Ventilator Strategies and Physiology

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As more and more veterinary hospitals purchase critical care ventilators the need to understand the basics of ventilator use and its effects on respiratory physiology are essential. Veterinary technicians are often with the ventilated patient while the veterinarian has to see new clients or treat additional critical patients. This presentation serves to overview ventilators, ventilator monitor screens and waveforms, and discuss common strategies in ventilating small animals.

Indications for ventilation and ventilator types

There are three main indications for initiating mechanical ventilation. The first is severe hypoxemia that does not respond to additional oxygen therapy. This might include severe respiratory disease where an oxygen cage, nasal oxygen cannulas, or other oxygen supplementation has not provided relief or to the patient or raised their blood oxygen levels. An additional indication for mechanical ventilation would be severe hypercapnia which often does not respond to oxygen supplementation. Lastly, increased work of breathing (such as prolonged dyspnea) is also recognized as a valid indication for mechanical ventilation.

There are several different types of ventilators that can be used in mechanical ventilation. Older types created a negative pressure environment to expand the thorax and instigate respiration. Newer mechanical ventilators produce a positive pressure to work against the muscles of the thorax and expand the lungs. Ventilators may be volume ventilators, pressure ventilators, or ventilators that can have each variable set independently. Volume ventilators deliver a specific tidal volume without regard for pressure. These ventilators typically have a pressure release valve so overdistension doesn't occur. Pressure limited ventilators deliver a tidal volume that is limited by the pressure set on the machine. Lastly, expensive long-term ventilators can have each respiratory parameter set individually.

Ventilator modes

Various ventilator modes exist which are either generally categorized into breaths that are delivered directly from the machine, or triggered by the patient. Assist/control ventilation refers to breaths that are generally directed by the machine. Respiratory rate and pressures/volumes are set by the machine. There is a patient-initiated trigger setting that is dialed on the machine so that if a patient does initiate a breath the ventilator will simply assist the patient with that breath. These breaths can either be pressure or volume-limited breaths. This setting is used in patients that require a dedicated respirator, most often these patients cannot breathe on their own.

Synchronized intermittent mandatory ventilation (SIMV) allows the operator to set a minimum number of breaths but the patient can breathe in between these breaths. The ventilator will synchronize.

Initial ventilator settings

Critical care ventilators allow the operator to set several different physiologic variables to individualize the ventilation therapy.

Tidal volume

Tidal volume is the volume of a normal breath. Normal tidal volume is 10-15 ml/kg and initial settings on the ventilator are typically 10 ml/kg or less. If the patient has lung disease a lower tidal volume is often used. If volume ventilation modes are used the tidal volume is set by the clinician and each breath is delivered until that specific tidal volume is met. If using pressure ventilator modes the peak airway pressure is set and the tidal volume that results is the tidal volume for that patient. The pressure settings may often be adjusted to ensure an adequate tidal volume.

Airway pressure

Peak airway pressure is the pressure either set by the operator in pressure modes or what results from a specific tidal volume setting if using volume modes. Normal is around 20 cmH_20 but patients with lung disease may require lower settings. Depending on the pathophysiology of the patient's disease process they may require higher airway pressure to inflate their stiff lungs.

Trigger

The trigger setting is used to allow the machine to sense a patient initiated breath. The trigger setting is usually measured in negative cmH_20 or changes in flow. The typical trigger setting is -2cmH2O, meaning when a drop in pressures in the ventilator circuit are sensed by the machine (remember PPV ventilator breaths are POSITIVE) the ventilator realizes the patient is trying to breathe and assists them. If the trigger is set too low, the ventilator will not sense any attempts by the patient to breathe, and if the setting is too high even slight changes in pressure will trigger a ventilator breath.

Positive-end expiratory pressure (PEEP)

PEEP is added airway pressure at the end of the ventilator breath. Instead of the pressure in the breathing circuit returning to atmospheric pressure (after an inhalation/exhalation) cycle the ventilator will keep a small amount of positive pressure in the circuit.

This allows alveoli and small airways to be kept open between breaths. PEEP is often set at 2-3 cmH_20 to avoid atelectasis but patients with severe lung disease may need higher PEEP levels to maintain appropriate oxygenation.

Respiratory rate

This rate can be set by the clinician and should be physiologic at first (10-20 BPM). However, changes in ventilator settings can be made if the patient requires them.

Inspiratory time

On some ventilators the inspiratory time can be set. It is typically left at 1 second and the expiratory phase is slightly longer than inspiration.

I:E ratio

The inspiratory time:expiratory time ratio can be set in addition to the inspiratory time. If the I:E ratio is set at 1:2 (which is common), the expiratory time will be twice as long as the inspiratory time. The ratio is of some importance in that an I:E ratio of 1:1 or higher allows the patient to fully exhale before the next breath is given. Breath stacking, also called intrinsic PEEP, can occur if I:E ratios aren't adjusted when changing respiratory rates. If a respiratory rate is increased without changing the I:E ratio, the patient may not fully exhale before another ventilator breath is initiated.

Physiologic parameter	**Initial settings**
Tidal volume	8-10 ml/kg
Ventilator mode	A/C or SIMV typically
Airway pressure (PIP)	10-15 cmH_20
Trigger	-2 cmH_20
PEEP	1-5 cmH_20
Respiratory rate	10-20 breaths/minute
Inspiratory time	1 second
I:E ratio	1:2
FiO2	100%

Interpreting ventilator waveforms and making adjustments to the ventilator

Once the patient has been sedated and intubated and the initial ventilator settings have been established monitoring and adjustment of the ventilator settings may ensue. Patients need to have the inspired oxygen concentration reduced to avoid oxygen toxicity. As a result they may need changes in airway pressure, tidal volume, respiration rate, PEEP or other values. Patients with consolidation or alveolar flooding may require increases in airway pressure or additional PEEP levels. To avoid breath stacking changes in respiration rate may be a secondary change. Various adjustments can be made depending on the patient's disease and physiologic tolerance to mechanical ventilation. Many ventilators have graphs that provide information about ventilator pressure, volume, and other values and can indicate problems that may arise during the course of ventilation. Ventilator waveforms will be discussed in greater detail in the presentation.

Strategies in ventilation

There are some "advanced" modes of ventilation being investigated in humans and animals with severe lung disease. Indeed, prolonged mechanical ventilation can induce inflammatory changes in lungs that can add to their already weak and sick lungs. Several of these modes are presented here.

Continuous positive airway pressure (CPAP)

This is a completely patient-initiated breath setting where the patient breathes on their own respiratory rate, tidal volume and pressures. Positive airway pressure is kept throughout the entire breath cycle (as opposed to PEEP that is just at the end). This mode can be used in weaning and patients who have neuromuscular causes for hypoventilation as these patients may be able to generate some semblance of a tidal volume and pressure and the ventilator helps with pressure "support."

Airway pressure release ventilation (APRV)

This mode consists of long inspiratory times (4-6 seconds) and very short expiratory times. There is CPAP applied in the circuit so the pressure is above atmosphere, and actually is set to the mean airway pressure (20-30 cmH20) initially.

High frequency jet ventilation (HJFV)

This mode utilizes extremely high respiratory rates to affect tidal volume and pressure. This mode utilizes a gas jet to add additional airway gas and provides a smaller tidal volume (2-5 ml/kg) at rapid breath cycles (up to 120 breaths per minute).

Inverse-ratio ventilation (IRV)

This changes the inspiratory and expiratory ratios (typically set at 1:2) to their opposite. A longer inspiratory time helps recruit airway units. However, as inspiration increases and expiration decreases CO2 elimination may be affected. This method of expanding inspiratory times to increase recruitment does not take into account any changes in pressure and as CO2 builds the patient will develop hypercapnia. Although permissive respiratory acidosis can be favorable to higher pressures, APRV is a newer method of achieving long inspiratory times but still providing pressure changes to allow for effective gas exchange.

Problems in mechanical ventilation

De-recruitment/alveolar collapse

A common problem with mechanically ventilating sick lungs is that hypoxemia or hypercarbia persist despite interventions. The belief is that large amounts of alveoli are lost due to flooding with fluid. These alveoli can be "recruited" to aid in gas exchange. Instead of increasing tidal volume to achieve this recruitment maneuvers are used. The first involves PEEP which allows a small residual pressure (above atmospheric) to remain in the circuit after expiration. This assists in opening previously closed alveoli. Additionally, use of ventilator waveforms can assist by adjusting and observing the pressure-volume curve so that upper level (peak) pressures are monitored. An increase in airway pressure can be applied for 20-40 seconds to recruit alveoli and then the airway pressure returned to normal.

Cardiovascular consequences of mechanical ventilation

Mechanical ventilation, and the increase in mean airway base pressures (PEEP) can raise intrathoracic pressure which decreases venous return and affects cardiac contractility. Blood pressure may suffer at the hands of PPV and organ function can be affected. PEEP often must be balanced in conjunction with cardiac output variables to maintain perfusion to vital organs.

Ventilator induced lung injury (VILI)

There are three different types of VILI: volutrama, which is trauma caused by over-expansion of lung tissue, atelectrauma caused by repeated opening and closing of alveoli which can cause rupture, and finally biotrauma, which causes alveolar injury secondary to inflammatory mediators released as a result of mechanical ventilation.

Ventilator associated pneumonia (VAP)

VAP is pneumonia associated with a patient undergoing mechanical ventilation. This is often due to silent aspiration of gastric contents and potentially due to overgrowth of bacteria in the GI tract associated with GI protectant/antacid use. Development of signs of pneumonia while a patient is ventilated can indicate VAP. Prevention involves minimizing changes in ventilator circuits, using appropriate nosocomial infection policies, and preventing or intervening during aspiration events.

Oxygen toxicity

High levels of inspired oxygen incite free radical formation and will cause lung injury. Recommendations include lowering FiO2 as soon as possible to prevent free radical formation, not maintaining a patient on an FiO2 of 0.6 or greater for more than 12-18 hours, and using PEEP and other recruitment procedures to influence and improve oxygenation.