

Evidence-Based Practice of Weaning from Ventilator: A Review

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KEY POINTS

- Mechanically ventilated patients should have a daily assessment relating to their ability to be weaned from ventilatory support.
- A spontaneous breathing trial helps to identify patients who may be successfully extubated and the available evidence would suggest this should be in the form of an intermittent T-piece or a minimal-level pressure support trial for 30 minutes.
- Noninvasive ventilation can have a role in reducing the duration of mechanical ventilation in chronic obstructive pulmonary disease (COPD) patients but should not be used to treat extubation failure.

INTRODUCTION

Liberation from mechanical ventilation in intensive care unit (ICU) patients often appears to be a blend of art and science. The science component exists in identifying clinical indicators of improving or recovering physiology whilst clinical judgement still plays a crucial role in selecting those who can breathe without support. Some patients wean quickly and uneventfully and, in this respect, their management may be simple. For other patients, this process may be long and protracted. There has been a significant volume of work on weaning since the early 1990s but there is a lack of reproducibility and predictive value in the evidence.

WHAT DO WE MEAN BY WEANING?

Weaning from ventilator comprises 2 separate aspects:

1. Liberation from the ventilator and the mechanical support that it offers.
2. Removal of the artificial airway.

IDENTIFYING PATIENTS SUITABLE FOR WEANING

Many studies show that a spontaneous breathing trial (SBT) is a good method of identifying patients ready to be weaned from mechanical ventilation. This is commonly done using a pressure support ventilation (PSV) mode or a T-piece trial. If the patient can maintain gas exchange at minimal levels of pressure support (usually 5 to 10 cm H₂O) or when on the T-piece, the feasibility of weaning from mechanical ventilatory support can be assessed.

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Modifiable factors that can hinder progress towards extubation also need to be sought and addressed, preferably with a daily screen by the intensive care team. In an analysis of weaning protocols, Ely suggested the 'WHEANS NOT' mnemonic to aid clinicians in identifying such issues:¹

- **W**heeze (especially COPD and asthma)
- **H**eat disease and fluid overload
- **E**lectrolytes and metabolic derangement
- **A**nxiety and delirium
- **N**euromuscular disease and weakness
- **S**epsis
- **N**utrition insufficiency
- **O**piates and other sedatives
- **T**h thyroid disease

Finally, a protocol-driven team approach has been shown to be more successful than a physician-driven approach.²

WEANING INDICES

Multiple criteria have been used to assess readiness to wean.

- Subjective criteria include tachypnoea, diaphoresis, haemodynamic stability, delirium, and other signs of increased work of breathing.
- Integrated indices include the compliance, resistance, oxygenation, and pressure index; the simplified weaning index; and the rapid shallow breathing index (RSBI).³

Many studies have demonstrated the validity of the RSBI (respiratory rate [$f \text{ min}^{-1}$]/tidal volume [V_T ; in milliliters]) on T-piece in terms of predicting successful weaning; the actual index number used may vary according to the manner in which it is measured.⁴

How to Measure the Rapid Shallow Breathing Index

A study comparing the RSBI value in patients on pressure support versus continuous positive airway pressure (CPAP) versus a T-piece trial showed, not surprisingly, that the value of RSBI is significantly altered by the mode of ventilatory support that a patient is on when the RSBI is measured. It showed mean values of 46 with pressure support, 63 with CPAP, and 100 during a T-piece trial.⁴ This reflects the fact that pressure support or CPAP can affect V_T and therefore f/V_T ratio. Therefore, if the RSBI is to be used, it is advisable to either calculate it under the conditions originally applied by Yang and Tobin, namely with a handheld spirometer attached to the endotracheal tube 1 minute into a T-piece trial after disconnecting from the ventilator, or acknowledge that different cut offs for the index may need to be used in its interpretation.⁴

WHAT IS THE BEST VENTILATOR MODE TO WEAN ON?

Esteban et al compared 4 modes for weaning in patients who experienced respiratory distress during a 2-hour spontaneous breathing trial: synchronized intermittent mandatory ventilation (SIMV; mandatory rate gradually reduced), PSV (pressure support gradually reduced), daily multiple T-piece trials, and a daily single T-piece trial.⁵ They found the mean duration of ventilation in the SIMV group was 5 days, versus 4 days for the PSV group and 3 days for both T-piece groups. They concluded that, in this study, the T-piece spontaneous breathing trial patients weaned more quickly than the PSV group, who weaned more quickly than the SIMV group.

However, another study comparing the same methods of weaning showed the best results with PSV as the weaning mode in terms of highest rates of successful weaning, shortest duration of weaning, and shortest ICU length of stay, with little difference between SIMV and spontaneous breathing trials.⁶

Finally, a third study comparing low levels of pressure support against a T-piece system in patients undertaking a 2-hour spontaneous breathing trial prior to considering extubation found both methods to be equally effective in terms of predicting successful extubation with similar reintubation rates, although the weaning trials themselves failed more often in the T-piece group (22% versus 14%).⁷

Whilst the reason for this discrepancy in findings is perhaps not easy to explain, the heterogeneity in the evidence base is not uncommon and demonstrates that there is still much that needs clarification on this subject.

Many research studies set the duration of spontaneous breathing trials to be 2 hours. Esteban et al compared T-piece trials of 2 hours versus 30 minutes and reported that a 30-minute trial was as useful as a 2-hour trial in predicting weaning.⁸

In summary, there appears to be little difference between the different modes of ventilation when weaning but the evidence that does exist would suggest that PSV or intermittent T-piece trials are effective and superior to SIMV as a weaning mode.

DIFFICULT WEANING

Factors responsible for difficult weaning may be grouped under the following headings:

1. Respiratory
 - a. Poor lung compliance (e.g., oedema, consolidation, fibrosis, atelectasis, pulmonary secretions)
 - b. Poor chest wall compliance (e.g., pleural effusion, obesity)
 - c. Increased resistive load (e.g., bronchoconstriction, dynamic hyperinflation in COPD, blocked artificial airway, airway swelling or obstruction)
2. Neuromuscular
 - a. Decreased central respiratory drive (e.g., coma, obesity hypoventilation syndrome, myxoedema)
 - b. Decreased airway reflexes (e.g., toxin- or drug-related, bulbar neurological dysfunction)
 - c. Neuromuscular weakness (e.g., critical illness, neuromyopathy, myasthenia)
3. Neuropsychiatric
 - a. Delirium, anxiety, sleep disturbance
4. Metabolic
 - a. Hypokalaemia, hypophosphataemia, hypomagnesaemia
5. Cardiac failure

DO AUTOMATED WEANING MODES HAVE ANY ADVANTAGE OVER CONVENTIONAL APPROACHES?

Automated weaning modes such as adaptive support ventilation, Smart Care/PS, proportional assist ventilation, mandatory minute ventilation, and volume support have come onto the market with a promise of faster weaning. However, the exact role of these modes in weaning is still unclear, though there is considerable enthusiasm in using advanced closed loop systems in weaning.

For example, Schädler et al found no overall ventilation time difference between weaning using automatic control of PSV and weaning based on a standardized written protocol among an unselected surgical patient population.⁹

As of June 2014, the Cochrane database declared that whilst automated modes might reduce the duration of weaning, particularly in mixed ICU populations, the evidence is limited to only 2 types (adaptive support ventilation and Smart Care) and no conclusions can therefore be drawn about automated modes in general. They recommend further research and technological development.¹⁰

IS THERE A ROLE FOR NONINVASIVE VENTILATION (NIV) IN WEANING?

In a randomised controlled trial, Nava et al compared continuing mechanical ventilation against extubation and noninvasive PSV in patients with COPD who had failed a T-piece SBT 48 hours after intubation for hypercapnic respiratory failure. They showed that the duration of ICU stay, nosocomial pneumonia, and 60-day mortality were lower in the patients weaned via NIV versus those weaned via invasive pressure support.¹¹ The mean duration of mechanical ventilation was 16.6 ± 11.8 days and 10.2 ± 6.8 days for the invasive and NIV groups, respectively ($p = .021$). Survival rate at 60 days was 92% and 72% for patients who received NIV and invasive ventilation, respectively ($p = .009$). Seven patients weaned without the use of NIV developed nosocomial pneumonia, whereas none from the NIV group did.

A small randomised controlled trial by Girault et al looked at patients with acute or chronic respiratory failure and compared planned extubation and conversion to NIV against continuing invasive PSV. However, they showed no difference in overall weaning success with NIV when compared to PSV and no difference in ICU or hospital stay or 3-month mortality, although the total duration of invasive mechanical ventilation was significantly shorter in the NIV group (4.56 ± 1.85 days) than in the PSV group (7.69 ± 3.79 days) ($p = .004$). They concluded that NIV may be of help and that it did not increase the risk of weaning failure.¹²

The Cochrane database has also reported evidence for a beneficial effect on decreasing mortality and ventilator-associated pneumonia without increasing the risk of weaning failure or reintubation among patients with acute hypercapnic respiratory failure weaned with the help of NIV—most notably those patients with COPD.¹³

The data are less convincing in more heterogeneous populations; only trials looking at COPD or cardiogenic pulmonary oedema have really demonstrated benefits.

HOW CARDIAC DYSFUNCTION AFFECTS WEANING

The transition from positive-pressure ventilation to spontaneous breathing may precipitate or worsen pre-existing heart failure. Strategies to circumvent this problem include achieving significant negative fluid balance before extubation or transitioning from

low pressure support ventilation to NIV (in order to maintain some positive end-expiratory pressure). Failure to wean should prompt consideration of an echocardiographic evaluation for cardiac dysfunction, including diastolic heart failure.

A prospective observational study compared plasma levels of N-terminal pro-brain natriuretic peptide before and after a spontaneous breathing trial and demonstrated rises in patients who either failed the SBT or failed extubation, compared with a fall in levels in those successfully extubated ($p = .004$). This supported previous studies in concluding that the variation in brain natriuretic peptide level before and after SBT could provide a noninvasive manner in which to augment the value of a SBT in predicting weaning outcome.¹⁴ At this time, this is not routine or widespread practice.

Transthoracic echocardiography is widely used in ICUs to assist in the assessment of haemodynamic status, and certain aspects of haemodynamic status may impact weaning. The E/A ratio is the ratio of the early (E: ventricular filling during ventricular relaxation) to late (A: ventricular filling from atrial contraction) ventricular filling velocities. In a healthy heart, the E velocity is greater than the A velocity. However, in diastolic dysfunction, due to impairment of ventricular relaxation, a greater portion of the end-diastolic volume results from late filling rather than early filling and the normal E/A ratio (i.e., <1) is reversed. The E/Ea ratio is a Doppler-derived index that may be more sensitive than the E/A ratio in identifying left ventricular diastolic dysfunction in patients with preserved left ventricular systolic function. Lamia et al reported that in a group of patients who had already failed an SBT, the combination of $E/A > 0.95$ and $E/Ea > 8.5$ measured with transthoracic echocardiography at the end of an SBT allowed an accurate noninvasive detection of weaning-induced pulmonary artery occlusion pressure elevation.¹⁵

WHAT IS THE ROLE OF ULTRASONOGRAPHY IN WEANING?

In addition to echocardiography, ultrasonography of the lungs and airways has potential use as a bedside procedure in predicting some aspects of weaning failure.

- B-lines are vertical reverberation artefacts (as opposed to horizontal A-lines, which are present in normal lungs) that arise from the pleural line and move in synchrony with the lung. They are usually considered to be a sign of increasing lung density and decreasing air content. The presence of B-lines on lung ultrasonography may give an early indication of heart failure or consolidation.
- Using M-mode ultrasonography, diaphragmatic dysfunction (vertical excursion of <10 mm and paradoxical movement) was found in 29% of medical critical care unit patients without any history of diaphragmatic disease. A statistically significant higher rate of early and delayed weaning failure occurred in these patients with diaphragmatic dysfunction.¹⁶
- A cuff-leak test can be used prior to extubation if there is concern about postextubation stridor due to airway oedema or swelling. It has been suggested that a measured difference of at least 110 mL or 10% of the inspiratory tidal volume, measured by a ventilator before and after cuff-down during an assist-control mode of ventilation, essentially rules out postextubation stridor. However, a leak volume of less than this is often associated with successful extubation.¹⁷ One study showed that B-mode laryngeal ultrasonography could be used to look at the air-column width on endotracheal tube cuff deflation and hence evaluate the air leak. A narrower air column on cuff deflation was found to correlate with a lower risk of postextubation stridor.¹⁸ It should be emphasised that this aids in the prediction of *extubation* failure rather than *weaning* failure per se.

LONG-TERM AND PROLONGED MECHANICAL VENTILATION

Some patients may simply never wean from mechanical ventilation. Up to 50% of difficult-to-wean patients require prolonged ventilation. According to a National Association for Medical Direction of Respiratory Care Consensus Conference, prolonged mechanical ventilation should be defined as the need for ≥ 21 consecutive days of mechanical ventilation for ≥ 6 h/d.¹⁹

Successful weaning in prolonged mechanical ventilation constitutes complete liberation from mechanical ventilation (or a requirement for only nocturnal NIV) for 7 consecutive days.

The previously described clinical review also highlights that there is no evidence-based time limit for when further attempts at weaning can be declared futile. Similarly, there are also no evidence-based guidelines to inform decisions as to whether withdrawal of or continued use of potentially lifelong ventilatory support is the correct course of action. Decisions such as these should clearly involve the wider interdisciplinary team; the patient, where possible; and the patient's family. Input from a palliative care team may add significant value for the patient and their family.

Continuing the weaning process in an alternative environment may become appropriate depending upon the individual patient's physiological needs. There are advantages to providing ongoing weaning and ventilatory support in other environments, not only for the patient, in terms of the special expertise and access to medical and nonmedical therapies that may not be universally available, but also for the demands on the critical care unit where the patient may be moved from.

WHAT IS THE ROLE OF TRACHEOSTOMY IN WEANING?

Neither the performance of a tracheostomy nor its timing have been shown conclusively to lead to reductions in patient mortality, the incidence of ventilator-associated pneumonia, or the duration of mechanical ventilation.

The TracMan study in the United Kingdom demonstrated no improvement in ICU mortality and many other secondary outcomes with an early (<4 days) versus a late (>10 days) tracheostomy. In addition, the ability of clinicians to identify patients that would require prolonged ventilation was limited. The study concluded that early tracheostomy could result in more tracheostomies being performed with the potential for more procedural complications and no improvement in mortality of ICU length of stay.²⁰

Tracheostomy may, however, be advantageous for an individual patient. Mechanically ventilated patients may no longer require any sedation after insertion of a tracheostomy and thus may avoid some of the complications and disadvantages of long-term sedation and may be weaned more rapidly. Patients with marginal respiratory mechanics may be weaned quickly after tracheostomy because of lower airway resistance, especially if respiratory rates are high. The ability to eat orally, the ability to communicate, and the enhanced mobility after tracheostomy can provide psychological well-being and help weaning in prolonged mechanical ventilation. In addition, the ability to receive physical therapy and use mobility aids can aid the recovery of respiratory and skeletal muscle strength.

CONCLUSION

Although weaning over the years has become more objective and evidence based, there are still questions relating to predictive models of weaning, newer weaning modes, and the role of tracheostomy. Technologies such as ultrasound, echocardiography, and biomarkers have been trialled in the trouble-shooting algorithm for weaning failure. In COPD patients, there seems to be a benefit in transitioning to NIV following extubation. Finally, failure to wean may result in prolonged ventilation in specialised respiratory care units outside an ICU.

Weaning from mechanical ventilation remains an evolving domain of intensive care where more research is required to clarify unsettled terrains. In the meantime, as with many aspects of healthcare, there appears to be a role for a protocol-based, multidisciplinary approach with an emphasis on getting the basics right by minimising sedation, using daily sedation holds, and maximising early nutrition and mobility.

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