several changes in $\dot{V}_E$ over an actual 60 seconds of observation. In others, every little change in tidal-volume delivery or respiratory rate, whether real or artifactual (cough, patient-ventilator asynchrony, or the result of a leak), is factored into the final output. This may explain the variation in $\dot{V}_E$ noted in the tracings in the article by Seymour et al.[11] In Figure 2 the $\dot{V}_E$ ranges from about 6 L/min to 14 L/min, but for the most part seems to hover around 10 L/min. In Figure 4 it ranges from about 5 L/min to 10 L/min, and seems to hover around 7 L/min. Surely the high values are outliers and probably not reflective of a patient's baseline, but raises the question as to why there should be such variation. What was the patient doing or what was being done to the patient to produce such increases? Or were these changes the result of the ventilator's algorithm at that minute? What was the role of sedation, if any? Is the increase legitimate or was it an artifact or "noise"? Should this "noise" be included or should it be edited, and if edited, using what criteria?

Closer examination of the tracings raises further questions. Based on the definition, all that is required to determine a nadir $\dot{V}_E$ would be 2 stable points, since that would represent a 15-min period. This would appear to be a relatively simple interpretation and would not require more than a few seconds of review. One might expect over 90% concordance with this type of definition. While 80% concordance is fairly high, it also represents 20% discordance. These tracings represent 8-hour recordings, as opposed to the original investigation, which reviewed 24 hours of data. Is it valid to reduce the sampling time? This prompts one to ask, what is the normal variation in $\dot{V}_E$ in

a sedentary (bedbound) ventilator patient? While sampling 1 min every 15 min should provide representative data in unchanging patients, it may not be representative in those more active. It may be easier to identify outliers, especially high values, with more frequent sampling. More frequent sampling, perhaps every 5 min, may also make it easier to determine the nadir $\dot{V}_E$, with less room for interpretation. That in turn may further improve inter-observer agreement and reliability.

Figure 4 highlights a tracing with substantial discordance. One might consider the nadir in this patient to be somewhere in the 5-L/min range. Why then did 2 readers choose a value in the 7-L/min range? Which reading is truly representative? Choosing one over the other (5 vs 7) may result in markedly different recovery times and possibly misclassify a patient with respect to potential extubation. And all are aware of the consequences of prolonged mechanical ventilation.[14] Alternatively, 2 stable points may not be representative of the patient's baseline. Instead of a nadir, perhaps an average of a stable period would be a more representative value.

What can one conclude? The search for the optimal weaning parameter(s) continues. $\dot{V}_E$ recovery time is promising, but hinges on consistent measurement of $\dot{V}_E$. This is easier said than done. Automating data collection would be fine, but one must be aware of the algorithms used for data collection and potential causes of error. The ideal method must be simple, reliable, and reproducible, with high inter-observer agreement between health care providers with multiple levels of expertise. The study by Seymour et al[11] provides support for trending ventilator-acquired data. They have described a reasonably reliable technique, but there are many potential causes of error. It needs to be refined, standardized, and retested by many more observers before the main measure, $\dot{V}_E$ recovery time, can be assessed. They are close, as evidenced by an 80% concordance, but for such a "straightforward" measurement, one would expect nearly perfect concordance—a task surely to require more hours of study of a measurement designed to take only a minute.

Guy W Soo Hoo MD MPH
Pulmonary and Critical Care Section
West Los Angeles Healthcare Center
Veterans Affairs Greater Los Angeles
Healthcare System
Geffen School of Medicine
University of California, Los Angeles
Los Angeles, California

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Correspondence: Guy W Soo Hoo MD MPH, Pulmonary and Critical Care Section, West Los Angeles Healthcare Center (111Q), Veterans Affairs Greater Los Angeles Healthcare System, 11301 Wilshire Boulevard, Los Angeles, CA 90073. E-mail: guy.soohoo@med.va.gov.