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Serial Measurements of the Rapid-Shallow-Breathing Index as a Predictor of Weaning Outcome in Elderly Medical Patients*

Bruce P. Krieger, MD, FCCP; Jamal Isber, MD; Albe Breitenbucher, MD; Georgene Throop, RRT; and Patti Ershowsky, MHSA, RRT

**Study objectives:** To determine the usefulness of serial measurements of the rapid-shallow-breathing index (f/Vt) as a predictor for successfully weaning elderly medical patients from mechanical ventilator support using a threshold value (\(\leq 130\)) derived specifically for this population.

**Design:** Prospective observational study using parameters suggested from retrospective analysis.

**Setting:** Medical ICUs of a university-affiliated private teaching hospital.

**Patients:** Using data obtained from a retrospective analysis of 10 medical patients \(\geq 70\) years old who had failed weaning, 49 additional medical patients older than 70 years were studied prospectively.

**Interventions:** Standard weaning parameters were determined using a hand-held spirometer. Respiratory rate (f, breaths/min) and tidal volume (Vt, liters) were measured at the beginning of a spontaneous breathing trial and hourly thereafter for up to 5 h using the same hand-held spirometer.

**Measurements and results:** Retrospective analysis showed that the published threshold value for f/Vt (\(\leq 105\)) had poor predictability for weaning success when measured at the beginning of the weaning trial. In the 9 of 10 patients who failed to wean in the retrospective review, the f/Vt increased to \(\geq 130\) as the trial progressed over 2 to 3 h. Using an f/Vt \(\leq 130\) as the threshold value for prospectively predicting successful weaning, the diagnostic accuracy, sensitivity, specificity, positive predictive value, and negative predictive value increased from 84%, 92%, 57%, 87%, and 67%, respectively, when measured at the beginning of the weaning trial to 92%, 93%, 89%, 97%, and 80%, respectively, when measured 3 h later. The area under the receiver operating characteristic curve for f/Vt also improved from 0.81 to 0.93.

**Conclusions:** Serial measurements of the rapid-shallow-breathing index in medical elderly patients during a period of spontaneous breathing can accurately predict the ability to be successfully weaned from mechanical ventilator support.

(CHEST 1997; 112:1029-34)

**Key words:** elderly; inductive plethysmography; mechanical ventilation; ventilator weaning; weaning criteria

**Abbreviations:** ETT=endotracheal tube; f/Vt=respiratory rate divided by spontaneous tidal volume; MVS=mechanical ventilator support; NPV=negative predictor value; PPR=positive predictive value; ROC=receiver operating characteristic curve; \(T_0\)=baseline measurements; \(T_{1-3}\)=measurements made 1 to 3 h after beginning of spontaneous breathing trial

**W**eaning from mechanical ventilator support (MVS) is the transition from MVS to spontaneous breathing by the patient.\(^1\)\(^2\) A controversy still remains as to whether weaning is an "art or a science."\(^3\) Clinicians have been frustrated by their inability to accurately predict weaning success despite the introduction of numerous prediction parameters.\(^4\) The rapid-shallow-breathing index (respiratory rate divided by tidal volume, f/Vt) was introduced by Yang and Tobin\(^5\) and found to be the most accurate index for predicting weaning success as determined by prospective analysis of receiver operating characteristic (ROC) curves. However, subsequent articles have questioned the accuracy of this index as well.\(^6\)\(^7\) In our retrospective analysis of...
257 elderly patients, the f/VT threshold value of \( \leq 105 \) had a positive predictive value \( \geq 88\% \) but a negative predictive value of 11\%, resulting in a diagnostic accuracy of only 75\%.\(^8\)

The difficulty in using parameters to determine the ability of a patient to breathe spontaneously without MVS has to do with two factors. First, patient populations differ and therefore parameters determined from one group of patients may not apply to other populations, such as the elderly.\(^2,9\) Second, weaning parameters published so far have been measured at the beginning of a weaning trial, often after a patient has been fully or partially supported by MVS.\(^1,4-7,10-12\) Many clinicians, nurses, and respiratory therapists realize that a patient’s breathing pattern may be stable for a short period when the patient is removed from MVS only to deteriorate a few hours later. This deterioration is ascribed to lack of respiratory muscle endurance or worsening pulmonary mechanics that may not be apparent when weaning parameters are initially determined in a well-rested patient.\(^13\)

Spontaneous breathing trials have been proposed recently as the most efficient method of weaning patients from MVS.\(^14\) The purpose of this study was to investigate the hypothesis that the rapid-shallow-breathing index in an elderly medical population is useful in predicting weaning success when measured serially over time during a spontaneous breathing trial.

### Materials and Methods

**Patients**

This study was divided into two parts: the first part was a retrospective analysis of 10 patients from the medical ICU who failed their weaning trials; the second part of the study was a prospective analysis of 49 consecutive patients from the medical ICU. All patients were \( \geq 70 \) years old and were deemed capable of being weaned and extubated by the primary physicians in the ICU. Patients were excluded from the study who (1) required reintubation due to laryngeal edema, (2) extubated themselves, (3) were status-posturgery, (4) required tracheostomy, or (5) had required short-term MVS only \(<48 \text{ h})\). The decision to extubate the patient or to reintubate MVS was determined by the primary physicians in the ICU. The primary physicians were aware of the initial weaning parameters but none of the subsequent measurements. The initial parameters were performed at approximately 8 AM on the same day as the weaning trial. Since patient care was not influenced by this study, the institutional review board did not require informed consent.

The characteristics of patients who were prospectively studied are listed in Table 1. The various diagnoses were evenly distributed between patients who were successfully weaned and those who failed weaning. Table 2 shows the baseline pulmonary mechanics and gas exchange parameters of all the patients who were studied prospectively. In the successfully weaned patients, one had a size 6.5-mm endotracheal tube (ETT), five had size 7.0-mm ETT, and 32 had ETT \( \geq 7.5 \text{ mm} \). In the failed-to-wean patients, two had a size 7.0-mm ETT and nine had ETT \( \geq 7.5 \text{ mm} \).

### Table 1—Patient Characteristics*

<table>
<thead>
<tr>
<th></th>
<th>Successfully Weaned</th>
<th>Failed Weaning</th>
</tr>
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<tbody>
<tr>
<td>No. of patients</td>
<td>38</td>
<td>11</td>
</tr>
<tr>
<td>Age, yr</td>
<td>79±6</td>
<td>80±7</td>
</tr>
<tr>
<td>Days of MVS</td>
<td>5.5±6</td>
<td>13±11(^1)</td>
</tr>
<tr>
<td>Diagnosis</td>
<td></td>
<td></td>
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<tr>
<td>Pneumonia</td>
<td>14 (37%)</td>
<td>5 (45%)</td>
</tr>
<tr>
<td>CHF(^1)</td>
<td>9 (24%)</td>
<td>3 (27%)</td>
</tr>
<tr>
<td>COPD</td>
<td>6 (16%)</td>
<td>2 (18%)</td>
</tr>
<tr>
<td>ARDS</td>
<td>4 (10%)</td>
<td>1 (9%)</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>5 (13%)</td>
<td>—</td>
</tr>
</tbody>
</table>

*Data presented as mean±SD.
\(^1\)CHF=congestive heart failure.
\(^{1}\)p<0.05 compared to successfully weaned group.

### Rapid-Shallow-Breathing Index

All spontaneous breathing trials were performed while the patient breathed on continuous positive airway pressure (7200 or 7200a, Puritan Bennett Corp., Carlsbad, Calif) without pressure support or low-by. The sensitivity of the ventilator ranged between 1.5 and 2 cm H\(_2\)O. In the prospective trials, all measurements of the spontaneous respiratory rate (f, breaths/min) and tidal volume (Vt liters) were made using a hand-held calibrated spirometer (Boehringer Laboratory; Wynnewood, Pa) while the patient temporarily breathed through a T-piece setup for 60 s.\(^1\) The f/VT measurements were repeated using the same hand-held spirometer at hourly intervals as long as the patient continued his or her spontaneous breathing trial. The length of the trial was determined by the primary physicians in the ICU who were monitoring the patients using the criteria listed below. In the retrospective part of this study, a respiratory inductive plethysmograph (Respigraph; Noninvasive Monitoring Systems, Inc; Miami Beach, Fla) that was calibrated using a natural breathing, single posture method based on isovolume equation

### Table 2—Baseline Pulmonary Mechanics and Gas Exchange*

<table>
<thead>
<tr>
<th></th>
<th>Successfully Weaned</th>
<th>Failed Weaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory frequency, breaths/min</td>
<td>22±7</td>
<td>28±5(^1)</td>
</tr>
<tr>
<td>Tidal volume, L</td>
<td>0.31±0.137</td>
<td>0.22±0.76</td>
</tr>
<tr>
<td>Minute ventilation, L</td>
<td>6.4±2.5</td>
<td>6.1±2.1</td>
</tr>
<tr>
<td>Maximal inspiratory pressure, cm H(_2)O</td>
<td>−43±11</td>
<td>−35±11</td>
</tr>
<tr>
<td>Compliance, static, L/cm H(_2)O</td>
<td>0.049±0.014</td>
<td>0.040±0.014</td>
</tr>
<tr>
<td>PEEP, extrinsic, cm H(_2)O</td>
<td>3.82±1.5</td>
<td>4.0±1.8</td>
</tr>
<tr>
<td>PEEP, intrinsic, cm H(_2)O</td>
<td>0.53±1.3</td>
<td>1.5±2.8</td>
</tr>
<tr>
<td>Peak inspiratory pressure, cm H(_2)O</td>
<td>25±8</td>
<td>29±7.5</td>
</tr>
<tr>
<td>Arterial pH</td>
<td>7.46±0.05</td>
<td>7.44±0.04</td>
</tr>
<tr>
<td>Arterial P(_{CO_2}), mm Hg</td>
<td>36±7</td>
<td>45±7(^1)</td>
</tr>
<tr>
<td>Arterial/alveolar Pa(_O_2)</td>
<td>0.53±0.18</td>
<td>0.49±0.16</td>
</tr>
<tr>
<td>Fractional inspired O(_2)</td>
<td>0.40±0.06</td>
<td>0.38±0.06</td>
</tr>
</tbody>
</table>

*Data presented as mean±SD; PEEP = positive end-expiratory pressure.
\(^1\)p<0.05 compared to successfully weaned group.
principles, continuously monitored patients during spontaneous breathing trials. All patients studied in the retrospective analysis failed their weaning trial and required reinstitution of MVS.

Criteria for Determining Weaning Outcome

Weaning failure was defined as requiring the reinstitution of MVS within 48 h after extubation. The laboratory criteria for instituting MVS included a pH in arterial blood ≥7.32 or a decrease in partial pressure of oxygen (PaO2) ≤60 mm Hg or oxygen saturation by pulse oximeter ≤88% with a fraction of inspired oxygen ≥0.5. Five patients in the retrospective analysis met these criteria. The other five patients in the retrospective study who failed weaning met one of the following criteria: new-onset tachycardia (heart rate >135 beats/min) or cardiac dysrhythmias, hypotension (systolic BP <100 mm Hg), or subjective evidence of respiratory distress as evidenced by a combination of diaphoresis, accessory muscle use, and accessory efforts, and change in mental status. In the prospective group of patients who failed weaning, 9 of 11 patients showed subjective signs of weaning failure, 4 of 11 developed new onset of tachycardia, and 2 of 11 developed hypotension. Six patients studied prospectively had arterial blood gases (ABGs) performed prior to MVS being reinstituted. Five of these six patients met ABG criteria for weaning failure as well.

Statistics

Standard formulas were used to calculate the sensitivity (true positives/[true positives + false negatives]), specificity, (true negatives/[true negatives + false positives]), positive predictive value (PPV) (true positives/[true positives + false positives]), negative predictive value (NPV) (true negatives/[true negatives + false negatives]), and diagnostic accuracy ([true positives + true negatives]/[true positives + true negatives + false positives + false negatives]), for the rapid-shallow-breathing index. A true positive was defined as an fVT ≤130 in a patient who was successfully weaned, while a true negative result occurred when the fVT was >130 and the patient required reinstitution of MVS within 48 h of extubation. The predictive performance of fVT was assessed with ROC curves. The true positive rate was plotted on the vertical axis and the false positive fraction on the horizontal axis. The area under the curve was calculated and used to assess the performance of fVT in predicting weaning outcome. In the prospective trials, 9 of 11 patients who failed weaning were studied at 3 h while 30 of 38 patients who were successfully weaned had data available at 3 h. Multiple comparisons were made by the Newman-Keuls procedure with p<0.05 being considered significant.

RESULTS

The retrospective study showed that the fVT equaled 130±32 (mean±SD) when the 10 patients failed weaning. Four patients had an fVT >130 within 1 h of starting their spontaneous breathing trials, three additional patients after 2 h, two more patients after 3 h, and one patient (with an fVT = 154) after 5 h of spontaneous breathing. A threshold value of fVT ≤130 was chosen for the prospective trials and the ROC curves for fVT were analyzed at baseline (T0) and 3 h later (T3) in the prospective analysis. The choice of the threshold value of fVT was extrapolated from the retrospective analysis of patients who failed weaning only. Therefore, this cannot be considered to be a statistically derived discriminatory value.

The sensitivity, specificity, PPV, NPV, and diagnostic accuracy of fVT ≤130 was superior to fVT ≤105 when measured at T3 (Table 3). When measured at baseline (T0), the specificity and PPV of fVT ≤130 was less than a threshold value of ≤105, although the diagnostic accuracy remained superior. Thirty-six patients had required MVS for ≤7 days (30 successfully weaned, 6 who failed weaning). The remaining 13 patients had been receiving MVS for >7 days (8 successfully weaned, 5 who failed weaning). The greatest improvement in specificity, PPV, NPV, and diagnostic accuracy when fVT ≤130 was used as the threshold value at T3 was seen in the long-term mechanically ventilated patients. In the group of patients who required MVS for ≤7 days, fVT ≤130 was more accurate but less specific than fVT ≤105 when measured at baseline. The sensitivity, specificity, PPV, NPV, and diagnostic accuracy of fVT ≤130 at T0 was similar to fVT ≤130 when measured at T3 in the short-term mechanically ventilated group.

In the patients who failed weaning, the mean fVT was greatest at T2 (2 h after commencing their spontaneous breathing trial). However, because of a large variability, the fVT did not reach statistical significance compared to baseline (T0) until T3 (Fig 1). Figure 1 displays the number of patients studied at each time point. The area under the ROC curve for fVT at the beginning of the weaning trial was 0.81. This improved to 0.93 when analyzed at T3 (Fig 2).

DISCUSSION

The term “weaning” has been criticized as not being an appropriate description of the process that
occurs when a patient undergoes the transition from MVS to spontaneous breathing\textsuperscript{4,8}. One criticism is that weaning implies that the transition needs to be a gradual process. In actuality, a gradual transition is only required in <30% of patients receiving MVS\textsuperscript{1}. Being able to identify the majority of patients who do not require a gradual transition would lessen the likelihood of ventilator-associated complications as well as being cost-effective\textsuperscript{13,19}. Expeditious removal from MVS has been the impetus for developing various parameters to guide the clinician in this important decision\textsuperscript{20}. Because traditional weaning parameters lack the sensitivity and specificity for predicting weaning outcome, newer parameters were developed that have been shown to have superior predictive values\textsuperscript{1}. However, most of these indexes require the use of specialized equipment such as an esophageal balloon (to record transdiaphragmatic pressure\textsuperscript{21}, airway occlusion pressure\textsuperscript{10,11} or work of breathing\textsuperscript{11,22}), a gastric catheter (for gastric pH recording\textsuperscript{12}), a metabolic cart (to calculate $O_2$ consumption\textsuperscript{7}), or respiratory inductive plethysmography (to record breathing patterns\textsuperscript{23,24}). Yang and Tobin\textsuperscript{2} incorporated two easily measurable\textsuperscript{1} and reproducible parameters\textsuperscript{23}, the spontaneous respiratory rate and tidal volume, into a rapid-shallow-breathing-index which was the most accurate predictor of weaning success in their patient population. These results were not duplicated when the parameters were measured with patients breathing on continuous positive airway pressure or pressure support\textsuperscript{6,7}. We also found that the $f/V_t$ threshold of $\leq 105$ results was not accurate in predicting weaning success in a large group of elderly patients\textsuperscript{8}. This lack of accuracy was not surprising given the fact that elderly patients’ traditional weaning parameters were also inaccurate predictors of weaning success\textsuperscript{2,9}. It has been suggested previously that the poor performance of conventional predictors of weaning success is due to the use of criteria derived from studies which included patients who differed from the population being evaluated\textsuperscript{20}. The changes that occur with aging could significantly influence the measurement of weaning parameters. Senescent changes include decreases in lung volumes, elastic recoil, diffusion, oxygenation, and ventilatory responses to carbon dioxide\textsuperscript{2}. In addition, diagnostic categories may affect weaning success as well as weaning parameters by altering the patient’s breathing pattern\textsuperscript{24}. Another reason for the inaccuracy of previously tested weaning parameters may be due to when they are measured. Usually, this occurs at the beginning of a weaning trial after a patient has been “rested” by being maintained on a regimen of full or partial MVS\textsuperscript{4,7,10-12}. Traditional weaning parameters are

![Figure 2: ROC curve for $f/V_t$ measured after 3 h of spontaneous breathing (T3).](image-url)
therefore static while breathing is an active, ongoing process. Although it has been suggested that discriminant analyses should be developed to help predict successful weaning,\textsuperscript{2,6} to our knowledge, no one has used trend analysis to improve the accuracy of predicting weaning success. We therefore chose a predictive threshold for the rapid-shallow-breathing-index using data that were extrapolated from a retrospective analysis of a small group of patients and then applied this value (f\textsubscript{VT} ≤130) serially over time in a well-defined patient population, that being elderly medical patients with similar diagnosis.

The prevalence of weaning failure in our study (22.5\%) is similar to other recent studies that have attempted to predict weaning outcome, in which weaning failure ranged from 22 to 44\%.\textsuperscript{5,10,12,27} One criticism of our study design is that the spontaneous breathing trial did not have a set time limit, although most patients were either extubated or required reinstitution of MVS after approximately 3 h of spontaneous breathing (Fig 1). The reason for this lack of uniformity is that the decision to extubate was left to the primary physician and no attempt was made to influence this decision.\textsuperscript{5}

ROC curve analysis has been used to assess the predictive performance of various weaning parameters. Yang and Tobin\textsuperscript{9} found the area under the ROC curve to be highest (0.89) for f\textsubscript{VT} followed by VT (0.87), an integrated index (CROP, 0.78), and respiratory rate (0.76). Sassoon and Malnute\textsuperscript{10} noted the area under the ROC curve for f\textsubscript{VT} to be 0.78 which was not improved (area=0.80) by integrating the airway occlusion pressure into an index (occlusion pressure × f\textsubscript{VT}). In the present study, the area (±SEM) under the curve for f\textsubscript{VT} at T\textsubscript{0} and T\textsubscript{3} was significantly larger (p<10\textsuperscript{-6}) than that of an arbitrary test, which would have no discriminatory value (area=0.50). The area under the ROC curve (Fig 2) for f\textsubscript{VT} at T\textsubscript{3} was larger (0.93±0.05) than the area under the ROC curve for f\textsubscript{VT} when measured at baseline (0.81±0.05).

The diagnostic accuracy for all parameters tested was greatest for the f\textsubscript{VT} ≤130 when measured at T\textsubscript{3}. However, this diagnostic accuracy was not significantly different than baseline when measured in the subset of patients who required short-term (≤7 days) MVS. In the patients who required long-term MVS (>7 days), serial measurements of f\textsubscript{VT} significantly improved the diagnostic accuracy of this test. This is expected, since patients who require long-term MVS frequently have more serious pulmonary mechanical abnormalities or nonpulmonary systemic illnesses than patients who require only short-term MVS. Therefore, respiratory muscle endurance may be limited and a measurement of strength after a rest period (at baseline) may not be predictive of the patient’s ability to maintain a stable breathing pattern over a prolonged period.\textsuperscript{28} This has been studied previously using respiratory inductive plethysmography, both over a short-term trial of weaning\textsuperscript{23} and during longer spontaneous breathing trials.\textsuperscript{24}

The rapid-shallow-breathing index is simple to measure and is independent of patient cooperation.\textsuperscript{1} Therefore, it offers a distinct advantage over more complicated parameters that have similar diagnostic accuracy in predicting weaning success. In addition, it incorporates the intuitive bedside clinical skills that have been traditionally relied on for determining when to terminate MVS, that being “eyeballing” the patient.\textsuperscript{11} In actuality, eyeballing the patient is a subjective assessment of the patient’s work of breathing, oxygenation, and ventilation.\textsuperscript{2} Although the rapid-shallow-breathing index does not measure oxygenation, the widespread availability of continuous pulse oximetry obviates the need for this to be incorporated into the index.\textsuperscript{20} The f\textsubscript{VT} emphasizes the patient’s breathing pattern as the important parameter to follow when evaluating the patient’s ability to breathe spontaneously without support,\textsuperscript{5,13,19,30} By incorporating serial measurements, an estimate of respiratory and hemodynamic endurance is provided. The sensitivity, specificity, PPV, and NPV of f\textsubscript{VT} at T\textsubscript{3} (Table 3) compares favorably to recent studies that used more complicated parameters to predict weaning success. An airway occlusion pressure ≤5.5 cm H\textsubscript{2}O has a PPV=0.85 and NPV=0.80,\textsuperscript{10} while the oxygen cost of breathing <15% has a PPV=0.63 and NPV=1.00.\textsuperscript{7} Interestingly, the high sensitivity (1.00) of the oxygen cost of breathing parameter was determined in well-defined populations. This emphasizes the importance of defining parameters within specific patient populations and not extrapolating data from other age groups or diagnostic categories. As noted in previous studies,\textsuperscript{10} the prevalence of weaning failure can influence the performance of a weaning index. The prevalence of weaning failure in turn can be influenced by various factors that differ among institutions, including physicians’ clinical judgment, criteria for selecting patients for weaning trials, and criteria for defining respiratory failure.

This study was not designed to determine the appropriate length of a weaning trial. To do this, specific patient populations would have to be randomized prospectively to various lengths of weaning trials and extubated using preset, strict criteria.\textsuperscript{31} Patients who require short-term ventilator support are generally believed to require a shorter weaning trial. This practice is supported by the findings herein, although our post hoc analysis cannot be used as definitive proof. The data presented in this report do give some credence to the customary method of
following a patient’s spontaneous breathing for 1 to 3 h before deciding on the advisability of discontinuing MVS and for not unnecessarily prolonging trials and perpetuating or causing weaning failure.

Another criticism of this study’s design is the lack of uniformity for the length of weaning trials. However, the protocol was constructed to mimic what is usually done in most ICUs where protocols are not strictly followed. Future studies will need to be performed to better define the most appropriate length of a weaning trial.

CONCLUSION

In elderly medical patients, the rapid-shallow-breathing index (f/VT) is a valuable guide for predicting weaning outcome. A threshold value of ≤130 is more appropriate for this population than previously published values of ≤105. Serial measurements of weaning parameters over time improve the accuracy of predicting weaning success.

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