AN INTRODUCTION
TO MECHANICAL VENTILATION

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ABSTRACT

Mechanical ventilation is a life-saving treatment to support patients that are unable to ventilate and oxygenate on their own. The skills required by health teams to manage a ventilation unit are typically standardized to ensure safe handling of ventilation equipment and for proper management of patients during their course of care. Mechanically ventilated patients often receive medication for sedation and pain control that require a qualified interdisciplinary team to administer and evaluate outcomes. Therapeutic modalities of mechanical ventilation and pharmacology needed to support treatment and patient comfort are reviewed.
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Pharmacology content is 0.5 hours (30 minutes).

Statement of Learning Need
Health clinicians require up-to-date information about basic aspects of mechanical ventilation, specifically, the indications for use, complications, basic care, medication management and weaning of the patient from the ventilator. Clinicians working in the Intensive Care Unit need to know the commonly used terms of mechanical ventilation and respiratory care.
Course Purpose

To provide clinicians working in the Intensive Care Unit with basic knowledge of how to care for the mechanically ventilated patient.

Continuing Nursing Education (CNE) Target Audience

Advanced Practice Registered Nurses and Registered Nurses

(Interdisciplinary Health Team Members, including Vocational Nurses and Medical Assistants may obtain a Certificate of Completion)

Course Author & Planning Team Conflict of Interest Disclosures

Dana Bartlett, BSN, MSN, MA, CSPI, William S. Cook, PhD, Douglas Lawrence, MA, Susan DePasquale, MSN, FPMHNP-BC all have no disclosures

Acknowledgement of Commercial Support

There is no commercial support for this course.

Please take time to complete a self-assessment of knowledge, on page 4, sample questions before reading the article. Opportunity to complete a self-assessment of knowledge learned will be provided at the end of the course.
1. The amount of oxygen delivered by a ventilator is
   a. fraction of inspired oxygen.
   b. positive expiratory volume.
   c. inspiratory pressure.
   d. tidal volume.

2. Which of the following is a complication of mechanical ventilation?
   a. Cellulitis.
   b. Atrial fibrillation.
   c. Barotrauma.
   d. Pulmonary fibrosis.

3. True or False: High arterial oxygen levels are always benign.
   a. True
   b. False

4. Common complications of mechanical ventilation include
   a. ventricular arrhythmias and hypotension.
   b. delirium and hypothermia.
   c. stress ulcers and renal failure.
   d. sinus infections and ventilator-associated pneumonia.

5. Suctioning a mechanically ventilated patient should be done
   a. every two hours.
   b. only when it is clinically indicated.
   c. if the patient has a temperature > 102° F.
   d. when the patient is receiving sedation with a benzodiazepine.
**Introduction**

Mechanical ventilation is a life-saving treatment to support patients when they are unable to ventilate and oxygenate on their own. The skills required by health teams, in particular of nurses, to manage a ventilation unit are typically standardized to ensure safe handling of ventilation equipment and for proper management of patients during their course of care. This article discusses various components of care, pharmacological approaches to calm and treat pain and methods to wean the patient from mechanical ventilation. Appendix A, at the end of the course, explains some of the commonly used terms of mechanical ventilation and respiratory care.

**What Is Mechanical Ventilation?**

Mechanical ventilation uses endotracheal intubation and a ventilator to replace spontaneous respiration and ventilation. The ventilator provides the functions of the respiratory muscles; the endotracheal tube establishes a patent and unobstructed airway; and, the exogenous oxygen source gives a patient a therapeutic concentration of the gas. (Note: The terms respiration and ventilation will be discussed in Appendix A at the end of the article).

**Learning Break:**
Mechanical ventilation can be done non-invasively by using a facemask and oxygen, and endotracheal intubation can be used without a ventilator. In this module mechanical ventilation refers to endotracheal intubation and the use of a ventilator.
Indications For The Use Of Mechanical Ventilation

Mechanical ventilation improves gas exchange and decreases a patient’s work of breathing, and it is used to treat patients who are having acute or chronic respiratory distress.\(^1\) The definition of respiratory distress is somewhat fluid, but it can reasonably be described as insufficient oxygenation and/or insufficient alveolar ventilation, reflected by a Pa\(_{O_2}\) of less than 60 mm Hg, sometimes in conjunction with a Pa\(_{CO_2}\) of >50 mm Hg.\(^1,2\)

General indications for the use of mechanical ventilation are listed in Table 1.\(^2\) These indications primarily refer to patients in acute respiratory distress.

Table 1: Indications for Mechanical Ventilation

<table>
<thead>
<tr>
<th>Apnea</th>
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<tbody>
<tr>
<td>Clinical signs of increased work of breathing</td>
</tr>
<tr>
<td>Hypoxemic respiratory failure</td>
</tr>
<tr>
<td>Hypercapnic respiratory failure</td>
</tr>
<tr>
<td>Post-operative respiratory failure</td>
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</tbody>
</table>

Clinical Signs of Increased Work of Breathing

Clinical signs where the patient exhibits increased work of breathing include diaphoresis, nasal flaring, tachypnea, use of accessory muscles, and (possibly) elevations of blood pressure and heart rate.
**Hypoxemia**

Hypoxemia is defined as a decrease in partial pressure of oxygen in the blood ($P_aO_2$) causing insufficient oxygenation. Hypoxemic respiratory failure can be caused by asthma, acute respiratory distress syndrome, a cerebrovascular accident (CVA, aka, stroke), drug overdose, pulmonary edema, and pulmonary embolism. Hypoxemic respiratory failure is manifested by cyanosis, neurological changes such as confusion and/or drowsiness, loss of consciousness, and seizures, tachycardia, and tachypnea.

**Hypercapnia**

Hypercapnia is an elevation of the arterial carbon dioxide level ($P_aCO_2$). Hypercapnic respiratory failure can be caused as a result of a CVA, drug overdose, chronic obstructive pulmonary disease (COPD), neurological disorders such as amyotrophic lateral sclerosis and Guillain Barré syndrome, obstructive sleep apnea, pneumonia, and pulmonary vascular disease. Signs of hypercapnic respiratory failure include confusion, diaphoresis, drowsiness, dyspnea, elevated blood pressure, tachycardia, and tachypnea. A $P_aCO_2 > 45$ mm HG is diagnostic for hypercapnia.

**Post-Operative Respiratory Failure**

Post-operative respiratory failure has been defined by Laghi and Tobin as “... the need for intubation and mechanical ventilation in the 48 hours after surgery.” Post-operative respiratory failure can be caused by pulmonary issues such as acute respiratory distress syndrome (ARDS) and atelectasis or by non-pulmonary issues such as sepsis or shock.
Mechanical ventilation is clearly needed in certain emergencies and there are accepted clinical indications for intubation and mechanical ventilation. However, these indications are somewhat imprecise and open to interpretation and Laghi and Tobin write: “We believe that the most honest description of a physician’s judgment at this juncture is: ‘The patient looks like he (or she) needs to be placed on the ventilator.’ That is, a physician institutes mechanical ventilation based on his or her gestalt of disease severity as opposed to slotting a patient into a particular diagnostic pigeonhole.”

**Modes Of Mechanical Ventilation And Ventilator Settings**

There are a wide variety of mechanical ventilation modes and it is beyond the scope of this module to review them all. Commonly used modes of mechanical ventilation are outlined in the section below.

**Assist-Control**

Respiratory rate and tidal volume are adjusted to deliver a specific minute ventilation. The patient’s spontaneous inspiratory efforts can initiate (trigger) the ventilator to deliver breaths that have the same tidal volume as the breaths delivered by the ventilator. Ventilator-delivered and patient-initiated breaths are ended when a set volume of air has been delivered or when a specific duration of inspiration is reached. Assist-control (AC) is used for patients who are in acute respiratory failure.

**Controlled Mechanical Ventilation**

Respiratory rate and tidal volume are adjusted to deliver a specific minute ventilation. A patient cannot trigger the ventilator to deliver a
breath. Ventilator-delivered breaths end when a set volume of air has been delivered or when a specific duration of inspiration is reached. Controlled mechanical ventilation (CMV) is used for patients who are pharmacologically paralyzed or comatose.

**Synchronized Intermittent Mandatory Ventilation**

Respiratory rate and tidal volume are adjusted to deliver a specific minute ventilation. A patient can breathe spontaneously between the ventilator-delivered breaths, but with synchronized intermittent mandatory ventilation (SIMV) the ventilator is adjusted so that spontaneous breathing and ventilator breaths do not interfere with one another.

**Basic Ventilator Settings**

The basic ventilator settings are outlined below.

- **Fraction of inspired oxygen:**
  
  Fraction of inspired oxygen (FiO₂) is the percentage of oxygen in each ventilator breath.

- **Positive end-expiratory pressure:**
  
  Positive end-expiratory pressure (PEEP) is the pressure in the alveoli at the end of expiration.

- **Respiratory rate:**
  
  The number of breaths delivered each minute. The abbreviation for the *frequency* of respiratory rate is *f*. 
• Tidal volume:

Tidal volume (TV) is the amount of air delivered with each ventilator breath.

Complications Of Mechanical Ventilation

Barotrauma

Pulmonary barotraumas are uncommon, potentially serious complications of mechanical ventilation, usually caused by over-distention of the alveoli. This creates a pressure difference that precipitates a rupture of the alveolar walls and movement of air into the adjacent interstitial lung tissue. Pneumomediastinum and pulmonary interstitial emphysema are seen most often; intraparenchymal air cysts, pneumopericardium, pneumoperitoneum, pneumothorax, subcutaneous emphysema, and systemic air embolism have been reported, as well.3-7

The incidence of pulmonary barotraumas in patients who are mechanically ventilated has been reported to be between 1.4% to 13%.3-7 The risk appears to be greatest for patients who have interstitial lung disease. It is not clear if specific ventilator settings such as the amount of PEEP increase the risk of developing pulmonary barotrauma.

Gastrointestinal Complications

Patients who are mechanically ventilated are at risk for developing acalculous cholecystitis, aspiration of enteral feedings, decreased gastrointestinal motility, gastrointestinal bleeding and stress ulcers.8-12
**Oxygen Toxicity**

Oxygen toxicity is defined as parenchymal lung injury caused by supplemental oxygen. This condition of hyperoxia, defined as a P$_{aO_2}$ > 300 mm Hg, can result in significant pathologies: 1) a decreased cardiac output and vasoconstriction; 2) oxidative stress and an inflammatory response; and, 3) lung and respiratory tract injuries. The latter can include atelectasis, diffuse alveolar damage similar to ARDS, interstitial fibrosis, tracheobronchitis, and ventilator-associated lung injury.$^{13-18}$

**Sinus Infections**

Sinus infections are a common cause of fever in patients who are mechanically ventilated. The reported incidence is 25%-75%, and these infections are a cause of ventilator-associated pneumonia and other respiratory tract and neurological infections.$^{19,20}$

**Ventilator-Associated Lung Injury**

Ventilator-associated lung injury is an acute lung disorder that develops during mechanical ventilation.$^{21,22}$ Ventilator-associated lung injury cannot be clinically distinguished from ARDS,$^{21}$ and it has been reported to occur in as many as 24% of patients who are mechanically ventilated.$^{23}$

The causes of ventilator-associated injury are over-distension of the alveoli and the speed and time during which the alveoli are inflated.$^{21,24}$ Factors that increase the risk of developing ventilator-associated lung injury are acidemia, ARDS, blood transfusion, high plateau airway pressure, hyperoxia, tidal volume > 6 mL/kg,
restrictive lung diseases. High tidal volume has been clearly identified as a risk factor,\textsuperscript{23-27} and the level of PEEP and the plateau airway pressure may increase the risk, as well.

**Ventilator-Associated Pneumonia**

Ventilator-associated pneumonia (VAP) is defined as a hospital-acquired pneumonia that occurs 48-72 hours after endotracheal intubation has been performed.\textsuperscript{28} The incidence of VAP has been reported to be 10\%-25\% and it is associated with a high mortality rate.\textsuperscript{29}

Factors that increase the risk of developing VAP are listed in Table 2. The list is not all-inclusive.\textsuperscript{28-31}

**Table 2: Risk Factors for Ventilator-Associated Pneumonia**

<table>
<thead>
<tr>
<th>Risk Factor</th>
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</thead>
<tbody>
<tr>
<td>Age &gt; 60 years</td>
</tr>
<tr>
<td>Antacids</td>
</tr>
<tr>
<td>ARDS</td>
</tr>
<tr>
<td>Aspiration</td>
</tr>
<tr>
<td>Coma</td>
</tr>
<tr>
<td>COPD</td>
</tr>
<tr>
<td>Daily ventilator circuit changes</td>
</tr>
<tr>
<td>Duration of mechanical ventilation</td>
</tr>
<tr>
<td>Enteral nutrition</td>
</tr>
<tr>
<td>( \text{H}_2 ) blockers</td>
</tr>
<tr>
<td>Nasogastric tube placement</td>
</tr>
<tr>
<td>Proton pump inhibitors</td>
</tr>
<tr>
<td>Sinusitis</td>
</tr>
<tr>
<td>Supine position</td>
</tr>
<tr>
<td>Tracheostomy</td>
</tr>
</tbody>
</table>
Complications Of Intubation

The process of inserting an endotracheal tube will not be discussed, but there are complications associated with/caused by intubation that nurses should be aware of.

Table 3: Complications of Intubation

<table>
<thead>
<tr>
<th>Complication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspiration of gastric contents</td>
</tr>
<tr>
<td>Damage to the lips, teeth, or tongue</td>
</tr>
<tr>
<td>Injury to the esophagus or vocal cords</td>
</tr>
<tr>
<td>Pneumothorax</td>
</tr>
<tr>
<td>Trauma to the larynx, oropharynx, or trachea</td>
</tr>
</tbody>
</table>

Basic Care Of A Patient Who Is Mechanically Ventilated

Suctioning, the use of sedating and analgesic drugs, and psychological issues of a patient who is mechanically ventilated will be discussed. The use of ventilator bundles will be covered in a separate section.

Suctioning

Mechanically ventilated patients retain secretions in the lungs and the endotracheal tube. Retained secretions narrow the airways, increase the work of breathing, decrease gas exchange, increase the risk of developing VAP, they can cause atelectasis, and make weaning more difficult. Endotracheal suctioning removes mucous and secretions
and it is considered essential care for a patient who is mechanically ventilated.\textsuperscript{32-34}

Endotracheal suctioning should be done when needed; it should be not be done routinely. Indications for endotracheal suctioning include abnormal sounds auscultated over the trachea, acute respiratory distress, aspiration of gastric or upper airway secretions, decreased tidal volume (if pressure-controlled ventilation is being used), dyspnea, increased peak inspiratory pressure (if volume-controlled ventilation is being used), oxygen desaturation, and visible secretions.\textsuperscript{32,35}

The procedure is usually completed uneventfully but endotracheal suctioning can cause significant complications: See Table 4.\textsuperscript{32,36}

\begin{table}[h]
\centering
\caption{Complications of Endotracheal Suctioning}
\begin{tabular}{|l|}
\hline
Atelectasis \\
Bleeding \\
Bradycardia \\
Bronchoconstriction \\
Infection \\
Hypertension \\
Hypotension \\
Increased intracranial pressure \\
Oxygen desaturation \\
Trauma \\
\hline
\end{tabular}
\end{table}
Procedure of Endotracheal Suctioning

Unless otherwise noted the following recommendations are from the AARC Clinical Practice Guidelines, *Respir Care*. 2010;55(6):758-764.

1. Measure blood pressure, heart rate, oxygen saturation, and intracranial pressure (ICP), if ICP is being measured, before, during, and after suctioning.

2. Pre-oxygenate for 30-60 seconds if suctioning the patient has caused significant reduction in oxygen saturation or if the patient is hypoxemic. Adult and pediatric patients should be given 100% oxygen. Neonates should be given a 10% increase of the baseline FiO₂.

3. Do not instill saline into the endotracheal tube. This may be harmful and it will not help loosen secretions.³⁷ Mucolytics such as N-acetylcysteine have been used to help promote mucous clearance but there is no conclusive evidence that they are effective.

4. The vacuum level should be ≤ 150 mm Hg if you are suctioning an adult and ≤ 80-100 mm Hg if you are suctioning an infant.

5. Closed suctioning should be used if a patient is receiving a high FiO₂, a high level of PEEP, is at risk for alveolar de-recruitment, or if you are suctioning a neonate. It has been proposed that closed suctioning can reduce the risk of developing VAP; there is evidence that supports and refutes this.³⁸-⁴¹ Closed suctioning will be discussed in more detail in the section on ventilator bundles.
6. Insert the suction catheter until the tip is at the end of the endotracheal tube; this is called shallow suctioning. Deep suctioning - inserting the suction catheter until resistance is met - may be harmful.\textsuperscript{42,43}

7. Apply suction and withdraw the suction catheter, rotating it continuously as it is removed. Do not apply suction for more than 15 seconds.

8. Consider hyper-oxygenation after finishing.

9. Consider a lung recruitment technique after finishing.

10. Document the amount, color, and consistency of the secretions.

\begin{boxed_text}
Learning Break:
Suctioning may collapse alveoli and contribute to acute lung injury. Recruitment techniques such as maximum insufflation that increase airway pressure may prevent this and their use should be considered.\textsuperscript{44,45}
\end{boxed_text}

\textbf{Sedation During Mechanical Ventilation}

Anxiety, confusion, drug and or alcohol withdrawal, post-operative pain, and discomfort from endotracheal intubation are common problems for patients who are mechanically ventilated, and these
patients need sedation. Benzodiazepines, butyrophenones, dexmedetomidine, ketamine, fentanyl, and propofol are commonly used for this purpose.\textsuperscript{46,47} Each drug has a different onset and duration of effects, indications for use, and side effects.

**Benzodiazepines**

Benzodiazepines are potent anxiolytics and they are central nervous system and respiratory depressants. These drugs also relax smooth muscle and cause venodilation. Diazepam, lorazepam and midazolam can be given as a single dose, intermittent infusion, or as a continuous infusion (lorazepam). Diazepam has a rapid onset and short duration of effects; lorazepam has a slow onset but its effects last for 6-8 hours; and, midazolam has an immediate onset of effects and duration of effects of 2-4 hours.

Side effects of the benzodiazepines include paradoxical agitation and delirium, confusion, hypotension, sedation, tolerance, withdrawal syndromes, and anion gap metabolic acidosis caused by the propylene glycol diluent in lorazepam.\textsuperscript{47-49} The benzodiazepines should be used with caution in patients who have hepatic or renal impairment as decreased metabolism and excretion and drug accumulation may occur.

**Butyrophenones**

Butyrophenones are a specific class of typical anti-psychotics that includes droperidol and haloperidol. Haloperidol is used off-label for prevention and treatment of delirium in critically ill patients, and haloperidol should only be used for short-term management of acutely agitated patients.\textsuperscript{46,50} The onset of action of IV haloperidol is very
quick, 2 to 5 minutes. Side effects include drowsiness, extrapyramidal effects, neuroleptic malignant syndrome, orthostatic hypotension, QTc prolongation, and torsades de pointes.

**Dexmedetomidine**

Dexmedetomidine is an alpha$_2$-adrenergic antagonist and a sedative and it also has analgesic properties. It has a labeled use for sedating patients who are mechanically ventilated, and studies have proven its effectiveness for this purpose.$^{51,52}$ Dexmedetomidine can be given as a single dose or as a continuous infusion; in certain circumstances a loading dose is given prior to starting a continuous infusion.

The onset of effects is 5 to 10 minutes and the duration of effects after a single dose is 30 to 60 minutes. Side effects include bradycardia and hypotension and hypertension after loading doses.

**Ketamine**

Ketamine is a general anesthetic, it has strong analgesic properties, and it produces a dissociative state in which perception and sensation are separated; the patient is conscious and feels as if she/he is observing surrounding events but not experiencing them. After an IV bolus the onset of effects is within one minute and the duration of action is 10 to 15 minutes.

Side effects of ketamine include amnesia, delirium, hallucinations, hypotension and hypertension, and tachycardia. It should be used cautiously if a patient’s blood pressure is elevated.
Ketamine is not commonly used to sedate patients who are mechanically ventilated, but some research has shown it to be effective for this purpose and having a side effect profile comparable to that of benzodiazepines and propofol. Using ketamine to sedate a patient who is mechanically ventilated is an off-label use of the drug and there are no standardized dosing regimens for a continuous IV infusion in this situation.

**Fentanyl**

Fentanyl is a powerful opioid analgesic. It is an effective sedative for patients who are mechanically ventilated, and there is evidence that using analgesics for these patients, a technique called analgosedation, is superior to using hypnotic sedatives. A continuous infusion of fentanyl is dosed in mcg/kg/hour.

Fentanyl has a rapid onset of action (minutes), and it is less likely to cause hypotension than other opioid analgesics. Side effects include drowsiness, respiratory depression, and tolerance. Fentanyl is lipophilic and metabolized by cytochrome P450 enzymes, so if a patient has hepatic impairment the drug can accumulate after prolonged use.

**Propofol**

Propofol is a general anesthetic and it is commonly used to sedate patients who are mechanically ventilated. It is especially useful when rapid onset and short duration of anesthesia is desired, and propofol also has anxiolytic properties. The onset of effects is < 1 minute, the duration of action after a single dose is 2 to 8 minutes, and the anesthetic effect is effectively ended 60 minutes after an infusion has been discontinued.
Propofol is not an analgesic. The drug can cause ventilatory depression and hypotension is a common side effect of the drug. Propofol uses intralipid as its carrier and triglyceride levels should be monitored. Intralipid is a good medium for bacterial growth, so strict aseptic technique must be used when IV tubing is changed, and it is recommended to change IV tubing and discard unused portions of propofol every 12 hours.

The propofol infusion syndrome is a rare complication of propofol. It is usually associated with high doses (> 4 mg/kg/hour) or a prolonged infusion (> 48 hours), but lower doses and a shorter duration of therapy can cause the syndrome as well. The propofol infusion syndrome is characterized by bradycardia, Brugada-like ECG changes, cardiovascular collapse, hyperkalemia, hyperlipidemia, metabolic acidosis, renal failure, and rhabdomyolysis. The incidence of propofol infusion syndrome is reported to be very low, probably < 1%, but different defining criteria for the syndrome have been used so the true incidence is not known. Mortality rates of the propofol infusion syndrome as high as 80% have been reported.

**Pain Assessment And Control**

Pain assessment and pain control is a vital aspect of treating patients who are mechanically ventilated and the following points emphasize its importance.

- Pain is very common in patients who are mechanically ventilated.
- These patients are often unable to tell you that they are having pain.
Pain can be mistaken for agitation, confusion, or delirium. If this happens, treatment with sedatives further reduces the patients’ ability to tell you about their pain and may result in over-sedation and continued pain.

Pain can cause many adverse physiological and psychological effects such as anxiety, confusion, sleep deprivation, increased metabolic demands, and an increase in levels of endogenous catecholamines. The last of these is particularly bad for the mechanically ventilated patient because a high circulating level of endogenous catecholamines can cause vasoconstriction, increased oxygen demand, impaired tissue perfusion, and ischemia.

Opioids such as fentanyl, morphine, and remifentanil are often used to treat mechanically ventilated patients who are having pain. These drugs are reliable and easy to titrate, and single doses or a continuous IV infusion can be used. If the patient has a functioning gut that can be accessed via a nasogastric tube, oral opioids are an option. The side effects of opioids include decreased peristalsis, hypotension, pharmacologic ileus, respiratory depression, sedation, serotonin syndrome (fentanyl), tolerance, and withdrawal.

**Psychological Care**

Three psychiatric issues are often found in patients who are mechanically ventilated: delirium, depression, and post-traumatic stress disorder.60

Delirium is a disturbance in awareness and attention. Delirium is not caused by a pre-existing neurocognitive disorder: it is the direct result of a physiological condition or stimulus such as drug or alcohol
withdrawal, dehydration, infection, or in this case, mechanical ventilation. Delirium has been reported to affect 75%-80% of patients who are mechanically ventilated,\textsuperscript{61} and it is an independent risk factor for increased duration of hospital stay, long-term cognitive impairment, death, and other complications.\textsuperscript{61-63}

Delirium develops quickly, in hours to days, and it is characterized by: 1) an inability to focus or sustain attention; 2) a disturbance in awareness, \textit{i.e.}, disorientation in relation to the environment that fluctuates throughout the day, often being worse at night; and, 3) other cognitive disturbances such as delusions, hallucinations, illusions, perceptual disorders, and memory loss. A delirious patient may ask the same questions again and again, he/she may think that the staff is trying to cause her/him harm, mistake objects in the environment for something else, or imagine he/she is hearing conversations.

Treatment for delirium can include early mobilization and judicious use of analgesics, sedatives, antipsychotics, and other medications.\textsuperscript{60,64-67} Unfortunately, there is very little evidence and only a small amount of research on the effectiveness of medications for treating delirium in this patient population.

Less is known about depression and post-traumatic stress disorder in patients who are mechanically ventilated. Both have been identified as common complications of weaning from mechanical ventilation and from prolonged mechanical ventilation.\textsuperscript{68-70} However, Skobrik notes that there are few studies of depression in mechanically ventilated patients, confounding factors make establishing a diagnosis of
depression difficult in this situation, and there are no established therapies for the management of depressed, mechanically ventilated patients.\textsuperscript{60}

**Ventilator Bundles**

Ventilator bundles are evidence-based, systematic approaches for the prevention of the common complications of mechanical ventilation. Ventilator bundles “... are groupings of best practices (and) evidence-based strategies that may prevent or reduce risk of these complications, and the bundle is an effort to design a standard approach to delivering these core elements.”\textsuperscript{71}

Several ventilator bundles have been developed and when they are properly and consistently used they can be effective.\textsuperscript{72-74} The primary focus of ventilator bundles has been preventing ventilator-associated pneumonia but some include advice for preventing other complications as well, and their specific care recommendations do vary from each other.

Aspects of ventilator bundles that will be discussed here are: 1) daily sedative interruption, 2) deep vein thrombosis prophylaxis, 3) in-line and subglottic suctioning, 4) endotracheal tube cuff pressure monitoring, 5) oral care with chlorhexidine and chlorhexidine bathing, 6) peptic ulcer prophylaxis; and, 7) patient positioning.

**Daily Sedative Interruption**

Patients who are mechanically ventilated need sedation but benefits come with risks, and sedation therapy is associated with delirium,
increased duration of intensive care unit stay, increased duration of mechanical ventilation, and ventilator-associated pneumonia.\textsuperscript{75,76}

Daily, scheduled interruptions in the delivery of sedative drugs, so-called \textit{sedation vacations}, can reduce the incidence of these and other complications \textsuperscript{75,76} and sedation vacations are typically included in ventilator bundles. Sedation vacations also encourage planned, judicious use of sedation and can help avoid under- and over-sedating patients.

\textbf{Deep Vein Thrombosis Prophylaxis}

The connection between deep vein thrombosis (DVT) and mechanical ventilation is not clearly defined. Ibrahim, \textit{et al.}, noted that 26 of 110 patients (23.6\%) who were mechanically ventilated developed a DVT,\textsuperscript{77} and Gaspard, \textit{et al.}, found that an incidence of 0.3\%-3.0\% of DVT and pulmonary embolism (PE) in their study group of mechanically ventilated patients,\textsuperscript{78} but the topic has not been well researched.

However, mechanical ventilation itself, the clinical conditions that precipitated the need for mechanical ventilation, bed rest, and time spent in an intensive care unit are all risk factors for the development of DVT, and prophylactic measures to prevent DVT are a standard part of ventilator bundles. Prophylaxis can be done using intermittent pneumatic compression devices, graduated compression stockings, or treatment with heparin or low-molecular weight heparin.\textsuperscript{78}
**Closed Suctioning and Subglottic Suctioning**

Disconnecting a patient from the ventilator to perform endotracheal suctioning can cause a loss of PEEP, decreased arterial oxygen content and increased carbon dioxide content, and bacterial contamination. Closed suctioning (also called in-line suctioning) allows for removal of secretions without disconnecting the patient from the ventilator. It is often included in ventilator bundles as part of the effort to reduce the incidence of ventilator-associated pneumonia. The American Association for Respiratory Care recommends closed suctioning for adults who require a high FiO₂, adults who require PEEP, adults who are at risk for lung decruitment, and for neonates.³⁵ There is evidence that closed endotracheal suctioning can be effective for this purpose,³⁹,⁷⁹ but recent reviews (2014, 2015) have been less positive. Kuriyama, et al., write: “Whether closed tracheal suctioning systems (CTSS) reduce the incidence of ventilator-associated pneumonia (VAP) compared with open tracheal suctioning systems (OTSS) is inconclusive.”³⁸ Hamishekar, et al., write that “... impact of suctioning is similar between CTSS and OTSS regarding the occurrence of VAP. It seems that physicians must consider many factors such as duration of mechanical ventilation, comorbidities, oxygenation parameters, number of required suctioning, and the cost prior to using each type of tracheal suction system.”³⁸

Endotracheal tubes are available that have a lumen above the cuff. This lumen can be connected to continuous or intermittent suction, and this process of subglottic suctioning removes secretions that accumulate above the cuff. Subglottic suctioning has been shown to be an effective way to prevent VAP and can help decrease the amount of time a patient needs mechanical ventilation.⁸¹-⁸⁴
evidence that subglottic suctioning may decrease the duration of mechanical ventilation in patients who will be mechanically ventilated for 48-72 hours or longer.\textsuperscript{85} Removing a standard endotracheal tube and replacing it with one that has a subglottic aspiration lumen port would not be recommended.\textsuperscript{85}

**Endotracheal Cuff Pressure**

Endotracheal cuff pressure should be maintained at 20-30 cm H\textsubscript{2}O to prevent VAP and to prevent damage to the surrounding tissues.\textsuperscript{86} Maintaining appropriate cuff pressure has been mentioned by some authors as part of a ventilator bundle,\textsuperscript{86,87} and continuous endotracheal cuff pressure monitoring has been shown in several studies to reduce the incidence of VAP.\textsuperscript{86,88}

**Oral Care with Chlorhexidine and Chlorhexidine Bathing**

Oral care with chlorhexidine can decrease the risk of developing VAP.\textsuperscript{89-91} Chlorhexidine is an antibacterial agent and a 0.12%-0.2% solution is applied to a sponge and the patient’s mouth is swabbed four times a day; the frequency of use and the protocol may vary from hospital to hospital. Some researchers have found that chlorhexidine bathing can reduce the incidence of VAP but others have not.\textsuperscript{92,93}

**Peptic Ulcer Prophylaxis**

Patients who are mechanically ventilated are at risk for stress ulcers and gastrointestinal bleeding.\textsuperscript{3} Antacids, histamine-2 blockers, proton pump inhibitors, and sulcralfate have all been successfully used to prevent stress ulcers in this patient population,\textsuperscript{3,94,95} but it is not clear which of these is the most effective.
Decreasing gastric pH can be an effective prophylaxis for stress ulcers, but it can allow for bacterial growth in the gut, and research has shown that stress ulcer prophylaxis may increase a patient’s risk of developing VAP.8,94-99

**Patient Positioning, Enteral Feedings, and Aspiration**

Patients who are mechanically ventilated and who are receiving enteral nutrition are at risk for aspiration, and aspiration is a common and potentially serious complication of enteral nutrition.100-102 Not all cases of aspiration cause significant harm but preventing this complication should be a priority.

Withholding enteral feeding if the residual gastric volume is above a certain level (checking residual volume) has been used as a method for preventing aspiration. This technique may still have value for selected patents,102 but there is significant evidence suggesting that it does not prevent aspiration100-103 and it is not generally recommended.100,104 Elevating the head of the head (if possible) to 30°-45° is the only proven technique for preventing aspiration in critically ill patients who are receiving enteral nutrition.100 Elevating the head of the bed is also a recommendation of many ventilator bundles as a method of preventing ventilator-associated pneumonia.85,105,106

**Weaning From Mechanical Ventilation**

Prolonged use of mechanical ventilation increases a patient’s exposure to complications so weaning is a high priority. The three steps of weaning from mechanical ventilation are: 1) recognizing when a
patient is ready to be weaned; 2) recognizing when a patient is ready to be extubated; and, 3) the weaning process itself.\textsuperscript{107,108}

Epstein (October, 2015) recommends using these objective criteria to determine if a patient is ready to be weaned.\textsuperscript{108}

- Arterial pH is > 7.25
- Hemodynamic stability, \textit{i.e.}, a systolic blood pressure > 90 mm Hg
- Adequate oxygenation, \textit{i.e.}, oxyhemoglobin saturation > 90\% with an FiO2 of \(\leq 40\%\) and a level of PEEP \(\leq 5\text{-}8\text{ cm H}_{2}\text{O}\).
- The patient can initiate an inspiratory effort.
- The cause of respiratory failure has resolved.

Readiness to be extubated is determined by: 1) assessing the patient’s ability to produce a cough; 2) assessing the patient’s level of consciousness; 3) checking the amount of secretions he/she is producing; and, 4) checking for a reduced cuff leak.\textsuperscript{110}

The cuff leak test is done by deflating the endotracheal tube cuff and assessing for an air leak; any air leak is inversely related to the amount of laryngeal edema.\textsuperscript{111} Some authors recommend the cuff leak test\textsuperscript{110,112} and if there is a significant leak, delaying extubating and giving the patient a short course of glucocorticoid therapy, but the test is not universally accepted as useful or sensitive.\textsuperscript{113,114}

If the patient is ready to wean and ready to be extubated the next step is a spontaneous breathing test (SBT). The patient is
disconnected from the ventilator for 30 minutes and placed on a T-piece or CPAP (there are several methods for performing an SBT) and the patient’s tolerance for this is assessed. There is objective criteria for determining tolerance for the SBT, parameters such as heart rate, respiratory rate, respiratory distress, and desaturation. If the patient tolerates the SBT and the clinician’s judgment is that the patient appears ready to be extubated, the endotracheal tube can be removed.

**Summary**

Mechanical ventilation uses endotracheal intubation and a ventilator to replace spontaneous respiration and ventilation. It improves gas exchange and decreases a patient’s work of breathing, and it is used to treat patients who are having acute or chronic respiratory distress. Mechanical ventilation can be a life-saving therapy. However, there are significant risks associated with its use. In addition, patients who are mechanically ventilated often have serous pre-existing medical problems and they need intubation and ventilation because of a serious acute process. Careful, vigilant monitoring and in-depth understanding of the complications of mechanical ventilation and their treatment is essential for a good outcome.
Appendix I: Pulmonary Terminology

Alveolar-arterial oxygen gradient:
The alveolar-alveolar oxygen gradient is the difference between the calculated amount of oxygen in the alveoli and the \( P_aO_2 \), and it is used to measure oxygenation. The alveolar-arterial oxygen gradient is abbreviated as A-a.

An abnormally high A-a can help indicate the source of hypoxemia, and a high A-a gradient (i.e., a higher than expected difference between the amount of oxygen in the alveoli and the amount of oxygen in the arterial blood) is commonly caused by a ventilation-perfusion (V/Q) mismatch or a right-to-left shunt.

A V/Q mismatch can result from poor ventilation caused by pneumonia or COPD or from poor perfusion caused by a pulmonary embolism.

A right-to-left shunt occurs when blood circulates from the right side of the heart to the left side without being oxygenated. This can occur when alveoli are being perfused but are not ventilated, as with adult respiratory distress syndrome (ARDS) or pneumonia.

A V/Q mismatch and a right-to-left shunt can occur concurrently.

Dead space:
Dead space is the part of the respiratory tract that does not participate in gas exchange. Dead space can be anatomic, i.e., the bronchi, or it can be physiologic.

In the latter there are parts of the respiratory tract that normally participate in gas exchange but do not. This may occur if the alveoli are not perfused or if gas exchange in the alveoli is hindered by an exacerbation of COPD or other disease processes such as pulmonary edema or pneumonia.
Hypercapnia:
Hypercapnia is an elevation of the arterial carbon dioxide level (P_aCO_2). The P_aCO_2 is determined by the amount of carbon dioxide that is produced and the amount that is eliminated by the lungs – alveolar ventilation. Hypercapnia is usually caused by decreased alveolar ventilation or an increase in dead space.

Hypercapnia from decreased alveolar ventilation often results from decreased minute ventilation. Minute ventilation is the amount of air moved inhaled (or exhaled) in one minute and conditions such as drug overdose or stroke decrease the respiratory rate, which in turn, decreases minute ventilation and alveolar ventilation. Alveolar ventilation is also determined in part by the amount of dead space. Dead space is increase by conditions such as atelectasis, exacerbations of COPD, and pneumonia.

Hypoxemia:
Hypoxemia is defined as a decrease in partial pressure of oxygen in the blood (P_aO_2) causing insufficient oxygenation. (Oxygenation is defined later in this list). Hypoxemia is caused by hypoventilation, a right-to-left shunt, or a ventilation-perfusion mismatch. (These terms are explained in this section, as well)

Hypoxia:
Hypoxia is abnormally low oxygen content in an organ or a tissue.

Hypoventilation: A reduced amount of air entering the alveoli. Common causes of hypoventilation would be a drug overdose or a CVA; both which depress the respiratory center in the brain, decreasing the rate and depth of breathing.

Oxygenation:
Oxygenation is the process of oxygen moving through the alveoli into the pulmonary capillaries, and then binding to hemoglobin or dissolving in plasma.
Partial pressure of carbon dioxide:
The partial pressure of carbon dioxide (sometimes referred to as arterial carbon dioxide tension) measures the amount of carbon dioxide that is in arterial blood. The partial pressure of carbon dioxide is abbreviated $P_{a}CO_{2}$. The normal $P_{a}CO_{2}$ is 35-45 mm Hg.

Partial pressure of oxygen:
The partial pressure of oxygen (sometimes referred to as arterial oxygen tension) measures the amount of oxygen that dissolved in arterial blood. It does not measure the amount of oxygen bound to hemoglobin. The partial pressure of oxygen is abbreviated as $P_{a}O_{2}$. There is no defined normal range for $P_{a}O_{2}$ as there is no $P_{a}O_{2}$ level below which hypoxia will always occur. However, for most people the $P_{a}O_{2}$ should be > 80 mm Hg.

Respiration: Respiration is the exchange of gases in the lung; transport of carbon dioxide and oxygen in the blood; and the movement of gases from the cells to the blood (carbon dioxide) and the blood to the cells (oxygen).

Respiration is the exchange of carbon dioxide and oxygen between the cells of the body and the atmosphere, and respiration and ventilation are obviously intimately linked. Cellular respiration is the process by which the cells use oxygen to produce adenosine triphosphate (ATP) and eliminate carbon dioxide.

Ventilation:
Ventilation is the process of breathing, moving air in and out of the lungs. Ventilation is defined as the exchange of air between the environment and the lungs; in simpler terms ventilation can be understood as inhalation and exhalation. Ventilation is divided into alveolar ventilation and pulmonary ventilation.

Alveolar ventilation is the amount of air that reaches the alveoli and is available for gas exchange with the blood. Pulmonary ventilation is the rate of ventilation, measured in liters of air per minute that are exchanged between the ambient air and the lungs.
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1. The amount of oxygen delivered by a ventilator is
   a. fraction of inspired oxygen.
   b. positive expiratory volume.
   c. inspiratory pressure.
   d. tidal volume.

2. Which of the following is a complication of mechanical ventilation?
   a. Cellulitis.
   b. Atrial fibrillation.
   c. Barotrauma.
   d. Pulmonary fibrosis.

3. True or False: High arterial oxygen levels are always benign.
   a. True
   b. False

4. Common complications of mechanical ventilation include
   a. ventricular arrhythmias and hypotension.
   b. delirium and hypothermia.
   c. stress ulcers and renal failure.
   d. sinus infections and ventilator-associated pneumonia.
5. **Suctioning a mechanically ventilated patient should be done**
   
   a. every two hours.
   b. only when it is clinically indicated.
   c. if the patient has a temperature > 102° F.
   d. when the patient is receiving sedation with a benzodiazepine.

6. **Drugs used to sedate patients who are mechanically ventilated are**
   
   a. benzodiazepines and propofol.
   b. selective serotonin re-uptake inhibitors and haloperidol.
   c. fentanyl and dextromethorphan.
   d. ketamine and lithium carbonate.

7. **Which of these is a common complication of mechanical ventilation?**
   
   a. Bipolar disorder
   b. Dissociative state
   c. Delirium
   d. Major depression

8. **Patients who are mechanically ventilated will benefit from**
   
   a. continual use of sedation until immediately before weaning.
   b. abrupt cessation of sedative drugs.
   c. low doses of sedative and high doses of analgesics.
   d. sedation vacations.

9. **Oral care with ______________ can reduce the incidence of ventilator-associated pneumonia.**
   
   a. bacitracin
   b. chlorhexidine
   c. hydrogen peroxide
   d. isopropyl alcohol
10. Readiness to wean from a ventilator is assessed, in part, by
   a. a lung scan.
   b. an FiO² requirement of < 30%.
   c. a spontaneous breathing trial.
   d. successive normal chest x-rays.

11. ________________ should be used cautiously in patients who have hepatic or renal impairment as decreased metabolism, excretion and drug accumulation may occur.
   a. Ketamine
   b. Benzodiazepines
   c. Propofol
   d. Dexemedetomidine

12. ________________ is used for patients who are pharmacologically paralyzed or comatose.
   a. Controlled mechanical ventilation (CMV)
   b. Assist-control (AC) ventilation
   c. A spontaneous breathing trial
   d. Synchronized intermittent mandatory ventilation (SIMV)

13. Using ________________ to sedate a patient who is mechanically ventilated is an off-label use of the drug.
   a. fentanyl
   b. benzodiazepines
   c. ketamine
   d. butyrophenones

14. Fentanyl is a powerful opioid analgesic
   a. but is inferior to using hypnotic sedatives.
   b. and has a slow onset of action.
   c. but is more likely to cause hypotension.
   d. and an effective sedative for mechanically ventilated patients.
15. True or False: Side effects of butyrophenones include drowsiness, extrapyramidal effects, neuroleptic malignant syndrome, orthostatic hypotension, QTc prolongation, and torsades de pointes.

a. True
b. False

Correct Answers:

1. a  6. a  11. a
2. c  7. c  12. a
3. b  8. d  13. c
4. d  9. b  14. d
5. b  10. c  15. a
References Section

The References below include published works and in-text citations of published works that are intended as helpful material for your further reading.


33. Ntoumenopoulos G. Endotracheal suctioning may or may not have an impact, but it does depend on what you measure! *Respir Care*. 2013; 58(10):1707-1710.


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