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Mechanical Ventilation: Ventilator Settings, Patient Management, and Nursing Care*

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ABSTRACT:

Successful mechanical ventilation requires a basic understanding of respiratory physiology and ventilator mechanics in addition to intensive nursing care. The type of breath delivered by a ventilator is determined by the combination of variables set by the operator. This combination of settings is known as a *mode*. The choice of appropriate ventilator settings is largely influenced by the animal's underlying disease process and usually requires some trial and error for each patient. This article reviews ventilator terminology and settings, patient setup, monitoring, and some of the common complications associated with mechanical ventilation.

Initiation and maintenance of an animal on a ventilator involves selection of appropriate settings, patient preparation, patient monitoring, and intensive nursing care. As the capabilities of modern ventilators have improved, so has their complexity, and a more advanced understanding of ventilator function is now required to maximally benefit from these advances. This article discusses only conventional intermittent positive-pressure ventilation (PPV), although other modalities such as high-frequency or jet ventilation are available.

VENTILATOR CLASSIFICATION AND TERMINOLOGY

To optimize gas delivery and comfort for a given ventilator patient, it is important to understand the determinants of a breath and how to modulate them. Depending on the type of ventilator used, different aspects of the breath can be adjusted by the operator to best suit the nature of the pathology and the patient.

The mode of ventilation refers to the machine settings determining the type of breath given, the breath frequency, and the points at which a breath is initiated and ended.[1,2] With each new generation of ventilators, the options become increasingly complicated. The lack of a standardized nomenclature for ventilator settings adds to the confusion. Different ventilator companies have varying names for settings used, making it difficult to standardize information and knowledge among machines.

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DEFINING VENTILATOR BREATH

The respiratory cycle can be divided into four phases (Figure 1):

- Inspiratory flow
- Inspiratory pause
- Expiratory flow
- Expiratory pause

Gas does not flow in or out of the lungs during the pause phases. Ventilator breaths are best understood by describing the machine's variables that alter these phases of the respiratory cycle.[2,3]

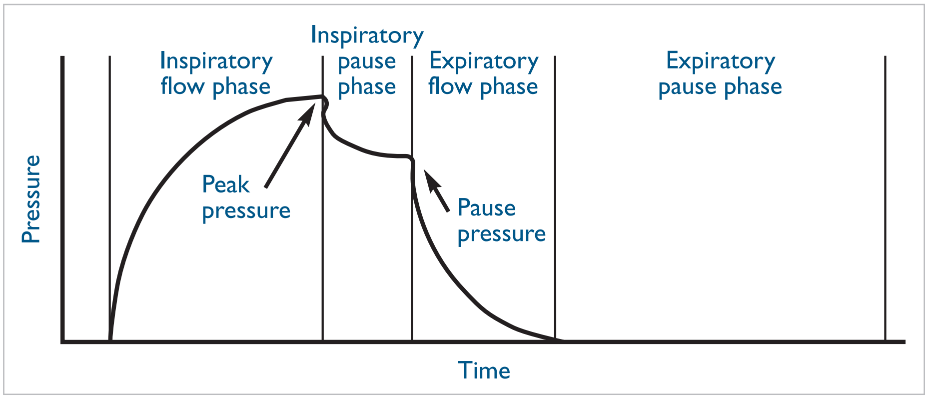

Figure 1. Phases of the respiratory cycle.[3]

Control Variables

The control variable is the single independent variable that is fixed during delivery of a breath. With most modern ventilators, the operator can set the magnitude of this variable. Volume, pressure, flow, and time can each be control variables, depending on the ventilator type.[2] In pressure-controlled ventilation, the lungs are inflated to a preset pressure. The tidal volume (TV) delivered depends on the mechanical properties of the lungs and chest wall; therefore, the pressure will be constant from breath to breath, but the resulting TVs may vary. In volume control, each breath has a preset TV (i.e., volume is the control variable), and inspiratory pressure becomes the dependent variable.[2,3]

Phase Variables

A given ventilator breath is further defined by how various phases of the respiratory cycle are controlled by the machine. The trigger variable initiates inspiration. Ventilators can be triggered by changes in pressure, flow, or volume, which can be preset by the operator. When a patient is not triggering breaths, the ventilator initiates inspiration based on a time period dictated by the preset respiratory rate.[2] The trigger variable allows the ventilator to respond to a patient's ventilatory effort and is also known as *ventilator sensitivity*. If the trigger variable is too sensitive, breaths may be inadvertently triggered by nonrespiratory movements such as patient handling or trembling, thereby creating patient distress and increasing patient–ventilator asynchrony.[2] An insensitive setting of the trigger variable prevents the ventilator from recognizing a patient's attempt to breathe and may disguise an animal's discomfort or distress.[4] An increase in the respiratory rate is one of the few ways that an animal on PPV is able to respond to life-threatening abnormalities such as hypoxemia or hypercapnia.[3,5] Therefore, the trigger variable should always be set so that the ventilator can recognize genuine patient ventilatory effort.[6] Table 1 provides some guidelines regarding the setting of this variable.

The cycle variable is the value that is set to terminate inspiration. Breaths can be time, flow, pressure, or volume cycled. Once the selected preset value is reached, the breath is terminated. A breath can have only a single cycle variable. This variable is set by the operator or predetermined by the machine, depending on the type of ventilator used.[2]

Breath Types

A ventilator breath can be classified as either mandatory or spontaneous. A mandatory ventilator breath is initiated and/or terminated by the machine. In contrast, a spontaneous breath must be both initiated and terminated by the patient. Mandatory breaths initiated by patients are further classified as assisted ventilation. Spontaneous breaths in which the inspiration is augmented by the ventilator are considered supported ventilation.[2]

Assist-controlled ventilation refers to ventilator settings that allow patients to initiate their own breaths (assisted), but the breath is still fully generated and terminated by the machine (mandatory breaths). The ventilator ensures that patients receive the respiratory rate set by the operator if patients are not triggering sufficient breaths.[6]

Table 1. Initial Settings for Pulmonary Versus Extrapulmonary Pathology[3,19]

Parameter	Normal Lungs	Abnormal Lungs
FIO_2	100% initially	100% initially
TV	8–15 ml/kg	8–15 ml/kg
Respiratory rate	8–15 breaths/min	8–15 breaths/min
Minute ventilation	150–250 ml/kg/min	150–250 ml/kg/min
PIP	10–20 cm H_2O	15–25 cm H_2O
PEEP	0–2 cm H_2O	2–8 cm H_2O
Trigger sensitivity	−2 cm H_2O or 2 L/min	−2 cm H_2O or 2 L/min
I:E ratio	1:2	1:2
Inspiratory time	Approximately 1 sec	Approximately 1 sec

Breath Patterns

Ventilators can deliver three primary breath patterns[2]:

- Continuous mandatory ventilation
- Intermittent mandatory ventilation (IMV)
- Continuous spontaneous ventilation

In continuous mandatory ventilation, all breaths are mandatory. IMV combines mandatory breaths with spontaneous breathing. Synchronous intermittent mandatory ventilation (SIMV) is a variation of IMV in which the ventilator attempts to coordinate mandatory breaths with patient effort and is preferable to IMV when available.[1,2] This mode can be beneficial in weaning patients off the ventilator because the number of mandatory breaths can be gradually reduced, allowing patients to slowly take over the work of breathing.[4,7]

In continuous spontaneous ventilation, all breaths are spontaneous. This mode is used in patients with a normal ventilatory drive. Some ventilators allow augmentation of spontaneous breaths with increased airway pressure during inspiration; this is known as *pressure support*.[8] Pressure support can be helpful in offsetting resistance associated with the ventilator tubing, humidifier, and machine valves in spontaneously breathing patients.[9] Guidelines from the human literature suggest setting a pressure support of 6 to 8 cm H_2O to overcome this increase in resistance.[6]

Another approach to aid patients on continuous spontaneous ventilation is to provide an elevated baseline airway pressure throughout inspiration and exhalation. This baseline pressure is known as *continuous positive airway pressure* (CPAP) and helps prevent atelectasis, thereby promoting better gas exchange.[10] CPAP is also a helpful breath pattern to use when weaning patients from mechanical ventilation. It is often used as an intermediate step between SIMV and complete removal of ventilator support.[11,12]

Ventilator Modes

The breath patterns already described are often mistakenly considered to be ventilatory modes. However, the accurate description of a ventilator mode requires mention of the control variable, breath types, breath pattern, and relevant phase variables.[2,3,6] Unfortunately, a systematic, unifying approach to the definition of ventilator modes does not exist.

VENTILATOR SETTINGS

Pressure Settings

Several pressure measurements are critical in PPV. Peak inspiratory pressure (PIP) is the highest proximal airway pressure achieved during inspiration. If the ventilator breath includes an end-inspiratory pause, the airway pressure measured at the end of this pause is known as the *pause pressure*. Mean airway pressure is the average pressure over the entire course of a ventilatory cycle.[3,6,13]

Most ventilators have the option of increasing airway pressure during exhalation to exceed atmospheric pressure; this is called *positive end-expiratory pressure* (PEEP). This pressure prevents exhalation of the entire TV, helping to prevent atelectasis and keeping more alveoli open for effective gas exchange.[14,15] Effective ventilation of animals with pulmonary parenchymal disease usually requires PEEP. Although there are numerous benefits to appropriate application of PEEP, high levels of PEEP can magnify the deleterious effects of PPV, including reduced cardiac output, and also contribute to increased PIP.[16,17]

Intrinsic or auto-PEEP is a phenomenon resulting from ventilatory modes that do not allow the patient to complete an exhalation before the next inspiration begins. This produces elevated expiratory airway pressure that has the same impact as exogenous PEEP. Intrinsic PEEP can be dangerous because it may develop insidiously and cannot be directly controlled.[12,17,18]

Volume Settings

The TV is the amount of gas that moves in and out of the patient during a respiratory cycle. It can be measured on the inspiratory or expiratory limb of the breathing circuit, depending on the ventilator.[2] The product of the TV and the respiratory rate is known as *minute ventilation*. In general, the programmed TV is recommended to be 8 to 15 ml/kg with an associated minute ventilation of 150 to 250 ml/kg/min[3,13,19] (Table 1).

Research on managing acute respiratory distress syndrome in human medicine has led to the development of protective ventilation strategies, including the use of low TVs (6 to 8 ml/kg).[20,21] Application of low TV ventilation has not been thoroughly investigated in veterinary medicine, making appropriate recommendations difficult. Research suggests that avoiding high TVs may be advisable in animals and humans with severe pulmonary parenchymal disease.[22,23]

Respiratory Rate and Inspiratory:Expiratory Ratios

The initial respiratory rate can be set from 8 to 15 breaths/min and then adjusted to optimize the partial pressure of carbon dioxide (CO_2) and patient comfort.[3,24] The ratio of the inspiratory time to the expiratory time is known as the *inspiratory:expiratory (I:E) ratio* and is determined by the respiratory rate and the duration of inspiration and expiration. In general, an I:E ratio of 1:2 is recommended. High respiratory rates can lead to inverse I:E ratios (i.e., inspiratory time longer than expiratory time). Inverse I:E ratios have been found to be beneficial in some human studies, but they place the patient at risk of developing intrinsic PEEP and cardiovascular compromise.[25]

Sigh

Some ventilators have the option of providing intermittent "sigh" breaths, which are ventilator breaths with higher TVs provided to reduce atelectasis. Sigh breaths are an optional addition to ventilatory strategy.[6]

Alarms

Ideal ventilator alarm settings aim to identify genuine problems with the machine or patient while minimizing the occurrence of false alarms. Turning ventilator alarms off or setting them to unrealistic levels in an attempt to minimize false alarms can be dangerous because life-threatening changes may occur in a ventilated patient without evidence of readily visible clinical signs.

CLINICAL APPLICATION

The general goals of PPV are to establish a partial pressure of arterial oxygen (PaO_2) of 80 to 120 mm Hg and a partial pressure of arterial CO_2 of 35 to 45 mm Hg as well as to decrease a patient's work of breathing. The choice of mode and initial settings depend on the patient's underlying pathology. Animals that have hypoventilation and thus hypercapnia as the primary problem are generally easier to ventilate and require less aggressive settings than do animals with significant pulmonary parenchymal disease.[12,26]

Establishing a patient on a ventilator often requires some trial and error because the appropriate settings for an individual patient cannot be precisely predicted. Because the respiratory function of patients can change rapidly, continual reevaluation of animals receiving PPV is essential.

Some general guidelines apply to all PPV patients. It is always appropriate to maintain patients on 100% oxygen until they are safely established on the ventilator and fully monitored. Because PPV is not a benign procedure, efforts to minimize the aggressiveness of the ventilator settings should be made continuously once the machine adequately supports the patient. A backup system for manual ventilation should always be readily available in case of equipment failure or operator error. A laryngoscope and spare endotracheal tube should be kept at hand in case of inadvertent extubation.[3]

Initial Settings for Hypoventilation

When the primary indication for PPV is hypoventilation, the ventilator settings should ensure that the patient receives adequate minute ventilation to maintain

Ventilator mode refers to a combination of control and phase variables, breath patterns, and breath types.

an acceptable partial pressure of arterial CO_2. Most affected patients have neuromuscular disease, and a controlled or assist-controlled breath type is suitable initially. Some patients have some respiratory drive and an ability to trigger the ventilator but require ventilator support to ensure an adequate TV. Breath patterns such as SIMV and CPAP with adjuncts such as pressure support may be ideal for these patients. Once a patient has been stabilized on the ventilator, the fraction of inspired oxygen (FIO_2) should be decreased to the lowest level that still provides adequate oxygenation.

The decision to use pressure-controlled ventilation versus volume-controlled ventilation is not critical in animals with healthy lungs as long as adequate minute ventilation is attained without excessive pressure (i.e., PIP < 20 cm H_2O).[27]

Following initiation of ventilation of the patient with routine machine settings such as suggested in Table 1, the animal's ability to oxygenate and ventilate should be evaluated. The ventilator settings should then be tailored to the patient's requirements. In hypoventilating animals, the primary focus should be manipulating the respiratory rate and TV to achieve the desired partial pressure of CO_2. PEEP is generally not required in affected patients, although a PEEP of 2 cm H_2O may help reduce atelectatic tendencies in a recumbent animal.[16,28]

Many patients with neuromuscular disease have impaired thoracic wall movements and possibly generalized paralysis or paresis. These animals often do not resist PPV and are ideal candidates for tracheostomy tube placement, thereby eliminating the need for full anesthesia.[3,28,29] Because many of these patients can still feel discomfort, finding ventilator settings that most closely resemble their natural respiratory pattern is important. Light analgesia or sedation should be used to relieve patient anxiety or discomfort as appropriate.[28]

Initial Settings for Hypoxemia Secondary to Pulmonary Disease

Diseased lungs generally require higher inspiratory pressures to accommodate the same TV as do healthy lungs. This loss of pulmonary elasticity is referred to as *decreased compliance*.[3,5,14,15]

As outlined for hypoventilating patients, animals with pulmonary parenchymal disease should be established on a ventilator with initial settings based on the guidelines in Table 1. An animal's ability to oxygenate can then be rapidly assessed ideally via arterial blood gas. The ventilator settings should then be altered to achieve the desired blood gas goals with minimally aggressive ventilator support.

To avoid oxygen toxicity, patients should be weaned from 100% oxygen to less than 60% once they have been stabilized on the ventilator.[30] PEEP is an important adjunct in managing patients with pulmonary disease.[14,15] High PEEP levels (e.g., 10 to 12 cm H_2O) may be required in some patients, but increases in PEEP should always be made with caution. If elevations in PEEP lead to deteriorating blood gas measurements or cardiovascular compromise, returning to the earlier settings is advisable.[15]

ADJUSTING VENTILATOR SETTINGS

Hypercapnia

If a patient becomes hypercapnic on its current ventilator settings, complications such as pneumothorax, endotracheal tube obstruction, excessive breathing-circuit dead space, and ventilator malfunction must first be ruled out. If these are not present, the settings should be adjusted with the goal of increasing minute ventilation. This can be accomplished by increasing the respiratory rate and/or TV. Care must be taken to avoid an excessively high respiratory rate, which may lead to intrinsic PEEP.

Hypoxemia

If a ventilated patient becomes hypoxemic, the FIO_2 should initially be increased while the patient is being assessed and other solutions are sought. Complications such as ventilator malfunction, oxygen source failure, and circuit disconnections should be investigated initially. Patient issues such as depth of anesthesia, correct intubation, and pneumothorax should also be considered. If hypoxemia cannot be resolved by these interventions, deterioration of the pulmonary parenchymal disease should be suspected. Small increases in PEEP in a stepwise fashion may increase oxygenation in affected patients. Adjustments in the I:E ratio may also be beneficial. Adjusting the patient's position from lateral to sternal may also improve oxygenation.[19,31] However, it is frequently necessary to increase the PIP to compensate for a patient's abnormal pulmonary compliance.[26]

PATIENT SETUP

Airway

Ventilation requires maintenance of a controlled airway. Most patients can be anesthetized and intubated with an endotracheal tube. Animals with neurologic disease or severe neuromuscular weakness may tolerate

Table 2. Anesthesia for Ventilation[3,17]

Anesthetic Type	Pros	Cons	Comments
Inhalants	Effective	Needs scavenging system Cardiovascular depression	Impairs hypoxic vasoconstriction
Propofol	Rapid onset and recovery	Expensive Causes lipemia Hypotension Respiratory depression	Not recommended for >1–2 days because of lipemia Can cause Heinz body anemia in cats
Etomidate	Cardiovascular-sparing effect	Expensive Propylene glycol carrier causes hemolysis Adrenocortical suppression	CRI is not recommended because of propylene glycol and high osmolality
Opioids	Cardiovascular-sparing effect Analgesic	Panting may worsen patient–ventilator asynchrony Ileus Hyperthermia	Intermittent doses may be a helpful adjunct for analgesia
Pentobarbital	Inexpensive Easy to manage as CRI Good choice for intracranial disease	Prolonged recovery Can cause seizures on recovery after use for >7 days	CRI must be decreased or stopped 12–24 hr before weaning
Diazepam	Good as an adjunct	Phlebitis concerns necessitate a central catheter	—
Neuromuscular blockade	Reduces patient–ventilator asynchrony	Risk of incomplete reversal of paralysis Patient cannot signal if there is a problem Muscle atrophy	Requires careful monitoring Should be used only by experienced intensive-care unit clinicians

ventilation without anesthesia. It may therefore be advantageous to place a temporary tracheostomy tube.[32] Eliminating the need for general anesthesia during the process of ventilation may help reduce patient complications and allow the clinician to monitor changes in the neurologic status of a patient.[26] Awake patients with tracheostomy tubes often eat and drink normally, making some aspects of patient management less complicated.

Anesthetized patients are unable to cough and remove secretions because of the endotracheal or tracheostomy tube. Occlusion of the tube lumen with airway secretions is a common and potentially life-threatening problem.[33] The airway should be suctioned using sterile technique every 4 hours or more frequently if secretions are copious. Suctioning the airway is important to maintain tube patency but can cause hypoxemia, collapse the alveoli and small airways, damage the airway epithelium, and introduce infection.[34] If secretions are especially thick or humidification is inadequate, aliquots of sterile saline can be instilled before suctioning. The tracheal tube cuff should also be deflated and repositioned during suctioning, and the tracheal tube should be replaced once daily with another sterile tube.[3,17,34]

Although basic ventilator circuit tubing sizes are adequate for most patients, adult circuits may produce an unacceptable amount of resistance and dead space in smaller patients; thus a set of pediatric tubing should also be available. Because tubing can be a source of nosocomial infection, it should be changed regularly. Resterilized tubing or new disposable tubing can be used. We suggest changing the ventilator circuit every 48 hours. Ventilator circuits and filters should always be changed between patients.[26] During ventilation, gas flow bypasses the nasal passages and is therefore not humidified or filtered. Providing properly humidified gas is important for keeping secretions moist and protecting the epithelial lining.[3,34] Humidification can be provided by attaching a humidifier to the circuit. Another less expensive method of humidification is the use of heat and moisture exchanger filters. These specialized filters are attached between the patient's endotracheal tube and the breathing circuit and serve as an artificial nose by trapping exhaled water particles and viral and bacterial particles.[3] These filters are not as effective as humidifiers and are not recommended in patients that are hypothermic or have thick copious secretions.[35]

Anesthesia

There is no perfect anesthetic protocol for ventilated patients. The choice of anesthetic agents should be based on the disease process, predicted length of ventilation, species, and concurrent diseases or problems (Table 2).[3,17] In general, a balanced anesthetic approach using more than one agent is preferred to minimize the total dose and hence the adverse effects of individual drugs.[26]

Patient Monitoring

A ventilated patient requires the highest level of nursing care and should ideally have a technician dedicated solely to its care. In essence, a ventilated patient requires the same monitoring as any critically ill patient under anesthesia. Recommended monitoring equipment includes a pulse oximeter, capnograph, electrocardiograph, Doppler or oscillometric blood pressure (BP) monitor, and continuous temperature monitor.[26] Mechanical ventilation should not be attempted without a pulse oximeter and electrocardiograph at a minimum.[19,36]

If possible, patients should have an arterial catheter for blood sampling that can also be used for direct BP measurements. Arterial blood sampling is one of the best methods of monitoring changes in oxygenation. Determining the PaO_2:FIO_2 ratio is a simple means of evaluating a patient's ability to oxygenate over time despite variable FIO_2 settings. Periodic reevaluation of thoracic radiographs is recommended, especially in patients with a deteriorating ability to oxygenate.

Detailed record keeping is essential for monitoring trends and identifying problems early. Ventilator settings, including FIO_2, pressure and volume settings, respiratory rate, and breath patterns (mode), should be recorded at least hourly. Hourly measurement of patient parameters (e.g., BP, heart rate, percent saturation of hemoglobin with oxygen, end-tidal CO_2) is also critical.

SUPPORTIVE THERAPY

Fluid Therapy and Nutrition

A ventilated patient requires a fluid therapy plan tailored to its specific medical issues; this plan must be frequently altered as the patient's status changes. The general goals are to optimize perfusion and maintain proper moisture of the lower airways without creating pulmonary edema.[37] Daily monitoring of serum electrolytes and frequent physical examinations are required.[3]

Nutritional support of ventilated patients is challenging because they are often under anesthesia and unable to protect their airway. These patients are at high risk of regurgitation and aspiration. Anesthetic-related ileus can also become an important concern. If enteral feeding is administered, gastric residual volumes should be monitored to avoid gastric distention and an increased risk of regurgitation.[3] Parenteral nutrition is often indicated when patients cannot tolerate enteral nutrition.

Common complications of mechanical ventilation include pneumothorax, pneumonia, patient–ventilator asynchrony, and accidental disconnection.

General Nursing Care

Oral secretions can migrate down the airway and are believed to be an important cause of nosocomial pneumonia. Therefore, it is critical to provide regular oral care with an antibacterial solution and to suction the pharynx.[19] Patients can also develop lingual swelling and ulceration. Applying glycerin to the tongue may be beneficial in preventing lingual drying and damage.[3]

Ophthalmic ointment should be applied at least every 2 hours to protect against corneal drying and ulceration. Fluorescein staining should be performed if an ulcer is suspected so that proper therapy can be initiated.[3]

Ventilated patients are also at risk of muscle atrophy, pressure sores, and nerve damage.[38] Body position should be changed every 4 hours and passive range of motion exercises performed. Adequate bedding and heat support should be provided. Absorbent padding for urine collection can help keep animals dry and prevent urine scalding. A urinary catheter may be placed in patients that require precise monitoring of urine output. Regular palpation of the colon is advised, and enemas should be administered as needed.[3]

Intravenous catheters should be rewrapped daily and veins evaluated for signs of phlebitis or infection. Catheter placement for blood sampling is helpful because electrolytes and venous blood gasses may be evaluated frequently.

WEANING

For successful removal from a ventilator, a patient must have an appropriate respiratory drive, adequate neuromuscular function, and sufficient pulmonary function.[12] The weaning process involves gradual reduction in ventilator support until an animal can maintain adequate respiratory function without the aid of the machine. Weaning is a continual process of trial and error that begins when ventilation is initiated. When a patient's oxygenation and ventilation status shows improvement, there may be an opportunity to reduce the level of ventilatory support. It is important to make small changes, and it is generally recommended to restrict changes to a single setting to enable the operator to identify the specific effects of the changes. Reduction in the level of ventilator support may involve a decrease in the magnitude of a preset setting or use of a breath pattern such as SIMV or pressure support to allow the patient to perform some of the work of breathing.[7,12,32,39] The patient should be closely monitored during and immediately after a change in ventilator settings, and measurement of ventilatory and oxygenating ability should be repeated shortly after each change to ensure that the patient is maintaining adequate respiratory function.

Before an animal can be weaned from a ventilator, it must first demonstrate an ability to maintain adequate respiratory function without high levels of PEEP or PIP. Animals with neuromuscular disease must have a strong respiratory drive and thoracic wall function sufficient to generate an acceptable TV.[12]

There are numerous approaches to patient weaning. When decreasing the level of ventilatory support, an initial priority is reduction of the FIO_2 to less than 60% to minimize risk of oxygen toxicosis. Once this is achieved, further reductions in FIO_2 are desirable although not essential because patients can be maintained on supplemental oxygen if they can perform adequately without PPV. Once an acceptable FIO_2 has been reached, the focus should be to reduce the level of PIP and PEEP as feasible.[3,12]

There is no way of predicting whether an animal is truly ready to be weaned. If a patient is on mild to moderate levels of ventilator support with an FIO_2 less than 40% and has a strong respiratory drive, whether to wean becomes a matter of clinical judgment. Removing ventilatory support should be seen as a trial during which patients are intensely monitored.[40] If an animal's blood gas parameters or degree of respiratory effort deteriorate significantly, the weaning trial should be halted and PPV reinstated.[3,7,12]

Modern positive-pressure ventilators offer many modes and settings to better match a variety of patients and their different needs. Appropriate initial settings and patient setup differ substantially between animals with pulmonary and extrapulmonary pathology.

As weaning becomes imminent, an animal's anesthetic state should be considered. If a long recovery is expected (e.g., with the use of pentobarbital), a preemptive change in anesthetic agents can help prevent unwanted delays in the weaning process.[3] Unfortunately, many patients never reach the point of weaning because their underlying disease worsens or other complications develop. Given the substantial financial expense of mechanical ventilation, time limitations are often imposed by owners. Careful monitoring of trends in oxygenation, neurologic status, cardiovascular status, and ventilation can help identify significant declines in a patient's condition and assist owners in deciding when withdrawal of support is appropriate.

COMPLICATIONS

Ventilator-Induced Lung Injury

Ventilator-induced lung injury is associated with overdistention of the alveoli, which is known as *volutrauma*.[6] Animals with underlying pulmonary parenchymal disease are at greater risk because their lungs are usually more fragile.[41,42] In addition, the areas of decreased compliance tend to redirect a disproportionate amount of TV to the more compliant normal alveoli, thereby overexpanding them.[43] Mechanical ventilation is not benign, and even patients with initially normal lungs may develop pulmonary pathology. Repetitive expansion and closure of alveoli leads to shearing injury and alveolar collapse.[44] Associated production and release of inflammatory mediators in response to this tissue trauma perpetuates pulmonary damage.[24] The resulting deterioration in gas exchange reduces the likelihood of successful patient weaning. Pneumothorax and pulmonary edema are two possible manifestations of ventilator-induced lung injury.

Patients that develop pneumothorax have an acute decrease in oxygenation, an increased CO_2 level, and a decreased TV. Pneumothorax often worsens rapidly because of PPV and must be identified quickly. Thoracic auscultation, radiography, and/or thoracocentesis can help identify pneumothorax. Affected patients usually require placement of a thoracostomy tube attached to a Heimlich valve or a continuous suction device to allow continuation of PPV.[3,18,22]

Ventilator-Associated Pneumonia

Ventilator-associated pneumonia is a common sequela of PPV in humans.[17] The endotracheal tube, ventilator tube, suction catheters, and humidifier are all potential sources of nosocomial infections; thus using sterile equipment and technique is essential. Aspiration of gastric contents is a major source of ventilator-associated pneumonia because recumbent patients frequently have visible or unapparent episodes of aspiration.[18,23] Unfortunately, the cuff on the endotracheal tube does not prevent aspiration.[18] Total gastrointestinal decontamination with antibiotic therapy is administered in human intensive-care units to decrease the incidence of ventilator-associated pneumonia. Saliva is another potential source of infection, making frequent oral care with chlorhexidine solutions an important component of patient care.[19,34] It is important to vigilantly watch for the onset of ventilator-associated pneumonia and to obtain cultures and initiate appropriate antibiotic therapy in a timely fashion if pneumonia is confirmed.

Other Complications

Other complications are related to both the act of PPV and issues regarding recumbent patients (see box on this page).[12] Patient–ventilator asynchrony is commonly referred to as *bucking the ventilator* and is usually the consequence of inappropriate settings or patient discomfort.[12] This asynchrony can lead to ineffective ventilation, muscle fatigue, and patient distress. The common causes of patient–ventilator asynchrony are hypoxemia, hypoventilation, inadequate depth of anesthesia, and hyperthermia. If these causes are ruled out, the ventilator settings may need to be modulated to find a more suitable breath pattern. Other common complications include accidental disconnection, excessive oral secretions, ocular and oral ulcers, pressure sores, and muscle atrophy.[12,26,45]

Complications Associated with Mechanical Ventilation[12]

Pulmonary
Ventilator-induced lung injury
Ventilator-associated pneumonia
Pneumothorax
Patient–ventilator asynchrony
Endotracheal tube occlusion and accidental disconnection
Oxygen toxicosis
Tracheal necrosis

Extrapulmonary
Oral ulcers
Ocular ulcers
Pressure sores
Muscle atrophy
Peripheral edema

CONCLUSION

Successful ventilation requires a basic understanding of respiratory physiology and ventilator mechanics in addition to extensive nursing care. Mechanical ventilation can allow stabilization and maintenance of patients in which other less invasive therapeutic options have been exhausted. PPV is an essential component of human intensive care and will inevitably become the advanced standard of respiratory care in veterinary medicine as veterinarians gain more experience with this modality.

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ARTICLE #1 CE TEST

CE

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1. A ventilator mode is defined by the

a. breath pattern.
b. control variable.
c. pressure settings.
d. all of the above

2. Supported ventilation is a subset of __________ ventilation.

a. assisted
b. spontaneous
c. mandatory
d. synchronous

3. A normal I:E ratio is

a. 2:1.
b. 1:3.
c. 1:2.
d. 2:3.

4. A known complication of excessively high respiratory rates or inverse I:E ratios is

a. hypercapnia.
b. pneumothorax.
c. low minute ventilation.
d. intrinsic PEEP.

5. Which of the following is an advantage of neuromuscular blockades?

a. The patient cannot signal if distressed.
b. Recovery from the blockade is sometimes incomplete.
c. Intensive monitoring is required.
d. Patient–ventilator asynchrony is decreased.

6. Which complication is not associated with using high levels of PEEP?

a. hypercapnia
b. barotrauma
c. atelectasis
d. decreased cardiac output

7. Which ventilator breath pattern theoretically requires the least amount of patient effort?

a. continuous mandatory ventilation
b. SIMV
c. pressure support
d. CPAP

8. In pressure-controlled ventilation, which scenario might cause a substantial decrease in the delivered TV?

a. increasing the PIP by 2 cm H_2O
b. decreasing the trigger variable by 1 cm H_2O
c. a 40% obstruction of the endotracheal tube lumen
d. an increase in the FIO_2 from 0.4 to 0.6

9. Animals with pulmonary pathology generally have

a. decreased compliance.
b. less fragile lungs.
c. a decreased risk of ventilator-induced lung injury.
d. a normal PaO_2:FIO_2 ratio.

10. Which of the following is not a likely source of ventilator-associated pneumonia?

a. pulse oximeters
b. oral bacteria
c. aspiration of gastric contents
d. suction catheters