Evidence-Based Ventilator Weaning and Discontinuation

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Ventilator management of a patient who is recovering from acute respiratory failure must balance competing objectives. Discontinuing mechanical ventilation and removing the artificial airway as soon as possible reduces the risk of ventilator-induced lung injury, nosocomial pneumonia, airway trauma from the endotracheal tube, and unnecessary sedation, but premature ventilator-discontinuation or extubation can cause ventilatory muscle fatigue, gas exchange failure, and loss of airway protection. In 1999 the McMaster University Outcomes Research Unit conducted a comprehensive evidence-based review of the literature on ventilator-discontinuation. Using that literature review, the American College of Chest Physicians, the Society of Critical Care Medicine, and the American Association for Respiratory Care created evidence-based guidelines, which include the following principles: 1. Frequent assessment is required to determine whether ventilatory support and the artificial airway are still needed. 2. Patients who continue to require support should be continually re-evaluated to assure that all factors contributing to ventilator dependence are addressed. 3. With patients who continue to require support, the support strategy should maximize patient comfort and provide muscle unloading. 4. Patients who require prolonged ventilatory support beyond the intensive care unit should go to specialized facilities that can provide more gradual support reduction strategies. 5. Ventilator-discontinuation and weaning protocols can be effectively carried out by nonphysician clinicians. *Key words: mechanical ventilation, weaning, practice guidelines, evidence-based medicine.* [Respir Care 2004;49(7):830–836. © 2004 Daedalus Enterprises]

Introduction

Patients are generally intubated and placed on positive-pressure ventilation when their own ventilatory capabili-

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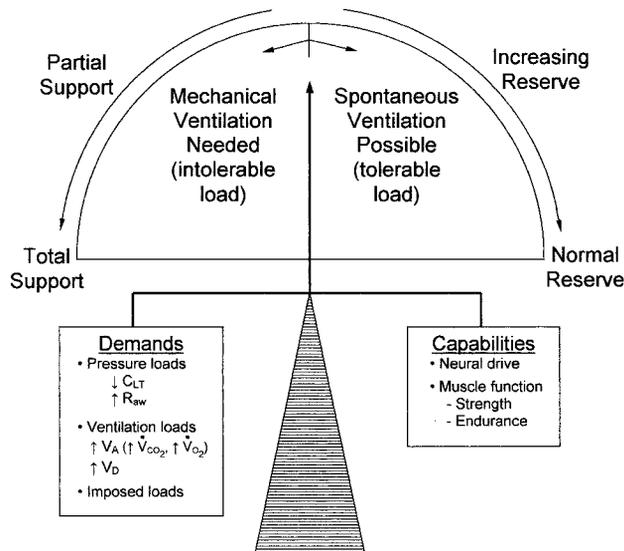
ties are outstripped by the ventilation demands imposed by disease or when the respiratory drive cannot initiate ventilatory activity, because of disease or drugs (Fig. 1). As the imbalance between ventilatory capability and ventilatory demand begins to resolve, the clinical focus shifts to removing the ventilator as quickly as possible. Unnecessary delay in withdrawing mechanical ventilation increases the likelihood of complications such as pneumonia, discomfort, and ventilator-induced lung injury, and increases cost. However, the value of removing the ventilator as soon as possible must be balanced against the risks of premature withdrawal, which include difficulty in re-establishing an artificial airway, ventilatory muscle fatigue, and compromised gas exchange. Esteban et al estimated

Fig. 1. The balance between respiratory loads and demands determine the need for mechanical ventilatory support. C_{LT} = compliance of the lungs and thorax. R_{aw} = airway resistance. V_A = alveolar ventilation. $\dot{V}_{CO2}$ = carbon dioxide production. $\dot{V}_{O2}$ = oxygen consumption. V_D = dead-space volume.

that as much as 42% of the time a medical patient spends on a mechanical ventilator is during the withdrawal process[1] and that percentage is likely to be much higher with a patient who has a more slowly resolving lung process.

There are 4 main issues in the management of a mechanically ventilated patient whose disease process has begun to stabilize and/or reverse. First, it is necessary to understand all the reasons the patient continues to require mechanical ventilation (eg, abnormal respiratory system mechanics, gas exchange, neuromuscular dysfunction, and/or cardiac compromise). Continued treatment of all of the identified reasons is obviously integral to any ventilator discontinuation strategy. Second, the clinician needs to use assessment techniques to identify whether the patient can tolerate ventilator withdrawal. Third, if the patient continues to require ventilatory support, the appropriate ventilator management strategies must be employed. Fourth, with a patient who most likely will remain permanently ventilator-dependent, an extended management plan is needed.

In 1999 the United States Agency for Healthcare Policy and Research (AHCPR) tasked the McMaster University Outcomes Research Unit to do a comprehensive evidence-based review of the literature on ventilator withdrawal issues.[2] Then, in 2000, the American College of Chest Physicians, the Society of Critical Care Medicine, and the American Association for Respiratory Care formed a task force to utilize the AHCPR/McMaster report as well as their own literature review to develop evidence-based recommendations on ventilator management of patients who

require ventilation for > 24 h.[3] The present report summarizes the most important of those recommendations (Table 1).

Assessing Ventilator-Discontinuation Potential

The process of discontinuing mechanical ventilatory support begins with the recognition that the patient has begun to recover from the problems that necessitated ventilatory support. Thereafter careful clinical assessments are required to determine whether the patient is ready for reduction of and then removal of ventilatory support and, then, extubation. However, the criteria by which clinicians decide whether the patient has recovered enough to tolerate withdrawal of ventilatory support have not been clearly defined nor prospectively evaluated in a randomized controlled trial. Instead, various combinations of subjective and objective assessment criteria (eg, assessment of gas exchange, mental status, cardiovascular function, neuromuscular function, and radiographic data) that may be surrogate markers of recovery have been employed (see Table 1, recommendation 1).[4–10] Note that some patients who never meet one or more of the suggested ventilator-discontinuation criteria are, nevertheless, eventually liberated from the ventilator.[11]

Assessment of the factors that initially required mechanical ventilation is not enough to make a discontinuation decision. For example, one survey of intensivists using clinical assessments alone for discontinuation potential found a sensitivity of only 35% (6 out of 17 who weaned were identified) and a specificity of 79% (11 out of 14 who failed to wean were identified).[12] Moreover, in 2 large trials,[4,5] despite apparent disease stability/reversal, the managing clinicians did not recognize prior to performing a spontaneous breathing trial (SBT) that discontinuation was feasible in almost two thirds of the subjects. The conclusion is thus that some evidence of clinical stability/reversal is a key first step in assessing discontinuation potential but that more focused assessments are needed before deciding to continue or discontinue ventilatory support.

Focused assessments done either while the patient is receiving substantial ventilatory support (eg, minute ventilation requirement) or during a brief period of spontaneous breathing (eg, vital capacity, negative inspiratory force, work of breathing, ratio of respiratory frequency to tidal volume [f/V_T]) can yield important information about discontinuation potential.[2] However, integrated assessments done during a longer and carefully monitored SBT provide the most useful information to guide the discontinuation decision (see Table 1, recommendation 2). SBT is safe, efficacious, and generally obviates other assessments.

A concern about SBT is that it may cause ventilatory muscle overload and fatigue. When this occurs, it often

Table 1. Selected Recommendations From the ACCP-SCCM-AARC Evidence-Based Weaning Guidelines Task Force

Recommendation 1: Patients receiving mechanical ventilation for respiratory failure should undergo a formal assessment of discontinuation potential if the following criteria are satisfied:
  1. Evidence of some reversal of the underlying cause of respiratory failure
  2. Adequate oxygenation: P_{aO_2} F_{IO_2} $\geq$ 150–200 mm Hg, required PEEP $\leq$ 5–8 cm H_2O, F_{IO_2} $\leq$ 0.4–0.5, and pH $\geq$ 7.25
  3. Hemodynamic stability as defined by the absence of clinically important hypotension and requiring no vasopressors or only low-dose vasopressors (eg, dopamine or dobutamine < 5 μg/kg/min)
  4. Patient is able to initiate an inspiratory effort
The decision to use these criteria must be individualized. Some patients who do not satisfy all the criteria may, nevertheless, be ready for an attempt to discontinue mechanical ventilation.
Recommendation 2: Formal discontinuation assessments should be done during spontaneous breathing rather than while the patient is still receiving substantial ventilatory support. An initial brief period of spontaneous breathing can be used to assess the patient's ability to do a formal SBT. Criteria to assess patient tolerance during SBT are the respiratory pattern, adequacy of gas exchange, hemodynamic stability, and subjective comfort. Patients who tolerate a 30–120 min SBT should promptly be considered for ventilator-discontinuation.
Recommendation 3: With patients whose ventilatory support has been successfully discontinued, the decision of whether to remove the artificial airway should be based on assessment of airway patency and the patient's ability to protect the airway.
Recommendation 4: If the patient fails an SBT, determine the reasons the patient continues to require ventilatory support. Once the reversible causes of failure are corrected an SBT should be performed every 24 h.
Recommendation 5: Patients who fail SBT should receive a stable, nonfatiguing, comfortable form of ventilatory support.
Recommendation 6: Weaning/discontinuation protocols designed for nonphysician clinicians should be developed and implemented by intensive care units. Protocols should aim to optimize sedation.
Recommendation 7: Critical care practitioners should be familiar with facilities in their communities or units in their hospital that specialize in managing patients who suffer prolonged ventilator-dependence, and practitioners should stay abreast of peer-reviewed reports from such units. When medically stable enough for transfer, patients who have failed discontinuation attempts in the intensive care unit should be transferred to facilities that have demonstrated success and safety in accomplishing ventilator discontinuation.
Recommendation 8: Unless there is evidence of clearly irreversible disease (eg, high spinal cord injury, advanced amyotrophic lateral sclerosis), a patient who requires prolonged ventilatory support for respiratory failure should not be considered permanently ventilator-dependent until 3 months of weaning attempts have failed.
Recommendation 9: With a patient who requires prolonged ventilation the weaning should be slow-paced and should include gradually lengthening SBTs.

ACCP = American College of Chest Physicians
SCCM = Society for Critical Care Medicine
AARC = American Association for Respiratory Care
P_{aO_2}/F_{IO_2} = ratio of arterial partial pressure of oxygen to fraction of inspired oxygen
PEEP = positive end-expiratory pressure
SBT = spontaneous breathing trial
(Adapted from Reference 3.)

occurs early in the SBT,[8,13] so the initial few minutes of the SBT should be closely monitored before a decision is made to continue. This is often referred to as the screening phase of the SBT, during which an f/V_T > 105 (breaths/min)/L predicts SBT failure. Thereafter the patient should continue the SBT for at least 30 min but no more than 120 min to assure maximum sensitivity and safety.[10] The assessment criteria for determining success/failure of the SBT are respiratory pattern, adequacy of gas exchange, hemodynamic stability, and subjective comfort (see Table 1, recommendation 2).

Whether the SBT is done with a low level of continuous positive airway pressure (eg, 5 cm H_2O), a low level of pressure support (eg, 5–7 cm H_2O), or with a T-piece has little effect on outcome.[6,14] However, continuous positive airway pressure may enhance breath triggering in patients who have substantial intrinsic positive end-expiratory pressure (auto-PEEP).[15]

Extubation

Extubation should be considered for all patients who tolerate SBT. It is important to note, however, that extubation failure often occurs for reasons distinct from those that cause ventilator-discontinuation failure. The most common reasons are upper-airway obstruction and inability to protect the airway and clear secretions (see Table 1, recommendation 3). The risk of post-extubation upper-airway obstruction increases with duration of mechanical ventilation, female sex, trauma, and repeated or traumatic intubation.[16]

The capacity to protect the airway and expel secretions with an effective cough would seem vital for extubation success, but there is no published evidence to support that concept. Airway assessments generally include noting the quality of cough with airway suctioning[8,17,18] and the absence of "excessive" secretions. "Excessive" has not been

adequately defined, but many experts use the frequency of airway suctioning (eg, ≥ every 2 h) as a surrogate. Peak cough flow of > 160 L/min predicts successful extubation or decannulation with patients who have neuromuscular or spinal cord injury.[19]

Managing the Patient Who Fails SBT

The patient who fails SBT raises 2 important questions. First, what caused the SBT failure and are there reversible factors that can be corrected? Second, how should subsequent ventilatory support be managed?

Although a failed SBT often reflects persistent respiratory-system mechanical abnormalities,[20] a failed SBT should prompt a search for other causes or complicating factors such as adequacy of pain control, appropriateness of sedation, fluid status, bronchodilator need, and control of myocardial ischemia and other disease processes that can affect discontinuation attempts.

Assuming medical management is optimized, several lines of evidence support waiting 24 h before re-attempting SBT with a patient who has required ventilatory support for > 1–2 d (see Table 1, recommendation 4). First, except with patients recovering from anesthesia, muscle relaxants, or sedatives, respiratory system abnormalities rarely recover over a period of hours, and thus frequent SBTs over a short period will probably not be helpful. Indeed, Jubran and Tobin found that SBT failure is often due to persistent respiratory-system mechanical abnormalities that are unlikely to reverse rapidly.[20] Second, a failed SBT may cause respiratory muscle fatigue,[17,21,22] complete recovery from which may require 24 h or more.[23] Third, Esteban et al[5] demonstrated that twice-daily SBT offers no advantage over once-daily SBT, so twice-daily SBT wastes clinical resources.

It is difficult to evaluate the evidence about ventilatory support strategies for patients who fail SBT, because the existing studies that have compared 2 or more approaches to ventilator management compared not only the ventilation modes but also how those modes are used. Ideally, trial design should be such that management philosophies and aggressiveness of support-reduction are similar in each strategy being evaluated. Unfortunately, that is often not the case, as investigator experience with one approach has a tendency to result in support-reduction rules that favor that approach.

Various ventilator modes can provide ventilatory support as well as the means to reduce partial ventilatory support with a patient who fails SBT (Table 2). A key question is whether gradually lowering the level of support (weaning) offers advantage over providing a stable, unchanging level of support between SBTs. The arguments for using gradual support-reduction are (1) placing some ventilatory load on the patient might provide muscle conditioning and (2) the transition to extubation or SBT might be easier from a low level of support than from a high level. Few data support either of those claims, however. On the other hand, maintaining a stable support level between SBTs reduces the risk of precipitating ventilatory muscle overload from overly aggressive support reduction. A stable support level also has the advantage of requiring far less practitioner time. The study by Esteban et al[5] partially addressed this issue; it compared daily SBTs (and a stable level of support for those who failed SBT) to 2 other approaches that used gradual support reductions (weaning with pressure-support and intermittent mandatory ventilation). Daily SBT with stable support in between SBTs provided the most rapid ventilator-discontinuation (see Table 1, recommendation 5). What has not been addressed is whether a strategy of gradual support reduction *coupled with* daily SBT offers any advantage.

The AHCPR/McMaster report identified 3 other randomized trials that compared gradual reduction strategies using different modes but *not* daily SBTs.[4,24,25] The Brochard et al[4] study, which was most similar in design to the Esteban et al study,[5] included a pressure-support group, an intermittent mandatory ventilation group, and a group that received gradually increasing periods of spontaneous breathing intended only to provide brief periods of respiratory work and not specifically to test for discontinuation (ie, they were not formal SBTs). The gradually lengthening spontaneous breathing periods strategy was inferior to the other strategies, and like the Esteban trial, the pressure-support strategy was easier to reduce than the intermittent mandatory ventilation strategy.

The other 2 randomized trials identified by the AHCPR/McMaster report were much smaller than the Esteban et al and Brochard et al studies, and both suggested that pressure-support ventilation was easier to reduce than intermittent mandatory ventilation alone. None of these studies offer evidence that a gradual-support-reduction strategy is superior to the strategy of stable support between SBTs, so the clinical focus during the 24 h after a failed SBT should be on maintaining adequate muscle unloading, optimizing comfort (and thus sedation needs), and avoiding complications. The ventilator mode and settings can affect those goals. Important factors in achieving patient comfort and minimizing imposed loads include sensitive/responsive ventilator triggering systems,[26] applied PEEP in the presence of a triggering threshold load from auto-PEEP,[15] flow patterns matched to patient demand,[27] and appropriate ventilator cycling to avoid air trapping.[28]

Several support modes (volume-support,[29] adaptive support ventilation,[29,30] minimum minute ventilation,[29] and a knowledge-based system for adjusting pressure support[31]) were recently developed in an attempt to wean automatically by using feedback from one or more ventilator-measured variables. The minimum-minute-ventilation strategy

Table 2. Modes of Partial Support

Mode	Patient Work Adjusted By
Synchronized intermittent mandatory ventilation (SIMV)	Number of machine breaths supplied (ie, the fewer the number of machine breaths, the more spontaneous breaths are required)
Pressure-support ventilation (PSV)	Level of inspiratory pressure assistance with spontaneous efforts
SIMV + PSV	Combining the adjustments of SIMV and PSV
Volume-support	PSV with a "guaranteed" minimum tidal volume (PSV level adjusts automatically according to the clinician-set tidal volume)
Volume-assured pressure support. Also known as pressure augmentation	PSV with "guaranteed" minimum tidal volume (additional flow is supplied at end-inspiration if necessary to provide clinician-set tidal volume)
Mandatory minute ventilation	SIMV with a "guaranteed" minute ventilation (machine breath rate automatically adjusts according to clinician minute ventilation setting)
Airway pressure-release ventilation	Pressure difference between inflation and release (ie, the less the pressure difference, the more spontaneous breaths are required)

(set at either 75% of measured minute ventilation or to a carbon dioxide target) and the knowledge-based system for adjusting pressure support can automatically reduce support safely with selected patients, but none of those systems has been compared to the daily-SBT approach described above. Moreover, the premises underlying some of these feedback features (eg, that an ideal volume can be set for volume support or that an ideal ventilatory pattern based on respiratory system mechanics can be set for adaptive support ventilation) may be flawed, especially in sick patients. Indeed, potentially flawed feedback logic may actually delay support reduction. Further research is needed on these automated approaches.

Protocols Implemented by Nonphysician Clinicians

In recent years 2 randomized controlled trials (which included 657 patients) demonstrated that the outcomes of mechanically ventilated patients managed under protocols driven by nonphysician clinicians were better than those of control patients managed with standard care (see Table 1, recommendation 6). Ely et al[32] studied a nonphysician-clinician-driven protocol that included a daily screening procedure and SBT for those who met the criteria. Discontinuation of mechanical ventilation was then recommended for patients who tolerated the SBT. Although the 151 patients managed with the protocol had a higher severity of illness than the 149 controls, the protocol patients were removed from the ventilator 1.5 d earlier (with 2 d less weaning), they had 50% fewer ventilator-related complications, and the mean intensive care unit (ICU) cost of care was $5,000 less per patient. In a slightly larger trial with a more diverse patient population, Kollef et al[33] used

3 different nonphysician-clinician-driven protocols and found that the protocol reduced the mean duration of mechanical ventilation by 30 h. Other smaller studies have also demonstrated benefits from nonphysician-clinician-driven ventilator management, in multiple settings.[2]

The Role of Long-Term Facilities

The patient who remains ventilator-dependent despite maximal medical/surgical therapy and aggressive attempts to remove ventilatory support is becoming an increasing challenge for critical care practitioners. In recent studies up to 20% of medical ICU patients met the 21-d United States Health Care Financing Administration definition of prolonged mechanical ventilation.[34] Advances in treatments and technologies are no doubt saving patients who would have died a decade ago but who now survive with substantial respiratory dysfunction. Prior to the 1980s those patients simply remained in ICUs and were managed using acute care resources. The only other option was permanent ventilatory support in the patient's home or in a nursing home. Financial pressures, coupled with the concept that the aggressive ICU mindset might not be optimal for the more slowly recovering patient, have led to creation of weaning facilities (both freestanding and units within hospitals) that are potentially more cost-effective and better suited to meet the needs of these patients. A body of literature is now emerging that suggests that many patients who would have previously been deemed unweanable may achieve ventilator independence in such facilities (see Table 1, recommendation 7).[35,36]

A critical clinical issue is determining if a patient who requires prolonged mechanical ventilation has any hope of

ventilator discontinuation or will remain permanently ventilator-dependent. Patients in the former category clearly need continued attempts at ventilator discontinuation, whereas patients in the latter category are only subjected to unnecessary episodes of worsening respiratory failure by such attempts. With these latter patients the clinical focus should be on establishing a lifelong support program.

In the study by Scheinhorn et al some patients who had suffered prolonged ventilator dependence following acute cardiorespiratory failure were nevertheless liberated from the ventilator, up to 3 (and on occasion 6) months after intubation.[35] Another study[36] suggested similar results among post-surgical and medical patients. The weight of evidence is thus that several months of attempts at ventilator discontinuation are required before most patients ventilated for acute respiratory failure can be declared permanently ventilator-dependent (see Table 1, recommendation 8).

Despite differences in patient population and physical facilities, the available studies on discontinuing prolonged mechanical ventilation show some similarities. Daily SBTs initially are uncommon because these patients have already established themselves as very unlikely to "turn around" in 24 h. Instead, ventilator support is gradually reduced, using common modes of partial support (see Table 2): synchronized intermittent mandatory ventilation and pressure-support ventilation. Usually at the point of approximately half-support, the patient is switched to the SBT approach described above, often with SBTs of increasing duration (see Table 1, recommendation 9). Since most of these patients are tracheotomized, tracheal collars are used, instead of the familiar T-piece used in the ICU, to supply oxygen and humidity. During these procedures it is important for the staff to remain patient. Psychological support and careful avoidance of unnecessary muscle overload are important for these types of patients.

Summary

With the patient who is recovering from acute respiratory failure, several ventilator management issues are important. First, frequent assessment is required to determine the need for continued ventilatory support. Second, patients who continue to require ventilatory support should be continually re-evaluated to assure that all factors contributing to ventilator dependence are addressed. Third, the ventilatory support strategy should maximize patient comfort and provide stable muscle unloading. Fourth, patients who require prolonged ventilatory support beyond the ICU should receive gradual support-reduction at a specialized weaning facility. Fifth, ventilator-discontinuation and weaning protocols can be effectively carried out by nonphysicians.

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