

VENTILATOR MANAGEMENT FOR THE NON-INTENSIVIST

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The management of the mechanical ventilator is one of the most complex and dynamic, yet ubiquitous issues to face the critical care physician. As we as a medical community have become more advanced, so too, have our ventilators, with new modes and variables having been added beyond more traditional modes like Assist Control and Intermittent Mandatory Ventilation. This article is designed to give a very basic understanding of what the individual ventilatory modes do and how they are set. It is in no way meant to be a replacement for either a medical intensivist or a respiratory therapist.

The Decision to Intubate

On a fundamental level, the decision to intubate a patient and to assume control of their breathing is a clinical judgment. However, there are several broad reasons why one may decide to intubate the patient. The first of these is to support the airway. This takes into account both physical reasons, such as airway compromise but it also includes those situations in which there is an anticipated need to control the airway, whether due to a significantly impaired mental status or because of high potential for needing to establish an airway when it may be difficult to do so.¹ The second set of circumstances under which intubation may be needed is due to a pulmonary process, such as inadequate oxygenation or ventilation. This includes having failed non-invasive techniques such as BiPAP or CPAP and also during a code situation, though we recognize that intubation is not strictly indicated in current ACLS guidelines¹. The third major indication for intubation is for other reasons not necessarily cardiopulmonary but rather as an adjunct. This is to say that intubation and mechanical ventilation may need to be used in other situations, such as hyperventilation for increased intracranial pressure.¹

Initial Ventilation

Once the decision is made to intubate and place the patient on a ventilator, the initial ventilator mode is almost always Assist Control and a knowledge of this mode should enable the practitioner to treat the ventilated patient in the first period of time after intubation and until more experienced providers can lend their expertise.

Assist Control Ventilation

Assist Control (AC) is essentially a derivative of Controlled Mechanical Ventilation (CMV), which was one of the first modes of mechanical ventilation and which gave a predetermined tidal volume at a set rate regardless of the patient's attempts at spontaneous respiration². In AC mode, the patient receives the preset tidal volume regardless of whether the breath is a

controlled breath or if it is patient initiated². In this mode, the ventilator does the overwhelming majority of the work of breathing though it remains possible to have "breath stacking," in which the patient triggers a breath prior to completing an exhalation of a prior breath.² In those patients who have no spontaneous respiration, such as those who are receiving paralytics or heavy sedation, AC essentially is a mimic of CMV and the patient will only receive the set number of breaths at the set tidal volume.

While Assist Control Ventilation has been in use for several decades, perhaps the greatest change to how it is used occurred with the series of Acute Respiratory Distress Syndrome Network (ARDSnet) trials. While these trials continue, a multicenter trial in the late 1990s found that low tidal volumes, initially set at 6 cc/kg and titrated based on plateau pressures, had a mortality benefit when compared with conventional, higher tidal volume ventilation.³ Of note, in this study, the pH of the patients was closely followed and corrected with bicarbonate infusions or ventilatory rate increases if needed for even mild acidosis.³

Pressure Control Ventilation

Similar to AC, and listed on some ventilators as "Pressure Assist Control," this mode is also either patient or time triggered but is pressure cycled, rather than volume cycled. In pressure control, there is a set rate over which the patient may breathe but each breath is delivered to a set inspiratory pressure, rather than to a set tidal volume. This mode has its primary use in those with poorly compliant lungs and in those in whom there is a significant concern for barotrauma. Unfortunately, it is more uncomfortable for the patient than the volume cycled assist control and may require more sedation to use.

Initial Ventilator Settings

While the settings used when initially placing a patient on the ventilator may vary based on the individual, there are several broad guidelines which can be used with subsequent titration based on the patient's needs. In the average patient, either AC or the Synchronized Intermittent Mandatory Ventilation (SIMV) mode, described below, can be used though AC is usually preferred.^{2,3} In order to maximize oxygenation, an F_iO_2 of 1 (100% oxygen) is used, though this is titrated rapidly based on P_aO_2 . Also in order to optimize oxygenation, positive end expiratory pressure (PEEP) is usually set at 5 cm H_2O in order to prevent alveolar collapse.² While earlier studies and recommendations were for the initial tidal volume to be at 8-10 cc/kg of ideal body weight, after the ARDSnet trial discussed above, it is now more common to have initial tidal volumes at 6-8 cc/kg of ideal body weight.^{2,3}

Subsequent to these initial settings, further adjustments can be made based on the patient's oxygenation and acid-base needs. Using conventional modes of ventilation such as AC, a patient's oxygenation can be augmented by raising F_iO_2 , if possible, or increasing the PEEP, though an increase in PEEP also comes with an increased danger of barotrauma. The respiratory rate and tidal volume can be manipulated based on the P_aCO_2 and pH, with an increase in rate or tidal volume yielding a lower P_aCO_2 and higher pH.¹

Weaning

Prior to any discussion of weaning on the mechanical ventilator, it should be noted that weaning is not a mode or set of modes on the ventilator, but rather a process involving daily determination of the patient's ability to do more of the work of breathing. This is in contrast to *liberating* the patient from the ventilator, which is a more rapid process and one which is used for those patients who have been mechanically ventilated for short periods.

Synchronized Intermittent Mandatory Ventilation (SIMV)

A derivative of Assist Control, SIMV is a mode of ventilation initially designed to be used in patients in anticipation of discontinuing mechanical ventilation. It is a mode which, at its base setting, will deliver a set tidal volume at a set rate, similar to assist control. It differs from assist control in that it allows the patient to breathe assisted breaths in between the controlled breaths. These assisted breaths can be with or without pressure support behind them. In theory, this mode works by resting respiratory muscles during the controlled breaths while working these same muscles during spontaneous breaths.⁴ Thus, a conventional weaning procedure using SIMV would involve a gradual decrease in the control rate while allowing more spontaneous breathing with, or without pressure support.

Unfortunately, it has been demonstrated in multiple studies that, in fact, rest of the respiratory muscles does not occur during the mandatory breaths. One study found that the brain's respiratory center does not anticipate the mandatory breaths from the ventilator, actually increasing the potential for fatigue.⁴ When compared against gradual Pressure Support trials or T-piece trials SIMV was actually found to be associated with significant increases in the time required for a successful wean.⁴

It should also be noted that, in spite of the paucity of evidence favoring SIMV as a weaning mode, this mode of ventilation continues to see some use as a primary form of ventilation. When compared to Assist Control, a multi-center observational study by Ortiz et al. failed to demonstrate any advantage to the use of SIMV over AC as a primary mode for mechanical ventilation.⁶

Pressure Support Ventilation (PSV)

Pressure Support is a form of mechanical ventilation in which all breaths are patient-triggered but each triggered breath is augmented by a set level of inspiratory pressure. Perhaps the best analogy is to equate PSV to an invasive BiPAP in which the pressure support set is equivalent to the inspiratory airway pressure on the BiPAP while the PEEP is equivalent to the expiratory airway pressure. Initially, the patient is started at a high degree of support wherein there is a disproportionate degree of work by the ventilator relative to patient effort.⁴ In a weaning protocol using this mode, the degree of support is decreased as tolerated by the patient from nearly full support to a low pressure support of approximately 6-10 cm H_2O , at which point the patient could theoretically be extubated.⁴

Spontaneous Breathing Trials (SBTs)

Of the different modalities used to wean a patient from the ventilator, the spontaneous breathing trial is the oldest.⁴ It usually is done either by CPAP, i.e., PEEP alone, or by a low pressure support setting.⁴ If no pressure support is to be used, it is possible to set the ventilator to allow CPAP only, but it is also possible to attempt spontaneous breathing via either a T-piece or via Tube Compensation (TC) on the ventilator itself, which theoretically allows only enough support by the ventilator to overcome the increased resistance of having an endotracheal tube in place.⁴

Success or Failure of Weaning Trials

As stated previously, weaning is a process, not a single mode of ventilation. The need to recognize probable success or failure is inherent in this and much study has gone into predicting the outcome of weaning. Perhaps the most common of the assessments for success at weaning is the Rapid Shallow Breathing Index (RSBI) or Tobin Index. Classically, this index was calculated by placing the ventilated patient on a T-piece and then measuring their tidal volumes on a spirometer.⁷ When calculated as respiratory rate in breaths per minute divided by tidal volume expressed as liters, a score of at least 105 is considered to be highly sensitive and specific for success at weaning from the ventilator.⁷ While this is the most commonly used indicator of potential success in the ICU setting, it also should be noted that there have been several challenges to modifications of the RSBI. Namely, the use of PEEP and low pressure support have both been shown to lower the RSBI, making their recommendation that this score only be considered if it is calculated in the traditional manner with a T-piece.⁶

Conversely, it is also necessary to be able to recognize when a weaning trial has failed. Broadly, any significant change in vital signs for a sustained period of time should be considered to be a trial failure, as should any agitation, anxiety, or diaphoresis in a patient in whom these findings have not been seen before.⁴

Rescue Modes

While the initial ARDSnet trials were done on Assist Control using low tidal volume ventilation, it should be noted that in the subsequent years, both new modes and re-emergent old ones have been increasingly used in those patients who are difficult to oxygenate or ventilate. These should not be used as the initial ventilatory mode in any patient but they serve an important role in the patient with ARDS and should be considered if more conventional forms of ventilation fail.

Airway Pressure Release Ventilation (APRV)

Also referred to by multiple proprietary names including BiLevel and DuoPAP, this mode, first described in 1987, is essentially a mode in which the patient is ventilated between two set ventilatory pressures (P_{HI} and P_{LOW}) for set time periods (T_{HI} and T_{LOW}).⁸ For this mode, the change between the high and low pressures allows for ventilation while breathing at the high pressure allows for minimizing recruitment of alveoli, and therefore maximizing oxygenation.⁸ In spite of this, some spontaneous breathing at the high pressure is required in order to allow adequate oxygenation. Initially, the majority of time is spent at the high pressure and the time at the lower pressure is limited to 0.6-0.8 seconds.⁹ The high pressure is set at the lower of either the plateau pressure measured on a conventional mode of ventilation or 30 cm H₂O in order to minimize barotrauma.⁹ On the other hand, the low pressure is initially set at 0 cm H₂O.⁹

To treat hypoxia using this mode, either the F_iO_2 or the pressure and time at the high pressure setting must be adjusted.⁹ Conversely, in order to treat hypercapnea, which is somewhat expected using this mode, the frequency of respiration will be increased.⁹ This does have the effect of concomitantly decreasing the T_{HI} . Once the patient has been stabilized on this mode and it is time to perform a wean, while the patient can be transitioned to a more conventional mode of ventilation, it is also possible to wean via APRV. In this setting, the P_{HI} is gradually lowered while the T_{HI} is increased so that once the P_{HI} is sufficiently lowered, say to 10-15 cm H₂O, the patient can be transitioned to CPAP.⁹

While the advantages of this ventilator mode include that it can be done with the same ventilator and the same equipment, and that its very design requires some effort on the part of the patient, the evidence to support its use has been variable. One single center trial of 58 patients comparing APRV against SIMV after initial use of AC found that initial peak inspiratory pressures were lower for APRV but that oxygenation, hemodynamic

indices, and 30-day mortality were identical.⁸ Conversely, a small single-center trial evaluating for atelectasis found that APRV was superior to PSV based on CT scans of the thorax.¹⁰

While APRV has yet to be conclusively shown to be of benefit, it should be considered in the patient with ARDS with high ventilatory pressures and in whom oxygenation is proving difficult with traditional ventilatory techniques.

High Frequency Oscillatory Ventilation (HFOV)

High frequency oscillatory ventilation is a type of mechanical ventilation in which small tidal volumes, usually 1-4 cc/kg, are delivered at a high frequency, ranging from 3-15 breaths per second. In theory, this is designed to maximize oxygenation while minimizing alveolar over-distention and derecruitment.¹⁰ The early data regarding this technique is conflicting and it has several disadvantages, most notably the need to obtain a specialized ventilator and the fact that often times, the use of paralytics is necessary in order to ensure patient-ventilator synchrony.¹⁰

One initial trial of 148 patients with ARDS found that at 30 days, there was no statistically significant difference in ventilator-free survival between the group assigned to receive HFOV and those who received conventional ventilation.¹¹ Of note, this initial trial involving HFOV was performed prior to the 2000 ARDSnet trial's publication and allowed permissive hypercapnea to a pH of 7.15, but also did not use low tidal volume ventilation universally in their conventionally ventilated patients.¹¹

In contrast to the study above, in 2010, a meta-analysis was released by Sudet al., based on eight trials involving a total of 431 pediatric and adult patients comparing HFOV to conventional ventilation. In this meta-analysis, HFOV was shown to reduce 30-day mortality, as well as reducing risk of treatment failure, but without a significant difference in the rates of barotrauma, obstruction of the endotracheal tube, or of hypotension.¹²

Though studies are ongoing, and in spite of the potential of this mode of ventilation, because of the need for specialized equipment and training, we would only advocate the use of this technique while the patient is under the care of a medical intensivist.

Extubating

Once the patient has passed a spontaneous breathing trial and has ensured sufficient respiratory muscle strength and ability to both oxygenate and ventilate, other factors which would require continued intubation need to be assessed. The patient must be able to protect their airway, both physiologically, and in terms of mental status, and also be able to manage secretions.¹³ If a patient requires frequent suctioning at more than every two hour intervals, it is possible that they may not yet be ready for extubation.¹³

If a patient is deemed ready for extubation, it should be noted that previous studies have found extubation failure rates, i.e.

re-intubation within 48-72 hours of extubation, of 5-20%.¹³ Nonetheless, delays in extubation have also been associated with increased rates of ventilator associated pneumonias, duration of ICU stay, and overall increased in-hospital mortality.¹³

Conclusions

While the decision to intubate a patient and assume control of their breathing should never be taken lightly, it is often necessary in the critically-ill patient. Once the patient has been intubated, we recommend initial use of Assist Control Ventilation using the setting outlined above. Then, with the guidance of the intensivist and the respiratory therapist, the patient's ventilator settings can be tailored to meet the patient's needs. It is our hope that this article provides a bit of guidance on how to transition your patient from that initial period to liberation or weaning from the ventilator to extubation.

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“Villa on a Hill”, photograph by Paurush Shah, MD