Variability of the Breathing Pattern Before and After Extubation*

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A stable breathing pattern during unassisted ventilation through an endotracheal tube (ETT) prior to extubation is an important factor in determining whether a patient can be successfully extubated. Proper interpretation of changes in the breathing pattern requires knowledge of the normal variability of the breathing pattern in critically ill, intubated patients. To establish these guidelines, 50 spontaneously breathing patients who were being weaned from mechanical ventilation were monitored with respiratory inductive plethysmography for one hour immediately prior to and following successful extubation. Immediately after extubation, respiratory rate (f), tidal volume (VT), minute ventilation, and mean inspiratory flow increased slightly. By 30 minutes postextubation, these parameters were similar to preextubation values. There was no significant change in variability of f or VT. Although the breathing pattern of these relatively stable, intensive care patients differed from values of normal ambulatory subjects, values were similar in the preextubation and postextubation periods.

Weaning from mechanical ventilation usually requires observation of a period of spontaneous ventilation while the patient is intubated. This time interval permits evaluation of the adequacy of ventilation while still allowing for prompt initiation of mechanical ventilatory support if necessary. The patient is carefully observed, vital signs and lung mechanics are measured, arterial blood gas values are obtained, and if all appear stable, extubation follows. Thus, the decision to extubate is primarily influenced by the stability of the breathing pattern and gas exchange observed during spontaneous ventilation through an endotracheal tube. In order to properly assess a weaning trial, it becomes essential to know the variability of the measured parameters. In stable intensive care unit (ICU) patients on constant FIO₂, the arterial oxygen tension can vary by 16.2 ± 10.9 (mean ± SD) mm Hg, does not correlate well with the subjective sensation of dyspnea, and is a nonspecific indicator of a successful extubation. Similarly, lung mechanics can be significantly influenced by patient effort and technique. Although Gilbert et al asserted that changes in the breathing pattern were a poor predictor of a successful trial off the ventilator, they compared mechanically controlled ventilation patterns to spontaneous breathing patterns rather than analyzing spontaneous breathing patterns before and after extubation. To our knowledge, no data are available concerning the variability of breathing pattern in a large group of spontaneously breathing, stable patients in the ICU setting for both preextubation and postextubation periods.

Respiratory inductive plethysmography (RIP) is a reliable, noninvasive method of respiratory monitoring in health and disease and has proven to be accurate even in critically-ill, intubated patients. Therefore, it was used to analyze the breathing pattern of spontaneously breathing subjects for one hour before and after successful extubation. Our aim was to assess the variability of the breathing pattern and establish guidelines for the interpretation of changes in the breathing pattern.

Materials and Methods

Subjects

Fifty monitored intubated patients who were clinically ready for extubation were selected from the medical and surgical intensive care units (ICU) of our institution. This group consisted of 17 women and 33 men ranging in age from 30 to 95 (73 ± 14, mean ± SD) years. Diagnoses included cardiogenic pulmonary edema (19) chronic obstructive pulmonary disease (seven), pneumonia (six), postcardiac arrest (nine), adult respiratory distress syndrome (two), drug overdose (two), pleural effusion (one), postcardiac arrest (one), head trauma (one), and massive aspiration (one). Patients had required mechanical ventilation for periods ranging from 1 to 16 (4.0 ± 4.1) days. At the onset of the study, all had been weaned to unassisted breathing through a T-piece (or an intermittent mandatory ventilation rate of zero) without positive airway pressure. None required reintubation. The inspired oxygen concentration was selected by the patient's attending physician and remained unchanged throughout the period of observation.

Respiratory Inductive Plethysmography

Detailed description of RIP has been published. Briefly, the RIP consists of two coils of Teflon-insulated wire sewn into elastic bands which encircle the rib cage (RC) and abdomen (AB). These are connected to an oscillator module which is led to a Z80A based microprocessor system incorporating RIP technology (Respigraph), Noninvasive Monitoring Systems, Inc, Miami Beach. Changes in cross-sectional areas of the IC and AB alter the self inductance of the coils and the frequency of oscillations, which, after calibration, reflect volume as measured by spirometry (SP). The signals from the

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The one hour of spontaneous breathing prior to extubation was divided into five, 15-minute intervals (—60, —45, —30, —15, 0) and compared to the five, 15-minute intervals immediately following extubation (0, 15, 30, 45, 60). All parameters were averaged over these 15-minute epochs and expressed as mean ± standard deviation (SD). The data were analyzed by a two-factor analysis of variance with repeated measures on both factors. Where applicable, multiple comparisons were made using the Newman-Keuls procedure. The f-COV% was compared to VT-COV% preextubation and postextubation by Wilcoxon signed ranks test (n = 50). A p<0.05 was considered significant. In order to compare our data to previously reported studies which averaged values over varying time periods (rather than at set 15-minute intervals as in this study), we calculated one hour preextubation and postextubation mean ± SD for each parameter by summing the five preextubation and the five postextubation 15-minute intervals for each individual subject. The individual values were then averaged to determine group means ± SD. In addition, the 95 percent confidence intervals for the mean difference in preextubation vs postextubation respiratory frequency were determined by using the mean square error of the interaction effect.

**RESULTS**

Table 1 lists the mean ± SD values of f, VT, Vt, TCD/VT, Ti, VT/Ti, Ti/Tt and %RC over the hour of spontaneous ventilation immediately prior to and following extubation (n = 50 for f, TCD/VT, Ti, VT/Ti, Ti/Tt and %RC; n = 32 for VT, VI and VT/Ti). Analysis of the data by 15-minute intervals revealed a small but significant in-
crease in f, VT, VI and VT/TI immediately after extubation (Fig 1 and 2). The VT and VI and a return to base level with no significant changes. Their data are similar to ours (Table 1). The mean values which we recorded for f and VT prior to extubation are similar to the data presented by Tobin et al who used RIP to follow ten patients for approximately one hour before and after successful weaning. They found that f varied between 21 and 26 breaths per minute and VT from approximately 425 ml to 360 ml. Similarly, Gilbert et al used magnetometers to demonstrate that mean f, VT and VI were stable during one hour of spontaneous breathing in 14 intubated subjects who had just been removed from mechanical ventilation.

Respiratory inductive plethysmography was used in this study so that preextubation and postextubation measurements could be compared without the need to compensate for the known alterations which occur when respiration is measured with a mouthpiece connected to a spiro meter or pneumotachygraph. In addition, RIP provided volume and timing relations from the rib cage and abdominal compartments. Compared to normal subjects monitored by RIP, our patients had elevated f, VT, VI, and VT/TI and briefer TI. The major reason for these differences probably emanated from the underlying diseases since most of these differences paralleled the breathing patterns of subjects with chronic obstructive pulmonary disease, pulmonary hypertension, restrictive lung disease, and symptomatic asthma when compared to healthy subjects.

The breathing pattern postextubation was similar to what was recorded while the patients were intubated (Table 1). Although there were statistically significant increases in f, VT, VI, and VT/TI upon extubation (Fig 1 and 2), the absolute increases were small (2.2 breaths per minute, 50.3 ml, 1.56 L/min, and 62 ml/s, respectively) and returned to preextubation values within 30 minutes of extubation. The basis for these small changes was not rigorously investigated by us or by Tobin et al who noted similar trends in ten patients.

**Table 2—Breathing Pattern Variability, Group Means for Coefficients of Variation**

<table>
<thead>
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<th></th>
<th>Pre</th>
<th>Post</th>
<th>ΔCOV%</th>
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<tbody>
<tr>
<td>f-COV%*</td>
<td>26.0±9.1</td>
<td>27.9±11.5</td>
<td>1.9±11.1</td>
</tr>
<tr>
<td>VT-COV%†</td>
<td>34.6±10.5</td>
<td>34.1±10.8</td>
<td>-0.5±10.1</td>
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*Data reported as mean±SD, n=50. COV% is coefficient of variation for each subject analyzed by 15 min intervals; ΔCOV%, change in COV% pre- vs postexpiration; f, respiratory frequency.†Significantly more variable than f-COV% both preextubation and postextubation (p<0.001).
However, the increase in \( V_r/T_i \) suggests that the transient changes in \( f \), \( V_r \), and \( V_t \) were a response to enhanced respiratory center drive.\(^{15} \) The enhanced drive may have been a result of patient anxiety or increased anatomic dead space upon removal of the ETT.\(^{16} \)

The coefficients of variation for \( f \) and \( V_r \) were also nearly identical preextubation and postextubation (Table 2). The \( V_r \) was significantly more variable than \( f \) (\( p<0.001 \)) before and after extubation. Tobin et al\(^{20} \) reported similar findings in 65 healthy subjects in which the COV% for \( V_r \) (33 ± 14.4) was also greater than the COV% for \( f \) (20.8 ± 11.5). In general, individual variability for \( f \) and \( V_r \) was small. The mean change in COV% for \( f \) and \( V_r \) analyzed by individual patients was 1.9 and -0.5, respectively (Table 2).

The proper interpretation of any biologic test requires knowledge of the natural variability of that parameter. Although the breathing pattern of patients in the intensive care unit is widely utilized for clinical decision-making, this is the first rigorous evaluation of it in critically-ill patients. Besides establishing the overall means for the breathing pattern before and after extubation, our results highlight the relative stability of the breathing pattern in these patients. Since the spontaneous breathing pattern of a stable patient prior to extubation is almost identical to the postextubation pattern, any significant alteration in the breathing pattern of patients in the ICU requires investigation. Prospective studies will be necessary to establish whether changes in the spontaneous breathing pattern will be clinically helpful in predicting respiratory failure or weaning success.\(^{16}21 \)

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APPENDIX

**Calibration of Respiratory Inductive Plethysmography Using a Natural Breathing, Single Posture Method**

Since untrained subjects find it difficult to perform the various maneuvers necessary for proper calibration of the respiratory inductive plethysmograph (RIP), the natural breathing, single posture calibration method was utilized in this study. This calibration takes advantage of the isovolume maneuver principles\(^{22} \) while utilizing data collected during natural breathing. It has been proven to be very reliable in continuously monitoring the critically ill patient as well as during various position changes.\(^* \)

The respiratory system can be envisioned as a two compartment model:22

\[
SP = RC + AB \quad [1]
\]

where SP equals the spirometric volume, RC is the rib cage volume, and AB the abdominal volume as measured by RIP. To adjust for differences in volume-motion properties of the RC and AB, the equation is modified as follows:

\[
SP = M[K(RC) + AB] \quad [2]
\]

where "K" establishes the proportional relationship between RC and AB and "M" scales the quantity \( [K(RC) + AB] \) to SP. Equations [1] and [2] form the basis for the isovolume calibration procedure which is a well established method for RIP calibration.\(^{22} \) If a subject breathes with a constant tidal volume for a set period of time, then equation [2] can be transformed utilizing breath-by-breath variances of RC and AB excursions. Since the variance of a constant tidal volume is zero, "SP" in equation [2] drops out and "M" becomes unity. According to statistical theory, equation [2] can be rewritten as follows:

\[
K^2 = \text{Variance}(RC) = - \text{Variance}(AB) \quad [3]
\]

Knowing that the square root of a variance equals the standard deviation (SD), equation [4] is obtained by taking the square root of both sides of equation [3] and solving for K:

\[
K = - \frac{\text{SD}(AB)}{\text{SD}(RC)} \quad [4]
\]

Equation [4] allows the proportionality factor (K) to be solved from data collected during natural breathing. Since it is technically impossible for untrained subjects to breathe at a constant tidal volume, and since the uncalibrated sum of the RC and AB excursions from one breath does not necessarily equal the sum derived from another breath, one cannot select breaths of equivalent amplitude from the sum waveforms and be certain that conditions of a constant tidal volume (which is necessary to solve equation [4]) have been fulfilled. Therefore, equation [4] has to be approximated by collecting a large number of breaths and excluding breaths with large deviations. In practice, breaths are collected over a five-minute period of natural breathing with exclusion of breaths ±1.0 SD from the mean of the uncalibrated sum of (RC + AB), thus providing an approximation for a constant tidal volume. Equation [4] can then be rewritten as:

\[
K \approx - \frac{\text{SD}(AB)}{\text{SD}(RC)} \quad [5]
\]

The validity of using equation [5] was easily demonstrated in intubated subjects in whom an isovolume maneuver was produced by brief occlusions of the endotracheal tube during spontaneous breathing. This led to the expected alteration of the RIP breath waveforms, viz, the RC and AB excursions were opposite in direction such that the sum signal approximated zero.

Once "K" is determined, then the term "M" can be solved by rearranging equation [2]:

\[
M = SP/[K(RC) + AB] \quad [6]
\]

and breathing into a spirometer to determine SP.

To test this model in intubated subjects, ten intubated but spontaneously breathing patients (four women, six men, ages 54 to 90 years) from the ICU (who were not included in the variability testing) were
selected. Their diagnosis included chronic obstructive pulmonary disease, acute pulmonary edema, pneumonia, stroke, and status-postcardiac arrest. After calibration of RIP by the natural breathing, single posture calibration method in the semirecumbent position, validation of $V_T$ (RIP) was carried out against $V_T$ (SP) using the ZS0A based RIP microprocessor system for data acquisition and analysis. The subject was then turned to the left lateral decubitus position and $V_T$ (RIP) was validated against $V_T$ (SP) utilizing the calibration factors obtained in the original semirecumbent position. These maneuvers were done to simulate patients’ spontaneous movements.

All values of $V_T$ (RIP) fell within 10 percent $V_T$ (SP) in the original posture. In the left lateral decubitus position, nine of ten patients’ $V_T$ (RIP) were within 10 percent $V_T$ (SP); one patient’s $V_T$ (RIP) deviated 17 percent from $V_T$ (SP). Table 4 shows the mean ($\pm$ SD) $V_T$ and the %$V_T$ deviation from $V_T$ (SP) for the two positions using the calibration factors derived during the original semirecumbent position.

Similar good correlation using this calibration method has been reported in abstract form for normal subjects. If halted after “$K$” is solved in equation [5] without resorting to breathing into a spirometer, then relative changes of $V_T$ compared to an arbitrary baseline can be utilized for evaluating trends in $V_T$. This calibration system is particularly useful in the ICU where medical personnel may be unable to calibrate RIP using other procedures (such as the isovolume maneuver) because of the severity of the patients’ illnesses, time restraints, or inadequate operator training and experience. With an appropriate computer system, “$K$” can be solved during five minutes of natural breathing followed by immediate automatic collection and display of the breathing pattern. For clinical decision-making, changes in the absolute value of tidal volume for data acquisition and analysis. The subject was then turned to the left lateral decubitus position and $V_T$ (RIP) was validated against $V_T$ (SP) utilizing the calibration factors obtained in the original semirecumbent position.

**Table 4—Comparison of the Two Positions**

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<thead>
<tr>
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<th>Original Semirecumbent</th>
<th>Left Lateral Decubitus</th>
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<tbody>
<tr>
<td></td>
<td>$V_T$ Mean [ml] (SD-ml)</td>
<td>$V_T$ Mean [ml] (SD-ml)</td>
</tr>
<tr>
<td></td>
<td>SP RIP SP RIP</td>
<td>SP RIP SP RIP</td>
</tr>
<tr>
<td>Mean</td>
<td>415 401 335 336</td>
<td>5.5 6.4</td>
</tr>
<tr>
<td>SD</td>
<td>(139) (134) (80) (77)</td>
<td>(2.9) (8.4)</td>
</tr>
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</table>

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