PROCEDURE

29 Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes

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PURPOSE: Initiation and maintenance of positive-pressure ventilation through an artificial airway are accomplished to maintain or improve oxygenation and ventilation and to provide respiratory muscle rest. Selection of volume or pressure modes is dependent on the available evidence, clinical goals, availability of modes, and practitioner preference.

PREREQUISITE NURSING KNOWLEDGE

- Indications for the initiation of mechanical ventilation include the following:
  - Apnea (e.g., neuromuscular or cardiopulmonary collapse)
  - Acute ventilatory failure, which is generally defined as a pH of less than or equal to 7.25 with an arterial partial pressure of carbon dioxide ($Paco_2$) greater than or equal to 50 mm Hg
  - Impending ventilatory failure (serial decrement of arterial blood gas values or progressive increase in signs and symptoms of increased work of breathing)
  - Severe hypoxemia: an arterial partial pressure of oxygen (Pao_2) of less than or equal to 50 mm Hg on room air indicates a critical level of oxygen in the blood. Although oxygen-delivery devices may be used before intubation, the refractory nature of shunt (perfusion without ventilation) may necessitate that positive pressure be applied to reexpand closed alveoli. Restoration of functional residual capacity (FRC; lung volume that remains at the end of a passive exhalation) is the goal.
  - Respiratory muscle fatigue: the muscles of respiration can become fatigued if they are made to contract repetitively at high workloads.[86] Fatigue occurs when muscle-energy stores become depleted. Weakness, hypermetabolic states, and chronic lung disease are examples of conditions in which patients are especially prone to fatigue. When fatigue occurs, the muscles no longer contract optimally and hypercarbia results.[8,24] Twelve to 24 hours of rest are typically needed to rest the muscles. Respiratory muscle rest requires that the workload of the muscles (or muscle loading) be offset so that mitochondrial energy stores can be repleted.[8,24] Respiratory work and rest vary with different modes and the application of the same. In general, when hypercarbia is present, mechanical ventilation is necessary to relieve the work of breathing. Muscle unloading is accomplished differently and depends on patient-ventilator interaction and the mode.[13,14,63,67]
- Ventilators are categorized as either negative or positive pressure. Although negative-pressure ventilation (i.e., the iron lung) was used extensively in the 1940s, introduction of the cuffed endotracheal tube resulted in the dominance of positive-pressure ventilation (PPV) in clinical practice during the second half of the 20th century. Although sporadic interest in negative-pressure ventilation continues, the cumbersome nature of the ventilators and the lack of airway protection associated with this form of ventilation preclude a serious resurgence of this mode of ventilation.[11,21]
  - Positive-pressure ventilation: positive-pressure modes of ventilation have traditionally been categorized into volume and pressure. However, with the advent of microprocessor technology, sophisticated iterations of traditional volume and pressure modes of ventilation have evolved.[11,25] Many of the modes have names that are different from traditional volume and pressure modes, but they are similar in many characteristics. Little data exist to show that the newer modes improve outcomes.[11,17,25,57] A wide variety of modes described in this procedure are actually a combination of volume and pressure but for ease of learning are classified into specific categories.
  - Volume ventilation has traditionally been the most popular form of PPV, largely because tidal volume (Vt) and minute ventilation (MV) are ensured, which is an essential goal in the patient with acute illness. With

volume ventilation, a predetermined Vt is delivered with each breath regardless of resistance and compliance. Vt is stable from breath to breath, but airway pressure may vary. The gas flow-rate pattern of volume ventilation is generally constant from the beginning to the end of the breath (square wave). In modern ventilators, this can be changed to accelerating, decelerating, or even sine patterns. To rest the respiratory muscles with volume ventilation, the ventilator rate must be increased until spontaneous respiratory effort ceases. When spontaneous effort is present, such as with initiation of an assist/control (A/C) breath, respiratory muscle work continues throughout the breath.[67,96]

- With traditional *pressure ventilation,* the practitioner selects the desired pressure level and the Vt is determined by the selected pressure level, airway resistance, and lung compliance. This characteristic is important to note in caring for a patient with an unstable condition on a pressure mode of ventilation. Careful attention to Vt is necessary to prevent inadvertent hyperventilation or hypoventilation. To ensure respiratory muscle rest on pressure-support ventilation (PSV), workload must be offset with the appropriate adjustment of the pressure-support level. To accomplish this adjustment, the pressure-support level is increased to lower the spontaneous respiratory rate to less than or equal to 20 breaths/min and to attain a Vt of 6 to 10 mL/kg of predicted body weight (PBW).[13,14,17,61]
- Pressure ventilation provides for an augmented inspiration (pressure is maintained throughout inspiration). The flow pattern (speed of the gas) is described as decelerating; that is, gas-flow delivery is high at the beginning of the breath and tapers off toward the end of the breath. This pattern is in contrast to volume ventilation, in which the flow rate is typically more consistent during inspiration (i.e., the same at the beginning of the breath as at the end of the breath). The decelerating flow pattern associated with pressure ventilation is thought to provide better gas distribution and more efficient ventilation.[61,63,87]
- Increasingly, sophisticated ventilator technology has resulted in the development of volume-assured pressure modes of ventilation. Ventilator manufacturers have responded rapidly to the request of practitioners that pressure modes of ventilation be designed in such a way that the minimum desired tidal volume be can be achieved on a breath-to-breath basis. These are called *adaptive pressure control* or *dual control pressure modes*. The potential value of such modes is obvious. The more desirable decelerating flow pattern may be provided and plateau pressures controlled, with more consistent Vt and MV.
- Additional modes of ventilation have been promoted for use in patients with acute respiratory distress syndrome (ARDS), including high-frequency oscillation, airway pressure-release ventilation (APRV), and other ventilator-specific modes, such as biphasic, adaptive support, and proportional assist ventilation. Although some data exist that suggest the modes may be beneficial in patients with ARDS, to date no change in mortality rate has been noted, although positive trends have been demonstrated in some variables of interest such as oxygenation.[17,28,31,39,46,47,69,83,84]

- Summary descriptions of modes, mode parameters, and ventilator alarms are provided within this procedure and in Boxes 29-1 and 29-2, and Table 29-1.

BOX 29-1 Traditional Modes of Mechanical Ventilation (On All Ventilators)

VOLUME MODES

Control Ventilation (CV) or Controlled Mandatory Ventilation (CMV)

Description: With this mode, the ventilator provides all of the patient's minute ventilation. The clinician sets the rate, Vt, inspiratory time, and PEEP. Generally, this term is used to describe situations in which the patient is chemically relaxed or is paralyzed from a spinal cord or neuromuscular disease and is unable to initiate spontaneous breaths. This mode does not exist as a standard mode on modern ventilators. Patients on assist/control (A/C) mode who are unable to trigger the machine are essentially in CMV.

Assist/Control (A/C) Ventilation

Description: This option requires that a rate, Vt, inspiratory time, and PEEP be set for the patient. The ventilator sensitivity also is set, and when the patient initiates a spontaneous breath, a full-volume breath is delivered.

Synchronized Intermittent Mandatory Ventilation (SIMV)

Description: This mode requires that rate, Vt, inspiratory time, sensitivity, and PEEP are set by the clinician. In between mandatory breaths, patients can spontaneously breathe at their own rates and Vt. With SIMV, the ventilator synchronizes the mandatory breaths with the patient's own breaths.

PRESSURE MODES

Pressure Support Ventilation (PSV)

Description: This mode provides augmented inspiration to a patient who is spontaneously breathing. With pressure support (PS), the clinician selects an inspiratory pressure level, PEEP, and sensitivity. When the patient initiates a breath, a high flow of gas is delivered to the preselected pressure level, and pressure is maintained throughout inspiration. The patient determines the parameters of Vt, rate, and inspiratory time.

Pressure-Controlled (PC) and Pressure-Controlled Inverse Ratio Ventilation (PC/IRV)

Description: This mode may provide pressure-limited ventilation (PC) alone, or combined with an inverse ratio of inspiration to expiration (PC/IRV). The clinician selects the pressure level, rate, inspiratory time (1:1, 2:1, 3:1, 4:1), and PEEP level. With prolonged inspiratory times, auto-PEEP may result. The auto-PEEP may be a desirable outcome of the inverse ratios. In PC without IRV, conventional inspiratory times are used, and rate, pressure level, and PEEP are selected.

Positive End-Expiratory Pressure (PEEP) and Continuous Positive Airway Pressure (CPAP)

Description: This ventilatory option creates positive pressure at end exhalation. PEEP restores functional residual capacity. The term PEEP is used when end-expiratory pressure is provided during ventilator positive pressure breaths.

BOX 29-2 Ventilator Alarms

DISCONNECT ALARMS (LOW-PRESSURE OR LOW-VOLUME ALARMS)

When disconnection occurs, the clinician must be immediately notified. Generally, this alarm is a continuous one and is triggered when a preselected inspiratory pressure level or minute ventilation is not sensed. With circuit leaks, this same alarm may be activated even though the patient may still be receiving a portion of the preset breath. Physical assessment, digital displays, and manometers are helpful in troubleshooting the cause of the alarms.

PRESSURE ALARMS

High-pressure alarms are set to ensure notification of pressures that exceed the selected threshold. These alarms are usually set 10–15 cm H_2O above the usual peak inspiratory pressure (PIP). Some causes for alarm activation (generally an intermittent alarm) include secretions, condensate in the tubing, biting on the endotracheal tubing, increased resistance (i.e., bronchospasm), decreased compliance (e.g., pulmonary edema, pneumothorax), and tubing compression. When this alarm is triggered, the breath delivery is halted and the remaining tidal volume to be delivered by the machine is not delivered. This will then often result in the occurrence of a low-volume alarm.

Low-pressure alarms are used to sense disconnection, circuit leaks, and changing compliance and resistance. They are generally set 5–10 cm H_2O below the usual PIP or 1–2 cm H_2O below the PEEP level or both.

Minute ventilation alarms may be used to sense disconnection or changes in breathing pattern (rate and volume). Generally, low-minute ventilation and high-minute ventilation alarms are set (usually 5–10 L/min above and below usual minute ventilation). When stand-alone pressure support ventilation (PSV) is in use, this alarm may be the only audible alarm available on some ventilators.

FiO_2 alarms are provided on most new ventilators and are set 5–10 mm Hg above and below the selected FiO_2 level.

Alarm silence or pause options are built in by ventilator manufacturers so that clinicians can temporarily silence alarms for short periods (i.e., 20 seconds) because alarms must stay activated at all times. The ventilators reset the alarms automatically.

Alarms provide important protection for patients on ventilation. However, inappropriate threshold settings decrease usefulness. When threshold gradients are set too narrowly, alarms occur needlessly and frequently. Conversely, alarms that are set too loosely (wide gradients) do not allow for accurate and timely assessments.

From Burns SM: Mechanical ventilation and weaning. In Kinney MR, et al, editors: AACN clinical reference for critical care nursing, *ed 4. St Louis, 1998, Mosby.*

- Complications of PPV include volume-pressure trauma, hemodynamic changes, and pulmonary barotrauma.
  - Volume-pressure trauma, in contrast to barotrauma (or air-leak disease), was first described in animals with stiff noncompliant lungs who were ventilated with traditional lung volumes (range, 10 to 12 mL/kg PBW). The investigators noted that the large volumes translated into high plateau pressures (also known as static, distending, or alveolar pressure) and subsequent acute lung injury. The lung injury was described as a loss of alveolar integrity (i.e., alveolar fractures) and movement of fluids and proteins into the alveolar space (sometimes called non-ARDS-ARDS).[33,34,43,52] Plateau pressures of 30 cm H_2O or more for greater than 48 to 72 hours were associated with the injury.[34,49,52]
  - Studies in humans followed the recognition that large Vts may be associated with lung injury.[1] The ARDS Network conducted a randomized controlled trial of adult patients with ARDS that compared low lung-volume ventilation (6 mL/kg) with more traditional volumes (i.e., 12 mL/kg). The results showed that the lower-volume ventilation resulted in a lower mortality rate.[1] As a result, current recommendations are to limit volumes (and lower pressures) in patients with stiff lungs. With pressure ventilation, pressure is limited by definition; however, until additional evidence emerges on the efficacy of controlling pressures versus volumes in ARDS, a goal should be to ensure a Vt in the 6 mL/kg range. Another lung-protective strategy is that of "recruitment" and the prevention of "derecruitment." Investigators showed that stiff noncompliant lungs were at risk of trauma from the repetitive opening associated with tidal breaths. The application of higher levels of positive end-expiratory pressure (PEEP) was associated with better recruitment and resulted in improved mortality rates.[3,4,18,44,85]
  - The extent of hemodynamic changes associated with PPV depends on the level of applied positive pressure, the duration of positive pressure during different phases of the breathing cycle, the amount of pressure transmitted to the vascular structures, the patient's intravascular volume, and the adequacy of hemodynamic compensatory mechanisms. PPV can reduce venous return, shift the intraventricular septum to the left, and increase right-ventricular afterload as a result of increased pulmonary vascular resistance.[22,38,53,54] The hemodynamic effects of PPV may be prevented or corrected by optimizing filling pressures to accommodate the PPV-induced changes in intrathoracic pressures; by minimizing the peak pressure, plateau pressure, and PEEP; and by optimizing the inspiratory-to-expiratory (I:E) ratio.
  - Pulmonary barotrauma (i.e., air-leak disease) is damage to the lung from extrapulmonary air that may result from changes in intrathoracic pressures during PPV. Barotrauma is manifested by pneumothorax, pneumomediastinum, pneumopericardium, pneumoperitoneum, and subcutaneous emphysema. The risk of barotrauma in a patient receiving PPV is increased with preexisting lung lesions (e.g., localized infections, blebs), high inflation pressures (i.e., large Vt, PEEP, main-stem bronchus intubation, patient-ventilator asynchrony), and invasive thoracic procedures (e.g., subclavian catheter insertion, bronchoscopy, thoracentesis). Barotrauma from PPV may be prevented by controlling peak and plateau pressures, optimizing PEEP, preventing auto-PEEP, ensuring patient-ventilator synchrony, and ensuring proper artificial airway position.

TABLE 29-1 Volume and Pressure Modes and Corresponding Ventilator Parameters

Mode Name and Description	Main Parameters	Comments
Assist Control (A/C)	Vt Rate Inspiratory time (Ti) Sensitivity FiO_2 PEEP	Generally considered a support mode. Must switch to another mode or method for weaning.
Synchronized Mandatory Ventilation (SIMV)	Vt Rate Ti Sensitivity FiO_2 PEEP	Originally used as a weaning mode; however, work of breathing is high at low SIMV rates. Often used in conjunction with PSV.
Pressure Support Ventilation (PSV)	PS level Sensitivity FiO_2 PEEP	Often pressure is arbitrarily selected (e.g., 10–20 cm H_2O) then adjusted up or down to attain the desired tidal volume. Some use the plateau pressure if transitioning from volume ventilation as a starting point.
Pressure-Controlled Ventilation (PCV)	Inspiratory pressure limit (IPL) Rate Ti Sensitivity FiO_2 PEEP	Variants of PCV include Volume-Assured Pressure Options and some other modes such as Airway Pressure Release Ventilation and Bilevel Ventilation.
Pressure Controlled–Inverse Ratio Ventilation	As for PCV, but an inverse inspiratory : expiratory (I : E) ratio is attained by lengthening the Ti. Inverse ratios include 1 : 1, 2 : 1, 3 : 1, and 4 : 1.	Some ventilators allow for the I : E ratio to be selected.
Bilevel Positive Airway Pressure (Bilevel or BiPAP)	$Pressure_{HIGH}$ (P_{HIGH}) $Pressure_{LOW}$(P_{LOW}) T_{HIGH}(Similar to I Time in PC) T_{LOW} (Similar to E time in PC) Or set ratio T_{HIGH}/T_{LOW} ratio Rate FIO_2	Similar in many ways to PC in that an inspiratory pressure ($Pressure_{HIGH}$) and PEEP ($Pressure_{LOW}$) are set. However, unlike PC, the patient may take spontaneous breaths as well. If additional support is desired for patient-initiated breathing, pressure support in bilevel mode (Psupp) may be selected as well. Attention to Vt is important because the patient can augment Vt significantly with supported spontaneous breaths.
Airway Pressure Release Ventilation (APRV)	Pressure high (P_{HIGH}): high CPAP level. Pressure low (P_{LOW}) is generally 0–5 cm H_2O. Time high (T_{HIGH}). Time low (T_{LOW}). FiO_2	APRV is a form of biphasic ventilation with a very short expiratory time. Generally, the CPAP level is adjusted to ensure adequate oxygenation while the rate of the releases are increased or decreased to meet ventilation goals. Vt is variably dependent on the CPAP level, compliance and resistance of the patient, and patient spontaneous effort.
Dual Control or Volume-Assured Pressure Modes (1–5 listed here)	These modes provide pressure breaths with a minimum tidal volume assurance.	These modes are ventilator specific. Although the similarities are greater than the differences, they are called different names. Often the names suggest that the mode is a volume mode, yet a decelerating flow pattern (associated with pressure ventilation) is always provided.
1. Volume Support (VS)	Vt Sensitivity FiO_2 PEEP	The pressure level is automatically adjusted to attain the desired Vt. If control of pressure is desired, it must be carefully monitored.
2. Pressure-Regulated Control (PRVC)	Rate and Ti set in addition to those set for VS.	As with VS. The difference is that this is a control mode. Spontaneous breaths, however, may also occur.

TABLE 29-1 Volume and Pressure Modes and Corresponding Ventilator Parameters—cont'd

Mode Name and Description	Main Parameters	Comments
3. Volume Control Plus (VC+)	Rate and Ti are set in addition to those set for VS.	This is a mode option listed in the category called Volume Ventilation Plus. To access this mode, the user selects the SIMV or A/C (both control modes) then selects VC+. For some clinicians, this is confusing because it appears that the patient is on two different modes versus VC+.
4. Adaptive Support Ventilation (ASV)	Body weight %MinVol (minute volume), high pressure limit	Once basic settings are selected, ASV is started and %MinVol is adjusted if indicated. Spontaneous breathing is automatically encouraged, and when the inspiratory pressure (Pinsp) is consistently 0 and rate is 0, extubation may be considered.
5. Proportional Assist Ventilation (PAV)	Proportional Pressure Support (PPS): PEEP, Fio_2, percent volume assist and flow assist Proportional Assist Plus: PAV+: PEEP, Fio_2, percent support	Depending on the ventilator, the amount of assist that is provided is determined by the clinician and different parameters are selected to do so. Default percent support numbers are recommended, but the clinician must determine the timing of reductions of same.
6. Automatic Tube Compensation (ATC)	Endotracheal tube internal diameter Percent compensation	This is not a mode but rather a pressure option to offset the work associated with tube resistance. It can be combined with other modes or used alone as in a CPAP weaning trial.

Adapted with permission from Burns S: *Pressure modes of mechanical ventilation: The good, bad and the ugly,* AACN Adv Crit Care *19:399–411, 2008.*

- Auto-PEEP is a common complication of mechanical ventilation and can result in hemodynamic compromise and even death. Because increased intrathoracic pressures are transmitted to the adjacent capillaries, venous return is decreased and the effect can be profound. Auto-PEEP and dynamic hyperinflation should be assumed in the patient on ventilation with acute severe asthma whose condition is hemodynamically compromised, and a brief cessation of mechanical ventilation or decrease in rate and shortening of inspiratory time should be accomplished.[16,59,65,79] Auto-PEEP is caused by inadequate expiratory time relative to the patient's lung condition. Auto-PEEP is often seen in patients with prolonged inspiratory times, short expiratory times, high minute ventilation requirements, bronchospasm, low elastic recoil, mucus hypersecretion, increased wall thickness, airway closure or collapse, and mechanical factors (e.g., water in the ventilator circuit, pinched ventilator tubing).[16,59,65,79] Correcting these factors reduces auto-PEEP. In some cases where auto-PEEP cannot be eliminated, adding set PEEP to the level of auto-PEEP results in reduction of the inspiratory trigger threshold and thus improvement of patient triggering.[16,59,62,79]

- Complications of PPV include ventilator-associated pneumonia (VAP).
  - VAP occurs after 3 to 5 days of mechanical ventilation and accounts for one third of all healthcare-associated infections and between 50% and 83% of infections in the patient with MV.[23,74,75,82]
  - Modifiable risk factors to the aspiration of colonized organisms in the patient on ventilation include interventions such as proper endotracheal tube cuff inflation (secretions that collect above the cuff of the endotracheal or tracheostomy tube and leak past the cuff into the lungs), use of continuous-aspiration subglottic suctioning (CASS) tubes, decreased ventilator tubing changes, use of heat and moisture exchangers (HMEs), stringent hand washing, backrest elevation (BRE) of greater than 30 degrees, and when possible the use of noninvasive ventilation (especially in patients with immunocompromise).[23,74,75,82]
  - Other interventions with a lower level of evidence supporting their use include oral care techniques such as mouth care and oral decontamination with agents such as chlorhexidine or oral antibiotics.[45] Of interest, gastric residual volumes have not been found to be consistently associated with VAP.[73] Box 29-3 lists the top recommendations of authoritative professional organizations for the prevention of VAP.

EQUIPMENT

- Endotracheal or tracheostomy tube
- Electrocardiogram and pulse oximetry
- Supplemental oxygen source
- Manual self-inflating resuscitation bag-valve device (with PEEP adjusted to patient baseline level or with a PEEP valve)
- Appropriately sized resuscitation face mask
- Ventilator
- Suction equipment

PATIENT AND FAMILY EDUCATION

- Explain the procedure and the reasons for PPV to the patient and family. ***Rationale:*** Communication and explanations for therapy are important needs of patients and families.
- Discuss the potential sensations the patient will experience, such as relief of dyspnea, lung inflations, noise of

BOX 29-3 Top Modifiable VAP Prevention Interventions: Guidelines by Authoritative Professional Organizations*

- Back rest elevation (>30–45 degrees)
- Continuous aspiration of subglottic secretions tubes
- Limit/interrupt sedation (spontaneous awakening trial)
- Spontaneous breathing trial/assess readiness to extubate daily.
- Noninvasive ventilation when possible
- Early Mobility
- No routine ventilator circuit change
- Hand washing and aseptic technique

***Professional Associations:**

- AHRQ, Prevention of Ventilator Associated Pneumonia (2011). http://www.guideline.gov/content.aspx?id=36063. Accessed January 27, 2016.
- Association for Professionals in Infection Control (APIC) (2009). Guideline to Eliminating Ventilator Associated Pneumonia. http://www.apic.org/Resource_/EliminationGuideForm/18e326ad-b484-471c-9c35-6822a53ee4a2/File/VAP_09.pdf: Accessed: January 27, 2016.
- Institute for Clinical Systems Improvement (2011). https://www.icsi.org/_asset/y24ruh/VAP.pdf. Accessed: January 27 2016.
- Society for Healthcare Epidemiology in America (SHEA) (2014). Strategies to Prevent Ventilator Associated Pneumonia in Acute Care Hospitals.

ventilator operation, and alarm sounds. ***Rationale:*** Knowledge of anticipated sensory experiences reduces anxiety and distress.

- Encourage the patient to relax. ***Rationale:*** This encouragement promotes general relaxation, oxygenation, and ventilation.
- Explain that the patient will be unable to speak. Establish a method of communication in conjunction with the patient and family before initiating mechanical ventilation, if necessary. ***Rationale:*** Ensuring the patient's ability to communicate is important to alleviate anxiety.
- Teach the family how to perform desired and appropriate activities of direct patient care, such as pharyngeal suction with the tonsil-tip suction device, range-of-motion exercises, and reconnection to ventilator if inadvertent disconnection occurs. Demonstrate use of the call bell. ***Rationale:*** Family members have identified the need and desire to help in the patient's care.
- Explain to the patient and family the importance of not touching the ventilator controls, including silencing and resetting alarms. ***Rationale:*** Families may become familiar with the ventilator over time and, in a desire to help, reset or silence an alarm without an understanding of the cause/underlying problem.
- Provide the patient and family with information on the critical nature of the patient's dependence on PPV. ***Rationale:*** Knowledge of the prognosis, probable outcome, or chance for recovery is cited as an important need of patients and families.
- Offer the opportunity for the patient and family to ask questions about PPV. ***Rationale:*** Asking questions and having questions answered honestly are cited consistently as the most important need of patients and families.

PATIENT ASSESSMENT AND PREPARATION

Patient Assessment

- Assess for signs and symptoms of acute ventilatory failure and fatigue. ***Rationale:*** Ventilatory failure indicates the need for initiation of PPV. While PPV is being considered and assembled, support ventilation via a self-inflating manual resuscitation bag-valve-mask (BVM), if necessary.
  - Rising arterial carbon dioxide tension
  - Chest-abdominal dyssynchrony
  - Shallow or irregular respirations
  - Tachypnea, bradypnea, or dyspnea
  - Decreased mental status
  - Restlessness, confusion, or lethargy
  - Increasing or decreasing arterial blood pressure
  - Tachycardia
  - Atrial or ventricular dysrhythmias
- Determine arterial pH and carbon dioxide tension. ***Rationale:*** Acute ventilatory failure is confirmed by an uncompensated respiratory acidosis. Ventilatory failure is an indication for PPV.
- Assess for signs and symptoms of inadequate oxygenation. ***Rationale:*** Hypoxemia may indicate the need for PPV. While PPV is being considered and assembled, provide 100% oxygen via manual resuscitation bag and mask or via an oxygen delivery device, such as a nonrebreather mask.
  - Decreasing arterial oxygen tension
  - Tachypnea
  - Dyspnea
  - Central cyanosis
  - Alterations in level of consciousness
  - Restlessness
  - Confusion
  - Agitation
  - Tachycardia
  - Bradycardia
  - Dysrhythmias
  - Intercostal and suprasternal retractions
  - Increasing or decreasing arterial blood pressure
  - Adventitious breath sounds
  - Decreasing urine output
  - Metabolic acidosis
- Determine Pao_2 or arterial oxygen saturation (Sao_2). ***Rationale:*** Hypoxemia is confirmed by Pao_2 of <60 mm Hg or Sao_2 of less than 90% on supplemental oxygen. Hypoxemia may indicate the need for PPV.
- Assess for signs and symptoms of inadequate breathing patterns. ***Rationale:*** Respiratory distress is an indication for PPV.
  - Dyspnea
  - Chest-abdominal dyssynchrony
  - Rapid-shallow breathing pattern
  - Irregular respirations
  - Intercostal or suprasternal retractions
  - Inability to say a whole sentence

Patient Preparation

- Verify that the patient is the correct patient using two identifiers. ***Rationale:*** Before performing a procedure, the nurse should ensure the correct identification of the patient for the intended intervention.
- Perform a preprocedure verification and time out, if nonemergent. ***Rationale:*** Ensures patient safety.
- If patient is not in distress ensure that the patient understands preprocedural teachings. Answer questions as they arise, and reinforce information as needed. ***Rationale:*** This communication evaluates and reinforces understanding of previously taught information.
- Premedicate as needed. ***Rationale:*** Administration of sedatives, narcotics, or muscle relaxants may be necessary to provide adequate oxygenation and ventilation in some patients.
- Ensure patient is positioned properly for optimum ventilation. ***Rationale:*** Placement of the patient in a head-of-bed elevation of at least 30 degrees enhances diaphragmatic excursion, decreases intrathoracic pressure, and helps prevent aspiration and VAP.

Procedure for Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes

Steps	Rationale	Special Considerations
1. HH 2. PE		
Volume-Control Modes		
3. Select mode (see Box 29-1 and Table 29-1). The three traditional volume modes and mode settings are control mechanical ventilation (CMV), assist/control (A/C), and synchronized intermittent mandatory ventilation (SIMV). A. CMV: The intent of control ventilation is to have volume and rate ensured. As with all modes of ventilation, the patient is never completely "locked out" and can breathe between the control breaths, which is ensured by setting the sensitivity or flow triggers **(see Step 8)**. However, should control over ventilation be desired, sedation and often paralytic agents are provided to ensure the goal. B. A/C: Ventilation ensures that a control rate and volume are set. Patient-initiated breaths are delivered at the predetermined volume selected for the control breaths. C. SIMV: With this mode, a rate (fx) and Vt are set and are delivered in synchrony with the patient's respiratory effort. Between mandatory breaths, the patient may initiate breaths at a patient-determined volume and rate.	Mode selection varies depending on the clinical goal and clinician preference. Traditional volume modes that may provide total ventilatory support include control, SIMV, and A/C. With SIMV and A/C the ventilator rate must be high enough or the patient sedated so that spontaneous effort is not present. Other modes may also provide complete support depending on the settings. Remember that the goal is to offset the patient's work of breathing. See subsequent description of other modes and their application.	SIMV is often used in conjunction with PSV (to overcome circuit resistance and to decrease the work of breathing associated with spontaneous effort). The use of SIMV plus PSV has been associated with prolonged weaning times. If respiratory muscle rest is the goal with SIMV plus PSV, the level of PSV should be high enough to provide a Vt of 6–12 mL/kg and to maintain a total rate (IMV plus PSV breaths) of ≤20 breaths/min.[13,14,36,37,41,67,68,86]

Procedure continues on following page

Procedure **for Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes—*Continued***

Steps	Rationale	Special Considerations
4. Set Vt <10 mL/kg PBW. In patients with ARDS, Vt should be set at 4–6 mL/kg PBW. **(Level B*)**	Vt is selected in conjunction with fx to attain an MV 5–10 L/min with a $Paco_2$ 35–45 mm Hg. Large Vt values (12 mL/kg) have been associated with lung injury in patients with ARDS.[3,4,18,44,85]	When lower Vt values are used in an attempt to reduce lung injury, patients may need sedation and potentially muscle relaxants if they are dyssynchronous with the ventilator. Hypercarbia is an expected outcome of low Vt values.[7,26,27,78] Permissive hypercarbia is generally well tolerated in patients if the pH is reduced gradually (over 24–48 hours); pH around 7.2 is cited as an end point if tolerated.[77] Occasionally, bicarbonate infusions are used to keep the pH within an acceptable range. However, this temporizing maneuver may result in a higher $Paco_2$ because bicarbonate is metabolized into CO_2 and H_2O. Permissive hypercarbia should not be attempted in patients with elevated intracranial pressure or patients with myocardial ischemia, myocardial injury, or dysrhythmias. Patients who are allowed to become hypercarbic may need sedation and often muscle relaxants (paralytic agents) to control ventilation.
5. Select respiratory rate (frequency) between 10 and 20 breaths/min.	Vt and rate are selected to maintain an acceptable $Paco_2$ with an MV between 5 and 10 L/min. Generally, once Vt is selected, rate is the parameter adjusted to attain a desired $Paco_2$; the rate selected depends on whether or not the clinical goal is to rest or work the respiratory muscles.	When low Vts are used, as in ARDS, a higher rate may be necessary to maintain pH and $Paco_2$ at acceptable levels because smaller Vt provides less-efficient ventilation; the result is higher CO_2 and lower pH.[27,33,34,78]

*Level B: Well-designed, controlled studies with results that consistently support a specific action, intervention, or treatment.

Procedure for Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes—*Continued*

Steps	Rationale	Special Considerations
6. For I:E times, select inspiratory time (this parameter name is different, depending on the ventilator). Examples of parameter names include percent inspiratory time, inspiratory time, flow rate, and peak flow. I:E ratios are usually 1:2 or 1:3. A typical inspiratory time for an adult is in the range of 0.75–1.2 second.	Inspiratory flow refers to the speed with which Vt is delivered during inspiration. Increasing the flow rate shortens the inspiratory time. Conversely, slowing the flow rate lengthens the inspiratory time.	Generally, flow rates of approximately 50 L/min are used initially and adjusted to provide an inspiratory time that synchronizes with patient effort. Short inspiratory times and long expiratory times are necessary in patients with obstructive lung diseases (e.g., emphysema, asthma). In contrast, patients with restrictive diseases, such as ARDS, have noncompliant lungs. Longer inspiratory times enhance recruitment and prevent derecruitment.[1,3,16,59,65,79]
7. Adjust flow as necessary to attain patient ventilator synchrony.	Achieves the desired I:E ratio and comfortable breathing patterns.	
8. Set the sensitivity (trigger sensitivity). Most ventilators have pressure-sensing sensitivity mechanisms that trigger flow, which means that the patient must generate a decrease in the system pressure with an inspiratory effort. When the ventilator senses the drop in pressure, flow (or a breath) is delivered. If a pressure trigger is used, sensitivity is set between −1 and −2 cm H_2O pressure.	The more negative the number, the less sensitive the ventilator is to patient effort, which increases the patient respiratory workload and may lead to dyssynchrony.	When auto-PEEP is present, the patient has to generate a negative pressure equal to the set sensitivity plus the level of auto-PEEP. Auto-PEEP is common in patients with asthma, chronic obstructive pulmonary disease, and high respiratory rates and minute ventilation. This additional work may fatigue the patient. Patient ventilator dyssynchrony is likely.[6,62,65]
9. If the ventilator has a flow-triggering option, select the flow trigger in L/min. The smaller the number, the more sensitive the ventilator. Flow triggering is set in conjunction with a base flow (flow in L/min that is provided between ventilator breaths). Flow rate is monitored in the expiratory limb of the ventilator. When flow is disrupted during a spontaneous breath, a decrease in flow downstream is sensed; additional flow or a breath is delivered.	Flow triggering has been associated with faster ventilator response times and less work of breathing than pressure sensing.[6]	
10. Set Fio_2 to 0.60–1.0 (60%–100%), if Pao_2 is unknown. A. Adjust Fio_2 downward as tolerated by monitoring Sao_2 and arterial blood gas values.	Initiation of PPV with maximal oxygen concentration avoids hypoxemia while optimal ventilator settings are being determined and evaluated. In addition, it permits measurement of the percentage of venous admixture (shunt), which provides an estimate of the severity of the gas-exchange abnormality.	The goal is an Fio_2 ≤0.5; high levels of Fio_2 result in increased risk of oxygen toxicity, absorption atelectasis, and reduction of surfactant synthesis.[30,42,48]

Procedure continues on following page

Procedure for Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes—*Continued*

Steps	Rationale	Special Considerations
11. Select PEEP or continuous positive airway pressure (CPAP) level. Initial setting is often 5 cm H_2O. A. PEEP may be adjusted as needed after evaluation of tolerance (e.g., Sao_2, Pao_2, physical assessment). PEEP levels are increased to restore FRC and allow for reduction of Fio_2 to safe levels (i.e., ≤0.5) to decrease the risk of oxygen toxicity.	A PEEP level of 5 cm H_2O is considered physiological (essentially the amount of pressure at end exhalation normally provided by the glottis). Higher levels of PEEP may be used to prevent alveolar collapse during the expiratory phase of the ventilator breath in atelectasis or ARDS.	High levels of PEEP ≥10 cm H_2O rarely should be interrupted because reestablishment of FRC (and Pao_2) may take hours. Prevention of this derecruitment in the patient with ARDS is especially important. Super-PEEP levels (i.e., ≥20 cm H_2O) may be necessary in patients with noncompliant lungs (e.g., patients with ARDS) to prevent lung injury. The repetitive opening and closing of stiff alveoli is thought to result in alveolar damage; to that end, the use of high PEEP levels to maintain alveolar distention and to prevent injury during PPV is considered a protective lung strategy.[3–5,12,33,34,44] In general, when high PEEP levels are used, Vt values are lower than normal and subsequent hypercarbia may be anticipated. Use of muscle relaxants, sedatives, and narcotics is often necessary to prevent patient spontaneous breathing.
B. CPAP is often referred to as PEEP without the positive pressure breaths. CPAP is a spontaneous breathing mode that provides continuous pressure throughout the ventilator cycle. It is commonly used as a mode for spontaneous-breathing weaning trials.	Patients who are spontaneously breathing may not require delivery of ventilator breaths, but positive pressure applied to the airways and alveoli to prevent collapse or obstruction during exhalation.	Generally, the pressure levels of CPAP are relatively low but vary with individual patient conditions. A traditional application of CPAP is for obstructive sleep apnea (OSA) through a noninvasive mask or prongs. When used for OSA, the mode provides a pneumatic splint to the airways to prevent obstruction during sleep.
Pressure Modes (Invasive)		
1. Select mode: PSV, pressure-controlled/inverse ratio ventilation (PC/IRV), volume-assured pressure support option, APRV, adaptive support ventilation, proportional assist ventilation (PAV), automatic tube compensation (ATC), or high-frequency oscillation (HFO).	Mode selection depends on clinical goals, mode availability (these vary widely with different ventilators), and clinician preference. To date, no mode has emerged as superior.[17,81,89] Modes include those designed for spontaneous breathing and those for control or partial control of ventilation.	Many new modes that use microprocessor technology are available on specific ventilators. Although many are similar to traditional modes, others are not. Parameter names also vary. Refer to specific ventilator operating manuals and websites for details not contained in this procedure.

Procedure for Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes—*Continued*

Steps	Rationale	Special Considerations
2. PSV augments spontaneous respirations with a clinician-selected pressure level. Adjust the PSV level to attain a Vt <10 mL/kg PBW with a spontaneous respiratory rate (RR) ≤20 breaths/min (if respiratory muscle rest is desired; this is called PSVmax). Decrease PSV level during weaning trials as tolerated by patient. Tolerance criteria for trials may be predetermined by protocols or on an individual basis. Often during trials, Vt values are allowed to be lower (i.e., 5–8 mL/kg) and RR higher (i.e., 25–30 breaths/min) than when rest is the goal. However, these parameters are always evaluated in conjunction with other signs and symptoms of fatigue and intolerance.[13,14,41,61,63,95] **(Level B*)**	Pressure level in conjunction with compliance and resistance determines delivered Vt.	PSV sometimes is used between IMV breaths to offset the work of breathing associated with artificial airways and circuits during spontaneous breathing. PSV generally is considered a weaning mode of ventilation, which necessitates stability of patient condition. PSV may be used in patients with less stable conditions provided that close attention is given to changes in Vt and RR. High levels of PSV may provide respiratory muscle unloading.
A. Set sensitivity (as with volume ventilation).	The more negative the number, the less sensitive the ventilator is to patient effort, which increases the patient respiratory workload and may lead to dyssynchrony.	
B. Set Fio_2 (as with volume ventilation).	Initiation of PPV with maximal oxygen concentration avoids hypoxemia while optimal ventilator settings are being determined and evaluated. In addition, it permits measurement of the percentage of venous admixture (shunt), which provides an estimate of the severity of the gas-exchange abnormality.	
C. Set PEEP (as with volume ventilation).	A PEEP level of 5 cm H_2O is considered physiological (essentially the amount of pressure at end exhalation normally provided by the glottis). Higher levels of PEEP may be used to prevent alveolar collapse during the expiratory phase of the ventilator breath in atelectasis or ARDS.	

*Level B: Well-designed, controlled studies with results that consistently support a specific action, intervention, or treatment.

Procedure continues on following page

Procedure **for Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes—*Continued***

Steps	Rationale	Special Considerations
3. PC/IRV are both control modes of ventilation. With these modes, a pressure level is selected; the rate and inspiratory time are selected as well. They were originally used to manage patients with ARDS in whom the goal was to limit the pressure level. In addition, the decelerating flow pattern of the modes was considered desirable. PC/IRV was used to enhance lung recruitment by prolonging inspiration. Expiration was shortened, thereby decreasing the potential for derecruitment.	Absolute pressure level is the sum of the inspiratory pressure level (IPL) and PEEP.	If the clinical goal is to ensure a plateau pressure of ≤30 cm H_2O, the pressure level may be lowered gradually over 24–48 hours to prevent sudden changes in $Paco_2$ and pH.[50,76,78]
A. Select IPL. With this pressure mode, the level of pressure support is often identified as IPL versus PSV.	Rate and IPL determine MV.	
B. Select rate.	Vt and rate are selected to maintain an acceptable $Paco_2$ with an MV between 5 and 10 L/min. Generally, once Vt is selected, rate is the parameter adjusted to attain a desired $Paco_2$; the rate selected depends on whether or not the clinical goal is to rest or work the respiratory muscles.	When low Vts are used, as in ARDS, a higher rate may be necessary to maintain pH and $Paco_2$ at acceptable levels because smaller Vts provide less-efficient ventilation; the result is higher CO_2 and lower pH.[27,33,34,79]
C. Select inspiratory time or inverse I:E ratio (ventilators vary).	I:E ratios are set at 1:1, 2:1, 3:1, or 4:1 by selecting the appropriate inspiratory time. Ratios are adjusted upward to improve shunt and oxygenation. Blood pressure may be adversely affected. Rate is usually relatively high (e.g., 20–25 breaths/min).	Generally, clinicians start with 1:1 ratios and increase as necessary to improve oxygenation. A limiting factor related to prolonged inspiratory times is hemodynamic compromise and hypotension, which is generally why the use of ratios >2:1 rarely is seen clinically. Auto-PEEP is common and may be a desired outcome of PC/IRV.[66,76]
D. Select PEEP level. When transitioning from volume ventilation to PC/IRV, the PEEP initially is maintained at the level used previously until the effect of the IRV is assessed. **(Level C*)**	Because IRV may result in auto-PEEP, evaluation of the total amount of PEEP present is important. This can be measured through the performance of an expiratory hold maneuver on the ventilator.	Auto-PEEP generated by IRV is expected and helpful in expanding collapsed alveoli.

*Level C: Qualitative studies, descriptive or correlational studies, integrative reviews, systematic reviews, or randomized controlled trials with inconsistent results.

Procedure **for Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes—*Continued***

Steps	Rationale	Special Considerations
E. Set Fio_2 to 0.60–1.0 (60%–100%) if Pao_2 is unknown. Adjust Fio_2 downward as tolerated by monitoring Sao_2 and arterial blood gas values.	Initiation of PPV with maximal oxygen concentration avoids hypoxemia while optimal ventilator settings are being determined and evaluated. In addition, it permits measurement of the percentage of venous admixture (shunt), which provides an estimate of the severity of the gas-exchange abnormality.	The goal is an Fio_2 ≤0.5; high levels of Fio_2 result in increased risk of oxygen toxicity, absorption atelectasis, and reduction of surfactant synthesis.[30,42,48]
F. Set sensitivity (as with volume ventilation). **(Level B*)**	The goal of PC/IRV is to improve oxygenation and allow for reduction of Fio_2 to ≤0.5.[17,50,76,87] This is done in conjunction with the addition of PEEP. Always set sensitivity so that the patient can get a breath if needed.	If controlled ventilation is the goal, chemical relaxation may be necessary in conjunction with sedatives and narcotics. Patient tolerance of IRV (i.e., the prolonged inspiratory times) is unlikely without such interventions. Remember that IRV may result in auto-PEEP (which may be a desirable outcome of the mode). Regardless, auto-PEEP should be anticipated and measured regularly.
4. Dual-control pressure mode options are pressure modes that assure a minimum set tidal volume. The breath delivery varies with the specific mode. For dual control pressure support options, parameter selection (i.e., pressure, volume, rate) is specific to the ventilator; however, selection of desired (or guaranteed) Vt is required. Some ventilators also require selection of the pressure level. Spontaneous breathing modes and controlled modes are available.[2,11,15,17, 58,87,90] **(Level C*)**	Specific names vary depending on ventilator manufacturer. Examples include Pressure Augmentation (Carefusion, San Diego, CA) and Volume Support and Pressure Regulated Volume Control (Maquet, Wayne, NJ); similar modes are available on other manufacturers' ventilators.	Few studies have been accomplished that show the superiority of these modes. In addition, many modes are available only on specific ventilators. These modes are complex; concurrent use of pressure, flow, and volume waveform displays may be necessary to assess the modes accurately. Refer to specific ventilator operating manuals or websites for additional information.
A. For volume-guaranteed pressure options, please see specific ventilator manual for parameter setting. **(Level M*)**		See Table 29-1 parameters for volume-guaranteed pressure options.
B. PEEP, Fio_2 and sensitivity are set as per volume ventilation, as are rate and inspiratory time if the mode is a control mode. However, the desired Vt must be selected as well.[17]		

*Level B: Well-designed, controlled studies with results that consistently support a specific action, intervention, or treatment.
*Level C: Qualitative studies, descriptive or correlational studies, integrative reviews, systematic reviews, or randomized controlled trials with inconsistent results.
*Level M: Manufacturer's recommendations only.

Procedure continues on following page

Procedure for Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes—*Continued*

Steps	Rationale	Special Considerations
5. Biphasic and APRV ventilation are relatively new modes that appear on selected ventilators. Used most commonly for patients with ARDS, the modes use relatively high levels of pressure to recruit the lung (restore FRC). APRV is a type of biphasic ventilation with a very short expiratory (release) time.[56,69,71,80,81,88, 89,97] **(Level C*)**	Although the modes appear to be safe and effective, randomized controlled trials are not available. Regardless, one big advantage to these modes is that they do not require that the patient be heavily sedated or paralyzed. Spontaneous breathing is expected. Generally, the patient's breathing pattern is rapid.	Few studies have been accomplished that show the superiority of these modes. In addition, many modes are available on specific ventilators. These ventilatory modes require a steep learning curve on the part of physician, advanced practice nurse, and other healthcare professionals who care for the patients; as with most new forms of ventilation, education of staff should occur before the mode is used. Although the appeal of APRV and biphasic ventilation is in part because the patient may breath spontaneously, it is unclear whether the associated workload is advantageous.[72]
A. With APRV, a high level of CPAP is selected, and brief expiratory "releases" are provided at set intervals (similar to setting a RR); the releases are very brief (≤1.5 seconds).	The high level of CPAP helps "recruit" the lung. Alveolar filling and emptying time constants in the ARDS lung vary; the brief expiratory releases provided with APRV allow for more uniform emptying throughout the lung and ultimately improved gas distribution. An additional benefit of periodic airway pressure releases is that they may decrease the potential negative effect of the high CPAP level on venous return. At the high CPAP level, the patient may take spontaneous breaths at the rate that they require.[47,56,70,84]	On some machines, the formal mode name APRV may not be used. It may be incorporated under biphasic ventilation.
B. With the biphasic mode, two different levels of PEEP are selected and are called high-PEEP and low-PEEP. This is really an interaction of traditional PC ventilation. A rate is set, and the cycles look similar to PC or PC/IRV ventilation (depending on the I:E ratio). The major difference is that flow is available to the patient for spontaneous breathing at both pressure levels. In addition, Pressure Support (PS) may be added to assist in decreasing the work associated with spontaneous breathing.[17,56,81] **(Level E*)**	The theoretical advantage of this mode over traditional PC/IRV is that the mode may fully support lung recruitment while still allowing for spontaneous breathing at the two pressure levels.[17,56,81] In contrast to traditional PC/IRV, the patient receives additional flow adequate to meet inspiratory demands throughout the ventilatory cycle. Deterioration with spontaneous effort is less likely; as a result, heavy sedation and paralytics may be avoided.	APRV mode as described previously may be achieved in ventilators with biphasic modes. Biphasic modes have many trade names (BiVent, BiLevel, BiPAP, DuoPap). The APRV settings are achieved on each type of ventilator in a slightly different manner. Refer to the specific ventilator manual for parameter settings.

*Level C: Qualitative studies, descriptive or correlational studies, integrative reviews, systematic reviews, or randomized controlled trials with inconsistent results.
*Level E: Multiple case reports, theory-based evidence from expert opinions, or peer-reviewed professional organizational standards without clinical studies to support recommendations.

Procedure for Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes—*Continued*

Steps	Rationale	Special Considerations
C. For APRV and biphasic mode options, please see specific ventilator manual for parameter settings. (**Level M***)	Manufacturers have different names for parameters settings. Although there are similarities among the ventilator models, it is important to be familiar with the ventilators used in your practice area.	
D. Specific APRV settings: i. Pressure high (P_{HIGH}), which is the high-PEEP level. May be set at the measured plateau pressure to start. ii. Pressure low (P_{LOW}), which is the low-PEEP level, is generally set at 0 cm H_2O. iii. Time high (T_{HIGH}): 4–6 seconds. iv. Time low (T_{LOW}): 0.4–0.8 seconds (keep <1.5 seconds). Rate is determined by the combined inspiratory (T_{HIGH}) expiratory time (T_{LOW}).	The combination of the inspiratory pressure (P^{HIGH}) and inspiratory time (T^{HIGH}) determine the machine-delivered tidal volume. The expiratory time (T_{LOW}) determines the duration of exhalation. In APRV, the expiratory time is very short (usually <1.0 second). Therefore, the P_{LOW} is set at 0 cm H_20, because there is insufficient time for the alveoli to collapse before the next breath.	Patients on APRV should be transported on the ventilator to avoid alveolar derecruitment associated with disconnection from the ventilator circuit. This can occur when the patient is transitioned to a bag-valve mask for transport. If the patient must be disconnect from the ventilator, the endotracheal tube may be clamped during the inspiratory phase before circuit disconnection to reduce the chance of alveolar derecruitment.
E. Specific biphasic settings: i. Pressure high (P_{HIGH}) Set to achieve the desired tidal volume for the patient ii. Pressure low (P_{LOW}). Set to attain best PEEP iii. Rate: 8–10 iv. Inspiratory time (T_{HIGH}): 1.5 seconds or set T_{HIGH}/T_{LOW} ratio (I:E ratio) v. Fio_2.	The combination of the inspiratory pressure (P^{HIGH}) and inspiratory time (T^{HIGH}) determines the machine-delivered tidal volume. The expiratory time (T_{LOW}) determines the duration of exhalation. In biphasic (non-APRV), the I:E ratio is usually set at conventional ratios (1:2 or 1:3).	
F. Fio_2 and sensitivity are set as outlined in **Steps 8 and 9** above under Volume Control Modes.	See Steps 8 and 9.	

*Level M: Manufacturer's recommendations only.

Procedure continues on following page

Procedure **for Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes—*Continued***

Steps	Rationale	Special Considerations
6. Adaptive support ventilation: The mode is referred to by the ventilator manufacturer as "intelligent ventilation" and is designed to assess lung mechanics on a breath-to-breath basis (controlled loop ventilation) for spontaneous and control settings. It achieves an optimal Vt by automatically adjusting mandatory respiratory fx and inspiratory pressure. Built into the mode are algorithms that are "lung protective." The protective strategies are designed to minimize auto-PEEP and prevent apnea, tachypnea, excessive dead space, and excessively large breaths.[2,15,19,25,58,90] **(Level C*)**	The working concept with this mode is that the patient will breathe at fx and Vt that minimize elastic and resistive loads. In all modes, the opportunity for spontaneous breathing is promoted (the user does not have to switch back and forth from one mode to another to encourage spontaneous breathing because this is automatically done). Thus the interactions required by the clinician are few.	The higher the %MinVol, the higher the level of support provided to the patient.
Parameters to set include predicted body weight, minute volume (%MinVol), and high pressure limit in addition to Fio_2. **(Level M*)**		
7. PAV: The concept with this pressure mode is to prevent fatiguing workloads although still allowing the patient to breathe spontaneously. Current PAV modes take measurements throughout the inspiratory cycle and automatically adjust the pressure, flow, and volume proportionally to offset the resistance and elastance of the system with each inspiration (patient and circuit). Different names for the modes are provided by specific manufacturers, and parameters that require adjustment vary somewhat between the ventilators. **(Level M)**	PAV may provide a more physiological breathing pattern.[10,17,25,45,60,94] The modes recognize that patient effort reflects work and demand, and base the adjustments accordingly. The percent of assist is adjusted to a higher percent if less work is desired and a lower percent if more work is necessary.	Few studies have been accomplished that show the superiority of this mode. In addition, many modes are available on specific ventilators.
Parameter settings include PEEP, Fio_2, percent volume assist, and percent flow assist.		
8. ATC is a ventilatory adjunct rather than a mode and is available on many current ventilators. It is designed to overcome the work of breathing imposed by the artificial airway. Parameters include internal diameter size of the endotracheal tube and the desired percent of compensation.[17, 35,93] **(Level C)**	ATC adjusts the pressure (proportional to tube resistance) needed to provide a variable fast inspiratory flow during spontaneous breathing.	ATC is increased during inspiration and lowered during expiration, thus decreasing the work of breathing as a result of tube resistance. In some patients, the use of ATC has resulted in auto-PEEP.[35,93]

*Level C: Qualitative studies, descriptive or correlational studies, integrative reviews, systematic reviews, or randomized controlled trials with inconsistent results.
*Level M: Manufacturer's recommendations only.

Procedure for Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes—*Continued*

Steps	Rationale	Special Considerations
9. High-frequency oscillation ventilation (HFOV) differs significantly from conventional ventilator modes or mode options. HFOV does not require bulk movement of volume in and out of the lungs; rather, a bias flow of gases is provided, and an oscillator disperses the gases throughout the lung in what has been called augmented dispersion at high frequencies.[31,32,39,83] **(Level C*)**	The method achieves oscillation of the lung around a constant airway pressure (essentially opening the lung and keeping it open).[31,32,39,83]	Studies to date have not shown the superiority of this mode over traditional modes in adults with ARDS. The mode is safe if appropriately applied by those with experience in its use; however, it is not easily understood by clinicians. Especially of concern is the fact that patients on the mode often need sedation and neuromuscular blockade.
The parameters for HFOV are different from conventional ventilation and are outlined in the following.		
A. Bias flow: flow in L/min (usual range, 40–50 L/min).	The bias flow combined with the oscillatory activity (extremely rapid pulses in a back and forth motion) results in the constant infusion of fresh gases and evacuation of old gases.	
B. Oscillatory frequency (fx): In Hz (usual range, 3–6 Hz).[20,39,40]	Increases in frequency in HFOV actually reduces CO_2 elimination because there is less time for CO_2 to be removed from the lungs between the oscillatory breaths. This is different from conventional ventilation, with which an increase in rate may reduce CO_2.[20,39,40]	1 Hz is equivalent to 60 breaths.
C. Mean airway pressure: generally slightly greater than conventional ventilation initially.		
D. ΔP: The change in pressure or pressure amplitude (generally adjusted to achieve chest wall vibration).	ΔP and fx are adjusted to achieve $Paco_2$ within a target range.	
E. Fio_2 level and PEEP level: as in conventional ventilation (generally PEEP is >10).		
F. Percent inspiratory time: controls the percentage of time the oscillator spends in the inspiratory phase. A starting place is 33%.		
10. Discard used supplies and remove PE.		
11. HH		
Humidity		
1. Humidity is essential to prevent the drying effect of the gases provided by the ventilator.	Inspired gases may be humidified with the use of standard cascade or high-volume humidifiers. Many institutions use disposable HMEs in place of conventional humidifiers.	HMEs are popular because they decrease the risk of infection and are inexpensive.

*Level C: Qualitative studies, descriptive or correlational studies, integrative reviews, systematic reviews, or randomized controlled trials with inconsistent results.

Procedure continues on following page

Procedure for Invasive Mechanical Ventilation (Through an Artificial Airway): Volume and Pressure Modes—*Continued*

Steps	Rationale	Special Considerations
2. For conventional humidifiers, ensure that the humidifier has adequate fluid (sterile distilled water) and that the thermostat setting is adjusted according to manufacturer's recommendations. **(Level M*)**	Gases generally are humidified before entering the artificial airway. Temperature is measured at the patient's airway; temperatures between 35°C and 37°C (95°F and 98°F) are considered optimal.[72]	Cool circuits may be tolerated well in patients without secretions. In patients with thick or tenacious secretions, attention to inspired temperature is important to prevent mucus plugging; circuit temperatures may need to be closer to body temperature (37°C versus 35°C) in these cases.
3. HMEs are placed between the airway and the ventilator circuit.	The moisture in warmed exhaled gases passes through the vast surface area of the HME and condenses. With inspiration, dry gases pass through the HME and become humidified. The use of HMEs has been associated with decreased incidence of ventilator-associated pneumonias in patients on ventilation.[9,29,51,91,92] **(Level B*)**	
A. Change HMEs per manufacturer's instructions. **(Level M*)**	The longer the HME is in line, the more efficient the humidification; however, inspiratory resistance increases over time. HMEs are often changed every 2–3 days (refer to manufacturer's instructions).	In patients undergoing weaning, the additional resistive load added by these humidifiers may preclude their use.[51,55,64,77]
B. Do not use if secretions are copious or bloody.	Obstruction is possible, and HMEs are not indicated in these conditions.	
4. Discard used supplies and remove PE.		
5. HH		

*Level B: Well-designed, controlled studies with results that consistently support a specific action, intervention, or treatment.
*Level M: Manufacturer's recommendations only.

Expected Outcomes

- Maintenance of adequate pH and $Paco_2$
- Maintenance of adequate Pao_2
- Maintenance of adequate breathing pattern
- Respiratory muscle rest

Unexpected Outcomes

- Abnormal pH, $Paco_2$, and Pao_2
- Hemodynamic instability
- Pulmonary barotrauma
- Inadvertent extubation
- Malpositioned endotracheal tube
- Nosocomial lung infection
- Acid-base disturbance
- Respiratory muscle fatigue

Patient Monitoring and Care

Steps	Rationale	Reportable Conditions
		These conditions should be reported if they persist despite nursing interventions.
1. Ensure activation of all alarms each shift (see Box 29-2).	Ensures patient safety.	• Continued activation of alarms
2. Check for secure stabilization and maintenance of endotracheal or tracheostomy tube.	Reduces risk of inadvertent extubation or decannulation.	• Unplanned extubation or decannulation, • Dislodgment of airway
3. Monitor in-line thermometer to maintain inspired gas temperature (in the range 35–37°C [95–98°F]).	Reduces risk of thermal injury from overheated inspired gas and risk of poor humidity from underheated inspired gas.	• Temperature <35°C or >37°C
4. Keep ventilator tubing clear of condensation. Drain any condensation in the ventilator tubing toward condensation-collection reservoirs on the expiratory limb of the circuit (clean to dirty). Avoid draining condensation back toward the patient. (dirty to clean).	Reduces risk of respiratory infection by decreasing inhalation of contaminated water droplets.	• Continued condensation
5. Ensure availability of self-inflating manual resuscitation bag-valve device attached to supplemental oxygen at the head of the bed. Attach or adjust PEEP valve if the patient is on >5 cm H_2O.	Provides capability for immediate delivering of ventilation and oxygenation to relieve acute respiratory distress caused by hypoxemia or acidosis.	• Inability to oxygenate or ventilate
6. Check ventilator for baseline Fio_2, peak inspiratory pressure (PIP), Vt, fx, and alarm activation with initial assessment and after removal of ventilator from patient for suctioning, bagging, or draining ventilator tubing.	Ensures that prescribed ventilator parameters are used (e.g., 100% oxygen used for suctioning is not inadvertently delivered after suctioning procedure), provides diagnostic data to evaluate interventions (e.g., PIP is reduced after suctioning or bagging), and ensures that the monitoring and warning functions of the ventilator are functional (i.e., alarms).	• Fio_2, PIP, Vt, or fx settings different from prescribed
7. Explore any changes in peak inspiratory pressure >4 cm H_2O or decreased (sustained) Vt on PSV. Immediately explore the cause of high-pressure alarms.	Acute changes in PIP or Vt may indicate mechanical malfunction, such as tubing disconnection, cuff or connector leaks, tubing or airway kinks, or changes in resistance and compliance. Always consider possibility of tension pneumothorax.	• Unexplained high-pressure alarms
8. Place bite-block between the teeth if the patient is biting on the oral endotracheal tube.	An oral airway serves the same purpose but may not be tolerated as well as the bite-block because it may induce gagging.	• Biting on tube

Procedure continues on following page

Patient Monitoring and Care —*Continued*

Steps	Rationale	Reportable Conditions
9. Evaluate patient-ventilator dyssynchrony by manually ventilating the patient with a self-inflating manual resuscitation bag-valve device.	By taking the patient off the ventilator for manual ventilation, synchrony may be accomplished more quickly than on the ventilator. This intervention may reduce risk of barotrauma and cardiovascular depression. If patient breathes in synchrony with bagging, consider changes in ventilatory parameters. If patient does not breathe synchronously with bagging, explore differential diagnoses of problems distal to the airway. Respiratory care practitioner, nurse practitioner, or physician consultation may be necessary.	• Patient-ventilator dyssynchrony
10. Assess for signs of atelectasis.	May occur as a result of hypoventilation as well as mucous plugging of bronchioles. Early detection of atelectasis indicates the need for alteration to promote resolution (tidal volume adjustment, recruitment maneuver, PEEP adjustment).	• Localized changes in auscultation (increased or bronchial breath sounds) • Localized dullness to percussion • Increased breathing effort • Tracheal deviation toward the side of abnormal findings • Increased peak and plateau pressures • Decreased compliance • Decreased Pao_2 or Sao_2 (with constant ventilator parameters) • Localized consolidation ("whiteout," opacity) on chest radiograph
11. Assess for signs and symptoms of pulmonary barotrauma (i.e., pneumothorax).	Early detection of pneumothorax is essential to minimize progression to cardiac tamponade and death. Tension pneumothorax requires immediate emergency decompression with a large-bore needle (i.e., 14-gauge) into the second or third intercostal space, midclavicular line on the affected side, followed by immediate chest tube placement.	• Acute, increasing, or severe dyspnea • Restlessness • Agitation • Localized changes in auscultation (decreased or absent breath sounds) on the affected side • Localized hyperresonance or tympany to percussion on the affected side • Elevated chest on the affected side • Increased breathing effort • Tracheal deviation away from the side of abnormal findings • Increased peak and plateau pressures • Decreased compliance • Decreased Pao_2 or Sao_2 • Subcutaneous emphysema • Localized increased lucency with absent lung markings on chest radiograph. • Hypotension

Patient Monitoring and Care —*Continued*

Steps	Rationale	Reportable Conditions
12. Assess for signs of volume-pressure trauma that are consistent with ARDS.	Volume-pressure trauma is assumed if the patient has the last three criteria noted. Ventilatory management should focus on ensuring that lung-protective strategies are in place so that additional injury does not ensue. Some examples include Vt of 6 mL/kg and lung recruitment with PEEP. In general, these strategies result in hypercarbia because ventilation is not efficient.	• Acute, increasing, or severe dyspnea • Restlessness • Agitation • Generalized crackles, especially in the dependent portions of the lung • Refractory hypoxemia • Increased peak and plateau pressures • Decreased compliance • Decreased Pao_2 or Sao_2 • Bilateral diffuse lung opacity on chest radiograph or computer axial tomography (CAT) scan of the chest • Pao_2:Fio_2 of <200 • A noncardiac etiology for the "wet" lung
13. Monitor for signs and symptoms of acute respiratory distress, hypoxemia, hypercarbia, and fatigue.	Respiratory distress indicates the need for changes in PPV. While troubleshooting the difficulties, support ventilation via a manual self-inflating resuscitation bag if necessary.	• Chest-abdominal dyssynchrony • Shallow or irregular respirations • Tachypnea, bradypnea, or dyspnea • Decreased mental status • Restlessness, confusion, lethargy • Increasing or decreasing arterial blood pressure • Tachycardia • Atrial or ventricular dysrhythmias • Significant changes in arterial pH, Pao_2, $Paco_2$, or Sao_2
14. Assess for signs and symptoms of a malpositioned endotracheal tube.	Early detection and correction of a malpositioned endotracheal tube can prevent inadvertent extubation, atelectasis, barotrauma, and problems with gas exchange.	• Dyspnea • Restlessness or agitation • Unilateral decreased or absent breath sounds • Unilateral dullness to percussion • Increased breathing effort • Asymmetrical chest expansion • Increased PIP • Changes in endotracheal tube depth • Radiographic evidence of malposition. • Decreased Sao_2
15. Assess for signs and symptoms of inadvertent extubation.	Inadvertent extubation is sometimes obvious (e.g., the endotracheal tube is in the patient's hand). Often, the tip of the endotracheal tube is in the hypopharynx or in the esophagus; however, an inadvertent extubation may not be immediately apparent. Reintubation may be necessary, although some patients may not need reintubation. If reintubation is necessary, ventilation and oxygenation are assisted with a manual self-inflating resuscitation bag-valve device and face mask.	• Vocalization • Activated ventilator alarms • Low pressure • Low minute ventilation • Inability to deliver preset pressure • Decreased or absent breath sounds • Gastric distention • Changes in endotracheal tube depth • Signs and symptoms of inadequate ventilation, oxygenation, and breathing pattern

Procedure continues on following page

Patient Monitoring and Care —*Continued*

Steps	Rationale	Reportable Conditions
16. Evaluate the patient's need for long-term mechanical ventilation.	This evaluation allows the nurse to anticipate patient and family needs for the patient's discharge to an extended-care facility, rehabilitation center, or home on PPV.	• Spontaneous breathing trial failure • Inability to wean from the ventilator
17. Observe for hemodynamic changes associated with increased Vt, PEEP/CPAP, or recruitment maneuver.	PPV can cause decreased venous return and afterload because of the increase in intrathoracic pressure. This mechanism often manifests immediately after initiation of mechanical ventilation and with large Vt, increases in PEEP or CPAP levels and manual hyperinflation techniques. Cardiovascular depression associated with manual or periodic ventilator hyperinflation is immediately reversible with cessation of hyperinflation. Decreases in blood pressure with PPV also may be seen with hypovolemia. Always consider potential for pneumothorax with acute changes.	• Decreased blood pressure • Change in heart rate (increase or decrease of >10% of baseline) • Weak peripheral pulses, pulsus paradoxus, or decreased pulse pressure • Decreased cardiac output • Decreased mixed venous oxygen tension • Increased arterial-venous oxygen difference

Documentation

Documentation should include the following:

- Patient and family education
- Date and time ventilatory assistance was instituted
- Ventilator settings, including the following: Fio_2, mode of ventilation, Vt, respiratory frequency (total and mandatory), PEEP level, I:E ratio or inspiratory time, PIP, dynamic compliance, and static compliance
- Arterial blood gas results
- Sao_2 readings
- Reason for initiation of PPV
- Assessment of pain, interventions and response to intervention
- Patient responses to PPV (including the patient's indication of level of comfort and respiratory symptoms)
- Depth of endotracheal tube at the teeth or gum
- Hemodynamic values
- Vital signs
- Respiratory assessment findings
- Unexpected outcomes
- Nursing interventions
- Degree of backrest elevation
- Humidifier change maintenance

References and Additional Readings

For a complete list of references and additional readings for this procedure, scan this QR code with any freely available smartphone code reader app, or visit http://booksite.elsevier.com/9780323376624.

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