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Discontinuing Mechanical Ventilatory Support*

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The ventilator discontinuation process is a critical component of ICU care. Ongoing ventilator dependency is caused by both disease factors (eg, respiratory, cardiac, metabolic, and neuromuscular) and clinician management factors (eg, failing to recognize discontinuation potential and inappropriate ventilator settings/management). A multispecialty evidence-based task force has recommended a series of guidelines that begins with a daily ventilator weaning screen focusing on disease stability/recovery, gas exchange, hemodynamics, and respiratory drive that should be done on every patient receiving mechanical ventilatory support. In those passing this screen, a spontaneous breathing trial (SBT) should be performed. The decision to remove the artificial airway in those patients successfully passing an SBT requires further assessment of the patient's ability to protect the airway. Managing the patient who fails the SBT is one of the biggest challenges facing ICU clinicians. In general, stable, comfortable modes of assisted/supported ventilatory support should be provided between the daily weaning screen/SBT. New evidence suggests that early tracheostomy placement may facilitate the ventilator withdrawal process in those patients requiring prolonged ventilatory support. (CHEST 2007; 132:1049–1056)

Key words: mechanical ventilation; respiratory failure; weaning

Abbreviations: ASV = adaptive support ventilation; f = frequency; FI_{O_2} = fraction of inspired oxygen; NIV = noninvasive ventilation; PAV = proportional assist ventilation; PEEP = positive end-expiratory pressure; PES = esophageal pressure; $P_{i\max}$ = maximal inspiratory pressure; PRVC = pressure-regulated volume control; PTP = pressure-time product; SBT = spontaneous breathing trial; SIMV = synchronized intermittent mandatory ventilation; T_i = inspiratory time; \dot{V}_E = minute ventilation; VS = volume support; V_T = tidal volume

As respiratory failure and the need for mechanical ventilatory support stabilizes and begins to reverse, clinical attention shifts to the process of ventilator withdrawal or discontinuation. In these patients, ongoing ventilator dependency is caused by the following two fundamental problems: (1) disease-imposed factors, such as mechanical and/or gas exchange issues that continue to require positive pressure ventilation; and/or (2) clinician-imposed factors, such as either clinician delay in recognizing the ability of a patient to have mechanical ventilation

discontinued or inappropriate ventilator settings that overload (or underload) respiratory muscles, preventing recovery. With respect to this latter point, several large clinical trials^{1–3} have clearly demonstrated that many assessment/management strategies can cause considerable undue delay in ventilator withdrawal. Moreover, some trials^{4–7} of protocol-driven ventilator discontinuation procedures have clearly demonstrated that traditional “standard care” is often associated with significant delays in ventilator withdrawal.

Clearly, ventilator management should be aimed at getting the patient off ventilator support as rapidly as possible. Delayed discontinuation of mechanical ventilatory support exposes patients to unnecessary risks of infection, stretch injury, sedation needs, airway trauma, and costs. The discontinuation process must be performed with proper caution and monitoring, however, because premature withdrawal has its own problems. These include the loss of

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airway protection, cardiovascular stress, suboptimal gas exchange, and muscle overload and fatigue.^{8,9}

WHEN SHOULD VENTILATOR DISCONTINUATION BE CONSIDERED?

In general, when a patient's underlying respiratory disease begins to stabilize and reverse, consideration for the discontinuation of mechanical ventilation should begin. A multi-society-sponsored, evidence-based task force (hereafter referred to as the *task force*)¹ has recommended that a patient should be considered a candidate for withdrawal of ventilation if (1) the lung injury is stable/resolving; (2) the gas exchange is adequate with low positive end-expiratory pressure (PEEP)/fraction of inspired oxygen (FIO₂) requirements (*eg*, PEEP, < 5 to 8 cm H₂O; FIO₂, < 0.4 to 0.5); (3) hemodynamic variables are stable (*eg*, without significant needs for therapy with pressors); and (4) there is the capability to initiate spontaneous breaths. This information is usually readily available, and the task force recommends that these issues be assessed daily as a "wean screen."¹ An extrapolation of this concept could be taken to the postsurgical arena where respiratory recovery is often rapid and the wean screen could be performed on a more frequent basis (*eg*, every hour).

HOW SHOULD DISCONTINUATION POTENTIAL BE ASSESSED IN THOSE PASSING THE WEAN SCREEN?

A number of parameters have been found to be associated with the success or failure of ventilator discontinuation.¹⁰⁻¹³ A summary of the better studied ones is given in Table 1. Some of these are

readily obtained (*eg*, vital capacity, minute ventilation [V_E], frequency/tidal volume [VT] ratio, muscle force generated during 20 s of effort against a closed airway [maximal inspiratory pressure (P_{imax})], and patient observations). Other parameters, however, require more sophisticated measurements. For instance, an esophageal balloon to measure esophageal pressure (PES [an estimate of pleural pressure]) is necessary to assess patient muscle loads quantified as work or pressure-time products (PTPs) per breath (work = ∫ PES × VT; PTP = ∫ PES × Ti [where Ti is inspiratory time]).¹⁴⁻¹⁷ These indexes of muscle load can be expressed with respect to time (*eg*, work/min), to ventilation (*eg*, work/L) or to maximum muscle strength (*ie*, PTP/P_{imax} ratio). Multiplying the PTP/P_{imax} ratio by the Ti fraction (*ie*, Ti/total breathing cycle time ratio) results in the pressure-time index, which can be a useful predictor of fatigue when > 0.15.¹⁵

Integrated factors also have been employed.¹⁰ The CROP index multiplies dynamic compliance by PaO₂/alveolar PO₂ ratio by P_{imax} and divides this product by the respiratory rate.¹⁸ Other integrated scores incorporate PES load calculations and may use neural networks.¹⁹ Important clinical assessments in evaluating ventilator discontinuation potential include subjective dyspnea, accessory muscle use, diaphoresis, tachycardia, abdominal paradox, and subjective comfort.

Analyses of receiver operating characteristics curves have shown that none of these indexes alone are sufficiently sensitive and specific to be useful in predicting the success of ventilation discontinuation in an individual patient.^{1,10} Moreover, the likelihood ratios for all of these parameters (*ie*, the percentage increase in predicting success using the parameter), while always statistically significant in population

Table 1—Measurements Performed Either While Patient Is Receiving Ventilatory Support or During a Brief Period of Spontaneous Breathing That Have Been Shown To Have Statistically Significant Likelihood Ratios To Predict Outcome of a Ventilator Discontinuation Effort in More Than One Study*

Parameters	Studies, No.	Threshold Values	Range of Positive LRs
Measured on ventilator			
V _E	20	10 to 15 L/min	0.81 to 2.37
P _{imax} (NIF)†	36	-15 to -30 cm H ₂ O	0.23 to 3.01‡
P _{0.1} /P _{imax} ratio	4	0.30	2.14 to 25.3
CROP	2	13	1.05 to 19.74
Measured during a brief period of spontaneous breathing			
RR	24	30 to 38	1.00 to 3.89
VT	18	325 to 408 mL (4 to 6 mL/kg)	0.71 to 3.83
RR/VT ratio (f/VT ratio)	20	60 to 105/L	0.84 to 4.67

*CROP = dynamic compliance × PaO₂/alveolar PO₂ × P_{imax}/RR; RR = respiratory rate; LR = likelihood ratio; P_{0.1} = inspiratory pressure against a closed shutter 100 ms after effort initiation; NIF = negative inspiratory force. Table was adapted from MacIntyre et al.¹⁰

†Measured against a closed shutter after 20 s

‡One study reported an LR of 35.79.

studies, are not large enough to be of utility in making a decision on an individual patient. Because of these limitations, the task force did not recommend the routine use of these parameters in clinical practice.¹ Instead, because the direct assessment of spontaneous breathing capabilities for up to 2 h has been shown in several randomized trials^{2,4} to be the most effective way to shorten the ventilator discontinuation process, the task force has recommended that those patients passing the daily wean screen be assessed with a formal spontaneous breathing trial (SBT).

The SBT involves an integrated patient assessment during spontaneous breathing with little or no ventilator assistance (eg, T-piece trial or using 1 to 5 cm H₂O continuous positive airway pressure [CPAP], 5 to 7 cm H₂O of pressure support from the ventilator, or automatic tube/airway compensation).^{1,2,13,20} The task force further recommended that no single parameter be used to judge SBT success or failure. Indeed, a recent study²¹ has shown that reliance on only a single parameter such as the f/V_T ratio during the SBT can potentially delay ventilator discontinuation. Rather, an integrated assessment of the respiratory pattern (especially the development of tachypnea), hemodynamic status (especially tachycardias, bradycardias, or BP swings), gas exchange (especially decreases in pulse oximetric saturation), and patient comfort (especially the development of anxiety or diaphoresis). The task force emphasized that the trial must last at least 30 min but no longer than 120 min.¹ If it is not clear that the patient is an SBT success at the 120-min mark, then the patient should be considered an SBT failure.

WHAT IS THE NEXT STEP FOR A PATIENT WHO SUCCESSFULLY COMPLETES AN SBT?

A patient who successfully completes an SBT has been shown in multiple studies¹⁰ to have a high likelihood of tolerating ventilator discontinuation permanently. Ventilator discontinuation, however, is a two-step process. In successfully performing an SBT, the first step, removing positive pressure ventilation, can be accomplished. The second step is removing the artificial airway.

The decision to remove the artificial airway depends on a different set of assessments than that used to determine ventilator removal.^{1,10} First, artificial airway removal must be done only in patients with the ability to protect the airway.²² Thus, patients must demonstrate good coughing strength and a minimal need for suctioning (eg, no more than every 2 h). Second, alertness and the ability to follow commands can greatly improve the success rate of

artificial airway removal.²² This is the rationale behind protocols to reassess and minimize sedation needs on a regular basis.^{23,24} Third, in borderline cases, the decision to remove the artificial airway may need to take into account the difficulty anticipated in replacing the airway if needed. Finally, the risk for postextubation upper airway obstruction needs to be considered. Some have advocated the routine use of the “cuff leak test” (assessing the presence of air movement around a deflated endotracheal tube cuff) before extubation, but conflicting data exist on the utility of this practice.¹ If there is clinical concern about postextubation upper airway inflammation, corticosteroids can be administered 24 h before the planned extubation.²⁵

Because ventilator discontinuation and artificial airway removal are not exact sciences, a certain reintubation rate is to be expected for even the most skilled of clinicians. Large surveys suggest that reintubation rates of 10 to 15% are typical for most well-run ICUs.²⁶ Rates significantly above or below this range should prompt a reassessment of either potentially overaggressive practices (ie, high reintubation rates) or underaggressive practices (ie, low reintubation rates).

Several small studies have suggested that noninvasive ventilation (NIV) can be used to avert reintubations in recently extubated COPD patients who are failing.²⁷ This concept may also extend to COPD patients who have failed an SBT but are judged capable of protecting their airway.²⁸ In these patients, the artificial airway is removed and ventilatory support is supplied with NIV. Finally, some studies²⁹ have suggested that NIV may also be effective as a prophylactic measure in patients who are judged to be “high reintubation risks.” Importantly, these uses of NIV appear to be restricted to the COPD population as larger studies^{30,31} of these practices in non-COPD patients have shown no benefit (or even harm) with NIV.

MANAGING THE PATIENT WHO IS NOT YET READY TO HAVE VENTILATOR USE DISCONTINUED

Patients who fail an SBT pose an important management challenge. A first step in addressing this challenge is to determine the reasons for failure and address them. Common causes for failed ventilator discontinuation and continued ventilator dependence are as follows: (1) respiratory drive failure involving the inability of the patient to generate a reliable respiratory drive because of CNS injury or drugs³²; (2) oxygenation failure involving rapid hemoglobin desaturation from a loss of expiratory

pressure and/or a fall in FIO_2 ; (3) oxygen delivery failure resulting from anemia and/or cardiovascular failure involving dysrhythmias and/or hypotension from catecholamine release, edema formation, or coronary hypoxemia due to a loss of ventilatory support³³; (4) muscle failure involving muscle overload from abnormal respiratory system impedances in the setting of weakened, fatigued, or metabolically disturbed muscles^{14–17,34–39}; and (5) systemic inflammatory processes, nutritional impairments, and metabolic processes associated with ongoing disease.^{40,41}

Ventilator management in these patients should focus on avoiding ventilator-induced lung injury⁴² and properly loading the respiratory muscles. Strategies to avoid ventilator-induced lung injury involve minimizing tidal and maximal lung stretch and avoiding collapse/reopening stresses in atelectatic units.⁴² Proper muscle loading should avoid both fatigue and atrophy. Fatigue results from inadequate or dyssynchronous ventilatory support and can damage sarcomeres.^{34,35} Muscle atrophy (sometimes referred to as *ventilator induced diaphragmatic dysfunction*) results from a lack of neural stimulation and consequent muscle inactivity.⁴³

The ideal mode should thus be an assisted form of ventilation that provides nonfatiguing synchronous respiratory muscle loading. Flow-targeted, volume-cycled breaths, often with intermittent spontaneous or pressure-supported breaths (sometimes referred to as *synchronized intermittent mandatory ventilation* [SIMV]) have been used for decades for this purpose. More recently, stand-alone pressure-targeted modes such as pressure assist control ventilation with a low backup rate or stand-alone pressure support ventilation have been described for this purpose, and may be more synchronous with patient effort because of the variable-flow feature of pressure targeting.^{44,45}

A new interactive mode, called *proportional assist ventilation* (PAV), has been made available on some ventilators.⁴⁶ PAV supplies adjustable flow and pressure in response to patient effort. With PAV, the ventilator calculates the resistance and compliance components of the breathing load and the clinician selects the proportion of that load that PAV should supply. Conceptually, PAV should be a very synchronous interactive mode. It must be remembered, however, that accurate load calculations must be done very frequently to prevent “runaway” and that there is no inherent minimal level of support (*ie*, a very poor patient effort could receive very little ventilator assistance). Clinical studies⁴⁷ have shown PAV to be a comfortable form of interactive support, but its role in ventilator withdrawal outcomes has not been assessed in any clinical trials.

An important consideration with any interactive

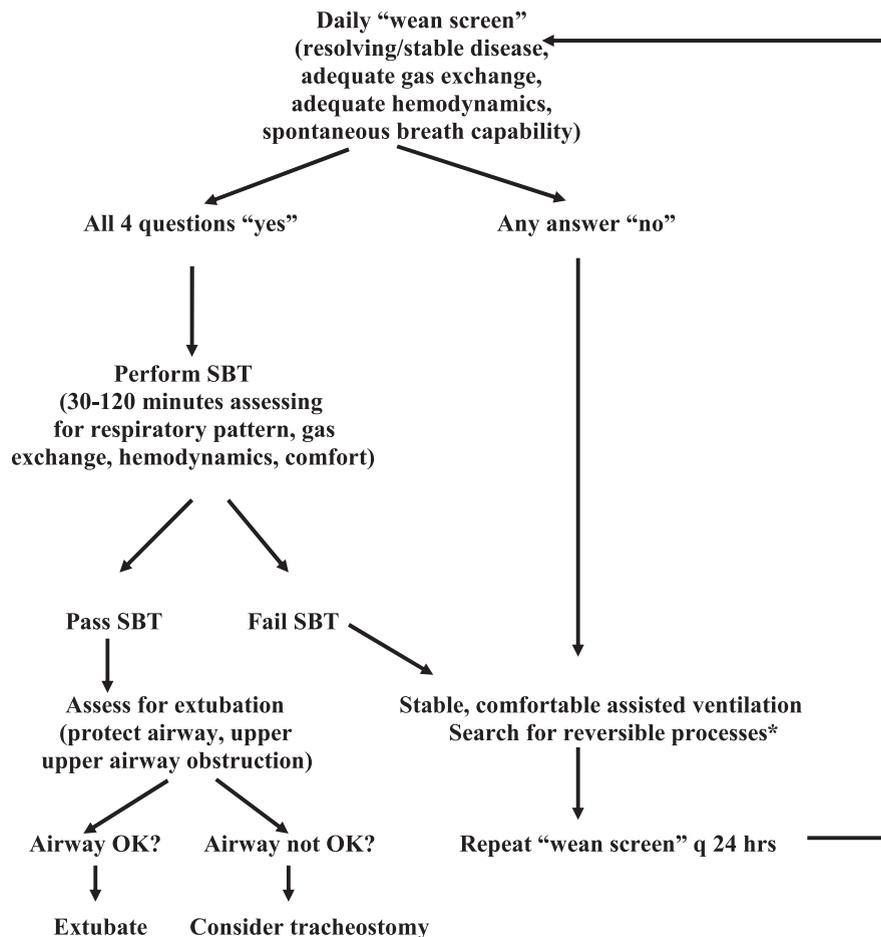
support mode is whether that level of support should be decreased over time (*ie*, decreasing an inspiratory pressure target and/or the SIMV backup rate, thereby allowing increasing spontaneous or pressure-supported breaths or decreasing the percentage of support with PAV). This is the traditional concept of ventilator weaning and is based on the notion that progressive loading (“exercising”) of the respiratory muscles would hasten the transition to unassisted spontaneous ventilation. However, there is no good evidence that loading recovering respiratory muscle above the level required for breath triggering and comfortable breathing provides any physiologic benefit.¹⁰ Moreover, the task force found no good evidence that a gradual reduction of ventilator support improved patient outcomes; often it only added to the complexity of ventilator management.¹ The recommendation thus was to set the ventilator to a comfortable level of assisted or supported ventilation (mode not important) and then to not adjust it unless the patient’s condition worsened. It is important to reemphasize that a critical additional part of this task force recommendation was that mechanical ventilation must always be coupled with the daily wean screen and subsequent SBT in those passing the screen.

DO NON-PHYSICIAN-RUN PROTOCOLS ENHANCE THE VENTILATOR DISCONTINUATION PROCESS?

The task force guidelines reviewed above can be operationalized into protocols run by nonphysicians (Fig 1). The advantages to protocols are that a consistent evidence-based approach is applied to all patients and that regular patient assessments are assured. In numerous studies, non-physician-run protocols consistently produce faster ventilator discontinuation times when compared to physician-run “usual care.”^{4,5,48} It must be pointed out, however, that if the physician-run usual care aggressively follows the above guidelines, ventilator discontinuation times can be similar to non-physician-protocolized care.⁴⁹

CAN NEWER FEEDBACK CONTROLLERS FACILITATE THE VENTILATOR DISCONTINUATION PROCESS?

The earliest approaches to feedback controllers involved adjusting the machine breath rate with SIMV according to the delivered \dot{V}_E . This was commonly referred to as *minimum minute ventilation*.⁵⁰ As noted above, because SIMV modes are less comfortable and more complex, and because wean-



* Consider tracheostomy and long term facility if progress not being made

FIGURE 1. Protocolized flow chart for ventilator discontinuation.

ing mandatory breaths have not been shown to improve outcomes when compared with stable support and daily wean screens/SBTs, minimum \dot{V}_E is less commonly used today.

On many modern ventilators, pressure-targeted modes can have a feedback controller of the inspiratory pressure to assure a minimal V_T .⁵⁰ With pressure assist control, this is termed *pressure-regulated volume control* (PRVC); with pressure support, this is termed *volume support* (VS). With these modes, a reduced effort or worsening mechanics would result in the ventilator automatically increasing the inspiratory pressure target; with increased effort or improving mechanics, the ventilator would automatically reduce the inspiratory pressure target.

PRVC/VS (with or without backup ventilator breaths) offer the obvious advantage of providing a volume "guarantee" for patients with unstable respiratory drives when using pressure-targeted modes. However, some investigators⁵¹⁻⁵³ have speculated

that PRVC/VS techniques could also be used to automatically decrease support to wean patients as their clinical status improved. A problem with this concept, however, is that if the minimal V_T is set too low, the resulting dyspnea may increase effort and thereby further reduce support inappropriately. Conversely, the setting of an inappropriately high V_T may never stimulate patient efforts, and thus no pressure reduction will ever occur. Perhaps more importantly, however, is the fact that the task force, as noted above, found no evidence that a gradual reduction of ventilation support accelerated the ventilator discontinuation process. Thus, automated weaning with PRVC/VS cannot be routinely recommended at the present time, until good outcome data are obtained that support the use of these approaches.

A more complex approach to automated feedback control of mechanical ventilatory support combines the PRVC/VS approach with an automated V_T/f

inspiratory/expiratory ratio setup based on respiratory system mechanics and a \dot{V}_E target set by the clinician. Known as *adaptive lung ventilation* or *adaptive support ventilation* (ASV),⁵¹ the breath control algorithm attempts to partition the f , V_T , and inspiratory/expiratory ratio in order to minimize both the combined ventilator-patient inspiratory work and the intrinsic PEEP potential. A number of studies^{52,53} have evaluated ASV in patients who were being weaned from mechanical ventilation. In general, these studies showed that ASV safely provided adequate ventilatory support and similar (or faster) weaning times when compared to various clinician-run SIMV and SIMV-pressure support approaches. However, caution must be exercised in evaluating these results as a more appropriate evaluation of an ASV weaning strategy (or any other automated approach) would be to compare it to an effective protocolized SBT approach to weaning as described above, not to simple (and potentially suboptimal) clinician usual care.

Several reports⁵³⁻⁵⁵ have shown that a feedback control of pressure support based on ventilatory pattern and end-tidal CO_2 could drive the patient to an automated SBT faster than a clinician-run protocol. While conceptually attractive, the clinician run usual-care approaches in the control groups of these studies were not particularly effective at performing SBTs appropriately, and thus the comparison with the automated approach is called into question.

DOES A TRACHEOSTOMY FACILITATE VENTILATOR WITHDRAWAL?

A tracheostomy offers several conceptual advantages in the management of patients requiring mechanical ventilatory support for a prolonged period. Specifically, compared to an endotracheal tube, tracheostomies are more comfortable and impose less breathing work; sedation needs may thus decrease.⁵⁶ There are also observational data that tracheostomies may reduce ventilator-associated pneumonia.⁵⁶ On the other hand, tracheostomy is a surgical procedure that has its own complication rate and expenses. The current guidelines from the task force¹ state that when a patient is judged to be likely to require mechanical ventilation for ≥ 21 days, a tracheostomy should be placed.

A 2004 trial⁵⁷ that was published subsequent to the task force guidelines has added insight into this issue. This trial randomized 120 patients who were projected to need ventilation for > 14 days and showed that an early-tracheostomy strategy resulted in lower mortality, fewer cases of pneumonia, fewer accidental extubations, and less time spent on a

mechanical ventilator in the ICU than a late-tracheostomy strategy. At the present time, especially in the era of easily placed percutaneous tracheostomies, strong consideration should thus be given to early tracheostomy placement in patients who are felt to be likely to need mechanical ventilation for > 2 weeks.

DOES THE PATIENT REQUIRING PROLONGED MECHANICAL VENTILATION (THE "DIFFICULT TO WEAN" PATIENT) REQUIRE A DIFFERENT APPROACH?

Patients consistently failing SBTs despite apparent stabilization or even reversal of their underlying disease comprise one of the most challenging management problems in the ICU. On occasion, an extubation attempt might be warranted in such patients if only to convince the care team that the irritant and loading effects of the artificial airway are not the cause of the SBT failure. In those patients, however, who are truly ventilator-dependent after 14 to 21 days despite disease stabilization or reversal, different management approaches might be indicated.⁵⁸ In general, these approaches involve comprehensive multidisciplinary rehabilitation interventions in addition to ventilatory support. These interventions are aimed at optimizing all of the other factors that are contributing to the patient's reliance on life support (*eg*, nutrition, physical therapy, and psychosocial support).

From the ventilatory support perspective, a strategy of gradual reduction in ventilation support (*ie*, weaning) might be appropriate in this population, as this is the approach used by most experts in the field.⁵⁸ A consistent recommendation from these clinician investigators is to wean patients to about 50% of their maximal support levels (*ie*, 50% of their initial inspiratory pressure settings) without using daily SBTs. When that has been achieved, daily SBTs should be reinstated. Subsequent decisions on ventilator withdrawal are then based on the assessments described above. Unfortunately, the success rate of ventilator discontinuation in this population remains at near 50 to 60%.

CONCLUSIONS

The ventilator discontinuation process is a critical component of ICU care. Ventilator dependency is caused by both disease factors and clinician management factors. The daily wean screen and subsequent SBT in those patients passing the screen is now the "gold standard" for ventilator withdrawal assessment

and should be performed in virtually all patients who are recovering from respiratory failure. The decision to remove the artificial airway in those patients successfully passing an SBT requires further assessments of the patient's ability to protect the airway. Managing the patient who fails the SBT is one of the biggest challenges facing ICU clinicians. In general, stable forms of assisted/supported ventilation are what is required between the daily wean screens/SBTs. Finally, in the patient requiring prolonged mechanical ventilatory support, specialized multidisciplinary units may offer value.

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Discontinuing Mechanical Ventilatory Support*

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