The coronavirus disease 2019 (COVID-19) respiratory illness has increased the number of people needing airway rescue and the support of mechanical ventilators. In doing so, the pandemic has increased the demand of healthcare professionals to manage these critically ill individuals. Certified Registered Nurse Anesthetists (CRNAs), who are trained experts in airway management and mechanical ventilation with experience in intensive care units (ICUs), rise to this challenge. However, many CRNAs may be unfamiliar with advancements in critical care ventilators. The purpose of this review is to provide a resource for CRNAs returning to the ICU to manage patients requiring invasive mechanical ventilation. The most common ventilator modes found in anesthesia machine ventilators and ICU ventilators are reviewed, as are the lung-protective ventilation strategies, including positive end-expiratory pressure, used to manage patients with COVID-19–induced acute respiratory distress syndrome. Adjuncts to mechanical ventilation, recruitment maneuvers, prone positioning, and extracorporeal membrane oxygenation are also reviewed. More research is needed concerning the management of COVID-19–infected patients, and CRNAs must become familiar with their ICU units’ individual ventilator machine, but this brief review provides a good place to start for those returning to the ICU.

Keywords: Acute respiratory distress syndrome, anesthesia ventilator, COVID-19, intensive care unit ventilator, ventilator modes.

The coronavirus disease 2019 (COVID-19) pandemic has caused an unprecedented impact on healthcare systems and healthcare professionals worldwide. This new respiratory illness has increased the number of people needing airway rescue and the support of mechanical ventilators, and has therefore increased the number of advanced healthcare providers needed to manage these critically ill patients. Certified Registered Nurse Anesthetists (CRNAs) who are trained in airway and mechanical ventilation have experience in critical care. However, many CRNAs may not have practiced in the ICU in a number of years and may be unfamiliar with advancements in critical care ventilators. Priorities of care are very different when managing ventilation of patients in the operating room (OR) vs patients in the intensive care unit (ICU). A review of current ventilator modes and patient management is needed to provide optimal patient care in this new yet still familiar setting.

This review describes common invasive ventilator modes found in anesthesia machine ventilators compared with ICU ventilator modes. Included are other methods used to improve ventilation and gas exchange in these critically ill patients. Although others are mentioned, the ventilator modes covered in this article are based primarily on an ICU ventilator (Servo-U, Maquet Medical Systems USA, Getinge Group) and an anesthesia ventilator (Avance CS2, GE Healthcare). Although many ventilators also include noninvasive (nonintubated) ventilator modes, only invasive (intubated) ventilator modes are covered in this review.

The complexity of ventilator modes and the differing names of modes associated with different manufacturers complicates succinct categorization. Therefore, it is imperative that readers familiarize themselves with the ventilator found in their individual practice setting by visiting the manufacturer’s website.

Basics of Ventilators
Despite the complexities and differences of ventilators among the different manufacturers and hospital settings, all ventilators have some basic characteristics, and there are simple ways to differentiate between the available modes. Ventilators have evolved since the negative pressure iron lung used during the polio epidemic of the 1950s. Ventilators are now positive pressure ventilators and can be described and classified based on their mechanics (bellows, piston, turbine, and sophisticated microprocessors) or their manufacturer. Ventilator modes are differentiated based on what triggers the breath (patient or machine), and whether the ventilation is volume-targeted or pressure-targeted. When a breath switches from inhalation to exhalation, this is called a cycle, and ventilator modes are often classified as time-cycled, pressure-cycled,
or volume-cycled.\textsuperscript{5} The 2 base modes found in ICU and anesthesia machine ventilators are pressure control ventilation and volume control ventilation.\textsuperscript{2}

Table 1 describes the major ICU and anesthesia machine ventilator configurations.\textsuperscript{2,4,6-12} Usually ICU ventilators offer more ventilator modes than can be found on anesthesia ventilators as well as a more complex functionality. See Table 2 for a list of common ventilator modes found in ICU ventilators.\textsuperscript{1,2,7-9,13-15}

The following discussion will highlight considerations for the anesthesia provider choosing a ventilator mode for a patient experiencing acute respiratory distress syndrome (ARDS), including COVID-19–induced ARDS presentation. However, the decision of choosing an effective mode of ventilation for any patient requiring mechanical ventilation in the ICU should be based on patient-specific considerations.

When one is choosing between a volume control mode and a pressure control mode to ventilate a patient experiencing COVID-19–induced ARDS or other forms of ARDS in either the ICU or the OR, the following should be considered. Earlier models of anesthesia ventilators suffered from poor performance when ventilation demands were high. The combination of poor lung compliance and high minute ventilation demand associated with ARDS requires that the ventilator deliver effective minute ventilation to avoid hypercapnia and respiratory acidosis. A volume control ventilation mode is commonly recommended for use with patients experiencing ARDS because of the tight control on low tidal volumes, a major component of lung-protective ventilation (LPV). However, with a volume control ventilation mode, the practitioner must vigilantly monitor for excessive peak inspiratory pressure to ensure injury does not occur. Benefits of using pressure control ventilation as an LPV strategy includes a more homogenous gas distribution due to the constant pressure delivered during the breath cycle.\textsuperscript{2,6,8,10,11} A disadvantage of using a pressure-controlled ventilation mode for this patient population includes the inability to guarantee a consistent and optimal low tidal volume. The tidal volume achieved is intimately dependent on compliance of the lung.\textsuperscript{2,6,8,10,11} The continuous and potential high flow rate pattern associated with pressure control ventilation could also lead to injury compared with the constant flow pattern of volume control ventilation.\textsuperscript{16} The practitioner must decide which

<table>
<thead>
<tr>
<th>Mode</th>
<th>Basic description</th>
<th>Considerations</th>
<th>Adjustable settings</th>
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<tbody>
<tr>
<td>Volume control ventilation (VCV)/controlled mandatory ventilation (CMV) (base mode)</td>
<td>Machine-triggered, time-cycled mode with a volume target\textsuperscript{2,7,8}</td>
<td>Not ideal for inhomogeneous lung units. Will not support spontaneous breaths\textsuperscript{2,7,9}</td>
<td>FiO\textsubscript{2}, RR, V\textsubscript{T}, I:E ratio, PEEP\textsuperscript{2,7,8}</td>
</tr>
<tr>
<td>Pressure control ventilation (PCV)/CMV-pressure control</td>
<td>Machine-triggered, time-cycled, pressure-targeted mode\textsuperscript{9,10}</td>
<td>V\textsubscript{T} achieved is variable between breaths, because it is based on the compliance of the patient’s lungs and the resistance in the airway\textsuperscript{2,6,8,10,11}</td>
<td>FiO\textsubscript{2}, inspiratory pressure, I:E ratio, RR, PEEP\textsuperscript{2,6,8,10,11}</td>
</tr>
<tr>
<td>PCV-volume guarantee (VG)/volume mode with autoflow Pressure-regulated volume control (PRVC)\textsuperscript{4,12}</td>
<td>A preset pressure will be delivered to achieve a volume target. Combines VCV and PCV</td>
<td>First breath is sensing breath used by the ventilator to determine what pressure is needed to deliver subsequent breaths.</td>
<td>FiO\textsubscript{2}, RR, V\textsubscript{T}, I:E ratio, inspiratory pressure, PEEP\textsuperscript{2,7}</td>
</tr>
<tr>
<td>Synchronized intermittent mandatory ventilation (SIMV); can be combined with PCV, VCV, PRVC/PCV-VG, or pressure support\textsuperscript{2,4}</td>
<td>Patient is able to initiate his or her own breaths outside those set by the base mode; weaning ventilatory mode</td>
<td>In SIMV-PC and SIMV-PSV ventilatory modes, the patient’s spontaneous breath is sensed and supported by a pressure support setting\textsuperscript{2,7}</td>
<td>Depends on the specific version used; basic adjustable settings include FiO\textsubscript{2}, minimum RR, V\textsubscript{T}, sensitivity trigger, PEEP, pressure support\textsuperscript{2,7}</td>
</tr>
<tr>
<td>Pressure support ventilation (PSV)/PSV-Protect</td>
<td>Spontaneous breath is sensed and supported with pressure support\textsuperscript{1,1}; weaning ventilatory mode</td>
<td>Protect feature includes a backup mode that will be activated if the patient is apneic or if RR drops below the minimum setting for an extended time.\textsuperscript{2} Sensitivity trigger in anesthesia ventilators is flow vs negative pressure in ICU ventilators.\textsuperscript{7}</td>
<td>FiO\textsubscript{2}, minimum RR, sensitivity, pressure support, PEEP\textsuperscript{2,9}</td>
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Table 1. Shared Modes of Ventilation

Abbreviations: ARDS, acute respiratory distress syndrome; FiO\textsubscript{2}, fraction of inspired oxygen; ICU, intensive care unit; I:E, inspiratory to expiratory; PEEP, positive end-expiratory pressure; RR, respiratory rate; V\textsubscript{T}, tidal volume.
<table>
<thead>
<tr>
<th>Mode</th>
<th>Basic description</th>
<th>Considerations</th>
<th>Adjustable settings</th>
</tr>
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<tbody>
<tr>
<td>Mandatory minute ventilation/intermittent mandatory ventilation (IMV)</td>
<td>Desired minute ventilation is set using an initial mandatory RR and an ideal V&lt;sub&gt;T&lt;/sub&gt;(^2,^,,^7)</td>
<td>Patient is able to breathe spontaneously, and spontaneous breaths are supported by a preset pressure support. In IMV, the patient’s spontaneous breath is not supported by a pressure support breath.(^2)</td>
<td>Fio&lt;sub&gt;2&lt;/sub&gt;, RR, V&lt;sub&gt;T&lt;/sub&gt;, PEEP, pressure support(^2,^,,^7)</td>
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<tr>
<td>Assist control ventilation</td>
<td>Minimum RR and V&lt;sub&gt;T&lt;/sub&gt; are set; will ensure that the desired V&lt;sub&gt;T&lt;/sub&gt; is delivered with every breath, including the patient-initiated breaths(^2,^,,^7)</td>
<td>Disadvantage: if the patient’s RR is too high for the patient to be able to fully exhale the delivered V&lt;sub&gt;T&lt;/sub&gt;, then breath stacking and volutrauma can occur.(^2)</td>
<td>Fio&lt;sub&gt;2&lt;/sub&gt;, minimum RR and V&lt;sub&gt;T&lt;/sub&gt;, PEEP, backup mode(^4)</td>
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<td>Volume support ventilation vs pressure support ventilation</td>
<td>Ventilator will sense the patient’s breath and effort and will adjust the pressure support level to deliver the desired volume(^2)</td>
<td>Supports the patient’s spontaneous breath and ensures that a desired V&lt;sub&gt;T&lt;/sub&gt; is achieved.</td>
<td>Fio&lt;sub&gt;2&lt;/sub&gt;, minimum RR, sensitivity, target V&lt;sub&gt;T&lt;/sub&gt;, PEEP(^2)</td>
</tr>
<tr>
<td>Airway pressure release ventilation/bilevel ventilation</td>
<td>Time-cycled, pressure-targeted mode(^2,^,,^7). A type of inverse ratio ventilatory mode, it is intended that the patient spend more time in the inspiratory cycle, or T&lt;sub&gt;high&lt;/sub&gt;(^8,^,,^9)</td>
<td>Patient is able to breathe spontaneously throughout the ventilatory cycle.(^2,^,,^7,^,,^8) Used as a rescue mode to manage patients with ARDS in the ICU.(^2,^,,^13) Contraindicated in patients with severe COPD and lung disease.(^2)</td>
<td>Fio&lt;sub&gt;2&lt;/sub&gt;, P&lt;sub&gt;high&lt;/sub&gt;, P&lt;sub&gt;low&lt;/sub&gt;-Thigh, T&lt;sub&gt;low&lt;/sub&gt;(^2,^,,^8)</td>
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<tr>
<td>Proportional assist ventilation/proportional pressure support</td>
<td>Provider sets the percentage of work performed by the ventilator, and the remaining percentage of work is performed by the patient(^7,^,,^9)</td>
<td>6.0-cm ET tube or equivalent minimum.(^9) Consistent monitoring is recommended to ensure the ventilator is sensing the patient’s effort accurately.(^2) Considered one of the most comfortable modes of ventilation; promotes sleep.(^2,^,,^9)</td>
<td>Fio&lt;sub&gt;2&lt;/sub&gt;: PEEP, type and size of airway tube, sensitivity trigger, patient’s weight(^2,^,,^7,^,,^9)</td>
</tr>
<tr>
<td>Adaptive support ventilation</td>
<td>Ventilator will determine and initiate an RR and V&lt;sub&gt;T&lt;/sub&gt; that will produce the least amount of work for the patient while still maintaining ventilation(^2,^,,^9), weaning mode</td>
<td>Patient-initiated breaths supported by pressure support.(^2)</td>
<td>Fio&lt;sub&gt;2&lt;/sub&gt;: patient’s height, gender, goal minute ventilation, PEEP(^2,^,,^9)</td>
</tr>
<tr>
<td>Neurally adjusted ventilator assist (NAVA)</td>
<td>Mode driven by the neural input signals of the diaphragm; sensed using an esophageal catheter(^2,^,,^9)</td>
<td>Designed to decrease asynchrony associated with ventilator modes that depend on flow for input and are susceptible to miscalculations if a leak is present or flow devices are malfunctioning.(^9) Does not limit ET tube size.(^9) Should be avoided in patients in which one does not want the respiratory centers to drive ventilation, because hyperventilation can occur.(^2,^,,^7,^,,^9,^,,^14,^,,^15)</td>
<td>Fio&lt;sub&gt;2&lt;/sub&gt;: PEEP, NAVA level(^2,^,,^7,^,,^8)</td>
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<tr>
<td>High-frequency oscillatory ventilation (HFOV)</td>
<td>Delivery of a rapid RR with small V&lt;sub&gt;T&lt;/sub&gt; used as a rescue mode of ventilation for patients with severe ARDS(^2,^,,^7,^,,^9)</td>
<td>To increase the patient’s PaO&lt;sub&gt;2&lt;/sub&gt;, the Fio&lt;sub&gt;2&lt;/sub&gt; and mean airway pressure are adjusted, and intermittent recruitment maneuvers should be performed.(^2) To manipulate CO&lt;sub&gt;2&lt;/sub&gt; levels, the amplitude and frequency should be titrated.(^7,^,,^9,^,,^13) Frequency waves cause expiration of CO&lt;sub&gt;2&lt;/sub&gt;.(^7,^,,^9,^,,^13) The V&lt;sub&gt;T&lt;/sub&gt; delivered are lower than dead space volume, and patient may require recruitment maneuvers.(^2,^,,^13) Pneumothorax is a potential complication.(^2) The possibility of increased aerosolization should be considered before placing a COVID-19–positive patient on HFOV.(^1)</td>
<td>Fio&lt;sub&gt;2&lt;/sub&gt;: inspiratory time, frequency, amplitude, mean airway pressure(^7,^,,^9)</td>
</tr>
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</table>

Table 2. ICU Ventilator Modes

Abbreviations: CO<sub>2</sub>, carbon dioxide; COPD, chronic obstructive pulmonary disease; COVID-19, coronavirus disease 2019; ET, endotracheal; Fio<sub>2</sub>, fraction of inspired oxygen; ICU, intensive care unit; PEEP, positive end-expiratory pressure; P<sub>high</sub>- pressure high; P<sub>low</sub>- pressure low; RR, respiratory rate; T<sub>high</sub>- time spent at high pressure; T<sub>low</sub>- time spent at low pressure; V<sub>T</sub>- tidal volume.
ventilator mode is safest for management of the patient on an individual basis.\textsuperscript{13}

Management of Ventilation in Intensive Care Unit Patients

Ventilating a critically ill patient is more complicated than simply choosing a ventilator mode. In the OR setting, the reason for intubation and mechanical ventilation is often related to the surgical procedure itself and not always the condition of the patient. Patients coming to the OR range from healthy patients undergoing elective procedures to patients needing lifesaving operations. The goal of mechanical ventilation in the OR is to maintain homeostasis and optimize surgical conditions usually for short periods.\textsuperscript{2} Indications to intubate a patient in the ICU include increased work of breathing, Pao\textsubscript{2}/fraction of inspired oxygen (F\textsubscript{I}O\textsubscript{2}) ratio less than 200 mm Hg, PaCO\textsubscript{2} greater than 60 mm Hg, oxygen saturation measured by pulse oximetry (SpO\textsubscript{2}) less than 88% to 92%, or lack of airway protective reflexes.\textsuperscript{1,17,18} In the ICU, patients are intubated and mechanically ventilated, often for days to weeks, to treat hypoxemia and/or acidosis and to ease the work of breathing.\textsuperscript{2}

When deciding whether to intubate a patient who has a positive COVID-19 test result (is “COVID-19 positive”), the delayed symptoms and the increased time necessary to don personal protective equipment must be considered in the decision-making process. Many COVID-19–infected patients have a larger oxygen debt than would be predicted, because of the possibility of asymptomatic hypoxemia.\textsuperscript{1} The provider should follow institutional guidelines, consider the possibility of a difficult airway, and the comfort and experience level of the provider. The intubation may be more stressful and difficult with the increased personal protective equipment that must be worn, in addition to the stress of possibly contracting the virus or being the cause of its spread to the other providers in the room.\textsuperscript{1} The provider should consider using a video laryngoscope to intubate to further distance the provider from the patient, and should use a viral filter on the circuit.\textsuperscript{1,17,18} More research is needed to develop more specific, evidence-based parameters for intubation triggers for the COVID-19–positive patient.\textsuperscript{1,17}

Acute respiratory distress syndrome is a pathophysiological process that occurs after an initial insult—either trauma or an infection—that leads to a cytokine reaction, destruction of alveoli, pulmonary edema, and impaired gas exchange across alveolar membranes.\textsuperscript{19} See Table 3 for a definition of ARDS.\textsuperscript{8,19-21} Lung-protective ventilation strategies of ventilatory management are used to manage both COVID-19–induced ARDS and other ARDS presentations.\textsuperscript{1,17,22} See Table 4 for LPV strategies.\textsuperscript{1,17,19,23-29} The purpose of LPV is to prevent a ventilator-induced lung injury while still providing conditions that support gas exchange.\textsuperscript{19} The use of LPV strategies has been shown to decrease mortality in patients experiencing ARDS.\textsuperscript{19,30}

Ventilator-induced lung injury includes many possible mechanisms of injury, including volutrauma, barotrauma, atelectrauma, and biortrauma, which can contribute to multiorgan failure.\textsuperscript{23,31} Mechanical injury caused by excessive ventilatory strategies can lead to further injury and greater release of pro-inflammatory mediators, such as cytokines.\textsuperscript{23} Due to the high blood flow rate to the lungs, many of these inflammatory mediators are picked up in the bloodstream and distributed to other organs, leading to a multiorgan phenomenon, or biortrauma.\textsuperscript{23}

Volutrauma is caused when alveoli are overdistended vs barotrauma, which is caused by excessive pressures, either negative or positive.\textsuperscript{23} Both are related and are enveloped in considering the physiological effects of transpulmonary pressure, which is essential in the determination of lung injury risk.\textsuperscript{23,31} The future of ventilation titration strategies include a reassessment of current LPV strategies, with a greater focus on the “mechanical power/stress-strain,” and use of transpulmonary pressure for bedside management.\textsuperscript{16,23,26} Excessive, repetitive delivery of volume and pressure can lead to alveolar damage, or atelectrauma.\textsuperscript{23} The constant stress applied from stretching and releasing can cause further damage, the release of pro-inflammatory mediators, and edema formation. With allowance of permissive hypercapnia, lower respiratory rate, and maintenance of an appropriate level of positive end-expiratory pressure (PEEP), the atelectrauma risk may decrease.\textsuperscript{23} Permissive hypercapnia may also decrease cytokine production and decrease the risk of biortrauma.\textsuperscript{23}

Plateau pressure is an indicator of lung compliance and is used to initiate and titrate LPV settings in patients with ARDS. To assess the risk of lung injury, plateau pressure is the most important determinant of barotrauma. Plateau pressure represents the pressure in the alveoli and is a calculated measurement using an inspiratory pause procedure on ICU ventilators when the patient is on a volume control ventilation mode.\textsuperscript{32} Comparatively,

<table>
<thead>
<tr>
<th>Severity of ARDS</th>
<th>Pao\textsubscript{2}/F\textsubscript{I}O\textsubscript{2} (P/F) ratio, mm Hg\textsuperscript{b}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>&lt;300</td>
</tr>
<tr>
<td>Severe</td>
<td>&lt;100</td>
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</table>

Table 3. Berlin Definition of Acute Respiratory Distress Syndrome (ARDS)\textsuperscript{8,19-21,a}

\textsuperscript{a}Includes timing of symptoms, chest imaging results, origin of pulmonary edema (not attributable to cardiac or fluid overload), and Pao\textsubscript{2}/F\textsubscript{I}O\textsubscript{2} ratio (P/F ratio).\textsuperscript{20} For calculation of P/F ratio, the F\textsubscript{I}O\textsubscript{2} is represented as a fraction. For example, if a patient is receiving an F\textsubscript{I}O\textsubscript{2} of 80% and the Pao\textsubscript{2} is 98 mm Hg, the P/F ratio would be 98 mm Hg/0.8 or 122.5 mm Hg.

\textsuperscript{b}Practitioners usually implement lung-protective strategies when P/F ratio <200 mm Hg.
permissive hypoxemia to a PaO2 goal of 55-80 mm Hg\textsuperscript{1,17}.
Permissive hypercapnia to a goal of a pH >7.21,17,23
Respiratory rate <35/min\textsuperscript{1}

If the patient is breathing too fast or is dyssynchronous with the ventilator, additional sedation and perhaps muscle paralysis should be considered to limit airway pressures, improve compliance with tidal volumes, and decrease respiratory drive\textsuperscript{1,23-25}

Limit tidal volumes to <6 mL/patient’s ideal body weight (kg)\textsuperscript{1,19,23,26,27}
Plateau pressure <30 cm H\textsubscript{2}O\textsuperscript{1,23,26,27}
Titrated tidal volume and PEEP to decrease plateau pressure\textsuperscript{1,18,26,28}
Driving pressure <14-15 cm H\textsubscript{2}O\textsuperscript{1,18,28,29}
Titrated tidal volume and PEEP to decrease driving pressure\textsuperscript{1,18,26,28}
Goal-directed titration of PEEP to maintain alveolar recruitment

Table 4. Lung-Protective Ventilation Strategies
Abbreviation: PEEP, positive end-expiratory pressure.

Adjuncts to Mechanical Ventilation
• Recruitment Maneuvers. In the OR and the ICU, recruitment maneuvers are used by providers to prevent and correct atelectasis.\textsuperscript{33,34} These maneuvers are performed most often using 2 different methods: a sustained positive pressure breath to a high peak inspiratory pressure (usually 30–40 cm H\textsubscript{2}O), or a progressive increase in PEEP up to a PEEP level of 20 cm H\textsubscript{2}O.\textsuperscript{10,33,34} Many ventilators in the ICU and in the OR have a procedure button to perform a sustained vital capacity breath, which can serve as a recruitment maneuver. The purpose of the breath is to reinflate collapsed alveoli. Usually PEEP is increased from the baseline setting at the end of a recruitment maneuver to maintain the open alveoli.\textsuperscript{23,33,34}

Recruitment maneuvers in patients with ARDS, specifically cases due to COVID-19, are controversial and many factors should be taken into consideration before performing a recruitment maneuver. The purpose of a low tidal volume as an LPV strategy is to avoid alveoli overdistention, and the possibility of overdistention with a recruitment maneuver needs to be considered.\textsuperscript{34} Low tidal volumes are not always enough to prevent against the risk of overdistention. The improved gas exchange and oxygenation associated with occasional recruitment maneuvers may be beneficial in patients with ARDS provided that LPV strategies are also used to avoid ventilator-induced injury.\textsuperscript{1,35}

Acute respiratory distress syndrome induced by COVID-19 is described as a “nonrecruitable ARDS” because of the difficulty to open atelectatic areas and the vulnerability of unaffected domains to ventilator-induced injury.\textsuperscript{17} Any disconnect from mechanical ventilation carries a substantial risk of alveolar derecruitment.\textsuperscript{3}
• Prone Positioning. Turning patients from a supine to prone position is considered an effective way to recruit collapsed alveoli.\textsuperscript{34,35} Atelectatic areas of the lung cause intrapulmonary shunting and ventilation/perfusion mismatching, both of which play a role in hypoxemia seen in patients with COVID-19.\textsuperscript{1,17} When the patient is supine,
dependent atelectasis results in regional compliance differences and may contribute to volutrauma in normal lung segments. If these changes are gravity dependent, it is logical to assume that if the patient is turned from the supine to prone position that these would dissipate and improve gas exchange.23

Prone positioning decreases abdominal pressure on lung units, improves ventilation and perfusion matching, decreases the occurrence of ventilator-induced lung injury, and provides more homogenous ventilation of alveoli.16,21,34-36 Prone positioning should be initiated early in patients with COVID-19.3 The results of some studies show a benefit to prone positioning patients experiencing ARDS before their condition progresses to the point they need to be intubated.37,38 Patients should be positioned prone for greater than 12 hours a day (many experts recommend up to 16 hours) and then should be turned supine for the remainder of the day.1,17,21,35,36

Patients can be turned prone manually or using a specialty bed. This intervention can be technically challenging and requires a team skilled in turning patients prone.35,39 At least 4 to 5 providers are needed to position a patient prone, which increases the exposure of providers to infection with the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), the virus that causes COVID-19. More research is needed to determine if the benefit of prone positioning is worth the potential exposure to healthcare providers.

Skin breakdown, including pressure ulcer formation, is a common occurrence when a patient is in a prone position. Bony prominences and the facial area should have proper padding and be positioned carefully.36,40 The provider should ensure that intravenous catheter lines and devices do not put pressure on the patient’s skin.37 Other concerns include accidental extubation, bronchus intubation, and line and/or chest tube removal, and practitioners should have a plan for turning the patient supine quickly if the patient becomes unintentionally extubated or experiences cardiac arrest.

There is conflicting evidence regarding the effectiveness of prone positioning in decreasing mortality. The Proning Severe ARDS Patients (PROSEVA) study findings revealed that prone positioning during mechanical ventilation leads to decreased mortality when used early and for extended periods in patients with ARDS.35 Three limitations of the PROSEVA study are that it was performed in ICUs that had experience in prone positioning patients with ARDS, the prone phase of care was for at least 16 hours per day, and the study was pre-COVID-19.35 Munshi et al36 in 2017, performed a meta-analysis and systematic review and found an association between prone positioning for at least 12 hours a day and increased survival, especially in patients defined as having severe ARDS.

- Extracorporeal Membrane Oxygenation. Extracorporeal membrane oxygenation (ECMO) is used for patients with ARDS who are refractory to LPV strategies and other strategies, such as prone positioning. Venous-venous (V-V) ECMO is the most common form of ECMO used in patients with ARDS. Only the lungs are bypassed in V-V ECMO, and it is considered a type of lung rest.8,19,41,42 Intact cardiac function is still needed for V-V ECMO.8,19,41,42 Due to the invasiveness of ECMO, it is often considered a last-resort rescue therapy, although centers that specialize in ECMO may have a lower threshold for its initiation.19

Extracorporeal membrane oxygenation should be considered only in patients who have a reversible cause of respiratory failure.8,19,41 When patients with COVID-19 demonstrate refractory and worsening respiratory failure despite implementation of LPV evidence-based rescue therapies, such as prone positioning and use of neuromuscular blockers, ECMO may improve outcomes.3 Indications that may be used to consider initiating ECMO in these patients include the following: Pao2/Fio2 ratio below 100 mm Hg (some experts recommend <80 mm Hg), an Fio2 greater than 90%, persistent hypercarbia (PaCO2 >80 mm Hg) or a pH below 7.2, and plateau pressures above 30 cm H2O despite reduced tidal volumes to below 4 mL/kg.2,8,19,41-43 To be considered a candidate, the patient must be able to be anticoagulated, which has been associated with complications of thrombocytopenia and life-threatening bleeding.19,44

The 2018 ECMO to Rescue Lung Injury in Severe ARDS (EOLIA) study evaluated the mortality risk associated with ECMO for patients with severe ARDS, and the results found no statistically significant reduction in 60-day mortality in patients with ARDS randomly assigned to receive ECMO vs conventional LPV.19,45 Although the difference was not significant, this treatment may be clinically meaningful to providers who are using ECMO as a last resort in severely hypoxic patients.44 This study was limited by a 28% crossover rate from conventional therapy to ECMO and early termination due to futility, resulting in a likely underpowered study.43 Encouragingly, patients receiving ECMO had fewer days requiring renal replacement therapy.43 Also, the fact that the EOLIA investigators considered it necessary to cross over 28% of patients from the control group to the ECMO group is encouraging for the use of ECMO as a rescue therapy in dire cases.43,44 Given the limitations of the EOLIA trial, further studies are needed to elucidate the efficacy of ECMO in the management of severe ARDS, specifically those with COVID-19.44

Conclusion
Certified Registered Nurse Anesthetists returning to the ICU will encounter evolutions in mechanical ventilators that greatly differ from those seen in the traditional anesthesia machine ventilators. One major limitation of

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DISCLOSURES
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By Ron Whitchurch
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