Mechanical Ventilator Discontinuation Process

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KEYWORDS

• Critical illness • Mechanical ventilation • Weaning • Liberation • Protocol

KEY POINTS

- Ventilator discontinuation describes a process of both ventilator weaning and recognition of opportunities to assess for extubation.
- Protocol-driven weaning that incorporates the application of daily spontaneous breathing trials among eligible patients is currently the dominant management strategy.
- Weaning failure requires consideration of multiple contributing systemic factors.

DEFINITIONS

This article defines ventilator discontinuation as the process of removing the support of mechanical ventilation from a patient. This process may result in successful liberation or unsuccessful liberation requiring reintubation or reattachment of the ventilator to a tracheotomy tube (generally within 24–48 hours). Additionally, discontinuation may be viewed as a component of end-of-life care. As such, extubation may be performed in anticipation of short-term death or at least with a plan to avoid reintubation. Because of the consequences of potential failure and the multiple factors that can determine it, discontinuation of ventilation involves clinical judgment in every case.

Conceptually, ventilator discontinuation requires several elements. First is the process of weaning. Weaning refers to the gradual or stepwise reduction in the amount of ventilator support (ie, inspiratory pressure, mandatory breaths, Fio_2, positive end expiratory pressure [PEEP]) provided to the patient. Second is the recognition of opportunities to assess readiness for extubation in anticipation of performing spontaneous breathing trials (SBTs) or tracheotomy collar trials (TCTs). Specifically it means determining if critically ill patients have recovered sufficiently to handle the stress of these procedures (ie, Are they in shock? Are they tachypneic? Are they febrile?) These components of discontinuation in most centers are protocolized. Finally is the process of removing the artificial airway, a process guided by assessments of the patient's ability to protect the natural airway.

HISTORICAL CONTEXT

While ventilator management in 2016 is largely protocol-driven and focused on screening for readiness for spontaneous breathing trials, it was not always the standard. For many years, in fact, there was little evidence-based information to guide practitioners in the day-to-day management of mechanical ventilation, including its discontinuation.

For some time, clinicians used a number of strategies based generally on intuition. Some reduced the number of machine-delivered breaths in the synchronized intermittent mandatory ventilation (SIMV) mode. Others added pressure-supported (PS) breaths to IMV and gradually permitted

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patients to take spontaneous PS breaths in between mandatory machine breaths, weaning the inspiratory pressure over time. Still others would change from controlled modes (eg, volume control [VC] or pressure control [PC]) to PS as they felt progress was occurring. Some used trials of applying very low levels of support such as through T-pieces—oxygenated tubing connected to the endotracheal tube with either little or no PEEP—to predict how close patients were to a successful liberation.

A landmark multicenter, randomized prospective trial was published in 1995 that compared IMV, PS, multiple daily SBTs, and once-daily SBTs.[1] Spontaneous breathing was defined as using a T-piece or pressure support of 5 cm H_2O for up to 120 minutes. This study showed convincingly that patients weaned on daily SBTs were 3 times more likely to be extubated successfully than those weaned on SIMV and 2 times more likely than those weaned on PS. After a subsequent trial by Ely and colleagues[2] demonstrating superiority of a protocol incorporating daily SBTs, the field shifted away from SIMV for good, and the protocol-driven, SBT-focused era began. Although there seems to be no 1 superior method for performing SBTs (eg, low PEEP, T-piece), there is also currently no superior strategy for assessing extubation readiness.

CONCEPTS THAT ARE IMPORTANT BUT OFTEN NOT DISCUSSED

As alluded to in the introduction, all clinicians recognize that goals of ventilation, and its discontinuation may differ based on the patient's values, illness severity, and underlying condition. Although rarely discussed in reviews of this subject, they are clearly critical to the decision making involved in each case. Note that death among patients with mechanical ventilation is much more common after withdrawal of ventilation than due to an underlying medical condition while on mechanical ventilation.[3] Also, the contribution of clinical uncertainty is important to recognize. Even a successful 2-hour SBT has a significant extubation failure rate.[2] Last, the setting in which ventilator weaning and discontinuation are conducted is crucial. Poorly staffed ICUs in smaller hospitals may have limited physician oversight. The success of their clinical care may depend on the quality of their protocols, the numbers of respiratory therapists, and the staffing model of their hospital. Although evidence will be discussed in this review, these data may often diffuse into nonacademic settings less completely and slower.[4]

WHAT IS KNOWN ABOUT THE PROCESS?

The hospital mortality rate of patients who receive invasive mechanical ventilation is highly variable by age, underlying condition, and other factors. Generally speaking, approximately 60% to 65% of patients who receive mechanical ventilation survive the ICU stay.[3,5] Approximately 85% of mechanically ventilated patients in a medical ICU who are extubated are successfully liberated from the ventilator, whereas 15% or more require reintubation within approximately 48 hours.[6] As the duration of ventilation increases, the likelihood of liberation decreases.[7]

So what is the tradeoff between attaining a high pretest probability and unnecessarily delaying the weaning process? Although a target reintubation rate is unclear, many agree that a rate of about 10% to 15% is acceptable and that a very low rate (eg, 5%–10%) likely demonstrates timidity. Moreover, if a clinician's reintubation rate is close to zero, patients may in fact be systemically exposed to a higher risk of ventilator-associated lung injury. Yet reintubation is associated with longer ICU stays, length of hospitalization, need for long-term care and rehabilitation, and higher rates of mortality.[8] In fact, extubation failure is independently associated with increased mortality and need for stay in a long-term care facility if the patient survives.

WHY DO PEOPLE FAIL TO WEAN?

Successful weaning may be a physically stressful experience for critically ill, multimorbidity patients. It depends on the balance of function versus dysfunction of multiple organs. Seen in this light, failure to wean is often the result of a multifaceted array of dysfunctions affecting the lungs, muscles, nerves, heart, and brain. Other factors such as metabolic derangements, malnutrition, and unresolved infections are also important.

The most obvious and perhaps most prevalent cause of weaning failure is poor parenchymal lung function, whether due to chronic lung disease like chronic obstructive pulmonary disease (COPD) or acute lung injury. Airways-related issues such as bronchospasm may also be problematic. Yet less well appreciated to some extent is the impact of respiratory muscle weakness, itself part of a constellation of critical illness neuromyopathy.[9] Disuse atrophy of diaphragmatic myocytes begins within hours of mechanical ventilation.[10] Ventilator-induced diaphragmatic dysfunction (VIDD) in animal models is a well-described consequence of prolonged controlled ventilation.[11] In mice, controlled mechanical ventilator and diaphragmatic disuse

leads to muscle fiber atrophy and oxidative stress. Although VIDD has not been as well described in patients, 1 cohort study of 54 mechanically ventilated patients demonstrated a 32% decrease in diaphragmatic thickness as measured on ultrasound, with the largest decrease during the first 72 hours of mechanical ventilation.[12] A multitude of factors such as neuromuscular blockade, heavy sedation, shock, malnutrition, systemic inflammation, and electrolyte disturbances lead to skeletal muscle weakness and create a syndrome of critical care myopathy that inhibits successful wean.[13] Several medications are believed to contribute to muscle dysfunction such as corticosteroids, neuromuscular blockers, and aminoglycosides.

Unresolved cardiovascular issues also contribute to failure to wean.[14] SBTs can elicit tachyarrhythmias in patients with poorly controlled rhythms, and hypoxia or tachypnea in the setting of decompensated heart failure. Moreover, the loss of intrathoracic pressure during an SBT can worsen hypotension in those with ongoing pressor requirements, and induce cardiogenic pulmonary edema. Manifestations of any of these would be criteria to terminate an SBT and necessitate addressing the underlying issue.

WHAT TOOLS CAN HELP PREDICT SUCCESS OF THE DISCONTINUATION PROCESS?

Physicians are imperfect judges of both the duration of ventilation, especially prolonged ventilation, and likelihood of extubation success.[15] Therefore specific clinical metrics and protocols have become integral to systems-based approaches to weaning and ventilator discontinuation.

Many parameters are used to determine readiness for weaning and extubation such as respiratory rate, minute ventilation (MV), maximal inspiratory pressure (MIP), and rapid shallow breathing index.

Minute ventilation, the product of respiratory rate and tidal volume, is a measure of respiratory demand. In a healthy individual, the MV is approximately 5 to 6 L/min, and in situations of increased respiratory demand such as metabolic acidosis or respiratory failure, MV demands increases. Thus it stands to reason that the higher the respiratory demand, the lower likelihood of successful liberation. In practice, however, MV is an unreliable weaning predictor.

Maximal inspiratory pressure, sometimes also known as negative inspiratory force (NIF), is an indication of respiratory muscle strength. It is measured with a manometer occluding the end of the endotracheal tube and asking the patient to inhale deeply. Prior studies suggest that MIP of -20 cm H_2O and higher (less negative) is an indication for intubation; however, pooled data show that MIP predicts successful liberation with low sensitivity and specificity.

The rapid shallow breathing index (RSBI), the ratio of frequency to tidal volume (f/Vt), has been shown to be the most accurate predictor of failure to wean.[16] Although RSBI less than 105 breaths/L/min is relatively nonspecific at 67% for successful wean, RSBI greater than 105 breaths/L/min has a negative predictive value (ie, probability of failure to wean based on a negative test) of 95%. That is, to say, RSBI greater than 105 is very useful in predicting failure to wean. As an example, a patient breathing 30 times per minute with a tidal volume of 250 mL has an RSBI of 120 breaths/L/min, or a 95% chance of failure to wean.

A systematic review demonstrated, however, that all of these metrics, while used frequently in clinical practice, are not individually accurate predictors of successful liberation.[6]

There are also anatomic considerations relevant to ventilator discontinuation. Cuff leak is a commonly used method of predicting potentially life-threatening postextubation respiratory distress related to airway edema. To perform this test, the cuff of the endotracheal tube is deflated, and the presence (and sometimes quantity) of an air leak around the tube is assessed. Absence of air leak suggests laryngeal edema may be significant. Most studies of cuff leak, however, include heterogeneous populations, and 1 systematic review suggests that a positive cuff leak (ie, absent cuff leak) predicts upper airway obstruction with only approximately 50% sensitivity and 90% specificity.[17,18] Therefore, a positive cuff leak test is less helpful than a negative test—the actual purpose of performing the test. As such, clinicians must consider the cuff leak test in the context of other factors such as size of the endotracheal tube, the size of the patient's airway, duration of intubation, difficulty of intubation, upper airway trauma, and presence or absence of cough, which in combination with absent air leak, elevates the risk of postextubation stridor by a factor of 10.[19]

WHAT MANAGEMENT STRATEGIES CAN IMPROVE SUCCESS?

Ventilator weaning has historically been managed by physicians without any protocols. Understandably, this led to variability in practice depending on the physician's experience, time, and bias. Studies

comparing physician-led ventilator weaning versus protocol-driven ventilator weaning, the latter led by nurses and respiratory therapists, showed that protocolized weaning produced more favorable outcomes in terms of fewer days on the ventilator and in the ICU.[20–22] In fact, a systematic review found that weaning protocols were associated with 25% fewer days on the ventilator and 10% reduction in ICU stay.[22] The reason that protocols succeed over physician-led ventilator management is that protocols allow more consistent use of evidence-based practices such as sedation-reduction protocols (including daily spontaneous awakening trials)[23] and SBTs. Importantly, weaning protocols should be written with rules that do not hinder the discontinuation process. Examples would be excessively restrictive pressure reductions (eg 1–2 cm H_2O/d) or mandating certain criteria be met (eg RSBI <105) before progressing.[24] Indeed, the concern over potential discontinuation delays from protocolized weaning has led some to recommend avoiding weaning of inspiratory pressure or mandatory breaths altogether and simply perform SBTs in patients with minimal PEEP and Fio_2 requirements and who are otherwise stable and capable of initiating breaths.[25]

Regardless of whether weaning is part of the discontinuation protocol, a patient should be deemed appropriate for a spontaneous breathing trial if PEEP and Fio_2 requirements are low (eg, <5–8 cm H_2O and <0.4, respectively), if the patient is capable of initiating breaths, and if major active medical issues such as pressor or continuous renal replacement therapy (CRRT) requirements have been resolved. The SBT should be stopped if the patient demonstrates agitation, tachycardia, or respiratory distress. In general, an SBT should last at least 30 minutes but no more than 120 minutes.[6]

As already noted, SBTs should be done in conjunction with a sedation reduction protocol. If a spontaneous awakening trial (SAT) is undertaken,[26] all continuous intravenous analgesics and sedatives are shut off to allow the patient to reorient himself or herself. Studies consistently demonstrate that daily orientation, even to the chaos of the ICU, is preferable to leaving the patient in a drug-induced coma, both for reducing days on the ventilator and long-term neuropsychiatric outcome. An SAT should be considered for any patient who is not requiring escalating doses of sedation, on neuromuscular blockers, actively seizing or withdrawing, or with intracranial hypertension. An SAT should be stopped if the patient demonstrates significant pain or agitation, tachycardia, tachypnea, or hypoxia.

Early mobility has also been shown to decrease number of days on mechanical ventilation, especially when used in conjunction with sedation reduction protocols (eg SATs), SBTs, and delirium management. In fact, employing the ABCDE bundle (awakening, breathing, coordination, delirium, early mobilization) results in 3 additional ventilator-free days.[27] Physical therapy on the ventilator decreases critical illness myopathy, decreases likelihood of respiratory muscle atrophy, decreases atelectasis, and helps with secretion mobilization, all of which contribute to successful weaning.

Once it is determined that positive pressure ventilator support is no longer needed, attention turns to removal of the artificial airway. A patient may not be appropriate for extubation if poor mental status is present, manifesting as either delirium or deep sedation and coma (Glasgow Coma Scale <9).[6,28] The clinician must also ensure that the patient is alert enough to protect his or her airway from aspiration; otherwise the risk of reintubation may be high. One assessment often used in this regard is the need for suctioning of the artificial airway. A common practice is to delay extubation in those requiring suctioning more frequently than every 2 hours.[6]

Preventing postextubation respiratory distress and proactively addressing it if it occurs are both important management topics. Postextubation distress may be related to laryngeal edema, poor management of secretions, cardiogenic edema, or muscle weakness.

Noninvasive ventilation (NIV) has gained popularity in the management of postextubation distress. Key conceptual considerations in its application in this setting are noteworthy. Among patients at high risk for extubation failure, early application of NIV can reduce reintubation and even mortality.[29] However, much of the benefit appears to be isolated to patients with underlying chronic lung disease, especially COPD.[30] In contrast, waiting until respiratory distress develops before applying NIV does not reduce reintubation and may be harmful indirectly by delaying necessary reintubation.[31,32] Importantly, NIV should not be attempted in extubation failures resulting from airway protection issues.

High-flow nasal cannula application is increasingly popular in both the management of acute respiratory failure and postextubation hypoxemia. A recent study found that high-flow nasal cannula recipients compared with those receiving Venturi mask-delivered oxygen had lower rates of reintubation (4% vs 21%).[33]

WHAT ABOUT PATIENTS WITH CHRONIC CRITICAL ILLNESS OR THOSE WHO ARE IN LONG TERM ACUTE CARE?

Epidemiologic studies estimate that nearly 400,000 people develop chronic critical illness each year, and for these patients, prolonged mechanical ventilation is a key component.[34,35] Most patients with prolonged mechanical ventilation receive tracheotomies. In hospital-based settings, the ideal weaning strategy is unclear. Intuitively, the clinician most often directs his or her attention to the perceived mechanism of failure, such as those already described. But in general, how does one operationalize an approach? Many prefer to gradually increase the time of unassisted breathing over the course of days to weeks. There is not consensus about how long these tracheotomy collar trials (TCTs) should last, how frequently they should be performed each day, or how their length should be escalated over time.[6]

Many acute care-based clinicians have adapted the practice tested by Jubran and colleagues[36] in a randomized trail conducted in a long-term acute care setting. In this study, patients who could not remain off the ventilator for more than 5 days in a screening assessment were randomized to be weaned by 1 of 2 methods: unassisted breathing trials through a tracheotomy (ie, TCT) or a strategy of progressive reductions in pressure support. The TCT method reduced weaning times and increased weaning success. However, the main TCT affect appeared to be among those who failed later in the initial 5-day screening procedure.

CAN THE DISCONTINUATION PROCESS BE AUTOMATED?

Over the years, several attempts have been made to automate the weaning process with feedback control algorithms designed to progressively reduce support.[37] Common approaches include mandatory minute ventilation (an SIMV mode with feedback reductions in mandatory breath rates) and volume support (a pressure support mode with a volume feedback feature), The most recent approach uses a volume support feedback strategy but incorporates respiratory frequency, end tidal CO_2, and an SBT reminder into the algorithm.

Importantly, all of these strategies are based on the premise that support reduction in between SBTs improves outcomes, a premise that, as already noted, has little supporting evidence. Because of this, studies evaluating these approaches have only been able to show that support reduction strategies can effectively be automated (with consequently less clinician work). However, no study has shown that any of these approaches shorten the duration of mechanical ventilation when compared with strategies that mandate regular SBTs.[37] The lone exceptions to this generalization might be in the postoperative setting, where patient recovery is rapid and in the chronically critically ill, in whom patient recovery is slow. Under both of these circumstances, automated tools to assess this recovery might be helpful.

WHAT ABOUT DISCONTINUATION IN THE SETTING OF EXPECTED DEATH?

It is often clear that patients cannot be extubated successfully with the goal of survival. Several authors have described recommendations for a systematic approach to terminal ventilator withdrawal.[38] The key elements are preparation, information exchange with families about plans and expectations, good communication with nursing and respiratory therapy about the procedure, and aggressive management of symptoms before and after removal of the endotracheal tube. Many clinicians reduce ventilator support in anticipation of withdrawal to inform pharmacologic management designed to counteract possible postextubation air hunger. Families often want to know how long their loved one will survive after terminal withdrawal. Generally speaking, although time to death varies in these situations, most patients die within 24 hours; higher levels of PEEP and lower mean arterial pressure predict a lower postextubation survival time.[39,40]

SUMMARY

The process of mechanical ventilator discontinuation includes weaning and the recognition of opportunities to perform extubation readiness trials. Protocolized weaning is a dominant weaning strategy in acute care hospitals, and well designed protocols are effective whether led by respiratory therapists or physicians. A variety of correctable factors may delay or prevent weaning. Clinicians should appreciate the shortcomings of current methods of predicting weaning success or failure. Finally, discontinuation of ventilation among patients expected to die requires considerable planning.

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