Basics of Mechanical Ventilation

Airway pressure profile for a constant-flow, volume-controlled lung inflation with a brief end-inspiratory occlusion (inflation-hold). Ppeak is the peak airway pressure, Pplateau is the end-inspiratory occlusion pressure, and Ppeak (peak) is the peak alveolar pressure at end-inspiration. Pres is the pressure attributed to airway resistance, and Pel is the pressure attributed to the elastic recoil force of the lungs and chest wall.

Positive End Expiratory Pressure

Pressure and changes during a single ventilator breath using volume control and pressure control methods of lung inflation at equivalent tidal volumes. Changes in airway pressure (Paw) are indicated by the solid lines, and changes in alveolar pressure (Pav) are indicated by the dashed lines. I = inspiration, E = expiration.

Advantages:
- Constant tidal volume despite changes in lung compliance and airway resistance
- Airway pressures including alveolar pressures may be higher with decreased compliance of lungs due to constant TV
- Volume-targeted: vent delivers a set tidal volume, pressure depends on airway resistance and compliance. Patient remains at risk for barotraumas / volutrauma from high pressures

Disadvantages:
- Due to airflow at the end of inspiration, the peak pressure in the airways (Paw) is greater than the peak pressure in the alveoli (Pav)
- The difference (Paw – Pav) is the pressure dissipated by the resistance to flow in the airways.
- The peak alveolar pressure is a reflection of the alveolar volume at the end of lung inflation

Advantages:
- Major benefit of PCV is the ability to control the peak alveolar pressure, which is the pressure most closely related to the risk of alveolar overdistension and ventilator-induced lung injury
- Decrease in alveolar volume (and hence ventilation) that occurs when there is an increase in airway resistance or a decrease in lung compliance

Disadvantages:
- Pressure-targeted: vent delivers volume until a set pressure is achieved. Now, tidal volume is dependent on airway resistance and compliance. Patient remains at risk for low tidal volumes and inadequate minute ventilation

Pressure control

The change in mean airway pressure determines the influence of PEEP on alveolar ventilation (hence arterial oxygenation)

The change in peak alveolar pressure determines the influence of PEEP on alveolar ventilation (hence arterial oxygenation)

Auto-PEEP can occur when patient has inadequate time to exhale before next breath is delivered

Troubleshooting

- Low pO2 = oxygenation issue = increase FiO2, increase PEEP (to recruit more alveoli)
- High pCO2 = ventilation issue = Increase Minute Ventilation by increasing TV or rate (suction, bronchodilators)

High Peak pressures & High Plateau Pressures (non-compliant lungs)
- Pulmonary edema • Worsening consolidation • ARDS • Atelectasis • Mainstem intubation • Tension PTX • Decreased chest wall compliance

High peak pressure low & normal plateau pressure (airway problem)
- Bronchospasm • Mucus plug • Secretions • Obstructed tubing • Patient biting tube
ARDS - overview

### Table 2. Risk Factors for ARDS.

<table>
<thead>
<tr>
<th>Direct lung-injury risk factors</th>
<th>Indirect lung-injury risk factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneumonia (bacterial, viral, fungal, or opportunistic)*</td>
<td>Septis (nonpulmonary source)*</td>
</tr>
<tr>
<td>Aspiration</td>
<td>Nontropical trauma or hemorrhagic shock</td>
</tr>
<tr>
<td>Pulmonary contusion</td>
<td>Pancreatitis</td>
</tr>
<tr>
<td>Infection</td>
<td>Major burn injury</td>
</tr>
<tr>
<td>Inhalation injury</td>
<td>Drug overdose</td>
</tr>
<tr>
<td>Near drowning</td>
<td>Transfusion of blood products</td>
</tr>
<tr>
<td>Idiopathic lung injury risk factors</td>
<td>Cardiopulmonary bypass</td>
</tr>
<tr>
<td>Neutropenia</td>
<td>Reparative edema after lung transplantation or embolectomy</td>
</tr>
</tbody>
</table>

### Protocol for Lung Protective Ventilation in ARDS

**I. Tidal Volume Goal:**

1. Calculate patient’s predicted body weight (PBW):
   - Males: PBW = 50 + [2.3 (height in inches) - 5]
   - Females: PBW = 45.5 + [2.3 (height in inches) - 5]
2. Use volume-controlled ventilation and set initial tidal volume (VT) to 6 mL/kg (PBW)
3. Set respiratory rate (RR) to match baseline minute ventilation, but not > 35 bpm.
4. Set positive end-expiratory pressure (PEEP) at 5 cm H2O.
5. Reduce VT by 1 mL/kg every 1 to 2 hours until VT < 4 mL/kg (PBW)
6. Adjust PEEP and FiO2 to maintain SpO2 of 88-95%.

**II. Plateau Pressure Goal:**

1. If Pplat > 30 cm H2O and VT < 6 mL/kg, decrease VT in 1 mL/kg increments until Pplat falls to < 30 cm H2O or VT reaches a minimum of 4 mL/kg.

**III. pH Goal:**

1. If pH < 7.45, increase RR to pH > 7.30, PaCO2 < 25 mm Hg, or RR > 35 bpm.
2. If pH < 7.15, increase RR to 35 bpm. If pH remains < 7.15, increase VT in 1 mL/kg increments until pH > 7.15 (Pplat target may be exceeded).
3. If pH > 7.45, decrease RR, if possible.

### Summary


### Refractory Hypoxemia

- **Pneumonia Pneumonia:** Switching from the supine to prone position can improve pulmonary gas exchange by diverting blood away from poorly aerated lung regions in the posterior thorax and increasing blood flow in aerated lung regions in the anterior thorax and potentially reduces 28-day mortality in severe ARDS.
- **Neuromuscular blocking agents:** Improve ventilator synchrony and may potentially blunt the inflammatory cascade of ARDS and may potentially increase ventilator free days and 90-day survival in severe ARDS.

ECMO has had variable success in patients with refractory hypoxemia is a consideration only when other rescue therapies have failed.

### Ventilator settings

- **Oxygenation Goal:**
  - PaO2 55-80 mmHg or SpO2 88-95%
  - Use a minimum PEEP of 5 cm H2O

- **Respiratory rate:**
  - Set to match baseline minute ventilation but not > 35 bpm.

- **Positive end-expiratory pressure (PEEP):**
  - Set to 5 cm H2O.
  - Reduce VT by 1 mL/kg every 1 to 2 hours until VT < 4 mL/kg (PBW).

- **Plateau pressure:**
  - Set to < 30 cm H2O.
  - Adjust PEEP and FiO2 to maintain SpO2 of 88-95%.

- **pH goal:**
  - Maintain pH > 7.30.
  - Increase RR to pH > 7.30, PaCO2 < 25 mm Hg, or RR > 35 bpm.
  - If pH remains < 7.15, increase VT in 1 mL/kg increments until pH > 7.15.
  - If pH > 7.45, decrease RR, if possible.

### Acute Respiratory Distress Syndrome

**The Berlin Definition**

<table>
<thead>
<tr>
<th><strong>ACUTE RESPIRATORY DISTRESS SYNDROME</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>Timing</strong></td>
</tr>
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</table>

**Ventilator induced Lung Injury**

- Excessive inflation of the distal airspaces produce stress fractures in the alveolar capillary interface, and this leads to infiltration of the lung parenchyma and distal airspaces with an inflammatory exudate.
  - Lung Injury that is volume-related is called volutrauma.
  - Pressure-related lung injury is called barotrauma.
  - The decrease in lung distensibility in ARDS can result in the collapse of small airways at the end of expiration. When this occurs, mechanical ventilation can be associated with cyclic opening and closing of small airways, and this process can be a source of lung injury called atelectrauma.

**Positive End-Expiratory Pressure**

- Lung protective ventilation employs a PEEP of at least 5 cm H2O to prevent the collapse of small airways at the end of expiration. The goal is to reduce the risk of atelectrauma.
  - When a toxic level of inhaled oxygen (FiO2 >60%) is needed to maintain the target SpO2 of 88-95%, PEEP levels above 5 cm H2O can be used to improve arterial oxygenation and reduce the FiO2 to safer levels.

- It is important to emphasize that increases in PEEP can reduce PEF and output, and if the goal of increasing PEEP is to maintain the same SpO2 at a lower FiO2, the reduced cardiac output will reduce the systemic O2 delivery.

### Permissive hypercapnia

- The consequences of low tidal volume ventilation is a decrease in CO2 elimination in the lungs, which can result in hypercapnia and respiratory acidosis.
- Because of the benefits of low volume ventilation, hypercapnia is allowed to persist as long as there is no evidence of harm.

**Non Ventilatory Management**

- Fluid management avoiding a positive fluid balance will prevent unwanted fluid accumulation in the lungs, which could aggravate the respiratory insufficiency in ARDS.
- Clinical studies have shown that avoiding a positive fluid balance in patients with ARDS can reduce the time on mechanical ventilation and can even reduce mortality.

### Conclusion

- There is convincing evidence that mechanical ventilation can damage the lungs in ARDS as a result of overdistension of functional alveoli (volutrauma) and collapse of small airways (atelectrauma). Lung protective ventilation is designed to mitigate the mechanical forces that create ventilator-induced lung injury, and it has been adopted as a standard method of mechanical ventilation in ARDS.

M. Daniyal Hashmi, MD
Shock

- Syndrome of impaired oxygen delivery to tissues
- Mechanisms
  - Absolute/relative decrease in oxygen delivery
  - Ineffective tissue perfusion
  - Ineffective utilization of delivered oxygen

### Shock Classification

<table>
<thead>
<tr>
<th>Cardiogenic</th>
<th>Hypovolemic</th>
<th>Distributive</th>
<th>Obstructive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac output</td>
<td>↓</td>
<td>↓</td>
<td>↑ or N</td>
</tr>
<tr>
<td>Filling pressures</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Vascular resistance</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>SvO₂, Svo₂</td>
<td>↓</td>
<td>↓</td>
<td>↑</td>
</tr>
</tbody>
</table>

### Examination

- Decreased pulse pressure
- Warm extremities
- Poor cap refill
- SIReS criteria?
- Suspected infarct?

### Management of Hypotension

#### Septic Shock

- SIRS + IV fluids
- Anti-septic agents
- Vasopressors
- Antibiotics
- Adjunctive therapies

#### Cardiogenic Shock

- ABPM
- Dobutamine
- Inotrope support
- Electrolyte correction

### Interventions for Managing Shock

<table>
<thead>
<tr>
<th>Component</th>
<th>Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood pressure</td>
<td>Fluids, vasopressor, or vasodilator*</td>
</tr>
<tr>
<td>Cardiac Output</td>
<td>Fluids, vasodilator*</td>
</tr>
<tr>
<td>Contractility</td>
<td>Inotropic agents</td>
</tr>
<tr>
<td>Afterload</td>
<td>Vasopressor or vasodilator*</td>
</tr>
<tr>
<td>Oxygen Content</td>
<td>Supplemental oxygen, mechanical ventilation</td>
</tr>
</tbody>
</table>

*Vasodilator is only indicated when the patient is euveolic or hypovolemic and the blood pressure is adequate.
Surviving Sepsis Campaign: Guidelines on the Management of Critically Ill Adults with Coronavirus Disease 2019 (COVID-19)

Infection Control and Testing:

For healthcare workers performing aerosol-generating procedures* on patients with COVID-19 in the ICU, we recommend using fitted respirator masks (N95 respirators, FFP2, or equivalent), as opposed to surgical/medical masks, in addition to other personal protective equipment (i.e., gloves, gown, and eye protection, such as a face shield or safety goggles).

We recommend performing aerosol-generating procedures on ICU patients with COVID-19 in a negative pressure room.

For intubated and mechanically ventilated adults with suspicion of COVID-19, for diagnostic testing, we suggest obtaining lower respiratory tract samples in preference to upper respiratory tract (nasopharyngeal or oropharyngeal) samples.

For intubated and mechanically ventilated adults with suspicion of COVID-19, with regard to lower respiratory samples, we suggest obtaining endotracheal aspirates in preference to bronchial wash or bronchoalveolar lavage samples.

General facts

Spread: Droplet spread, survives 2-3 hours on most surfaces, 2 days on smooth metal/plastic

Incubation: 2-14 days

1st week: Fever, cough, headache, fatigue, myalgias, pharyngitis

2nd week: Resolves in 80%, Viral pneumonia 20%

Risk increased: Heart/lung disease, immunosuppression, poorly controlled DM

Exam: Non specific

Labs: Lymphopenia with normal WBC count or relative leukopenia, Elevated Ferritin/CRP/D-Dimer is negative prognostic indicator

Mortality: Due to oxygenation failure or septic shock/multiorgan failure

Imaging:

Testing: CBC, CMP, ABG, Troponin, G6PD, Rapid flu testing and bacterial sputum and blood cultures (coinfection with BACTERIAL respiratory pathogens unlikely), Coronavirus PCR testing, CRP, Ferritin, D-Dimer

Treatment: Symptomatic support for stable patients otherwise refer to guidelines for critical care support (Currently under investigation (Plaquenil, Azithromycin and Remdesivir))

*For presentation by Dr. Leon Liang-Yu Lai, MD

M. Daniyal Hashmi, MD
Concerning levels on ABG

**M. Daniyal Hashmi, MD**

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### Flowchart for choosing respiratory support

- If adequate spontaneous breathing:
  - Provide oxygen supplementation
- Manual assisted ventilation (NIPPV, bag mask ventilation) if:
  - Apnea
  - Inadequate spontaneous tidal volumes
  - Excessive work of breathing
  - Hypoxemia with poor ventilation
  - Hypoventilation with hypercapnia

**Indications for endotracheal intubation:**
- Airway protection
- Relief of obstruction
- Need for mechanical ventilation to improve oxygenation
- Respiratory failure
- Shock
- Hypoventilation
- Increased work of breathing
- Need to facilitate suctioning/pulmonary toilet – inability to clear secretions

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### Differential diagnosis for Hypoxia

**Normocapnic**
- Ventilation-perfusion mismatch
- Acute respiratory distress syndrome
- Aspiration
- Pulmonary edema
- Pulmonary embolus
- Pneumonia
- Sepsis
- Pulmonary contusion
- Pneumothorax

**Hypercapnic**
- Hypoventilation
- Obstructive sleep apnea
- Medications (Sedatives)
- Neurological causes
- Flail chest
- Chest wall burns
- Large pleural effusion
- Morbid obesity
- Laryngeal obstruction (epiglottitis, croup)
- Chronic obstructive pulmonary disease
- Asthma (marked obstruction)

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### General management

- **Hypoxia**
  - Work up: Hist/physical, ABG, CXR
  - Start supplemental oxygen
  - Titrated FIO2 for SpO2 >90%
  - Failure to keep SpO2 >90%
  - Altered mental status/Hemodynamically unstable
  - Normal mental status/Hemodynamically stable
- **Hypercapnea**
  - Room air PaO2 <60mmHg
  - Abnormal PaO2/FIO2 ratio with pH <7.35
  - PaCO2 >45 mmHg
  - Morbid obesity
  - Laryngeal obstruction (epiglottitis, croup)
  - Hypoventilation

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**Supplemental Oxygenation**
- Nasal cannula
- Flo2 = Po2 + (L oxygen x 4)
- Masks
- Venturi and Non-rebreather masks (Upto 15L flow, Non-rebreather actual delivery <75%)