Pattern of spontaneous breathing: potential marker for weaning outcome

Spontaneous breathing pattern and weaning from mechanical ventilation

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M. El-Khatib · G. Jamaeldine · R. Soubra · M. Muallem
Department of Anesthesiology, School of Medicine, American University of Beirut, P.O. Box 113-6044 Beirut, Lebanon
E-mail: mkt@aub.edu.lb
Fax: +961-1-744464

G. Jamaeldine
Department of Medicine, School of Medicine, American University of Beirut, Lebanon

Abstract  Objective: To quantitatively assess the spontaneous breathing (SB) pattern, during minimal ventilatory support, of patients who pass or fail weaning trials from mechanical ventilation.
Design: A prospective, clinical trial.
Setting: Intensive care unit of a university teaching hospital.
Patients: Fifty-two tracheally intubated and hemodynamically stable patients who were judged clinically ready for extubation.
Methods: Using a computerized respiratory profile monitor, continuous respiratory parameters were obtained while patients were receiving four or less synchronized intermittent mandatory (SIMV) breaths and during CPAP trials. Coefficients of variation (CV) of spontaneous tidal volumes and flows during SIMV trials as well as the entropies and dimensions of the breathing patterns during CPAP trials were used to assess the dynamical breathing behaviors of the patients who passed or failed weaning trials.
Measurements and results: Thirty-nine extubations were successful and 13 were not. The CV of the spontaneous tidal volumes (VT) and the spontaneous peak inspiratory flows (PF), the Kolmogorov entropy and the dimension of the SB patterns were compared in the two groups. The CV of VT (9.13 ± 4.11 vs 26.07 ± 6.94), the CV of PF (11.63 ± 4.18 vs 29.88 ± 12.07), the Kolmogorov entropy (0.09 ± 0.03 bits/cycle vs 0.39 ± 0.09 bits/cycle), and the dimension of the SB pattern (1.33 ± 0.07 vs 3.93 ± 0.47) were all significantly smaller (P < 0.05) in the successfully extubated group versus the group that failed extubation.
Conclusion: The spontaneous breathing pattern during minimal mechanical ventilatory support is more chaotic in patients who failed extubation trials compared to patients who passed extubation trials. Thus, we speculate that characterizing the SB pattern during minimal ventilatory support might be a useful tool in differentiating between extubation success and failure.

Keywords  Breathing pattern · Mechanical ventilation · Weaning outcome

Introduction
Mechanical ventilation is commonly used for both postoperative recoveries and as a life-saving measure for patients suffering from a multitude of medical conditions that result in respiratory failure [1]. However, numerous side effects related to its use exist [2, 3, 4, 5], and therefore mechanical ventilation should be discontinued as soon as the patient can sustain spontaneous respiration with adequate gas exchange [6]. Most commonly, pa-
tients are weaned from mechanical ventilation, a process which gradually removes mechanical support as the patient resumes spontaneous breathing. It is important to know when a patient’s medical condition is most compatible with an extubation trial. An extubation trial undertaken too early may predispose the patient to severe cardio-respiratory [7] and/or psychological decompensation [8] while prolonged unnecessary mechanical ventilation exposes the patient to serious risks [9, 10].

Recent studies [10, 11, 12, 13] revealed that new integrative indexes, such as the rapid shallow breathing and CROP (Compliance, Rate, Oxygenation, Pressure) indexes, used to predict outcome of weaning and extubation from mechanical ventilation, were superior to traditional indexes such as vital capacity, maximal inspiratory pressure, blood gases, respiratory rate, and minute ventilation. Because of their mathematical nature (i.e., mathematical ratios), these new integrative indexes could be misleading (i.e., same numerical value for the integrative index could be obtained with an infinite combination of its constituent parameters). This originates from the fact that most of the constituent parameters of the integrative indexes, such as the tidal volume and the respiratory rate, are derived at a single point in time such as end of inspiration or expiration in the case of tidal volume and the total number of breaths in a 1-minute time interval in the case of respiratory rate. The different possible rates of change of tidal volume (i.e., fast or slow delivery of tidal volume) and the distribution of breaths in 1-minute intervals are not reflected in these integrative indexes. Therefore, quantitative assessment of the respiratory pattern, which is continuously providing information in real-time at any point during the breathing cycle, might be needed for a better and superior decision-making process regarding weaning from mechanical ventilation.

The purpose of the present study is to quantitatively assess the spontaneous breathing pattern of patients who pass or fail weaning trials from mechanical ventilation.

### Materials and methods

This study was approved by the Institutional Review Board and written consent was waived due to the nature of the study.

#### Patient population

All hemodynamically and clinically stable patients receiving mechanical ventilation in the ICU due to acute respiratory failure of different origin, and judged ready to undergo an extubation trial by their primary physician, were included in the study. The primary physicians were blinded to the study design and to the measurements obtained during the study, although arterial blood gas values and routine measurements by respiratory therapists (i.e., spontaneous tidal volume, spontaneous and total respiratory rate, peak airway, and peak alveolar pressures) were available to them. All patients were monitored with continuous electrocardiography, blood pressure, and pulse oximetry during the whole study.

#### Study protocol

At the time of the inclusion in the study, all patients were mechanically ventilated (Puritan-Bennett 7200, Mallinckrodt, St. Louis, Mo., USA) with minimal ventilatory support (i.e., synchronized intermittent mandatory ventilation (SIMV) rate ≤4 breaths/min) with no pressure support ventilation and with an FiO₂ of 40%. A computerized pulmonary mechanics monitoring system (COSMO+, Novametrix Medical Systems, Conn., USA), incorporating an adult flow sensor placed between the endotracheal tube (ETT) and the Y-piece of the breathing circuit, was used to measure the pressure, volume, and flow signals for at least 60 min. These parameters were displayed and stored using a laptop computer. An additional 60 min of data were collected, as previously described, during a CPAP of 5 cmH₂O trial with no pressure support ventilation (PSV). Heart rate and blood pressure were also recorded. Once the above data have been collected, patients underwent extubation trials under the direction of the primary medical team responsible for their management. The decision to extubate the patient or to re-institute mechanical ventilation was made solely by the primary medical team who was totally blinded to the data collected. Unsuccessful extubation was defined as the need for re-intubation within the first 24 h following extubation trials. Re-intubation due to upper airway trauma (stridor) was not considered as failure and those patients were excluded from the study. Patients were finally separated into two different groups according to their extubation outcomes (group 1: passed extubation; group 2: failed extubation).

#### Data and statistical analysis

In both patient groups, breath-to-breath values for airway flow, volume, and proximal airway pressure collected on each patient were divided into three different intervals each of 300 breaths. During the SIMV trials, the spontaneous and mechanical peak flow versus the spontaneous and mechanical tidal-volume scattergrams were constructed for each data interval of each patient. Coefficients of variation for spontaneous peak flow (PF) and spontaneous tidal volume (VT) were determined for each data interval separately and for the whole 900 breaths.

Furthermore, in both groups, advanced chaos theories were employed for quantitative assessment of the breathing patterns during the continuous positive airway pressure trial (CPAP). The Kolmogorov entropy [14, 15, 16], which measures the amount of regularity in a series, and is defined as the divergence of nearby breaths within the respiratory phase space (i.e., flow-volume loops) was determined using at least 300 breaths collected during CPAP trials. Similarly, the dimension of the spontaneous respiratory pattern(s), defined as the number of clusters or clouds of trajectories in the flow-volume loops space was determined for each data interval. As such, higher values for the entropy and/or the dimension indicate less regularity in the pattern and thus more variability and chaos.

The Student t-test was used to compare the coefficients of variation of spontaneous peak flows and volumes, the Kolmogorov entropies, and the dimension of the spontaneous breathing pattern between the successful and unsuccessful extubation patient groups. Statistical significance was considered at the 5% level (i.e., P < 0.05).