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Reacquainting Cardiology with Mechanical Ventilation in Response to the COVID-19 Pandemic

Ann Gage, M.D.,1,2 Andrew Higgins, M.D.,1,2 Ran Lee, M.D.,1,2 Muhammad Siyab Panhwar, M.D.,3 Ankur Kalra, M.D.1,4

1Department of Cardiovascular Medicine, Heart, Vascular and Thoracic Institute, Cleveland Clinic, Cleveland, Ohio; 2Department of Critical Care Medicine, Respiratory Institute, Cleveland Clinic, Cleveland, Ohio; 3Tulane University Heart and Vascular Institute, Tulane University School of Medicine, New Orleans, Louisiana; 4Departments of Heart, Vascular and Thoracic and Cardiovascular Research, Cleveland Clinic Akron General, Akron, Ohio

Address for correspondence:
Ankur Kalra, MD, FACP, FACC, FSCAI
Cleveland Clinic Lerner College of Medicine of Case Western Reserve University
Department of Cardiovascular Medicine
Heart, Vascular and Thoracic Institute
Cleveland Clinic
Regional Section of Interventional Cardiology
Section Head, Cardiovascular Research
Cleveland Clinic Akron General
224 West Exchange St, Suite 225
Akron, Ohio 44302
Phone: 330-344-7400
Facsimile: 330-344-2015
Work: kalraa@ccf.org
Personal/Research: akalra@alumni.harvard.edu

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**Introduction**

Reports from countries struck by the coronavirus disease 2019 (COVID-19) pandemic have consistently highlighted physician shortages and the utilization of physicians not specifically trained in critical care to care for COVID-19 patients. Given the significant overlap between cardiology and critical care, cardiologists may be among the first physicians asked to step in to fill this shortage. If and when this occurs, a basic framework for recognition of acute respiratory failure, acute respiratory distress syndrome (ARDS), and initial ventilator management is imperative. The following is a brief review of ARDS and an overview of ventilator management designed to help ensure physician comfort and patient safety.

Data from China suggest respiratory findings are common in COVID-19-positive patients. Pneumonia was present in 91.1% of cases and 3.4% of patients developed ARDS. Oxygen therapy was utilized in 41.3% of patients and infection required mechanical ventilation in 6.1% of those infected. (1) The incidence has been even higher in the Italian series, with up to 10% of infected patients in Lombardy developing ARDS. (2) It is likely that many American physicians will be called upon to treat pneumonia, hypoxemic respiratory failure and acute respiratory distress syndrome, regardless of their specialty.

**Acute Respiratory Distress Syndrome**

Acute respiratory distress syndrome, or ARDS, is a life-threatening form of lung injury. This lung injury can be the result of primary pulmonary parenchymal injury such as pneumonia or aspiration or from a systemic process such as sepsis or trauma. Increased capillary permeability leading to inflammation is the inciting factor for ARDS. Damage to the capillary endothelium and alveolar epithelium results in protein accumulation within the alveoli, activation of pro-
inflammatory cytokines and then pulmonary fibrosis. This cascade leads to loss of functional lung tissue. Chest radiography demonstrates bilateral opacities. As ARDS progresses, lung compliance decreases, hypoxemia ensues and patients can progress to ventilator dependence. (3, 4)

In practice, ARDS is defined by the Berlin Definition. This requires that patients have acute onset of lung injury, bilateral opacities on chest radiography and non-hydrostatic pulmonary edema, i.e. respiratory failure may not be the result of left-sided heart failure. The Berlin Definition of ARDS stratifies the severity of lung injury using a ratio of the arterial partial pressure of oxygen (PaO$_2$) to the fraction of inhaled oxygen (FiO$_2$), measured at a pulmonary end-expiratory pressure (PEEP) or continuous positive airway pressure (CPAP) of ≥5-cm H$_2$O. Mild ARDS, moderate ARDS, and severe ARDS are defined as a PaO$_2$/FiO$_2$ of 200-300, 100-200 and <100, respectively. (5)

At present, there are no studies examining specific ventilatory strategies in patients with COVID-19, however, there is a large body of experience with ARDS patients. Until more COVID-19-specific evidence-based medicine is available, expert recommendations support adherence to these ventilatory strategies in COVID-19 patients. (6) Mechanical ventilation is recommended for patients with moderate or severe ARDS who remain hypoxemic or profoundly symptomatic despite supplemental oxygen. In mechanically ventilated patients, a lung-protective ventilation strategy should be employed to decrease ventilator-induced lung injury (VILI). When treating ARDS patients with mechanical ventilation, the target tidal volume is typically 6 mL/kg of predicted body weight with goal plateau pressure <30-cm H$_2$O. One interesting finding in COVID-19 ARDS is that some patients are found to be severely hypoxemic, but with surprisingly good lung compliance. In these patients, more liberal tidal volume settings may be
considered. PEEP should be adjusted based on FiO₂, with consideration of higher PEEP (>10 cm H₂O) in moderate and severe ARDS. Notably, lung protective ventilation (low tidal volume) allows permissive respiratory acidosis with maintenance of a pH ≥ 7.25. Relative hypoxemia with a PaO₂ of 55-80 mmHg or SpO₂ of 88-95% may also be considered to limit high oxygen requirements. (3) In ARDS patients with PaO₂/FiO₂ ≤ 150 mmHg, consideration should be given to initiation of prone positioning. If significant ventilator dyssynchrony is present, neuromuscular blockade may also be considered. (7)

It should be noted that mild ARDS may be managed with noninvasive forms of ventilation. However, during the present pandemic, modifications to usual critical care may be necessary. Given concern for viral transmission, current recommendations advise “caution when using high-flow nasal oxygen or noninvasive ventilation due to risk of dispersion of aerosolized virus in the healthcare environment with poorly fitting masks.” (8) Institution-specific policies should guide the decision for use of noninvasive ventilation versus early endotracheal intubation in this population.

**Invasive Mechanical Ventilation**

Invasive mechanical ventilation ensures oxygenation and ventilation via positive pressure delivered through a secure airway. In the intensive care unit, most patients undergoing mechanical ventilation will have an endotracheal tube (ETT) in place. This is a polyvinylchloride tube that is placed between the vocal cords and into the trachea. ETTs have various internal diameters. Most adults will be intubated with a 7.0 to 8.0 mm endotracheal tube. The smaller the internal diameter, the higher the resistance to airflow, and the more the patient and/or the ventilator will have to work to overcome this resistance. Endotracheal tubes have inflated cuffs
(balloons) that occupy the space of the trachea, ensuring all gas exchange occurs via the endotracheal tube, while offering some protection to the lung from gastric and oral secretions. On chest radiography, the distal end of the endotracheal tube should be 4±2 cm above the level of the carina to ensure correct placement. After placement of the ETT, auscultation for bilateral breath sounds is imperative. A chest radiograph should be ordered immediately to further confirm correct tube location.

In recent years, various taxonomies have been developed to describe the different types of ventilator breaths. In this taxonomy scheme, each ventilator mode is first named by its control variable, or the variable manipulated by you, the operator. This is most often either pressure or volume. The second variable in this scheme is breath sequence. This is based on whether the patient or the machine trigger (initiates) and cycle (terminates) the breath. When all breaths are triggered and/or cycled by the machine, this is CMV or continuous mandatory ventilation, whereas SIMV, or synchronized intermittent mandatory ventilation allows the patient to take spontaneous breaths between mandatory breaths. (9)

Assist-control (AC) ventilation, a form of continuous mandatory ventilation, is one of the most common ventilator modes in the modern intensive care unit. In Assist Control, the physician chooses to control either the pressure or volume delivered by the ventilator. In pressure-control, a set pressure is delivered to the patient with each breath, while a volume-control mode delivers a specific volume. In AC modes, the ventilator will then deliver this pre-specified volume or pressure for all breaths, regardless of whether the breath is triggered by the machine or the patient. These modes are most frequently referred to as VC (volume control), PC (pressure control), VC-CMV or PC-CMV.
In all assist-control ventilation, the operator additionally chooses the FiO₂, or fraction of inspired oxygen, the PEEP and the minimum respiratory rate. PEEP provides a continuous end-expiratory pressure to maintain alveolar recruitment. Taken together, PEEP and the FiO₂ are variables that directly affect oxygenation. Carbon dioxide clearance (i.e. ventilation) is maintained by the minute ventilation, which is a product of the respiratory rate and tidal volume.

No compelling data exist to support the use of one mode over another, suggesting the non-intensivist physician should utilize whichever mode he or she is most familiar. Assist-control is more typically used at the onset of respiratory failure, as it is more likely to relieve the patient from respiratory work.

Positive-pressure ventilation relies on an understanding of respiratory system compliance. Pulmonary compliance is defined as the change in volume over inspiration (tidal volume delivered) divided by the change in pressure from end-inspiration to end-expiration (plateau pressure – total PEEP). When using a pressure-control mode of ventilation, a given amount of positive pressure is introduced into the lungs and the delivered tidal volume then depends on the lung compliance. Conversely, in a volume-control mode, a given tidal volume is administered by the ventilator and the resultant pressures are dictated by the patient’s underlying respiratory mechanics. Both modes are effective methods of ventilating ARDS patients.

When faced with COVID-19 patients with hypoxemic respiratory failure secondary to ARDS, it is appropriate to initiate a lung-protective ventilation strategy. (6) Consider volume-control as the initial mode of mechanical ventilation. This ensures adequate tidal volume and minimizes the risk of volutrauma. In accordance with the ARDSnet study protocol (www.ardsnet.org), it is reasonable to choose an initial tidal volume of 6 mL/kg (predicted body weight). Begin with an initial FiO₂ of 1.0 which may then be gradually decreased as tolerated, while monitoring pulse
oximetry. It is advisable to reference the widely-published ARDSnet protocol for guidance in determining appropriate PEEP for a given FiO₂. Decisions regarding a lower versus higher PEEP strategy may be tailored based on underlying cardiac physiology. Initially, it is reasonable to consider a higher PEEP strategy. Initial respiratory rate should be set to approximate the patient’s pre-intubation minute ventilation (usually 20-28 breaths per minute); this may then be adjusted based on the patient’s arterial pCO₂ (Figure 1).

After initial stabilization, it is critical to appropriately titrate settings to minimize VILI. One of the most common methods for doing this is careful monitoring of the plateau pressure (Figure 2). Although the peak inspiratory pressure represents the pressure to which the proximal large airways are exposed, the plateau pressure is representative of the pressure present in the alveoli at end-inspiration, and thus is an indicator of transpulmonary pressure, lung over-distention and VILI. Plateau pressure is measured after a 0.5 to 1.0-second inspiratory pause maneuver. If the plateau pressure is > 30-cm H₂O, consider further reducing the delivered tidal volume. It is also important to monitor the patient’s driving pressure, or difference between the PEEP and plateau pressure, as increased driving pressures have been associated with higher mortality in ARDS. (10)

**Conclusion**

With a basic understanding of these fundamentals, it is possible for all cardiologists to provide safe and effective care for our COVID-19 patients. As many of us prepare to utilize skillsets long forgotten, it will be important to remember to ask for help when needed. One of the few bright spots in this pandemic has been the resurgence of interdisciplinary teamwork – we are all in this together.
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**Figure 1.** Proposed framework for initial ventilatory strategy for the care of coronavirus disease 2019 (COVID-19) patient. As knowledge of the pulmonary pathophysiology of this syndrome evolves, ventilator management should be adapted to target our understanding of the underlying process.

**Figure 2.** A representation of the most commonly assessed airway pressures.
Indication for Endotracheal intubation?

Yes

- Utilize most experienced provider available
- Video laryngoscopy, if available
- N95 or PAPR based on institutional policy

No

- Initiate supplemental oxygen if needed.
- Target SpO₂ of 92-96%
- Consider HFNC or NPPV based on local institutional policy for COVID-19
- Frequent re-evaluation for decompensation

Endotracheal Intubation

Initiate Lung-Protective Mechanical Ventilation

- Oxygenation: Initial FiO₂ 1.0
- Tidal Volume: Volume Control with V̇, 6 cc/kg (predicted body weight)
- RR Pressure Control with IPAP adjusted to similar target V̇
- Respiratory Rate: Set initial respiratory rate to approximate pre-intubation minute ventilation (usually 16-24 breaths per minute)
- PEEP: Initial PEEP at least 5-8 cm H₂O

Reassess and Titrate – ABG or VBG 30 minutes after intubation

- GOALS: pH ≥ 7.25 / PaO₂ 55-80 mmHg / SpO₂ of 92-96% / Plateau pressure <30 cm H₂O
- Decrease FiO₂ to target SpO₂ 92-96%
- Titrate PEEP based on FiO₂ (Reference ARDSnet Table)
- Plateau pressures < 30 cm H₂O. Consider decreasing V̇, or PEEP

Assess PaO₂: FiO₂ Ratio after Initial Stabilization

>200

- Mild or no ARDS
  - Frequent reassessment of ventilator settings to achieve above goals
  - Minimize fluid administration
  - Continue Supportive Care

<200

- Moderate to Severe ARDS
  - Pulmonary Medicine Consultation
  - Consider adjunctive therapy, including but not limited to:
    - Higher PEEP strategy
    - Neuromuscular blockade
    - Prone position ventilation
    - Venovenous extracorporeal membranous oxygenation

ARDS – Acute respiratory distress syndrome
SpO₂ – Peripheral capillary oxygen saturation
PaO₂ – Partial pressure of oxygen in the blood
FiO₂ – Fraction of inspired air
PEEP – Positive end expiratory pressure
V̇ – Tidal volume
IPAP – Inspiratory positive airway pressure
HFNC – High flow nasal cannula
NPPV – Noninvasive positive pressure ventilation