Mechanical Ventilation for COVID-19

Ventilation in ARDS

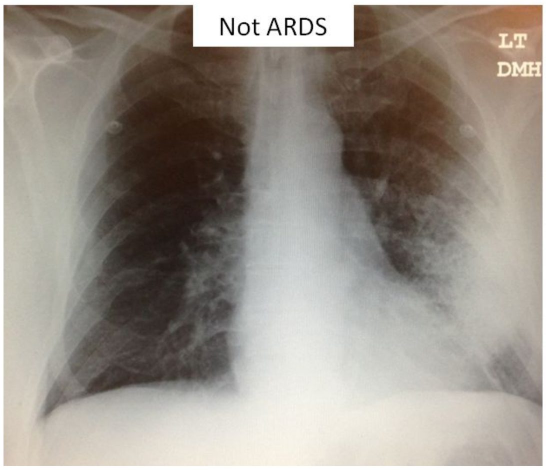
Readings adapted from Wilcox, Susan R., et al. *Mechanical Ventilation in Emergency Medicine.* Springer, 2019

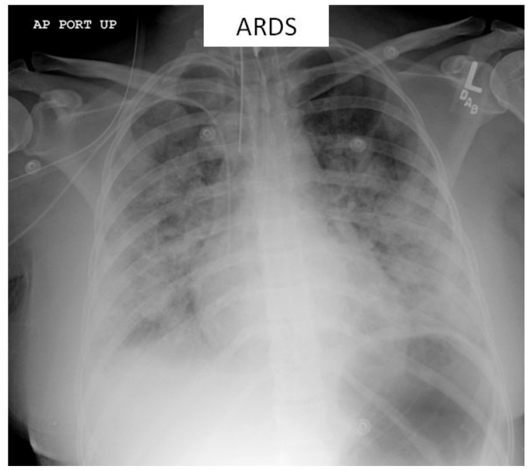
Introduction

Acute Respiratory Distress Syndrome, (ARDS) is a condition of diffuse alveolar damage and inflammation, secondary to any number of possible processes. While ARDS always causes hypoxemia, not all hypoxemia is ARDS. ARDS is the most common severe complication of COVID-19, contributing to the severe morbidity and mortality of the infection.
ARDS is defined by 4 criteria:

1. The condition must be acute (< 7 days)
2. The findings are not solely explained by cardiogenic pulmonary edema
3. The chest X-ray must have bilateral opacities

4. While on at least 5 cm H_2O of positive pressure ventilation, the ratio of PaO_2 to FiO_2 (expressed as a decimal, such as 0.7) must be < 300
    1. Mild ARDS is a PaO_2/FiO_2 ratio of 200-300
    2. Moderate ARDS is 100-199
    3. Severe ARDS is < 100

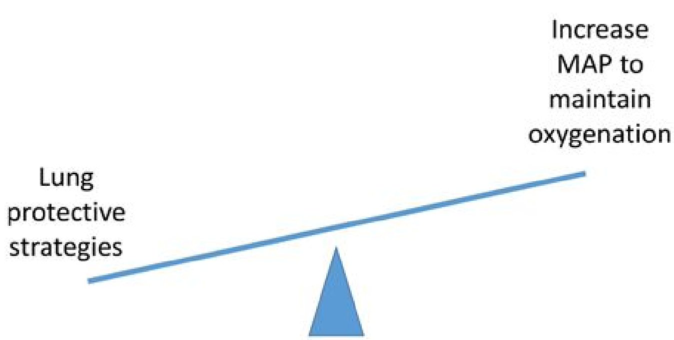




Positive pressure ventilation, especially with large tidal volumes or high pressures, has been shown to cause injury in both patients with ARDS as well as patients who do not yet have ARDS. Of all the interventions in critical care, few have been as reproducibly beneficial to patients as low tidal volume ventilation.

Many of the maneuvers used in severe hypoxemia to improve oxygenation and ventilation can be deleterious in the long term. Increasing the mean airway pressure (MAP) is one of the major goals of positive pressure ventilation, and higher MAPs are often associated with improved oxygenation. The factors that increase MAP are those that either increase the pressure in the airways, such as tidal volume, PEEP, or, AutoPEEP, or the amount of time the positive pressure is delivered, such as the inspiratory time.

However, despite short-term improvement in oxygenation, high pressures in the alveoli are also associated with worse long-term outcomes. Therefore, the clinician has to balance the risk of increasing the MAP with using good, evidence-based ventilator management.

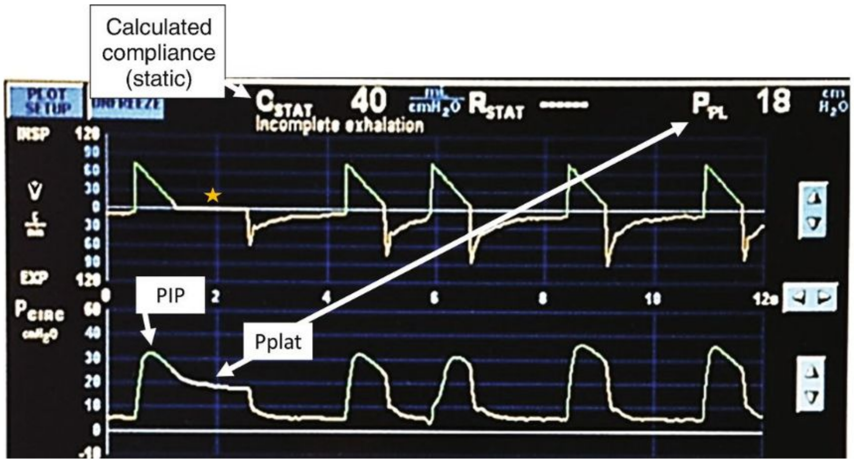


Tidal volumes are best represented in both mLs and mLs/kg of predicted body weight. The predicted body weight is a surrogate for the patient's anticipated lung volume. Lung volumes depend upon a patient's height and biological sex. Actual body weight should never be used as a replacement for the predicted body weight.

The ventilator screen below shows an example of a low tidal volume strategy. The patient was set on 330 ml/kg, or 6.35 ml/kg of PBW, as indicated in the bottom left-hand corner.

Once the initial tidal volume is selected, the pressures should be assessed. In ARDS, as well as other patients, maintaining a Pplat < 30 cm H_2O is key to preventing ventilator-induced lung injury. Note that the Pplat will be determined by the tidal volume given and the compliance of the respiratory system. ARDS usually results in decreased compliance, resulting in stiff lungs. Interestingly, in patients with COVID19, their compliance seems to be higher than other patients with comparable ARDS.

Using an inspiratory hold, the Pplat should be confirmed to be less than 30 cm H_20. If Pplat is > 30 cm H_20, a lower tidal volume should be initiated, even down to 4ml/kg.

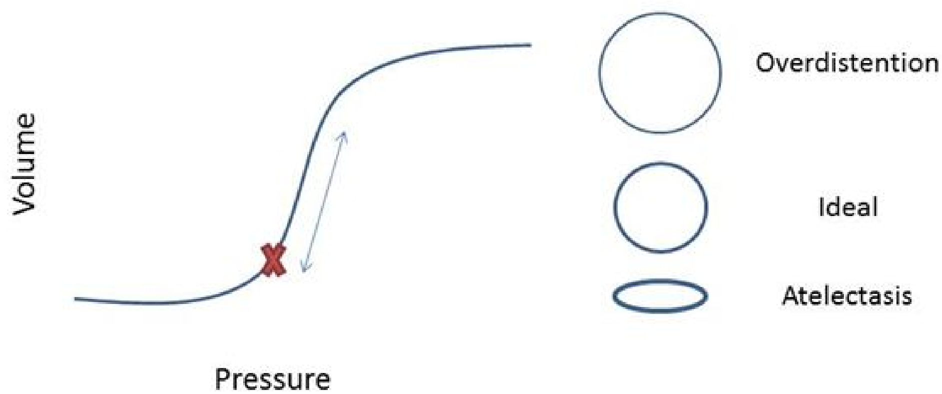


The image of a ventilator screen above shows an inspiratory pause to calculate a plateau pressure (Pplat). The gold star shows where flow has ceased to allow pressures to equilibrate. The Pplat is 18 cm H_2O in this example. The ventilator automatically calculates a compliance of 40 mL/cm H_2O. A normal compliance is about 80–100 mL/cm H_2O, and expected for a ventilated patient is approximately 60 mL/cm H_2O, as all ventilated patients are less compliant than those breathing with normal respirations.

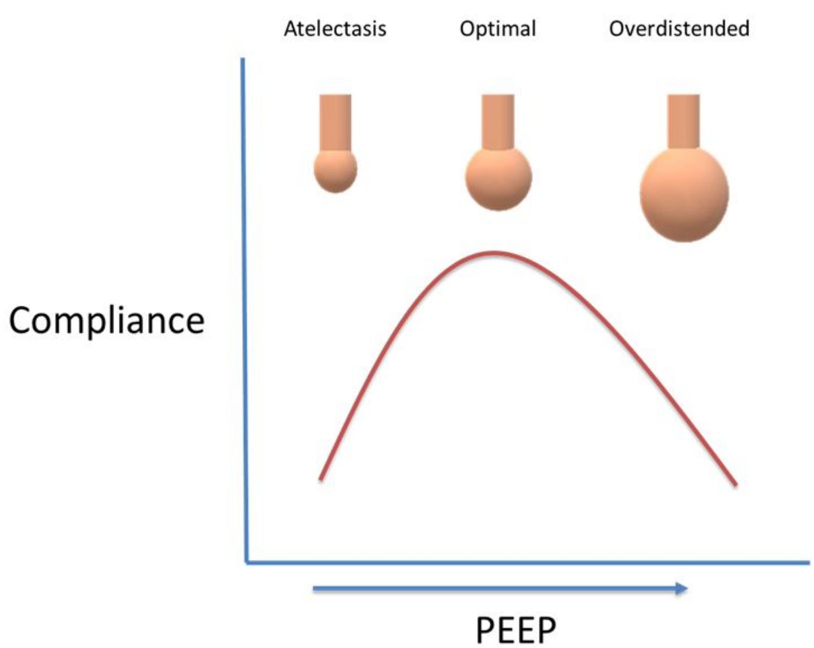
In the image below, an inspiratory hold has been performed, providing a Pplat of 32. This tells us two things:

1. There is a minimal difference between the PIP (35 cm H_2O) and the Pplat (32 cm H_2O) indicating that the patient has only a compliance problem without a resistance problem.
2. The Pplat is too high. The tidal volume should be lowered to 5 ml/kg PBW and reassessed.

PEEP is the next setting to address. Clearly, oxygenation is a critical factor for these patients. PEEP increases the mean airway pressure (MAP) and thereby improves oxygenation. PEEP additionally can help prevent further derecruitment. A physiologic goal in setting PEEP is to prevent atelectasis without extending into overdistention. A theoretical optimal PEEP would be at the red "X", and each breath would move up and down the pressure/volume slope as indicated by the light blue arrow.



Many of these patients will need moderate to high PEEPs of 8-16 cm H_2O, and at times, even greater. The PEEP may contribute to the Pplat, and therefore, the Pplat should be checked with any PEEP change, just as with any TV change. The time when an increase in PEEP will not, or will only minimally, increase the Pplat is when the patient is derecruited and increasing the PEEP helps recruit collapsed lung. In this instance, the increase in PEEP can actually improve compliance, and therefore not increase the Pplat.



This is the principle behind performing a recruitment maneuver and a “Best PEEP” trial to find a PEEP that optimizes compliance – preventing both atelectasis and overdistention. This is discussed in more detail below.

Driving pressure (ΔP) is the term that describes the pressure changes that occur during inspiration, and is equal to the difference between the plateau pressure and PEEP (Pplat – PEEP).   For example, a patient with a Pplat of 40 cm H_2O and a PEEP of 10 cm H_2O would have a driving pressure of 30 cmH_2O. In other words, 30 cm H_2O would be the pressure that extered to expand the lungs. Studies have shown that a driving pressure of < 15 cm H_2O is associated with better outcomes in patients with ARDS.

While most patients will be started on a FiO_2 of 100%, especially if hypoxemic, the FiO_2 should be decreased as tolerated after checking an ABG. Oxygen toxicity is increasingly appreciated in numerous conditions, as decreasing the FiO_2 as much as is safely tolerated is appropriate. A reasonable target is an SpO_2 of 92-96%.

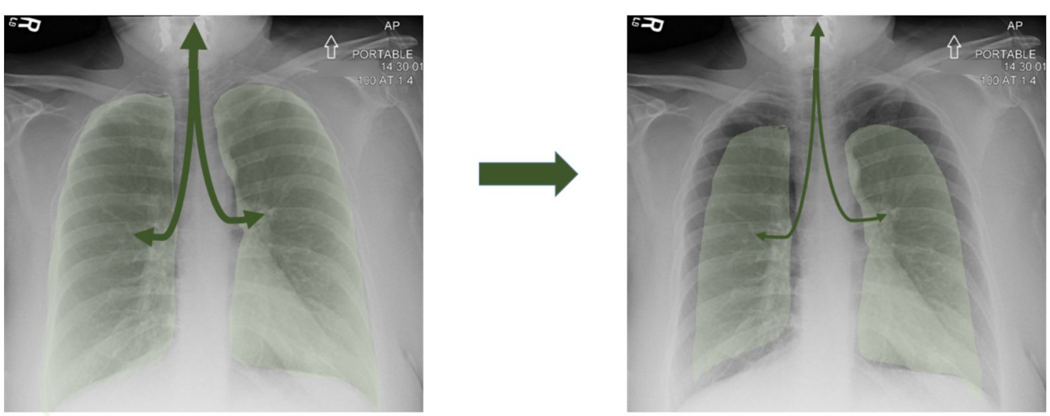
The following ventilator screen illustrates settings for a patient with ARDS. The tidal volume is 400, which is appropriate for the patient's height and sex. The respiratory rate is 30, to maintain minute ventilation of approximately 12. A PEEP of 18 is required, and the patient is still on 100% FiO_2. Note that the PIP is 47, and the Pplat is 43. The clinicians can try to decrease the tidal volume, however, these values are so far from 30 cm H_2O, it is unlikely that they will be able to achieve this goal.

An ABG provides important information, allowing the clinician to calculate the PaO_2 to FiO_2 (P/F) ratio, and thereby categorize the severity of the patient's ARDS.

Patients being ventilated with low tidal volumes will require a higher rate to maintain minute ventilation. Most patients with ARDS will require RR of 20 breaths per minute or greater. This is especially important to consider as many patients with ARDS will be hypermetabolic, with increased CO_2 production.

Minute ventilation
= tidal volume x breaths per minute

To maintain minute ventilation
as tidal volume decreases,
respiratory rate must increase



Initial Ventilator Settings in ARDS

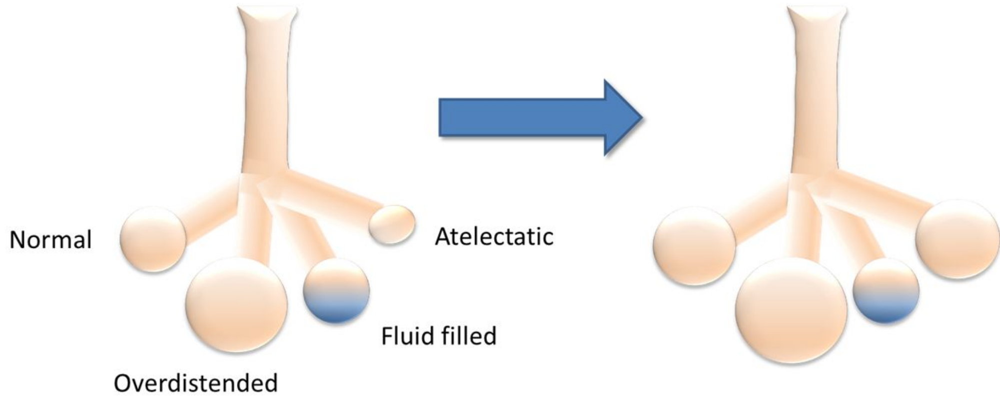
Tidal Volume	4-8 ml/kg PBW, starting with 6 ml/kg
Respiratory Rate	Higher, often > 20 breaths per minute
PEEP	≥ 8 cm H_2O, avoiding overdistention
FiO_2	Decrease as tolerated, SpO_2 ≥ 92%

Severe Hypoxemia

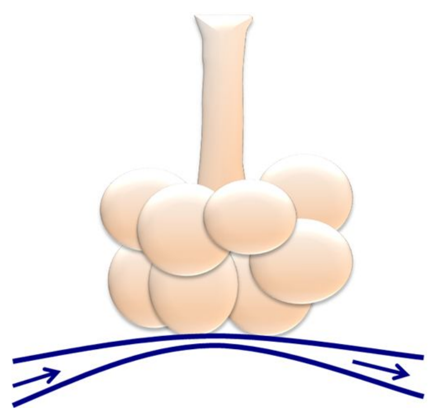
At times, patients may have refractory, severe hypoxemic respiratory failure. After checking all ventilator settings as described above, the clinician should employ additional evidence-based maneuvers.

At times, a patient may be well sedated yet dyssynchronous with the ventilator. Ventilator dyssynchrony is associated with worse outcomes and should be avoided. A recent trial published in 2019 did not find improved mortality with neuromuscular blockade use in ARDS. However, neuromuscular blockade was also not associated with increased harm. As such, it can be considered in patients who remain dyssynchronous with the ventilator despite appropriate sedation. This image of the ventilator shows how a patient looks when dyssynchronous. The waveforms should be smooth and fairly regular. When they are jagged and irregular as shown here, the patient is fighting the ventilator. Additionally, note that while the patient is set on low tidal volume ventilation at 380 ml, the patient is actually taking in about 800 ml through significant respiratory efforts.

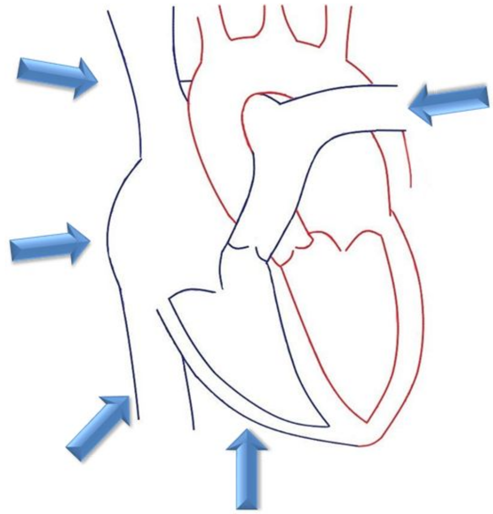
In well-sedated and possibly chemically relaxed patients, the first maneuver is to provide a recruitment maneuver. Recalling that decruitment is a common cause of hypoxemia, gently recruiting alveoli can improve oxygenation. The damage to the lungs is heterogeneous. Some areas are atelectatic, some are fluid-filled, some are already over distended, and some are even normal. The concept behind a recruitment maneuver is simple: the application of sustained pressure to open up collapsed alveoli. However, there are two potential downsides.



However, note that the normal and overdistended areas may also become even more overdistended. This overdistention from the previously "good" parts of the lung can lead to decreased gas exchange during the recruitment, causing desaturation. This effect should be temporary and improve after the maneuver.



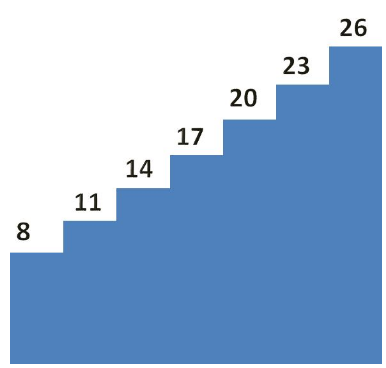
The second effect is that the patient can become hemodynamically unstable, due to a significant increase in the intrathoracic pressure and resultant decrease in preload and increase in right ventricular afterload. Again, this should be temporary and resolved with a reduction in the pressure, but in unstable or preload dependent patients, this can precipitate hemodynamic collapse. Recruitment maneuvers should never be performed without a respiratory therapist, nurse, and physician present. All clinicians should be aware of the risks of transient hypoxemia and hypotension.



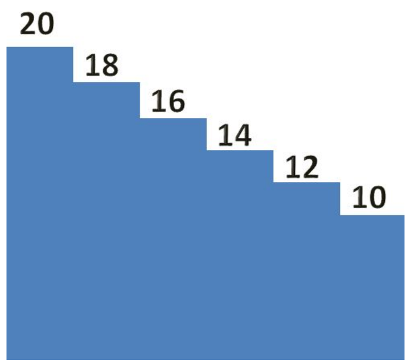
There are many methods of performing recruitment maneuvers. One of the methods least likely to cause hemodynamic perturbations is to serially increase PEEP in small increments. A trial of large increases in PEEP (25 cm H_2O, 35 cm H_2O, then 45 cm H_2O with a final PIP of up to 60 cm H_2O) was stopped early for futility. As such, we recommend a more gradual approach.

Once the patient is stabilized after intubation, the recruitment maneuver and the best PEEP can be determined, using a decremental compliance PEEP trial. This can be repeated every 24 hours for patients who continue to require high levels of ventilatory support.

The FiO_2 should be set at 1.0 and the patient appropriately sedated, and relaxed if needed. The ventilator should be set to pressure control ventilation, with a PC of 15 cm H_2O, inspiratory time of 3 sec, rate of 10 breaths per minute. Then, increase PEEP 3 cm H_2O every 5 breaths until the applied PEEP is between 25 to 35 cm H_2O and the maximum PIP is between 40 to 50 cm H_2O. Ventilate at this level for 1 min. If the patient desaturates or becomes hypotensive at any point, stop, and return to the prior PEEP. This illustration indicates the step-wise PEEP approach.



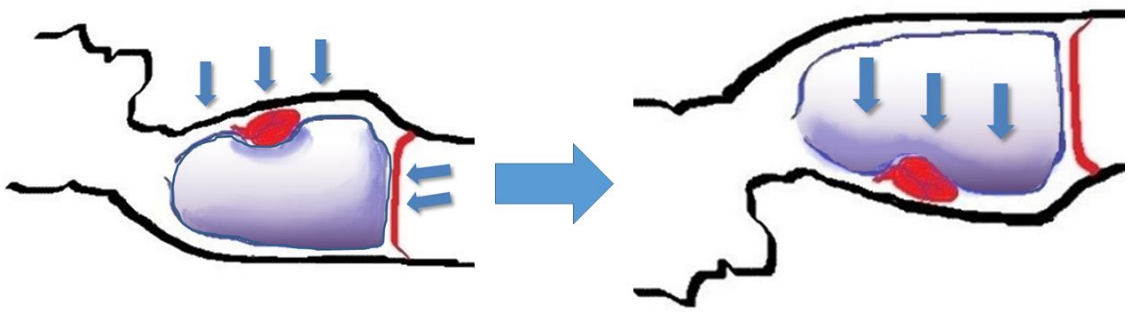
From here, the best compliance decremental PEEP trial should be performed. The next step is to change to volume control ventilation (VCV) at 4-6 ml/kg PBW and set PEEP at 20 to 25 dependent on patient severity of lung injury. The respiratory rate should be set to a rate that does not result in autoPEEP, usually 20 to 30 breaths/minute. Measure dynamic compliance, then decrease the PEEP by 2 cm H_2O, holding for 30 seconds at a time, and reassessing dynamic compliance each time. Initially the compliance will increase as PEEP is decreased, but with derecruitment, compliance will decrease. Once it is obvious that compliance is decreasing, the trial can be stopped. A clear pattern will indicate the PEEP with the best compliance. To set the ventilator, recruit the lung a second time, then set at the best PEEP + 2 cm H_2O to optimize oxygenation as well. The illustration below demonstrates the concept.



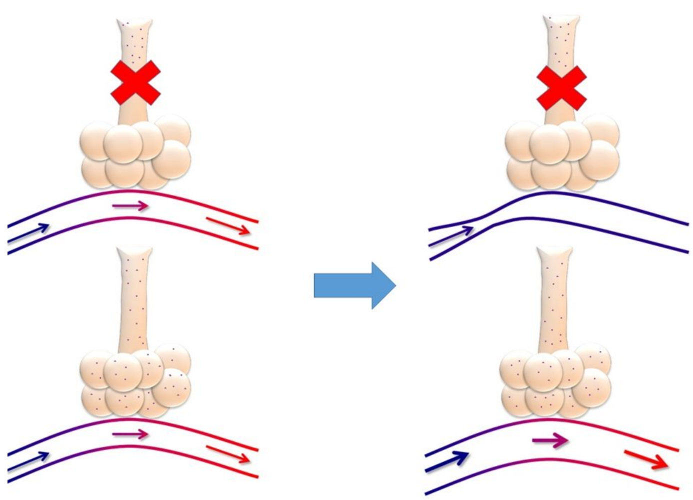
Below is an example from clinical practice. The patient was placed on PEEP of 20, a tidal volume of 400, and an incremental best PEEP trial performed as described. The values were recorded, and a worksheet with the driving pressure and compliance were then filled in to determine the optimum PEEP. As both 10 and 12 had good compliance, 12 cm H_2O was selected in this example.

PEEP (cm H_2O)	**Pplat (cm H_2O)**	**Driving Pressure (cm H_2O)**	**Compliance (TV 400 mL)**
20	37	17	23.5
18	37	19	21.1
16	33	17	23.5
14	29	15	26.7
12	26	14	28.6
10	24	14	28.6

For patients with a PaO_2/FiO_2 ratio of less than 150, the next maneuver is proning the patient, or placing them in the proned position, to improve oxygenation to the posterior lungs. Proning the patient improves V/Q matching and allows the patient to have gas exchange along the posterior aspects of the lungs. Proning has been shown to improve mortality in severe ARDS in a large multi-center study. Additionally, patients with COVID-19 seem responsive to proning. However, this maneuver requires specialized expertise and a coordinated effort amongst providers to avoid dislodging the endotracheal tube and patient harm. If a patient has such severe hypoxemia that non-Intensivists are considering proning, expert consultation should be sought.



Another consideration is the administration of inhaled pulmonary vasodilators, such as inhaled nitric oxide (not to be confused with nitrous oxide, the anesthetic agent) or prostacyclins, such as epoprostenol. Hypoxemic patients generally have heterogeneous lung pathology, with some damaged areas, not participating in oxygenation and ventilation, as well as some relatively unharmed areas that are doing the bulk of gas exchange. Inhaled pulmonary vasodilators will vasodilate the areas that are participating in gas exchange, effectively increasing blood flow to the good areas of the lung and allowing the ineffective areas to continue to have hypoxemic vasoconstriction. This principle is illustrated in the diagram below.



Finally, patients with severe, refractory hypoxemia may be referred to an extracorporeal membrane oxygenation (ECMO) center for consideration of ECMO support. The data for venovenous (VV) ECMO in severe ARDS not related to COVID-19 are mixed. In the largest trial, the EOLIA trial, ECMO for severe ARDS was stopped early at 249/331 patients enrolled for predefined futility. There was no significant mortality benefit at day 60, but 28% of the conventional treatment group had crossover to ECMO rescue. This has led to a lot of controversy as to how the results of the trial should be interpreted. Although it is a negative trial, proponents of ECMO note that when patients from the control group received ECMO, it was started later when they were sicker, and 7 crossover control patients even underwent VA ECMO for arrest. They also note that conventional treatment had a high rate of failure necessitating ECMO.

The role of ECMO in COVID-19 remains to be determined. Some centers are reporting successes, with new decannulation reported each day. However, others note that the natural history of COVID-19 appears to be a very prolonged respiratory failure. As such, some have expressed concerns that the respiratory failure could result in protracted ECMO runs with concomitant high rates of complications. As such, many are making referrals and initiating VV ECMO while data are being collected to determine best practices.