EMERGENCY MEDICINE REPORTS

Practical, Evidence-Based Reviews in Emergency Care

SEPTEMBER 15, 2020 VOL. 41, NO. 18

Mechanical Ventilation for Pneumonia, Acute Respiratory Distress Syndrome, and COVID-19

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Case Study

A 54-year-old male with a past medical history of hypertension and type II diabetes mellitus presents to the emergency department with a chief complaint of shortness of breath. The patient has had three days of worsening dyspnea and nonproductive cough. The patient also notes subjective fevers at home, with the highest recorded temperature of 101.7°F. The patient states that his girlfriend, with whom he lives, has had similar symptoms over the past week. The patient is a former smoker and his recorded body mass index is 35. On presentation to the emergency department, the patient is noted to be in moderate respiratory distress. The patient is tachypneic with a respiratory rate of 24 breaths per minute and pulse oximetry is 68% on room air. The patient is only able to speak in short sentences and is dyspneic with conversation. Subcostal retractions also are evident during examination. Diffuse rales are noted bilaterally on auscultation of the lungs. A portable bedside chest X-ray shows bilateral, multifocal opacification of the lungs. A non-rebreather mask is placed on the patient at 10 liters and does not improve his oxygen saturation. Despite receiving 30 liters of high-flow nasal cannula oxygen, the patient remains tachypneic and his oxygen saturation only improves to 82%. At this point, the providers at the bedside determine the patient requires intubation and mechanical ventilation for acute hypoxic respiratory failure.

Indications for Mechanical Ventilation

The indications for mechanical ventilation fall under three general categories. Patients require mechanical ventilation in the setting of hypoxia refractory to noninvasive efforts to improve oxygen saturation. Patients are usually trialed on noninvasive forms of oxygen delivery prior to the need for intubation. Common forms of noninvasive oxygenation include nasal cannula, non-rebreather masks, bilevel positive airway pressure (BiPAP), continuous positive airway pressure (CPAP), and high-flow nasal cannula. Further discussion of noninvasive oxygenation and ventilation are outside the scope of this article.

STATEMENT OF FINANCIAL DISCLOSURE

To reveal any potential bias in this publication, and in accordance with Accreditation Council for Continuing Medical Education guidelines, we disclose that Dr. Schneider (editor), Dr. Stapczynski (editor), Ms. Light (nurse planner), Dr. Rammohan (author), Dr. Meyers (author), Dr. Sharma (peer reviewer), Ms. Mark (executive editor), Mr. Gates (associate editor), and Ms. Coplin (editorial group manager) report no financial relationships with companies related to the field of study covered by this CME activity.

EXECUTIVE SUMMARY

- The tidal volume setting on the ventilator should be according to the patient's ideal body weight as estimated by patient height.
- Inspiratory triggering by change in flow (flow-triggering) is better tolerated by intubated patients than pressure-triggering and reduces mortality in chronic obstructive pulmonary disease patients.
- The initial ventilator settings after intubating a patient for refractory hypoxia is typically a tidal volume of 6 to 8 mL/kg ideal body weight, a respiratory rate of 12-16 breaths per minute, an FiO_2 of 100%, and a positive end-expiratory pressure (PEEP) between 5 and 10 cm H_2O.
- Titrate the FiO_2 setting down to below 80% once the patient stabilizes while maintaining an arterial saturation above 90%.
- Patients who are hypoxic despite high PEEP and FiO_2 may benefit from being placed in the prone position.

Patients with hypercapnia who are unable to autocorrect for carbon dioxide (CO_2) retention require mechanical ventilation. This scenario commonly arises in patients with underlying obstructive lung disease. The compensatory tachypnea required to correct for hypercapnia sometimes leads to patient fatigue. A patient who experiences a rising CO_2 despite noninvasive methods of ventilation is no longer able to adequately maintain the required minute ventilation. Intubation of patients with obstructive lung disease is considered a last resort effort. Despite intubation and ventilation, the respiratory acidosis still may be difficult to correct in patients with severe obstructive lung disease.

Lastly, patients who are obtunded or unable to protect their airway require intubation. In this setting, intubation serves as a prophylactic measure to prevent aspiration and subsequent clinical deterioration. Patients with status epilepticus or altered mental status secondary to trauma frequently require intubation for airway protection. Clinicians should make the decision to intubate this patient population after assessing whether the patient has proper consciousness and airway reflexes to prevent aspiration. It also is appropriate to intubate critically ill patients if the clinician believes that a patient's clinical course could lead to a point where the airway may become compromised. Although these indications for intubation are considered standard of care, the decision to perform intubation and mechanical ventilation for a patient can represent a gray area for providers. The patient's projected course and baseline health are considerations when deciding whether to pursue mechanical ventilation.

Prior to intubation, the provider must be certain that this plan of care is consistent with the patient's desires. All efforts should be made to seek out any documentation previously completed by the patient or their designated decision-maker. Many patients with terminal medical conditions elect to forego invasive ventilation and carry a do not intubate (DNI) status.

Ventilator Basics

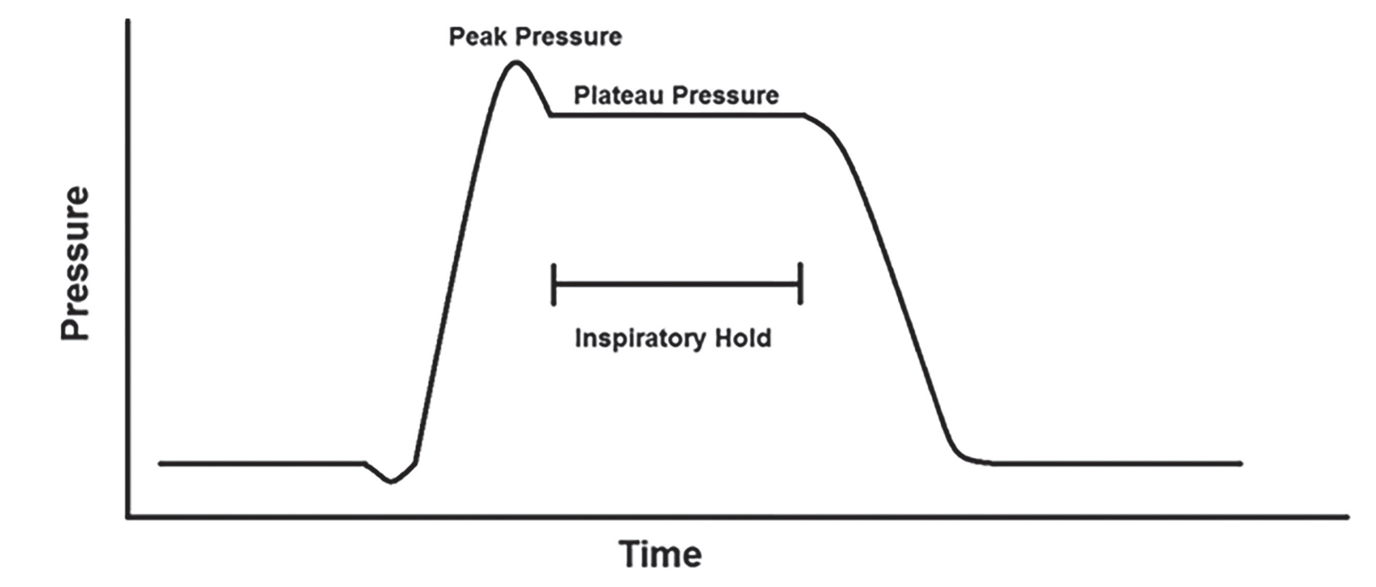
Oxygenation

The two main determinants of oxygenation for patients requiring mechanical ventilation are the positive end-expiratory pressure (PEEP) and fraction of inspired oxygen (FiO_2). These two values are manipulated in basic ventilator settings to adjust for hypoxia on pulse oximetry or a suboptimal PaO_2 on an arterial blood gas. When patients are first placed on ventilator support, a common approach is to set the FiO_2 to 100% and PEEP between 5 cm H_2O and 10 cm H_2O. The initial oxygen supplementation provided through the ventilator depends on the indication for intubating the patient in the first place. Patients who are intubated for respiratory failure and hypoxia will require more oxygen delivery than patients who do not have lung pathology and are intubated for protection of their airway. Providers should avoid maximal FiO_2 when choosing initial ventilator settings in patients who are not hypoxic prior to intubation.

Caution should be taken to avoid prolonged periods of FiO_2 above 80% because a theoretical risk of oxygen toxicity from free radical damage exists once the patient's hypoxia has resolved. Although many patients are placed on 100% FiO_2 as an initial ventilator setting, this should be titrated down as quickly as possible once hypoxia has improved. In general, it is preferable to titrate down FiO_2 prior to titrating down PEEP. However, there are situations in which this does not hold true or is not practical.

PEEP is the pressure maintained in the airway at the end of each breath. Without PEEP, the alveoli could collapse at the end of each exhalation and re-expand with each breath. Repetitive opening and closing of alveoli creates the potential for atelectrauma. PEEP allows for the alveoli to remain open at the end of each exhalation. Increasing PEEP allows for recruitment of alveoli and increases oxygen diffusion at the level of the pulmonary capillaries. Increasing PEEP is one mechanism for adjusting ventilator settings to improve hypoxemia. Physiologic PEEP is considered to be around 5 cm H_2O. As patients are liberated from the ventilator, a PEEP of 5 cm H_2O is considered the goal for titrating down oxygen supplementation. Increasing PEEP

Figure 1. Peak vs. Plateau Pressure



is not without a downside. The rise in intrathoracic pressure secondary to increasing PEEP raises the risk for pneumothorax. Elevated intrathoracic pressure also causes a decrease in venous return and, thus, a decrease in cardiac preload.

Ventilation

Efforts to improve hypercapnia through mechanical ventilation are achieved by adjustments to the patient's minute ventilation. Minute ventilation is defined as the product of respiratory rate and tidal volume and corresponds to the volume of gas delivered by the ventilator to the endotracheal tube per minute. Because minute ventilation is directly related to respiratory rate and tidal volume, changes to the minute ventilation are accomplished by increasing either of these two parameters. Care should be taken to avoid increasing the respiratory rate greater than 30 breaths per minute, as this would change the patient's inspiratory : expiratory ratio from 1:2 to 2:1. The ideal tidal volume has been laid out previously by Brower et al in the ARDSnet trial.[1] Determination of the ideal tidal volume for a patient will be discussed later in this article.

When calculating tidal volume, the ideal body weight should be used. The ideal body weight is derived from a patient's height and gender. For this reason, ventilator metrics can be predetermined using standardized tools correlating to a patient's height, such as the Broselow tape. Patients run the risk of receiving excessive tidal volumes and volume-related lung trauma if the actual body weight is used and does not correlate with the patient's ideal body weight.

Pressures

During normal inspiration, the airway pressure rises to a set point and, after a subtle drop, will maintain a set pressure for the duration of inspiration. The pressure in the airway at the end of inspiration is termed the peak pressure. The peak pressure is the sum of the inspiratory driving pressure and the PEEP. After peak pressure is reached, a small drop in the airway pressure occurs until the pressure reaches a plateau, which is maintained for several seconds prior to exhalation. In general, a goal plateau pressure should be less than 30 cm H_2O to avoid barotrauma (e.g., pneumothorax). The difference in pressure between the peak pressure and plateau pressure can be attributed to the degree of resistance to flow in the airway.

Elevated peak pressures can be caused by increased airway resistance. This can be the result of the patient biting down on the endotracheal tube, increased airway secretions, bronchospasm (asthma, chronic obstructive pulmonary disease [COPD]), or condensation in the ventilator tubing. In those scenarios, the peak pressure will be elevated but the plateau pressure should be normal.

Causes of an elevated peak and plateau pressure result from pneumothorax, mainstem bronchus intubation, underlying pulmonary pathology (congestive heart failure, pneumonia, or acute respiratory distress syndrome [ARDS]), or increased tidal volumes.

The peak pressure typically is measured and recorded with each breath on the ventilator. However, the plateau pressure requires an inspiratory hold for the ventilator to display. The inspiratory hold is not typically incorporated into standard mechanical ventilation and must be performed manually by the clinician. (*See Figure 1.*)

Typically, mean airway pressure refers to the mean pressure applied during positive pressure ventilation.

Mean airway pressure also can be illustrated by the area under the curve in a pressure vs. time graph. In general, the mean airway pressure correlates with the mean alveolar pressure and is affected by inspiratory pressures, volumes, and PEEP. Mean airway pressure also has effects on alveolar ventilation, arterial oxygenation, and risk for barotrauma.[2]

Flow, Inspiratory to Expiratory Ratio

Some modes of ventilation, as will be discussed later, allow for the patient to initiate a breath, and the ventilator subsequently augments that breath. Ventilators can be triggered by either a change in pressure or a change in flow. Pressure-triggering senses the fall in airway pressure, which signals the ventilator to augment a breath. Flow-triggering senses a certain rate of airflow as the indicator to initiate a breath. In general, flow-triggering is more comfortable and better tolerated than pressure-triggering. In COPD patients, the work of breathing is increased by about 20% with pressure-triggering, and so flow-triggering is preferred. Other than for COPD, there are no data to suggest improved outcomes with either flow-triggering or pressure-triggering.[3]

Inspiratory flow can be administered by the ventilator in three different patterns. The rate of flow varies depending on the mode of ventilation used. When charting change in flow over time, the flow rate can be represented as a square waveform, sinusoidal waveform, or descending ramp waveform. The descending ramp waveform is used most commonly since the rapid increase and gradual decrease in flow most closely resembles physiologic inspiration.

Adjustments can be made to alter the rate and amount of flow during inspiration. During a normal respiratory cycle, the amount of time spent in inspiration is half the amount of time spent in expiration. Under normal mechanical ventilator settings, the ratio of inspiration: expiration is abbreviated the I:E ratio. This setting usually is set to mimic normal respiratory cycle dynamics. In patients requiring aggressive ventilation, this ratio can be altered to provide a longer exhalation phase to increase exhalation of carbon dioxide.

Mechanical Ventilation Impact on Cardiac Function

The augmentation of lung volumes and intrathoracic pressure through mechanical ventilation can have untoward effects on cardiac physiology. Increased lung volumes cause compression of pulmonary vasculature and result in an increase of the pulmonary vascular resistance.[3,4] As a result, the venous return to the right side of the heart is decreased. The increase in intrathoracic pressure also causes impairment in venous return.[3] In studies comparing cardiac output in pressure control or volume control settings, no difference has been observed when the tidal volumes are similar between the two methods.[5] Additionally, positive pressure pushes against the heart in the chest and decreases cardiac distensibility, thereby reducing right ventricular filling in diastole.[3,4]

Modes of Ventilation

Volume Control

In volume control ventilation, the provider chooses a set tidal volume to deliver with each breath. The initial volume to deliver usually is determined by the patient's ideal body weight. Ideal body weight is determined by using the patient's height. As outlined in the ARDS Clinical Trial Network protocol, the patient's tidal volume is commonly set at 6 to 8 cc/kg.[1] While volume control ventilation allows the provider to ensure a reliable tidal volume with each breath, the pressure required to obtain this tidal volume is variable. The pressure required to obtain a set volume is dependent on airway compliance and varies depending on disease processes.

The amount of assistance provided by the ventilator is chosen by the provider. In assist control ventilation, the patient initiates a breath, and the total volume is augmented by the ventilator to achieve a goal tidal volume. This is considered an assisted breath. However, if the patient is unable to initiate a breath, this setting takes over full control and will deliver breaths to meet the preset respiratory rate and tidal volume that are set by the clinician. In patients who require more support from the ventilator, a volume control setting is preferable. Such settings commonly are required in patients who have suffered severe brain injury and have loss of brain stem-initiated respirations. Patients who are mechanically or pathologically paralyzed also require full control of ventilation.

Synchronized intermittent mandatory ventilation (SIMV) allows the provider to set pressure support settings for spontaneous breaths while also setting mandatory volume or pressure control settings. The patient can initiate their own breaths, and a predetermined amount of pressure is supplemented in a manner similar to pressure support. If the patient does not meet the minimum parameters set by the provider, the ventilator seizes full control of ventilation as in assist control ventilation.

SIMV is proposed to decrease the incidence of respiratory muscle atrophy because it allows patients to trigger breaths spontaneously. SIMV can be implemented as a weaning method for ventilation. As the patient's breaths become more autonomous, the minimum mandatory settings can be titrated down until the patient is completely breathing under pressure support settings.

Another form of assist control ventilation is pressure-regulated volume control (PRVC or VC+). In this setting, the ventilator uses data from the prior breaths to determine the inspiratory pressure needed to give a set tidal volume. This approach allows for real-time adjustments to ventilation based on the patient's lung compliance and mechanics. This is theorized to provide the lowest pressure necessary to obtain a set tidal volume.[7] This approach also theoretically decreases the risk of barotrauma. Clinical trials have shown a decrease in peak inspiratory pressures using PRVC compared to standard volume control ventilation, although a difference in patient outcomes has not been demonstrated.[6] The parameters set by the clinician are the same as those for standard volume-cycled assist control ventilation. If peak pressures are high using this approach, the provider can decrease the inspiratory time to lower this value.

Pressure Control and Pressure Support

While tidal volume and airway pressure are related according to lung compliance, it is not possible to precisely control both variables. In pressure control ventilation, a provider sets a predetermined pressure to provide with each ventilation. The inspiratory pressure, pressure support, and inspiratory time are variables that the provider predetermines. The pressure setting accounts for individual patient lung pathology, both acutely and chronically. While the pressure is determined by the provider, the volume delivered with each breath is variable. For this reason, clinicians must be certain that the pressure set on the ventilator is providing adequate tidal volumes for the patient. Pressure control ventilation theoretically decreases the risk of barotrauma on the lung tissue by controlling the peak and plateau pressures with each breath.[3] While this belief is widely held, no data have been published that support this theory.

Pressure support ventilation is used commonly in patients who have minimal ventilator requirements. This setting allows the patient to breathe spontaneously. Each breath is augmented with pressure that is set to a certain pressure limit. Pressure support ventilation augments spontaneous breathing and cannot be used in patients who are chemically paralyzed or who do not have autonomous respiratory drive. This mode of ventilation is used commonly to transition patients toward a spontaneous breathing trial in preparation for extubation.

Airway Pressure Release Ventilation

Airway pressure release ventilation (APRV) is a ventilation method that differs from traditional volume or pressure control. APRV is a variation of continuous positive airway pressure with a brief period of release to promote ventilation. In this setting, a provider chooses two separate pressures, deemed P_{high} and P_{low}, and the amount that the patient spends in these two pressures. Typically an extended period of time (T_{high}) is spent at the higher pressure, and the time at the lower pressure (T_{low}) is 0.5-1 second and is the release of pressure. Because the T_{low} is for such a short time, the P_{low} (usually set at 0) is never reached completely. Thus, the alveoli never fully collapse, minimizing atelectasis. Ventilation is achieved not only by the patient breathing spontaneously, but by the time spent at the higher pressure (P_{high}).

APRV allows for spontaneous patient breathing during the higher-pressure phase. This generally is considered more comfortable for the patient. Data supporting the use of APRV in ARDS patients are limited. A 2017 study by Zhou et al compared APRV to low tidal volume ventilation in patients with ARDS. The study noted a statistically significant decrease in intensive care unit (ICU) stay and sedation requirements, and better oxygenation.[8] The risk of pneumothorax is higher than traditional ventilatory modes, and the cardiovascular effects may be more pronounced because of the higher intrathoracic pressures.

Pneumonia

Definition

Pneumonia is an infectious disease that produces an immune response causing inflammation of lung tissue. Pneumonia has many different etiologies, including viral, bacterial, and fungal.

Pathophysiology

Pneumonia occurs after an infectious organism infiltrates the sterile lung parenchyma tissue. Certain populations, such as older adults, alcoholics, and immunocompromised patients, are increasingly susceptible to developing pneumonia. The local immune response causes inflammation, which impairs the ability for gas exchange at the level of the alveoli. Bacterial pneumonia classically causes inflammation and lung infiltrates within one lobe of lung tissue, while other bacteria and many viruses cause infection and inflammation in multiple areas within the lungs.

Ventilator Strategies

Patients intubated for pneumonia usually are intubated for hypoxia. As such, many patients require assist control support. The exudate, which forms in cases of pneumonia, impairs oxygen exchange and causes shunting of pulmonary blood flow to areas of the lung that are not as efficient in providing oxygenation. The ability to control the PEEP and FiO_2 allows for recruitment of alveoli and improved oxygenation. Per the ARDSnet protocol, there is an algorithmic approach in increasing FiO_2 and PEEP. As patients improve, the oxygen support can be titrated down. Once patients are titrated down to a PEEP of 5 cm H_2O and FiO_2 of 40%, they can be transitioned to a less invasive mode of ventilation. Ventilatory settings (i.e., respiratory rate [RR] and tidal volume) usually are set to mimic physiologic levels, with the 6 to 8 cc/kg recommended tidal volume and RR of 12-16. These may be adjusted based on the patient's minute ventilation and gas exchange parameters, such as pH and pCO_2 noted on blood gas analysis. Pressure support ventilation is used commonly as patients recover and are weaned from the ventilator.

Acute Respiratory Distress Syndrome

Definition

ARDS is the term used to describe the clinical phenomenon of tachypnea, hypoxia, and bilateral patchy opacification on chest imaging after an insulting event. The definition and severity of ARDS is outlined by the Berlin criteria published in the *Journal of the American Medical Association* (*JAMA*) in 2012.[9] Under this classification system, ARDS severity is tiered by calculating the ratio of PaO_2 taken from an arterial blood gas to the FiO_2 setting from when the blood gas was drawn.[9,10] Symptom onset must occur within seven days of a clinical insult or decline in respiratory status. A PEEP setting of ≥ 5 cm H_2O must be used to apply these criteria. Using this calculation, ARDS can be classified as mild, moderate, and severe.[9,10] (*See Table 1.*)

Table 1. Berlin Criteria for Acute Respiratory Distress Syndrome

$paO_2 : FiO_2$	Acute Respiratory Distress Syndrome Severity
201 mmHg to 300 mmHg	Mild
101 mmHg to 200 mmHg	Moderate
≤ 100 mmHg	Severe

Pathophysiology

In the setting of lung injury, endothelial injury at the level of capillaries allows for increased capillary permeability and loss of intravascular molecules. In normal physiology, these molecules allow for an oncotic pressure that draws interstitial fluid intravascularly. With acute lung injury and loss of intravascular oncotic pressure, excess fluid accumulates in the lung interstitial spaces and alveoli. This fluid accumulation creates a physical barrier that impairs gas exchange. Additionally, the increase in fluid decreases lung compliance and results in increased pulmonary arterial pressures.

ARDS Clinical Trial Network and Other Ventilator Strategies

In a study in 2000, Brower et al compared 12 cc/kg tidal volume with plateau pressure less than 50 cm H_2O to 6 cc/kg tidal volume with plateau pressure goals less than 30 cm H_2O.[11] They found a 31% mortality in patients managed with lower tidal volumes and plateau pressures compared to 39.8% mortality in the patients managed with higher tidal volumes and plateau pressures. These results were statistically significant, with a number needed to treat (NNT) of about 11. This study provided a protocolized, step-wise approach to titrate oxygenation and ventilation for ARDS patients managed with mechanical ventilation.

Patients in ARDS can decline despite treatment, as previously outlined. In patients who fall into the Berlin criteria of severe ARDS with a $PaO_2 : FiO_2$ less than 100, prone positioning to improve oxygenation is recommended. The lung infiltrate in ARDS is characteristically confined to the dependent areas of lung distribution. Prone positioning displaces the heart off the lung tissue, which improves alveolar recruitment and allows for improved drainage of secretions. These changes function to decrease airway resistance as well. Previous studies have proven that placing mechanically ventilated patients in the prone position improves oxygenation.[12,13] Prone positioning also has been demonstrated to significantly decrease 28-day and 90-day mortality in patients with a $PaO_2 : FiO_2$ ratio less than 150.[14] This also allows for redistribution of pulmonary interstitial fluid to the anterior lungs, where ventilation and oxygen exchange are less ideal.

In addition to these therapies, other interventions are used commonly in ARDS patients. Steroids, inhaled pulmonary vasodilators, continuous neuromuscular blockade, and extracorporeal membrane oxygentation (ECMO). None have shown any mortality benefits in ARDS.

ECMO has been recommended for patients with refractory hypoxia in ARDS. ECMO allows for blood oxygenation by draining venous blood from proximal central veins (e.g., superior vena cava, inferior vena cava, or femoral vein), transporting deoxygenated hypercarbic blood through an ECMO circuit, and returning it to the central circulation in or near the right atrium.[15] Specific clinical criteria for initiating ECMO therapy are laid out by the Extracorporeal Life Support Organization (ELSO). As ECMO is reserved for severe cases of ARDS, research regarding outcomes in ARDS patients treated with ECMO have failed to show a mortality benefit.[16]

COVID-19

Definition

Coronavirus disease 2019 (COVID-19) is a disease process that results from infection by novel severe acute respiratory distress syndrome coronavirus 2 (SARS-CoV-2).[17] The virus was identified in 2019 and linked to multiple cases of pneumonia in Wuhan, China. The illness quickly spread from China, resulting in a worldwide pandemic.[17] The epidemiology and impact of this viral pandemic continue to evolve daily.

Table 2. Indications for Venovenous Extracorporeal Membrane Oxygenation

Consider for PaO_2/FiO_2 ratios < 150 on FiO_2 > 90% and Murray score 2-3
Indicated for PaO_2/FiO_2 < 100 on FiO_2 > 90% and Murray score 3-4 despite optimal care for ≥ 6 hours

Pathophysiology

Knowledge of the process by which SARS-CoV-2 causes illness is continuing to evolve. The virus is spread through respiratory droplets and is transmitted primarily through the upper airway.[17] Once a person is infected, the virus causes a systemic immune response that affects multiple organ systems. The virus and resulting immune response have produced myocarditis, transaminitis, gastroenteritis, and colitis. In the lungs, the virus produces patchy areas of infiltration in a multifocal distribution. The classic findings on computed tomography of the chest are multiple areas with ground glass opacification (GGOs).[7] The infiltrates lead to alveolar and interstitial edema, a disease process resembling ARDS.

Ventilator Strategies

Patients with COVID-19 pneumonia who require intubation and ventilator support are commonly intubated due to hypoxia, which is refractory to noninvasive modes of oxygenation. Noninvasive modes, such as high-flow nasal cannula, CPAP, or BiPAP, may be adequate as oxygen supplementation. Patients with severe COVID-19 pneumonia are usually severely hypoxic but do not manifest many of the secondary effects of hypoxia, such as altered mental status and profound fatigue from increased work of breathing. The term "happy hypoxic" has been coined to describe these patients. Many can be managed with noninvasive modes of oxygenation, self-proning, steroids, and a variety of regimens tailored to combat a cytokine response. For those who worsen despite these interventions and do show signs of altered mentation, increased work of breathing, or refractory hypoxia, ventilator support is required. Many patients with COVID-19 pneumonia have multifocal areas of interstitial edema. As such, the disease process is similar to the multifocal infiltrates seen in ARDS.

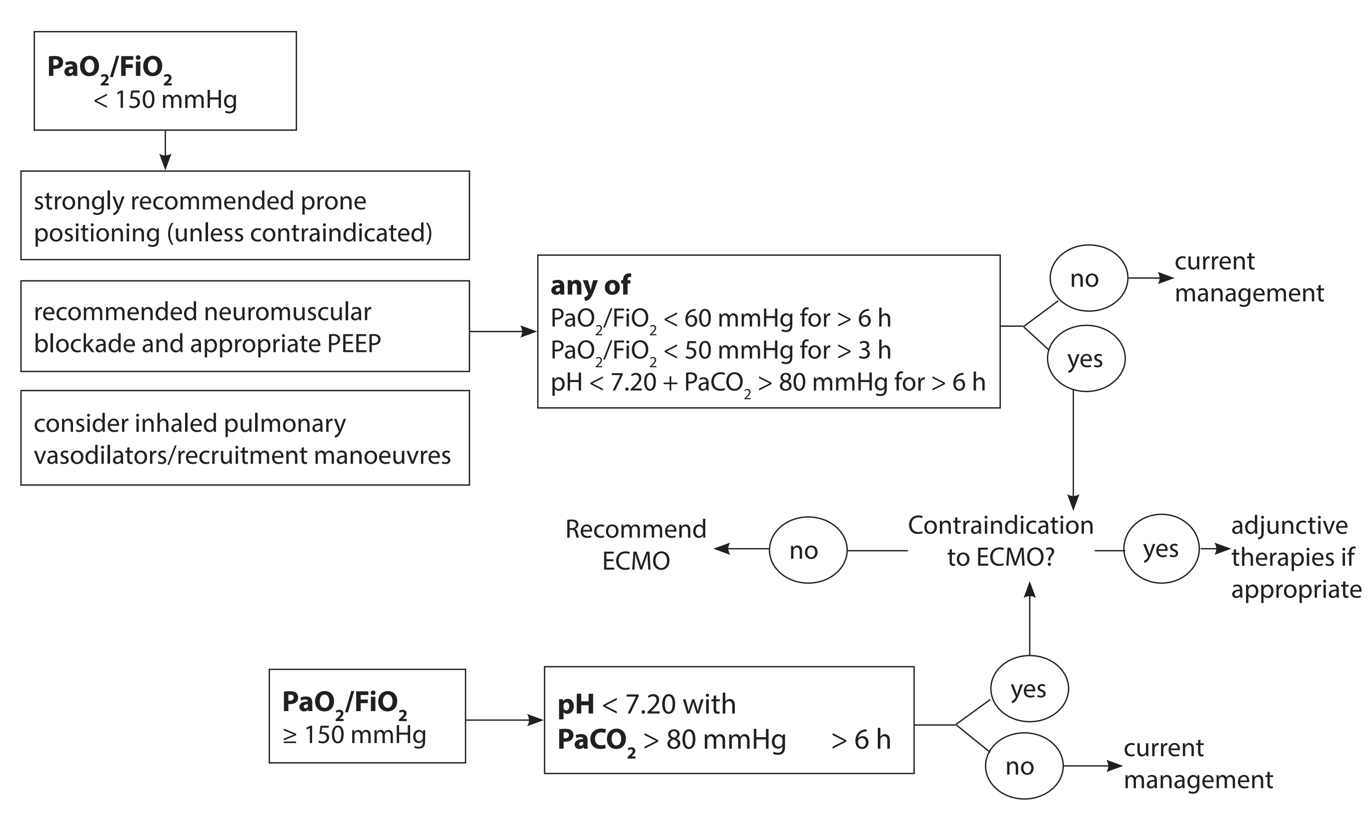
Managing patients with COVID-19 pneumonia on the ventilator is similar to managing patients with ARDS. Patients are placed on tidal volumes of 4 to 8 cc/kg. Goal plateau pressures should be < 30 cm H_2O. Oxygenation by adjustment of FiO_2 and PEEP settings also is dictated by incremental changes in these settings outlined by the ARDSnet protocol. Some patients require large amounts of PEEP and FiO_2. For this reason, oxygenation should be set for a goal oxygen saturation greater than 90%. Patients who are hypoxic despite high PEEP and FiO_2 settings may benefit from being placed in the prone position.

One key difference between previously described ARDS and the ARDS-type illness seen in COVID-19 patients revolves around differences in lung compliance. Compliance is defined as the ratio between the change in volume to a given change in pressure. ARDS traditionally is described as a disease process whereby lung compliance is decreased secondary to pulmonary interstitial edema. In patients with respiratory failure due to COVID-19 infection, lung compliance was previously thought to be unchanged.[18] However, more recent studies show that lung compliance in patients infected with COVID-19 may not be different than ARDS. Normal lung compliance seen in COVID-19 ARDS was thought to be a unique characteristic of the disease process.[18] However, cases of non-COVID-19 ARDS also have phenotypes that do not affect lung compliance.[19] This concept should be studied further in future investigations. At this time, we recommend managing COVID-19-infected patients with respiratory failure in the same manner that ARDS patients are managed on mechanical ventilation.

The strategy of proning is used to manage COVID-19 patients who remain hypoxic despite standard mechanical ventilation.[20] The decision to place patients in the prone position should be made as soon after intubation as possible.[21] Studies suggest that patients managed with prolonged prone positioning greater than 36 hours have improvement in PaO_2:FiO_2 ratios and no increase in adverse effects compared to COVID-19 patients managed with prone positioning for 16 hours.[22] Current recommendations are limited to case reports, expert opinion, and studies with small sample sizes. Recommendations regarding the treatment of patients with respiratory failure secondary to COVID-19 are likely to evolve as more is learned about the disease pathophysiology.

ECMO has been deployed in severe cases of COVID-19 as a last-resort option for patients who have failed other treatment options. Younger patients without medical conditions or only minor medical conditions are considered the highest priority candidates for initiating ECMO therapy.[19] Because of limited resources and availability, many recommend judicious eligibility criteria for patients who are selected to undergo this treatment option.[23] The ELSO is an international organization that is currently collecting data regarding ECMO management and outcomes for COVID-19-infected patients. The Murray Score is used in determining which patients may benefit from ECMO

Figure 2. Conventional Indications for Venovenous Extracorporeal Membrane Oxygenation in ARDS



Conventional VV indications for ARDS. ARDS, acute respiratory distress syndrome; ECMO, extracorporeal membrane oxygen-ation; FiO_2, fraction of inspired oxygen; $PaCO_2$, partial pressure of carbon dioxide; PaO_2, partial pressure of oxygen; PEEP, positive end-expiratory pressure; VV, venovenous.

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and takes into account consolidation on chest X-ray, P/F ratio, and PEEP. (*See Table 2 and Figure 2.*)

Brief Summary of Strategies in Pneumonia, ARDS, and COVID-19

The basics of mechanical ventilation hold true for all intubated patients. In patients who are intubated and placed on mechanical ventilation for hypoxic respiratory failure, there are subtle differences in management depending on the underlying pathology. Patients who are intubated for bacterial pneumonia generally are supported with standard ventilator settings while receiving antimicrobial therapy. As they improve, the amount of oxygen support administered by the ventilator is titrated down and can eventually be transitioned to pressure support ventilation prior to extubation.

Patients with ARDS have poor lung compliance and are best managed with low tidal volume ventilation. Permissive hypercapnia is employed to provide respiratory support and prevent ventilator-induced lung damage.

Although the management of patients with COVID-19 is continually evolving, current management is similar to that of patients with ARDS.

Case Study Conclusion

The patient was intubated in the emergency department and placed on mechanical ventilation. The initial ventilator settings were a respiratory rate of 12, a tidal volume of 6 cc/kg, PEEP of 10, and FiO_2 100%. The patient had improvement with arterial oxygen saturation increasing to 100%, allowing for down-titration of FiO_2 and PEEP per the ARDS Clinical Trial Network protocol. The patient was transitioned from volume control to pressure support ventilation on ICU day number three and was deemed appropriate for extubation. The patient was extubated successfully and transitioned out of the ICU. The patient had gradual improvement in oxygen requirements and was transitioned to room air oxygenation. The patient was discharged from the hospital on hospital day seven.

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CME/CE Questions

1. Which of following is *not* an indication for intubation and mechanical ventilation?
   a. A 45-year-old male with a respiratory rate of 22 breaths per minute and oxygen saturation of 85% on 4 liters nasal cannula
   b. A 50-year-old male with a respiratory rate of 22 breaths per minute who has an oxygen saturation of 97% on room air

c. A 35-year-old female with a history of asthma who has a respiratory rate of 26 while on bilevel positive airway pressure and a pCO_2 of 60 g/dL
d. A 20-year-old male brought into the emergency department after a high-speed motorcycle accident and who is actively seizing

2. A 60-year-old male presents to the emergency department in respiratory distress. He had tested positive for COVID-19 one week prior to presentation. You intubated the patient in the setting of acute hypoxic respiratory failure. What is the appropriate tidal volume to set on the ventilator?
   a. 4 cc/kg ideal body weight
   b. 6 cc/kg ideal body weight
   c. 10 cc/kg ideal body weight
   d. 14 cc/kg ideal body weight

3. Which of the following ventilator settings can be adjusted to affect the inspiratory : expiratory ratio?
   a. Positive end expiratory pressure
   b. Tidal volume
   c. Flow
   d. Inspiratory pressure

4. Which of the following will cause an increase in peak pressure, with no effect on the plateau pressure?
   a. A patient with chronic obstructive pulmonary disease who is noted to have bilateral wheezing
   b. A patient with acute respiratory distress syndrome (ARDS) who is difficult to oxygenate
   c. A patient with congestive heart failure who is being diuresed
   d. A patient with severe bilateral pneumonia

5. A 45-year-old male presents to the emergency department after a fall. On computed tomography scan of the head, he is noted to have an epidural hematoma. The patient becomes somnolent with a Glasgow Coma Scale (GCS) score of 6, and the decision is made to intubate the patient. His initial ventilator settings are assist control mode, FiO_2 100%, positive end expiratory pressure (PEEP) 5, respiratory rate (RR) 12, tidal volume (Vt) 500 mL. The patient is sedated and paralyzed in anticipation of going to the operating room. An arterial blood gas is obtained showing a pH of 7.24, pCO_2 of 60, HCO_3 24, PaO_2 of 500. Which ventilator parameters could be adjusted to correct the patient's pH?
   a. Decrease the tidal volume, respiratory rate, PEEP, and FiO_2
   b. Increase the PEEP and decrease the FiO_2
   c. Decrease the PEEP and tidal volume
   d. Increase the RR and tidal volume

6. Which mode of ventilation is commonly used as a weaning mode?
   a. Assist control
   b. Pressure support
   c. Airway pressure release ventilation
   d. Pressure-regulated volume control

7. The definition and severity or ARDS is defined by which of the following criteria?
   a. Berlin criteria
   b. Paris criteria

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CME/CE Objectives

Upon completion of this educational activity, participants should be able to:

- recognize specific conditions in patients presenting to the emergency department;
- apply state-of-the-art diagnostic and therapeutic techniques to patients with the particular medical problems discussed in the publication;
- discuss the differential diagnosis of the particular medical problems discussed in the publication;
- explain both the likely and rare complications that may be associated with the particular medical problems discussed in the publication.

c. Venice criteria
d. Budapest criteria

8. A 70-year-old female patient presents to the emergency department with shortness of breath. On examination, she is found to have a respiratory rate (RR) of 28, temperature of 100.7°F, heart rate of 120 beats/minute, blood pressure 136/72 mmHg, and pulse oximetry 65% on room air. She is immediately placed on non-rebreather oxygen at 12 liters. Her oxygenation improves with a saturation of 90%, RR of 20, and heart rate of 100. She states that she feels much better. A chest X-ray reveals bilateral ground glass opacities. What is the best management for this patient?
   a. Intubate this patient immediately because of the high probability of decompensation.
   b. Place the patient on bilevel positive airway pressure, admit to the intensive care unit, and treat for community-acquired pneumonia.
   c. Continue non-rebreather, diurese the patient with furosemide, and start nitro drip.
   d. Place the patient on high-flow nasal cannula, give the patient steroids, and have the patient self-prone.

9. Extracorporeal membrane oxygenation (ECMO) is used as an adjunctive therapy for cases of severe ARDS. It has been trialed in severe cases of COVID-19 infection as well. Is there any mortality benefit noted with the use of ECMO for either indication?
   a. Yes
   b. No

10. Lung compliance is always low in ARDS and normal in COVID-19.
   a. True
   b. False

EMERGENCY MEDICINE REPORTS™
(ISSN 0746-2506) is published semimonthly by Relias LLC, 1010 Sync St., Ste. 100, Morrisville, NC 27560-5468. Periodicals postage paid at Morrisville, NC, and additional mailing offices. POSTMASTER: Send address changes to *Emergency Medicine Reports*, Relias LLC, 1010 Sync St., Ste. 100, Morrisville, NC 27560-5468.

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GST Registration No.: R128870672

Back issues: $30. Missing issues will be fulfilled by customer service free of charge when contacted within one month of the missing issue's date.

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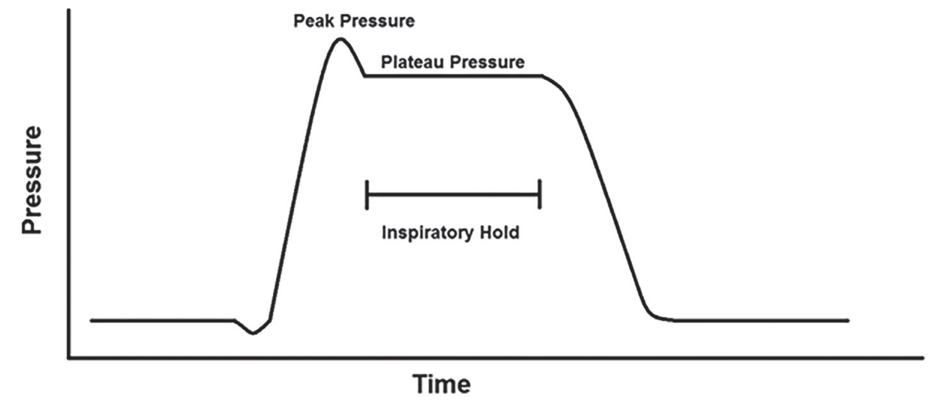
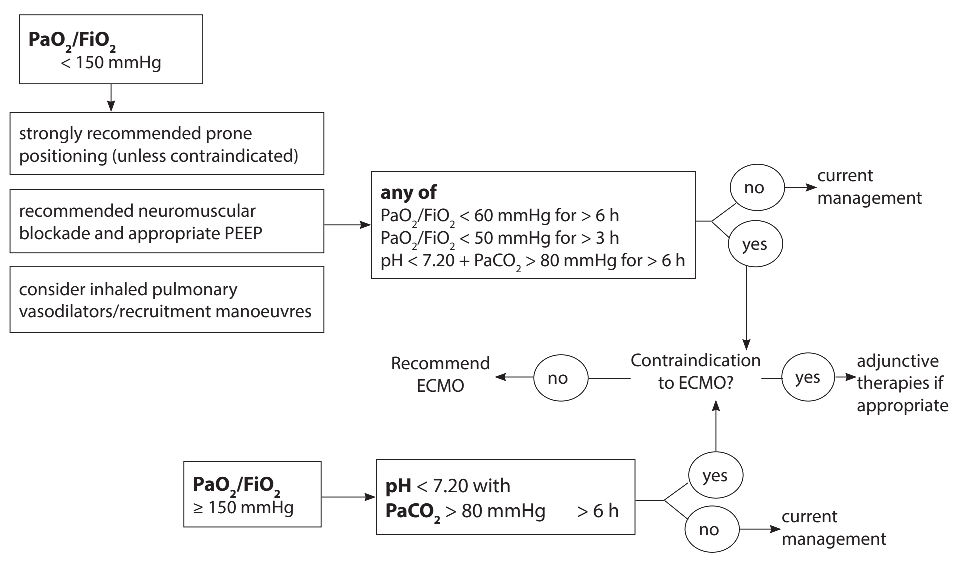
Mechanical Ventilation for Pneumonia, Acute Respiratory Distress Syndrome, and COVID-19

Peak vs. Plateau Pressure



Conventional Indications for Venovenous Extracorporeal Membrane Oxygenation in ARDS



Conventional VV indications for ARDS. ARDS, acute respiratory distress syndrome; ECMO, extracorporeal membrane oxygen-ation; FiO_2, fraction of inspired oxygen; $PaCO_2$, partial pressure of carbon dioxide; PaO_2, partial pressure of oxygen; PEEP, positive end-expiratory pressure; VV, venovenous.

Used with permission from: Shekar K, Badulak J, Peek G, et al. Extracorporeal Life Support Organization coronavirus disease 2019 interim guidelines: A consensus document from an international group of interdisciplinary extracorporeal membrane oxygenation providers. *ASAIO Journal* 2020;66:711.

Berlin Criteria for Acute Respiratory Distress Syndrome

$paO_2 : FiO_2$	Acute Respiratory Distress Syndrome Severity
201 mmHg to 300 mmHg	Mild
101 mmHg to 200 mmHg	Moderate
≤ 100 mmHg	Severe

Indications for Venovenous Extracorporeal Membrane Oxygenation

Consider for PaO_2/FiO_2 ratios < 150 on FiO_2 > 90% and Murray score 2-3
Indicated for PaO_2/FiO_2 < 100 on FiO_2 > 90% and Murray score 3-4 despite optimal care for ≥ 6 hours

Supplement to *Emergency Medicine Reports*, September 15, 2020: “Mechanical Ventilation for Pneumonia, Acute Respiratory Distress Syndrome, and COVID-19.” Authors: Guhan Rammohan, MD, FACEP, Emergency Medicine Faculty, St. Luke’s Hospital, Bethlehem, PA; and Matthew Meyers, DO, Emergency Medicine Resident, St. Luke’s Hospital, Bethlehem, PA