Weaning from mechanical ventilation: an update

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Many patients admitted to the intensive care unit have respiratory failure and thus require mechanical ventilation. Weaning patients from mechanical ventilation after their primary disease process has been treated can be difficult in approximately 30% of patients. Inadequacies in pulmonary gas exchange and in the performance of the respiratory muscle pump are the most common causes for failure to wean. Assessing whether a patient can be weaned from mechanical ventilation involves two major factors: (1) examining the patient for evidence of an increase in the work of breathing, and (2) measuring spontaneous breathing variables. Although different modalities have been used in weaning patients from mechanical ventilation, none has been shown to be more successful than repeated trials of spontaneous breathing.

(Key words: mechanical ventilation, weaning, rapid shallow breathing, intermittent mandatory ventilation, pressure support, flow-by ventilation, spontaneous breathing)

Respiratory failure, requiring mechanical ventilatory support, is a frequent cause for admission to the intensive care unit. Many causes exist for respiratory failure, including an acute exacerbation of obstructive airways disease (asthma and chronic obstructive pulmonary disease [COPD]), pneumonia or adult respiratory distress syndrome, and pulmonary complications that occur postsurgically or as a result of trauma—to name just a few. In patients who survive their initial disease process as a result of treatment, the time comes when consideration is given to discontinue mechanical ventilation, a process commonly referred to as *weaning*. Some prefer to use the term *liberate*[1] rather than *wean* when referring to removing a patient from mechanical ventilation because mechanical ventilation can be discontinued in most patients without difficulty. Recent studies[2,3] have demonstrated that approximately 70% of patients can discontinue mechanical ventilation successfully during their initial attempt at extubation. This leaves a substantial 30% of patients, however, in whom discontinuation of mechanical ventilatory support proves to be more challenging. Such patients require a coordinated effort to wean them from the ventilator.

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Determinants of respiratory failure

When considering whether to begin weaning a patient from mechanical ventilation, it is important to remember that discontinuation will depend on the adequacy of pulmonary gas exchange and the performance of the respiratory muscle pump.

When patients are allowed to resume spontaneous breathing, changes can occur in gas exchange as a result of (1) the development of hypoventilation, (2) changes in ventilation-perfusion (V/Q) ratios within the lungs, and (3) changes in overall cardiac output. Torres and others[4] studied eight patients with COPD and noted increased blood to low V/Q lung ratio unit during the weaning trial. Yet the Pa_{O_2} and alveolar-to-arterial (A-a) gradient remained unchanged as the result of a simultaneous increase in cardiac output. In 15 patients with COPD and coexistent cardiovascular disease, Lemaire and colleagues[5] noted that failed weaning trials in these patients were associated with the development of increasing pulmonary capillary wedge pressures (PCWP). Aggressive treatment with diuretic therapy led to successful attempts at extubation with no increase in the PCWP during the weaning trials. More recently, Jubran and coworkers[6] noted that in a group of patients who failed weaning trials, the decrease in mixed venous oxygen saturation was secondary to an inability to increase cardiac output during spontaneous breathing. This inability led to an overall decrease in arterial oxygen saturation (Sa_{O_2}).

Probably the most common cause for unsuccessful attempts to wean from mechanical ventilation is failure of the respiratory muscle pump. This failure can occur when there is a decrease in the neuromuscular capacity of the respiratory muscles or when an increased load is placed on them.

Although a decrease in central drive to the respiratory muscles may occur in patients who fail to wean from mechanical ventilation, this has not always been found to be the case. When inspiratory flow (V_T/T_I) was used as a measurement of central respiratory drive, Tobin and associates[7] noted that central drive actually increased at the end of a failed weaning trial.

For many patients who fail a trial of spontaneous breathing, an increased load is placed on their already mechanically

disadvantaged respiratory muscles. For instance, the lungs of patients with COPD are hyperinflated, which leads to a mechanically disadvantaged respiratory pump. When respiratory failure develops, the increased airway resistance from bronchospasm places an increased load on their respiratory pump that prevents sustained spontaneous breathing and possibly leads to the development of respiratory muscle fatigue.

Predicting outcome of weaning

Actively assessing patients to see if they can begin weaning is beneficial. Such assessment has been shown to decrease both the number of days a patient remains on mechanical ventilation and the number of complications.[8] In trying to predict whether a patient will successfully wean from mechanical ventilation, the first and most important step is examination of the patient. What is the patient's level of consciousness? Have all reversible causes of respiratory failure been adequately treated? And, most important, is there evidence of increased work of breathing, both as assessed while on mechanical ventilation and during a weaning trial? In pulmonary terms, work (W) can be expressed as:

$$W = P \times V$$

where P is pressure and V is volume. When a patient is on mechanical ventilation, the tidal volume is set or relatively stable—and one would examine the patient for evidence of increased intrapleural pressure swings, which would translate into increased work of breathing. Generation of elevated pleural pressure is evident by the use of accessory muscles of respiration (such as the sternocleidomastoid), tracheal tugging whereby the trachea is being pulled down into the thorax at the suprasternal notch, and supraclavicular recession. The physician also should look for the presence of abdominal–rib cage paradox. Once thought to be a sign of diaphragmatic fatigue, abdominal–rib cage paradox was subsequently shown to be a condition in which the diaphragm is forced to work against an increased resistive load.[9] When the patient is taken off the ventilator for a weaning trial, these signs are the key ones that should be considered to determine if there is evidence of increased work of breathing.

Respiratory criteria for weaning

Once the physician has determined by physical examination and by gas exchange that the patient appears stable enough to wean from mechanical ventilation, certain respiratory measurements—made during spontaneous breathing—are evaluated to further help predict successful extubation. These measurements include those of minute ventilation (V_E), respiratory rate, tidal volume (V_T), and maximal inspiratory pressure.

Other measurements of pulmonary function are not routinely obtained in most hospitals. These measurements include airway occlusion pressure, which is measured 0.1 second after initiating a breath ($P_{0.1}$) to measure central drive, and transdiaphragmatic pressure, for which gastric and esophageal balloons are used to measure the work of breathing.

In a retrospective study, Sahn and colleagues[10] noted that patients with a V_E less than 10 L/min could be successfully weaned if they could double the V_E value with a maximum voluntary ventilation maneuver. Yet, a number of patients who could not do this maneuver were weaned successfully (false-negative results). In addition, these investigators noted that if the maximal inspiratory pressure was less than 30 cm H_2O below atmospheric pressure, patients could be successfully weaned. However, a follow-up retrospective study[11] demonstrated no differences in weaning variables in patients who failed a weaning trial and those who succeeded and were extubated. More recently, Jubran and Tobin[12] demonstrated that passive mechanics, measured while the patient was still on the ventilator but before instituting a weaning trial, were not helpful in predicting successful extubation.

In 1986, Tobin and coworkers[7] examined the breathing patterns in patients who were being weaned from mechanical ventilation. These investigators noted that patients who were successfully weaned were able to maintain their respiratory rate and V_T during spontaneous breathing, whereas those who failed had an immediate increase in respiratory rate and decrease in V_T (that is, rapid shallow breathing). The fact that this abnormal breathing pattern developed as soon as the patients were weaned argues against the fact that it was due to the development of respiratory muscle fatigue.

Because of the lack of sensitivity and specificity of standard weaning variables and the prior observation of a rapid shallow breathing pattern in weaning failures, Yang and Tobin[13] examined 36 patients to try to develop threshold values that would help predict weanability. Following this effort, the investigators then prospectively applied these values to a group of 64 other patients to validate their findings. Among the individual pulmonary measurements, V_T had the greatest sensitivity and specificity, followed by respiratory rate. Minute ventilation had one of the lowest positive and negative predictive values, probably because it does not, for example, distinguish between a patient with a respiratory rate of 10 breaths/min and a V_T of 400 mL and a patient with a respiratory rate of 40 breaths/min and a V_T of 100 mL; both have a V_E of 4 L/min. Using a variation of minute ventilation, respiratory rate/V_T (L), helped identify the presence of rapid shallow breathing, and a value of less than 105 had a high sensitivity and specificity at predicting weanability. A set of measurements that incorporated compliance, maximal inspiratory pressure, and gas exchange was found to be highly predictive of weaning success but is much more cumbersome to perform than the other forms of evaluation. This index is referred to as CROP (thoracic compliance, respiratory rate, arterial oxygenation, and maximal inspiratory pressure [Plmax]).

Methods for discontinuation of mechanical ventilation

Once it has been determined, both by physical examination and assessment of respiratory criteria for weaning, that the patient is ready to be weaned, a method to discontinue mechanical ventilation must be chosen. When considering the

various methods of weaning from mechanical ventilation (*Figure*), the physician needs to take into account the increased resistance that is present with an endotracheal tube in place.

Certain modes of mechanical ventilation were initially thought to be well suited for use as a weaning modality. One of these was intermittent mandatory ventilation, which was reported to decrease respiratory muscle fatigue and decrease patient dyssynchrony because the patient resumed more spontaneous breathing as the number of ventilator-delivered breaths was decreased. However, the presence of the demand valve in the circuitry has been shown to increase the work of breathing greater than twofold, thereby contributing to the development of respiratory muscle fatigue.

Pressure support ventilation delivers breaths that are triggered by the patient and continues to deliver an inspiratory flow at the set pressure until flow decreases to 25% of the peak initial flow. The patient is able to control the respiratory rate, inspiratory time, and inspiratory flow rate. Determining the amount of pressure support needed to compensate for the increased work of breathing through the endotracheal tube has been difficult, though, and can vary from 3 cm H_2O to 14 cm H_2O, with higher values noted for patients with underlying COPD.

Flow-by ventilation is a modified continuous flow modality that allows the patient to breathe spontaneously through a flow-triggered circuit. The patient determines the respiratory rate, inspiratory flow rate, and the V_T. In one study,[14] the work of breathing with flow-by ventilation was actually less than that associated with breathing through a T-tube. It offers the advantage that the patient remains connected to the ventilator. Therefore, respiratory rate and V_T can be monitored and the apnea backup and alarm can continue to be used.

Comparisons of the different modalities used in weaning has been done in a number of studies. Bouchard and associates[15] compared pressure support ventilation with intermittent mandatory ventilation and T-tube trials in 109 patients who could not sustain spontaneous breathing for more than 2 hours. At 21 days, they found that patients in the group receiving pressure support were more likely to have been weaned from the ventilator, with a failure rate of 8% in that group compared with 39% in the group on intermittent mandatory ventilation and 33% in the group with the T-tube. Yet, in the group on intermittent mandatory ventilation, patients had to remain on a rate less than 4 breaths/min for 24 hours, and the T-tube group could have up to three 2-hour trials before being considered eligible for extubation. In both circumstances, these requirements represent a considerable ventilatory load to the patient to meet the criteria for extubation.

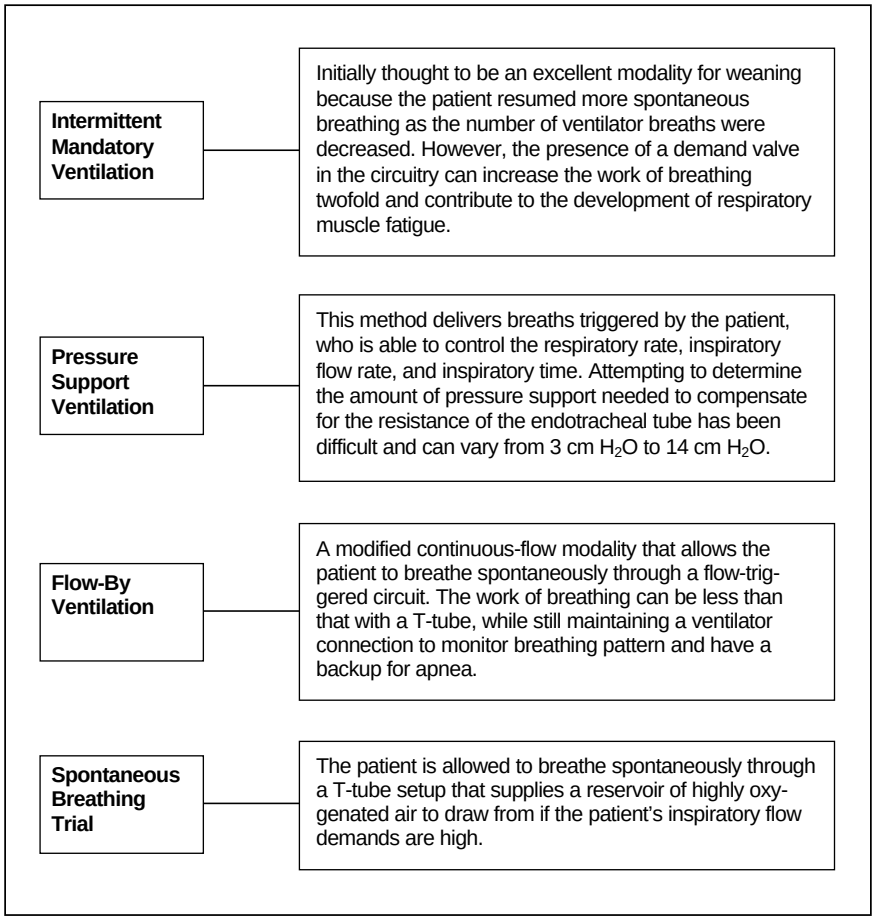

Figure. *Methods for weaning patients from mechanical ventilation.*

Esteban and colleagues[2] examined weanability in a group of 546 patients on mechanical ventilation. They noted that the majority (76%) were easily weaned with an initial trial of spontaneous breathing on a T-tube, with only 58 (15.6%) patients requiring reintubation. The remaining 133 difficult-to-wean patients were randomly assigned to one of four groups: (1) intermittent mandatory ventilation, (2) pressure support ventilation, (3) once-daily trial of spontaneous breathing, or (4) twice-daily spontaneous breathing. Extubation in the group on the trial of spontaneous breathing was performed when patients could tolerate a 2-hour trial without signs of distress. These investigators found that a once-a-day trial of spontaneous breathing led to extubation about three times more quickly than did intermittent mandatory ventilation and about twice as quickly as did pressure support ventilation. More recently, Esteban and associates[3] demonstrated that a 30-minute trial of spontaneous breathing predicted successful extubation just as well as did a

120-minute trial. Thus, difficult-to-wean patients often require individualized plans for weaning, with no strict regimen ever having been shown to be more successful than repeated attempts of spontaneous breathing separated by periods of rest.

Comment

Many patients are admitted to the intensive care unit because of the development of respiratory failure that requires mechanical ventilatory support. Although the causes of respiratory failure are multiple, most involve abnormalities in gas exchange or failure of the respiratory muscle pump. Discontinuation of mechanical ventilation involves treating reversible causes, followed by an assessment of weanability. Although most patients can be easily liberated from mechanical ventilation, difficult-to-wean patients often require individualized strategies, with no proven modality any better than simple repeated trials of spontaneous breathing.

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