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"What knob is this?" – Intensive care unit ventilation for the non-intensivist

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Abstract

Indications for intensive care unit (ICU) mechanical ventilation differ from those for intraoperative mechanical ventilation. Always, the fundamental goal is the provision of life-sustaining oxygen saturation, with the avoidance of ventilator-induced trauma. Once past the initial stabilisation phase, a high priority must be placed on liberating the patient from mechanical ventilation. Encouraging patient-ventilator synchrony may accelerate this. Modern ICU ventilators have a number of modes and tools which may be useful in facilitating both initial mechanical ventilation optimisation and accelerate subsequent weaning, and these are generically reviewed within a discussion of the general conduct of ICU ventilation.

Keywords: mechanical ventilation, lung protection, ventilator weaning, ventilator synchrony

Introduction

Anaesthetists are familiar with intraoperative mechanical ventilation, hence are often called on to supervise it in the intensive care unit (ICU). While the fundamental principles are constant, the indications and goals of ICU mechanical ventilation are broader than those for intraoperative mechanical ventilation, thus ICU ventilators have potentially useful ventilator modes and tools not encountered on anaesthetic workstations.

Key goals: preserve life and restrict iatrogenic lung damage

Positive-pressure mechanical ventilation saves the lives of patients with respiratory failure, but is unphysiological, inevitably causing cumulative lung damage, aggravated by complications imposed by airway access devices.[1] Key priorities of ICU mechanical ventilation, irrespective of mode or type of ventilator used, must be to:

- Ensure adequate life-sustaining oxygenation.
- Constantly strive to liberate the patient from the ventilator as soon as indications for mechanical ventilation are resolved.
- Minimise the factors known to aggravate lung trauma.[2]

If haemoglobin concentrations are adequate (> 7 g/dl), adequate blood oxygen content is provided by arterial oxygen saturation (SaO_2) in the range of 94-98% (88-92% is probably adequate in patients with chronic hypercarbic lung disease).[3] The use of unnecessarily high fraction of inspired oxygen (FiO_2) promotes inflammation, oxidation of the lung membranes and resorption atelectasis.[4] To limit this "oxytrauma", SaO_2 above 98% should not be deliberately targeted, and FiO_2 should be reduced if a high SaO_2 develops.

"Atelectrauma" is damage caused by repetitive alveolar collapse and re-expansion cycles, hence appropriate positive end-expiratory pressure (PEEP) needs to be maintained to prevent alveolar collapse, with higher levels being required in pathologies such as acute respiratory distress syndrome (ARDS) and pulmonary oedema where atelectasis is prominent.[1]

"Volutrauma" refers to lung damage from an overlarge tidal volume (VT). The VT of machine-initiated breaths should be kept low, at approximately 6 ml/kg of predicted mass for height. Limiting VT simultaneously reduces "barotrauma" (lung damage from high pressure), but plateau pressure (in volume-targeted modes) and maximum pressure (in pressure-targeted modes) should additionally be kept below 30 cmH_2O. Low VT ventilation is the core risk-reduction strategy for mechanical ventilation, and has demonstrated a meaningful mortality reduction in ARDS.[5] It has been argued that, as the presence of lung injury is often underestimated, low VT ventilation should be the default strategy for almost all ventilated patients.[6] Low VT ventilation, with resulting low minute volume, will result in moderate hypercarbia. In most patients, $PaCO_2$ of 5-7 kPa has few meaningful adverse effects, and may even be beneficial as it limits lung inflammation,[7] with the exception of patients with raised intracranial pressure or severe pulmonary hypertension. $PaCO_2$ must be controlled to normal levels (approximately 5kPa) in these latter patients, even if this requires a large VT ("the brain takes precedence over the lungs").

Clearly define the specific problem for which mechanical ventilation is deployed

In order to select the correct mechanical ventilation strategy and tools, ICU clinicians must clearly define the specific indications for mechanical ventilation in each individual patient.

Surgical and septic patients frequently require mechanical ventilation to relieve them of the increased work of breathing, induced by hyperventilation from compensation for metabolic (especially lactic) acidosis. Such work demands increased perfusion of the respiratory muscles, which may exceed the maximum cardiac output potential of the patient, especially in the elderly. Conversely, patients with an inadequate respiratory effort or respiratory depression may require mechanical ventilation to prevent hypoxaemia and hypercarbia. Patients with raised intracranial pressure may require mechanical ventilation to maintain cerebral oxygenation and prevent hypercarbia. All of these groups of patients may have normal lungs. If so, mechanical ventilation should be terminated as soon as the systemic problem is resolved.

Patients with alveolar lung disease, such as pneumonia, pulmonary oedema or ARDS, where alveolar consolidation and atelectasis are prominent, require careful lung-protective low VT ventilation to relieve the work of breathing and to optimise air delivery to the remaining functional alveoli. This can be achieved by utilising appropriate PEEP to prevent lung collapse and maintain end-expiratory lung volume as close as possible to the patient's normal functional residual capacity, with acceptance of mild hypercarbia. Patients with respiratory failure from severe bronchospasm may need prolonged mechanical ventilation to assist air movement through the narrowed airways until anti-inflammatory drugs resolve the causes of airway narrowing, with attention being given to allowing adequate expiratory time to limit gas trapping. The pulmonary pathology defines the course of ventilation in these patients.

Mode selection

ICU ventilators offer a confusing range of modes, reflecting various combinations of a gas delivery control pattern (either volume targeted or pressure targeted) and patterns of response to patient effort.[8] Understanding the properties of each mode facilitates the matching of the mode to the pathology. Unfortunately, ventilator manufacturers are inconsistent in their naming systems for the various modes, thus a generic terminology must be used in this discussion.

Mode classification: volume versus pressure targeting

There is no evidence to support a mortality benefit of either a pressure- or volume-targeted mechanical ventilation mode, but each has characteristics that may advantage secondary outcomes in specific patients.

The intrinsic decelerating inspiratory air flow pattern of pressure-targeted modes is similar to spontaneous inspiratory flow, facilitating synchrony with patient effort. The high initial flow may enhance efficiency of gas delivery to the alveoli. Pressure-targeted modes intrinsically compensate for moderate air leaks. Deficits include the potential for unpredictable changes in the VT if lung compliance or airway resistance change. Users must remember that the delivered VT depends on both the targeted pressure and the inspiratory time, and must be aware of the specific ventilator's conventions. Some ventilators require the setting of inspiratory pressure above PEEP and others require the setting of a maximum pressure.

Volume-targeted modes ensure that set VTs are delivered (unless pressure alarm settings are transgressed), which is advantageous when it is imperative to avoid volutrauma, or when $PaCO_2$ must be regulated. It is difficult for spontaneously breathing patients to synchronise with the constant-flow inspiratory pattern of classical volume-targeted modes, and is only of potential advantage when ventilating patients with bronchospasm (reduction of turbulent gas flow), or when evaluating lung compliance. Constant-flow, volume-targeted modes also require the setting of an inspiratory pause to ensure time for airflow to the distal alveoli. Manufacturers have introduced useful modifications to volume-targeted modes to minimise these deficits, such as electronically controlled forced decelerating gas flow patterns, and/or allowance for the spontaneously breathing patient to augment gas flow above the set flow rate.

Some machines feature modes which employ pressure targeting, with its advantageous intrinsic decelerating inspiratory flow pattern, but allow a specific VT target to be set. To achieve this, ventilators automatically adjust inspiratory time, based on data from the previous breath. Hence, these modes are unreliable in patients with erratic spontaneous breathing.

Mode classification: ventilator response to patient effort and its relation to the phase of the clinical course

ICU mechanical ventilation progresses through phases of emphasis. In the initial stabilisation phase, the achievement of adequate SaO_2, including consideration of recruitment manoeuvres for alveolar lung disease, control of patient effort, and reversal of threats to life, are emphasised. Patient effort is usually absent or appropriately suppressed and "control" modes of ventilation are often appropriate. Control modes do not allow patient interaction. The breath rate and duration and target characteristics of each inspiration are entirely machine determined.

A plateau phase typically follows, where established levels of support are maintained, while the physiological recovery process is established. Excessive or unnecessary mechanical ventilation settings are moderated. Some patient effort is often beneficial at this stage. Basal lung aeration is greatly facilitated by diaphragmatic activity. "Assist" modes are appropriate for this phase. Assist modes allow the patient to initiate additional breaths, in effect to breathe faster than the set breath rate, but once initiated, whether by patient effort or machine, the inspiration duration and target are machine controlled. Patient effort at this stage is not desired in certain clinical settings, i.e. patients with severe ARDS (spontaneous effort may increase the transpulmonary pressure, leading to barotrauma), patients with bronchospasm (additional breaths reduce the expiratory time and aggravate gas trapping), patients with raised ICP (where constant $PaCO_2$ levels must be maintained), and patients with greatly excessive breathing work. Control modes with pharmacological limitation of patient effort, possibly including the use of muscle relaxants, should be continued in these groups.

Most manufacturers combine the above into assist-control modes. The patient can be moved from controlled to assisted ventilation by simply reducing the set breath rate to below the patient's spontaneous rate. This works best if the ventilator is set up to allow the direct setting of inspiratory time, rather than the inspiration to expiration (I:E) ratio. The concept of the I:E ratio is actually meaningless once patient-initiated breaths are allowed, and so most modern ventilators can be set up by the technician to directly display the inspiratory time, rather than I:E ratio, if the clinician so requests. However achieved, inspiratory times of 1.0-1.2 seconds may be reasonable for adult patients in assist-control modes.

Ultimately a weaning phase must follow, with the active and deliberate reduction of ventilator support, aimed at liberating the patient from mechanical ventilation at the earliest appropriate opportunity. In this latter phase, the capabilities of current generation ventilators to synchronise mechanical ventilation with patient effort should be exploited, using support-type modes. Good synchronisation facilitates patient comfort, can improve lung aeration efficiency, may reduce diaphragmatic atrophy, and may facilitate earlier liberation from mechanical ventilation, if appropriately used. Once regular spontaneous breathing is established, support modes, which allow patients to assume control of their own inspiratory duration, are useful.[9] The ventilator contributes PEEP and some supportive positive pressure, which can be progressively reduced until the patient is effectively breathing unsupported. Support modes almost invariably use the pressure-targeted regulation of gas flow. So-called volume support modes simply automate the adjustment of the supporting pressure to achieve a set tidal volume.

Spontaneous effort is only of benefit if the patient effort is synchronous with the ventilator. If patients "fight" the ventilator, inadequate ventilation, barotrauma, and the need for excessive sedation occur. To facilitate patient synchrony in either assist or support modes, the ventilator should be as sensitive to patient inspiratory effort as possible, so that the patient receives breaths when demanded. This is achieved by setting the trigger , whether a pressure trigger, or the more sensitive flow trigger, to a numerical value as close to zero as can be achieved without causing automatic triggering. In support modes, most ventilators assess the patients' desire to cycle from inspiration to expiration by a preset percentage drop from peak inspiratory flow. Some models allow clinician adjustment of this percentage, but even so, cycle synchrony can be difficult to achieve in some patients.

It is possible to accommodate the majority of patients' mechanical ventilation course by initially using the assist-control mode, then transitioning to the pressure support mode, with a progressive pressure wean until the patient is essentially breathing without support, whereafter extubation can be considered if oxygenation, secretion clearance capability, airway protection ability and the exclusion of occult left ventricular dysfunction have been ensured. But patient variation and clinician preference warrant more options.

Synchronised intermittent mechanical ventilation and bi-level modes

Synchronised intermittent mandatory ventilation (SIMV) modes offer a supposed middle ground between assist-control and pure support modes. They allow a set number of "mandatory" (effectively assist-control; either volume- or pressure-targeted) breaths to be administered per minute, between which the patient can interpose pressure-supported breaths. The correct setting of these modes can be surprisingly complex, differs from machine to machine, and incorrect settings can aggravate patient-ventilator asynchrony. The fact that SIMV modes deliver two different types of breaths can also aggravate asynchrony as the neural respiratory centre is perpetually challenged by inconstant ventilator responses to inspiratory effort. Originally designed as a "weaning" mode, SIMV has demonstrated the potential to actually prolong patients' time on the ventilator.[10]

Some new-generation ventilators offer bi-level modes that cycle between two set pressure levels regardless of patient effort (effectively delivering an inspiration with each low to high pressure transition), but allow the patient to take spontaneous breaths in addition to whatever pressure level has been set. This may be advantageous in some asynchronous patients. The ventilator does not react to the erratic patient, but maintains a constant ventilatory pattern, while simultaneously allowing the patient to follow his or her own respiratory pattern. In this way, the benefits of control ventilation may be achievable with less need for sedation. When set to maintain the higher pressure level for most of the time (effectively an inverse I:E ratio), this mode is called airway pressure release ventilation, a technique which arguably enhances oxygenation in alveolar lung disease where atelectasis is prominent.[11]

Intelligent modes, diagnostic tools and the improvement of synchrony

The mode combinations mentioned are found on most reasonable current ICU ventilators. If there is dedicated clinician involvement to appropriate and timeous weaning, these modes are generally adequate to ensure good mechanical ventilation outcomes. But early liberation from mechanical ventilation can be frustrated if staffing constraints prevent appropriate timeous weaning of the support levels. Therefore, some manufacturers offer automated weaning modes. These proprietary modes vary considerably. Examples range from automated FiO_2 adjustment in response to SpO_2, to automated transition between controlled and supported modes if reliable patient effort is recognised, to Adaptive Support Ventilation, a proprietary comprehensive pressure and triggering adjustment algorithm, which continually targets the most efficient respiratory pattern to achieve a set target minute volume, while keeping the patient within safe limits. This has proved to be effective in driving the programmatic reduction of ventilator support.[12] These proprietary modes usefully accelerate patient liberation from the ventilator in many patients, simultaneously reducing the nursing staff workload and improving patient comfort. Currently, clinician input is still required to set appropriate parameters within which these modes can work, and to identify patients in whom their use is inappropriate.

Proprietary diagnostic and monitoring tools on higher-level ventilators are occasionally useful in patients with challenging lung pathology. These include:

- Automated manoeuvres to determine PEEP for optimal lung compliance.
- Volumetric capnography.
- Intraoesophageal pressure manometry to allow the determination of transpulmonary pressure to permit optimum inflation pressure in patients with alveolar lung disease or reduced chest wall compliance.[13]
- Intra-airway pressure measurements.
- Measurement systems to estimate and optimise end-expiratory lung volume.
- Measures of auto-PEEP to quantify gas trapping.
- Measures of inspiratory muscle strength (P0.1 and others) to assist in determining extubation readiness.

Improving patient synchrony, and optimal matching of ventilator support to the patient's workload so that the ventilator can appropriately and progressively return full control to the patient, are the current frontiers in ventilator development. The adaptive support ventilation concept has been developed progressively in both these directions.[12] Proportional Assist Ventilation is another proprietary technique used to estimate the patient's respiratory workload, and to allow control of the proportion offloaded by the ventilator. Ventilator synchrony depends on the detection of patient effort. Since the detection of conventional pneumatic trigger and cycle parameters may be delayed, Neurally Adjusted Ventilatory Assist, a proprietary technology using an electrode array to measure diaphragmatic electrical activity, may shorten the response time and may possibly better match ventilator assistance to neural effort. The latter two technologies may be of particular benefit in the debilitated patient who has received prolonged ventilation.[14] Further developments along these lines are to be expected.

Conclusion

ICU mechanical ventilation can be made easier, and perhaps safer, by matching the indication for mechanical ventilation to ventilator mode, and using specific relevant ventilator capabilities. The outcome, irrespective of ventilator used, still depends on the achievement of life-sustaining SpO_2, minimisation of trauma and early appropriate liberation from the ventilator.

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