Automatic Tube Compensation-Assisted Respiratory Rate to Tidal Volume Ratio Improves the Prediction of Weaning Outcome*

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Objective: To assess whether the respiratory rate to tidal volume ratio (RVR) measured while receiving automatic tube compensation (ATC) [RVRATC] would have a better predictive value as a weaning measure than unassisted RVR.

Design: Prospective cohort study.

Setting: General ICU of a tertiary-care university hospital.

Patients: Forty-three patients who received mechanical ventilation for > 24 h and were considered ready for weaning.

Interventions: All patients underwent a 60-min spontaneous breathing trial (SBT) [positive end-expiratory pressure of 5 cm H2O; ATC, 100%]. Patients tolerating the trial (n = 35) were extubated immediately. The following parameters were measured at the onset and end of the SBT: RVR, RVRATC, peak airway pressure (Paw), airway occlusion pressure, and minute ventilation. The outcome measure was successful extubation (ability to maintain spontaneous breathing for > 48 h).

Measurements and results: Median age was 55 years (range, 25 to 88 years), median APACHE (acute physiology and chronic health evaluation) II score was 15.5 (range, 3 to 29), and median duration of mechanical ventilation prior to the SBT was 7 days (range, 1 to 40 days). Extubation was successful in 25 patients (72%). There were no significant differences in baseline characteristics between patients successfully extubated (group 1) and those requiring reintubation. On multivariate analysis, RVRATC measured at 60 min (RVRATC) was most predictive of successful extubation (p = 0.03). The area under the receiver operator characteristic curve was also highest for RVRATC (0.81 ± 0.03) as compared to RVR (0.77 ± 0.03), RVR (0.75 ± 0.04), and RVR measured at 60 min (0.69 ± 0.05). The ratio of RVRATC to Paw was the best predictor (0.84 ± 0.02).

Conclusions: RVRATC measured at the end of the SBT was the best predictor of successful extubation. A new ratio (ratio of RVRATC to Paw) was most predictive and deserves further study.

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Key words: automatic tube compensation; mechanical ventilation; weaning; respiratory rate to tidal volume ratio

Abbreviations: APACHE = acute physiology and chronic health evaluation; ATC = automatic tube compensation; AUC = area under receiver operator characteristic curve; Crs = static compliance; DS = daily screen; FIO2 = fractional content of inspired oxygen; Paw = peak airway pressure; P0.1 = airway occlusion pressure; PEEP = positive end-expiratory pressure; PSV = pressure support ventilation; Raw = airway resistance; ROC = receiver operator characteristic; RVR = respiratory rate to tidal volume ratio; RVRATC = respiratory rate to tidal volume ratio measured while receiving automatic tube compensation; RVRATC = respiratory rate to tidal volume ratio measured at 60 min; RVRATC = respiratory rate to tidal volume ratio measured while receiving automatic tube compensation; RVRATC = respiratory rate to tidal volume ratio measured at 60 min; SBT = spontaneous breathing trial; TISS = therapeutic intervention scoring system; Ve = minute ventilation; Vt = tidal volume

Recognizing when a patient recovering from respiratory failure is ready to breathe spontaneously is an important treatment goal for intensivists. Of the many parameters suggested for the prediction of successful weaning, the respiratory rate to tidal...
volume ratio (RVR), expressed as breaths per minute per liter, is becoming increasingly popular.\textsuperscript{1,2} This simple, bedside test has been widely incorporated into weaning protocols aimed at hastening the process of liberation from ventilation.\textsuperscript{3-5}

Spontaneous breathing trials (SBTs) are usually performed prior to extubation to evaluate the capacity of patients to meet their ventilatory demands. However, the resistance of endotracheal tubes can significantly increase the ventilatory work of spontaneously breathing patients.\textsuperscript{6,7} Fabry et al.\textsuperscript{8} introduced a new mode of ventilatory support called automatic tube compensation (ATC). This mode delivers exactly the amount of pressure necessary to overcome the resistive load imposed by the endotracheal tube for the flow measured at the time (variable pressure support); hence its designation as "electronic extubation."\textsuperscript{9} This study was conducted to assess whether the RVR measured while receiving ATC (RVRATC) has a better predictive value than the unassisted RVR.

**Materials and Methods**

**Patients and Measurements**

Patients who were receiving mechanical ventilation in the adult general ICU for > 24 h and who met criteria for a daily screen (DS) of respiratory function were included in this prospective study. As ATC has been used routinely in all our patients for the past 5 years, and the general approach to extubation described subsequently is identical to current clinical practice, informed consent was not required from patients enrolled in this study. At the time of the DS, all patients were receiving pressure support ventilation (PSV) at < 15 cm H\textsubscript{2}O with 100% ATC (Evita 4; Dräger Medizintechnik; Luibeck, Germany). The following data were recorded by the study physicians: demographic data; APACHE (acute physiology and chronic health evaluation) II score,\textsuperscript{10} measured at the time of admission to the ICU; therapeutic intervention scoring system (TISS),\textsuperscript{11} measured at the onset of the weaning trial; respiratory parameters (determined from the digital display of the mechanical ventilator), including minute ventilation (Ve), respiratory rate, fraction of inspired oxygen (FiO\textsubscript{2}), static compliance (Crs), airway resistance (Raw), spontaneous tidal volume (V\textsubscript{t}), peak airway pressure (Paw), auto-positive end expiratory pressure (PEEP), and proximal airway occlusion pressure (P\textsubscript{a1}); laboratory data, including PaO\textsubscript{2} and PaCO\textsubscript{2}; and vital signs, including heart rate and intra-arterial systolic BP. The RVR was calculated after 1 min of spontaneous breathing (PEEP of 5 cm H\textsubscript{2}O, no mandatory machine breaths supplied from the ventilator, and no PSV),\textsuperscript{9} first without and immediately thereafter with the addition of 100% ATC (RVRATC).

**DS and SBT Protocols**

Patients were considered eligible for screening of respiratory function only if there was improvement or resolution of the underlying reason for mechanical ventilation. The DS result was considered positive if all the following criteria were met: the patient was fully awake; body temperature was > 37°C and < 38.5°C; hemoglobin level was > 8 g/dL; no need for vasoactive drugs; systolic BP was > 90 mm Hg; only minimal or no sedation; PaO\textsubscript{2}/FiO\textsubscript{2} ratio was > 200; PEEP was < 7.0 cm H\textsubscript{2}O; and RVR was < 105. In patients with a positive DS result, a 1-h SBT was commenced immediately. For the trial, patients were allowed to breathe through the ventilatory circuit using flow triggering and a continuous positive airway pressure of 5 cm H\textsubscript{2}O, with ATC of 100%; and FiO\textsubscript{2} < 0.5. These parameters were maintained throughout. Respiratory parameters (including RVR), laboratory data, and vital signs were recorded immediately prior to and at the end of the SBT. The trial was aborted in the presence of oxygen saturation in arterial blood < 90%, increase in heart rate to > 140 beats/min, increase in systolic BP to > 180 mm Hg or < 90 mm Hg, increased anxiety, or diaphoresis. All patients who tolerated the SBT underwent immediate extubation, while ventilatory support with PSV was reintroduced in patients showing poor tolerance. Criteria for reintubation were an increase in PaCO\textsubscript{2} by > 10 mm Hg; decrease in PaO\textsubscript{2} to < 60 mm Hg or oxygen saturation to < 90% while receiving FiO\textsubscript{2} > 0.5 to 1.0; inability to protect the airway because of upper-airway obstruction (stridor) or excessive secretions; and evidence of excessive respiratory work (respiratory rate ≥ 35 breaths/min for ≥ 5 min, or thoracoabdominal paradox). Time to reintubation was measured in hours from extubation and rounded off to the nearest hour.

**Outcome**

The primary outcome measure was successful extubation, defined as the ability to maintain spontaneous unassisted breathing for > 48 h. Patients were accordingly separated into two groups: group 1, successful extubation; group 2, requiring reintubation within 48 h of extubation. In group 2, a cause for extubation failure was assigned in each case as follows: (1) new episodes of sepsis, defined as increase in temperature to > 38.5°C, leukocytosis > 12,000/\mu L, tachycardia > 90 beats/min, and a probable site of infection; (2) hypoventilation, defined as an increase in PaCO\textsubscript{2} > 60 mm Hg with a decrease in pH to < 7.25; or (3) inability to adequately clear secretions.

**Statistical Analysis**

One-way analysis of covariance with repeated measures (BMISP Statistical Software; SPSS: Chicago, IL) was performed for all study variables by the outcome measure (successful extubation). Variables reaching statistical significance (p < 0.05) were then entered into a stepwise logistic regression analysis to identify independent variables that correlated with outcome. Receiver operator characteristic (ROC) curves were also derived from these variables to assess their ability to discriminate between the two groups of patients (successful and unsuccessful extubation).

**Results**

Forty-three patients were entered into the study. Eight patients did not tolerate the SBT, requiring reinstitution of mechanical ventilation within 60 min, and were therefore not included in the analyses. The demographic characteristics of the remaining patients (n = 35) are shown in Table 1. Their ages ranged from 25 to 88 years (median, 55.0 years). Sixty-eight percent of the patients were male. Rea-
The study shows that the RV RATC, particularly when assessed at the end of an SBT, improves the

Table 3—Characteristics at the End of the SBT*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group 1 (n = 25)</th>
<th>Group 2 (n = 10)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paw, cm H₂O</td>
<td>8.9 ± 1.9</td>
<td>7.5 ± 1.3</td>
<td>0.04</td>
</tr>
<tr>
<td>Auto-PEEP, cm H₂O</td>
<td>1.9 ± 1.2</td>
<td>3.0 ± 1.9</td>
<td>NS</td>
</tr>
<tr>
<td>Respiratory rate,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>breaths/min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vr, L</td>
<td>0.50 ± 0.1</td>
<td>0.40 ± 0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>V̇e, L/min</td>
<td>11.3 ± 2.9</td>
<td>11.1 ± 3.9</td>
<td>NS</td>
</tr>
<tr>
<td>P0.1, millibar</td>
<td>4.2 ± 1.6</td>
<td>4.7 ± 1.9</td>
<td>NS</td>
</tr>
<tr>
<td>RVR₆₀, breaths/min/L</td>
<td>54.4 ± 24.6</td>
<td>72.7 ± 18.9</td>
<td>0.05</td>
</tr>
<tr>
<td>RVR₆₀ATC, breaths/min/L</td>
<td>49.9 ± 24.2</td>
<td>73.9 ± 16.1</td>
<td>0.002</td>
</tr>
<tr>
<td>Heart rate, beats/min</td>
<td>96.6 ± 19.3</td>
<td>99.8 ± 16.7</td>
<td>NS</td>
</tr>
<tr>
<td>Systolic BP, mm Hg</td>
<td>137.5 ± 20.2</td>
<td>148.4 ± 20.2</td>
<td>NS</td>
</tr>
</tbody>
</table>

*Data are presented as mean ± SD. See Table 2 for expansion of abbreviation.

Discussion

The study shows that the RV RATC, particularly when assessed at the end of an SBT, improves the

Table 4—Multivariate Analysis*

<table>
<thead>
<tr>
<th>Parameters</th>
<th>OR</th>
<th>95% CI</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVR</td>
<td>1.46</td>
<td>1.02–2.14</td>
<td>0.58</td>
</tr>
<tr>
<td>RV RATC</td>
<td>1.50</td>
<td>1.03–2.17</td>
<td>0.61</td>
</tr>
<tr>
<td>RVR₆₀</td>
<td>1.42</td>
<td>0.96–2.10</td>
<td>0.63</td>
</tr>
<tr>
<td>RVR₆₀ATC</td>
<td>1.63</td>
<td>1.07–2.48</td>
<td>0.03</td>
</tr>
<tr>
<td>Paw₆₀</td>
<td>0.56</td>
<td>0.31–1.02</td>
<td>0.16</td>
</tr>
</tbody>
</table>

*OR = odds ratio; CI = confidence interval; Paw₆₀ = Paw measured at 60 min.
sensitivity of the RVR as a predictor of successful extubation. Many parameters have been used to predict a patient’s ability to tolerate spontaneous breathing.12 These include measures of neuromuscular function, such as maximal inspiratory pressure and P0.1; measures of respiratory load such as VE, Crs, and Raw; and integrative indexes, such as the oxygen cost of breathing and the RVR. The RVR, which quantifies the clinical finding that patients who failed to wean develop more rapid and shallower breathing, appears to be superior to many of the other parameters13,14 and is easily applied at the bedside. However, although the test is sensitive (92% in the study by Epstein15), the specificities from various studies are much lower (11 to 64%).3,16 The RVR is typically measured 1 min after the patient is allowed to breathe spontaneously. However, Chatila et al13 suggested that this may not be enough time for the respiratory drive to fully develop or to reflect respiratory muscle endurance, and this factor may account for the lack of specificity. They showed, in a prospective study of 100 patients undergoing weaning trials, that the RVR was a better predictor when measured after 30 to 60 min of an SBT than after 1 min.

We hypothesized that the sensitivity of the RVR might be further improved by considering the contribution of the endotracheal tube. It has been shown that the work of breathing imposed by the endotracheal tube is additive to the patient’s preexisting ventilatory work.17 The resistance of the endotracheal tube is flow dependent. Therefore, as the inspiratory gas flow changes constantly throughout each breath during spontaneous breathing, the tube resistance also varies considerably.18 Fabry et al19 suggested that ATC, in which the delivery of pressure support is adjusted automatically and continuously to the current flow rate, without affecting the patient’s breathing pattern, may more appropriately compensate for the concurrent pressure drop across the endotracheal tube, and thereby the concurrent tube resistance during both inspiration and expiration. In clinical studies, ATC effectively reduced the additional work of breathing imposed by the tube resistance in both orotracheally intubated and tra-cheotomized patients.19,20 Its addition also resulted in a higher degree of respiratory comfort and a more physiologic breathing pattern compared with PSV.21

In a previous study, we confirmed that the breathing pattern of patients receiving ventilatory support with PSV was significantly improved after the addition of ATC.22 This prompted us to suggest a new use for ATC, namely the estimation of a “resistance-free” or ATC-assisted RVR as a weaning predictor. In this prospective pilot study, we found that while both the assisted and nonassisted RVRs at 1 min and after 60 min of the SBT were significantly related to successful extubation on univariate analysis, only the RVR60ATC remained predictive on multivariate analysis. The predictive performance, as assessed by the AUC, was best for this same variable (0.81 ± 0.03). In contrast to the study of Chatila et al,13 however, the unassisted RVR60 was less predictive than the initial RVR. We also found that the Paw was significantly higher in patients who were successfully extubated (8.9 ± 1.9 cm H2O vs 7.5 ± 1.3 cm H2O; p = 0.04). Considering that ATC was the mode used for the weaning trials and that Paw is a reflection of the gas flow and, therefore, the inspiratory effort during breathing with ATC assistance, our finding suggests that group 1 patients were less fatigued by the SBT and therefore were able to generate higher flows. These higher flows were translated into higher VTs. The combination of these two significant variables (ie, RVR60ATC and Paw) into a ratio yielded the highest predictive value (AUC 0.84 ± 0.02).

Apart from shortening the ventilation time, an accurate predictor of weaning should decrease the need for reintubation, previously shown to be an independent predictor of hospital mortality, with rates exceeding 30%.23 The reintubation rate in our study (28%) was similar to that found (25%) in N Engl J Med 1991; 324:1445–1450. In conclusion, the present study shows that the predictive power of RVR60 as a weaning measure may be improved with ATC assistance. In addition, the ratio of RVRATC to Paw might be an even more specific tool. We believe additional prospective studies are warranted to confirm these results.

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REFERENCES
2. Tobin MJ, Perez W, Guenther SM, et al. The pattern of breathing during successful and unsuccessful weaning from

<table>
<thead>
<tr>
<th>Variables</th>
<th>ROC ± SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVR</td>
<td>0.77 ± 0.03</td>
</tr>
<tr>
<td>RVRATC</td>
<td>0.75 ± 0.04</td>
</tr>
<tr>
<td>RVR60</td>
<td>0.69 ± 0.05</td>
</tr>
<tr>
<td>RVR60ATC</td>
<td>0.81 ± 0.03</td>
</tr>
<tr>
<td>RVR60ATC/Paw ratio</td>
<td>0.84 ± 0.02</td>
</tr>
</tbody>
</table>

Table 5—AUC of Variables Predicting Successful Extubation