Basics of Mechanical Ventilation for the COVID-19 Patient

Hooman Poor, M.D.
Assistant Professor of Medicine
Director of Pulmonary Vascular Disease, Mount Sinai-National Jewish Health Respiratory Institute
Division of Pulmonary, Critical Care and Sleep Medicine
Zena and Michael A. Wiener Cardiovascular Institute
Icahn School of Medicine at Mount Sinai
Financial Disclosures

None
Talk Objectives

• discuss the rationale of positive pressure ventilation for patients with ARDS secondary to COVID-19

• review the basics of volume-controlled ventilation

• explain how to set and adjust the important parameters in volume-controlled ventilation for COVID-19 patients with ARDS
COVID-19 Causes ARDS

ARDS Definition:

• acute
• bilateral opacities
• $\text{PaO}_2/\text{F}_1\text{O}_2$ ratio < 300 mmHg with PEEP $\geq$ 5 cmH$_2$O
• not completely explained by cardiac failure or volume overload
ARDS Pathophysiology

- lung injury and inflammation create leaky capillaries and leaky alveoli
- alveoli fill up with fluid
- gas exchange impaired
- alveoli collapse
- lungs become stiffer
- patients ultimately develop respiratory failure

Thompson, NEJM 2017
Ventilator Support in ARDS

• deliver high amounts of oxygen
  - high $F_{1}O_{2}$

• provide positive pressure to reduce work of breathing
  - ventilator **PUSHES** air in so muscles of inspiration do not have to work as hard to **SUCK** air in

• provide positive end-expiratory pressure (PEEP)
  - prevents open alveoli from collapsing
How to Inflate Lungs

a) increase pressure inside of the lungs ($P_{alv}$)

b) decrease the pressure outside of the lungs ($P_{pl}$)

$P_{alv}$ = alveolar pressure
$P_{pl}$ = pleural pressure
spontaneous ventilation
Inflation by decreasing $P_{pl}$ (spontaneous breathing)

Inflation by increasing $P_{alv}$ (positive pressure ventilation)

spontaneous ventilation

positive pressure ventilation
\[ V = I \times R \]
\[ V = I \times R \]

\[ P_{\text{air}} - P_{\text{alv}} = Q \times R \]
\[ Q = P_{\text{air}} - \frac{P_{\text{alv}}}{R} \]

- \( P_{\text{air}} \) = proximal airway pressure
- \( P_{\text{alv}} \) = alveolar pressure
- \( Q \) = flow
- \( R \) = resistance
Spontaneous ventilation

\[ Q = \frac{P_{\text{air}} - P_{\text{alv}}}{R} \]

Suck air into lungs

- \( P_{\text{air}} \): proximal airway pressure
- \( P_{\text{alv}} \): alveolar pressure
- \( Q \): flow
- \( R \): resistance
positive pressure ventilation

\[ Q = P_{air} - \frac{P_{alv}}{R} \]

*Push air into lungs*

- \( P_{air} \) = proximal airway pressure
- \( P_{alv} \) = alveolar pressure
- \( Q \) = flow
- \( R \) = resistance
Regardless of the mode of ventilation...

- the ventilator increases airway pressure for a set time
  - airflow into the patient
  - culminates in delivered tidal volume

- “phase variables” determine the mode of ventilation
  - ventilator instructions
  - determine “when” and “how” breaths delivered

\[ Q = P_{\text{air}} - P_{\text{alv}} / R \]
Phase Variables:
“Anatomy of a Breath”

- trigger → when inspiration begins
- target → how flow is delivered during inspiration
- cycle → when inspiration ends
- baseline → proximal airway pressure during expiration
Modes of Ventilation

trigger

target

cycle
For the sake of simplicity, use volume-controlled ventilation (VCV)

What mode of ventilation should I use?
Trigger

• Who initiates the breath?
  - ventilator
  - patient

• ventilator-triggered
  - aka **CONTROL**
  - variable that is set $\rightarrow$ time
  - set respiratory rate (frequency $= 1$/time)
  - RR 12 bpm is one breath every 5 seconds

• patient-triggered
  - aka **ASSIST**
  - flow or pressure changes sensed by ventilator
Assist-Control $\rightarrow$ Hybrid Trigger

- assist trigger + control trigger = assist-control (A/C)

“A/C” refers only to the trigger.

Volume-controlled ventilation uses A/C as the trigger mechanism.
How Much Assist? How Much Control?

**control respiratory rate**
- 10 bpm
- breath every 6 sec

**neural respiratory rate**
- 20 bpm
- breath every 3 sec

What percentage of the breaths will be assist, what percentage will be control?

100% ASSIST

Control rate clock resets after an “assist” breath.
How Much Assist? How Much Control?

**control respiratory rate**
- 10 bpm

**neural respiratory rate**
- 20 bpm
- breath every 3 sec
How Much Assist? How Much Control?

**control respiratory rate**
- 30 bpm
- breath every 2 sec

**neural respiratory rate**
- 20 bpm
- breath every 3 sec

What percentage of the breaths will be assist, what percentage will be control?

100% CONTROL
last breath was a “control” breath

actual respiratory rate

control respiratory rate
How is flow during inspiration determined?
- flow rate is set in volume-controlled ventilation
VCV is a Flow-Targeted Mode
VCV is a Flow-Targeted Mode

\[ Q = P_{\text{air}} - P_{\text{alv}} / R \]

\( Q \) will not change with changes in respiratory system.

\( P_{\text{air}} \) will change with changes in respiratory system.
peak pressure

pressure waveform
Target

\[ Q = P_{\text{air}} - P_{\text{alv}}/R \]

- biting endotracheal tube
- flow-targeted mode
- flow unchanged

Poor, Basics of Mechanical Ventilation, 2018
\[ Q = P_{\text{air}} - P_{\text{alv}} / R \]

- **sustained inspiratory effort**
- **flow unchanged**
- **flow-targeted mode**

Poor, Basics of Mechanical Ventilation, 2018
Cycle

When does inspiration end?
- volume is set in volume-controlled ventilation
tidal volume

exhaled tidal volume returning to ventilator

tidal volume
Low Tidal Volume Ventilation

• high tidal volume in ARDS causes lung stretch and further lung damage
  - “volutrauma”

• low tidal volume ventilation is essential
  - set tidal volume to 6 cc/kg of **ideal body weight**
  - can be uncomfortable for patients (will likely need sedation, and sometimes even paralysis)
Baseline

• What is proximal airway pressure during expiration?
• aka PEEP
PEEP in ARDS

• repetitive opening and closing of alveoli causes further lung damage
  - “atelectrauma”

• PEEP prevents open alveoli from closing

• maintaining alveoli open will improve gas exchange
INCLUSION CRITERIA: Acute onset of
1. \( \text{PaO}_2 / \text{FiO}_2 \leq 300 \) (corrected for altitude)
2. Bilateral (patchy, diffuse, or homogeneous) infiltrates consistent with pulmonary edema
3. No clinical evidence of left atrial hypertension

PART I: VENTILATOR SETUP AND ADJUSTMENT
1. Calculate predicted body weight (PBW)
   - Males = 50 + 2.3 [height (inches) - 60]
   - Females = 45.5 + 2.3 [height (inches) - 60]
2. Select any ventilator mode
3. Set ventilator settings to achieve initial \( V_T = 8 \) ml/kg PBW
4. Reduce \( V_T \) by 1 ml/kg at intervals \( \leq 2 \) hours until \( V_T = 6 \) ml/kg PBW.
5. Set initial rate to approximate baseline minute ventilation (not > 35 bpm).
6. Adjust \( V_T \) and RR to achieve pH and plateau pressure goals below.

OXYGENATION GOAL: \( \text{PaO}_2 55-80 \) mmHg or \( \text{SpO}_2 88-95\%
Use a minimum PEEP of 5 cm H\(_2\)O. Consider use of incremental FiO\(_2\)/PEEP combinations such as shown below (not required) to achieve goal.

<table>
<thead>
<tr>
<th>( \text{FiO}_2 )</th>
<th>0.3</th>
<th>0.4</th>
<th>0.4</th>
<th>0.5</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{PEEP} )</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( \text{FiO}_2 )</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>0.9</th>
<th>0.9</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{PEEP} )</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>16</td>
<td>18</td>
<td>18-24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( \text{FiO}_2 )</th>
<th>0.5</th>
<th>0.5-0.8</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{PEEP} )</td>
<td>18</td>
<td>20</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>24</td>
</tr>
</tbody>
</table>

PLATEAU PRESSURE GOAL: \( \leq 30 \) cm H\(_2\)O
Check Pplat (0.5 second inspiratory pause), at least q 4h and after each change in PEEP or \( V_T \).
If Pplat \( > 30 \) cm H\(_2\)O: decrease \( V_T \) by 1ml/kg steps (minimum = 4 ml/kg).
If Pplat \( < 25 \) cm H\(_2\)O and \( V_T < 6 \) ml/kg, increase \( V_T \) by 1 ml/kg until Pplat \( > 25 \) cm H\(_2\)O or \( V_T = 6 \) ml/kg.
If Pplat \( < 30 \) and breath stacking or dys-synchrony occurs: may increase \( V_T \) in 1ml/kg increments to 7 or 8 ml/kg if Pplat remains \( \leq 30 \) cm H\(_2\)O.
INCLUSION CRITERIA

1. PaO₂/FiO₂ ≤ 300 (corrected for altitude)
2. Bilateral (patchy, diffuse, or homogeneous) infiltrates consistent with pulmonary edema
3. No clinical evidence of left atrial hypertension

PART I: VENTILATOR SETUP AND ADJUSTMENT

1. Calculate predicted body weight (PBW)
   - Males = 50 + 2.3 [height (inches) - 60]
   - Females = 45.5 + 2.3 [height (inches) - 60]
2. Select any ventilator mode
3. Set ventilator settings to achieve initial VT = 8 ml/kg PBW
4. Reduce VT by 1 ml/kg at intervals ≤ 2 hours until VT = 6 ml/kg PBW.
5. Set initial rate to approximate baseline minute ventilation (not > 35 bpm).
6. Adjust VT and RR to achieve pH and plateau pressure goals below.

OXYGENATION GOAL: PaO₂ 55-80 mmHg or SpO₂ 88-95%

Use a minimum PEEP of 5 cm H₂O. Consider use of incremental FiO₂/PEEP combinations such as shown below (not required) to achieve goal.

<table>
<thead>
<tr>
<th>FiO₂</th>
<th>0.3</th>
<th>0.3</th>
<th>0.3</th>
<th>0.3</th>
<th>0.3</th>
<th>0.4</th>
<th>0.4</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEEP</td>
<td>5</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>14</td>
<td>14</td>
<td>16</td>
<td>16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FiO₂</th>
<th>0.5</th>
<th>0.5-0.8</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEEP</td>
<td>18</td>
<td>20</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>24</td>
</tr>
</tbody>
</table>

Use the High PEEP Ladder

- COVID-19 patients appear to be very “PEEP-responsive”

- do not increase PEEP above 16 cm H₂O without guidance from a critical care physician
Plateau Pressure ($P_{pl}$)

• estimate of the maximum pressure in the alveolus during the respiratory cycle

• to measure $P_{pl}$, perform inspiratory pause maneuver
  - after tidal volume is delivered, expiratory valve remains shut and air does not leave patient
  - pressure measured at end of maneuver is called “plateau pressure”

• high $P_{pl}$ can lead to “barotrauma”
  - pneumothorax, pneumomediastinum
  - goal $P_{pl}$ in ARDS is $\leq 30$ cm H$_2$O
Plateau Pressure

Plateau pressure
Your COVID-19 Patient Just Got Intubated

- place on volume-controlled ventilation
- set respiratory rate to 20 bpm
- set tidal volume to 6 cc/kg of **ideal body weight**
- set F\textsubscript{1}O\textsubscript{2} to 100%
- set PEEP to 15 cm H\textsubscript{2}O
- check plateau pressure (P\textsubscript{pl})
  - if P\textsubscript{pl} > 30 cm H\textsubscript{2}O, reduce tidal volume to 5 cc/kg
  - if P\textsubscript{pl} still > 30 cm H\textsubscript{2}O, call for help
- ensure patient is well sedated
- check ABG or VBG 30 minutes after settings adjusted to ensure appropriate pH
  - if pH < 7.2, increase RR (maximum of 35 bpm)
Your COVID-19 Patient is Improving

• wean F\textsubscript{1}O\textsubscript{2} and PEEP as per the ARDSnet ladder to ensure SpO\textsubscript{2} 88-95%
• wait at least 12 hours between changes in PEEP

### Higher PEEP/lower FiO\textsubscript{2}

<table>
<thead>
<tr>
<th>FiO\textsubscript{2}</th>
<th>0.3</th>
<th>0.3</th>
<th>0.3</th>
<th>0.3</th>
<th>0.3</th>
<th>0.4</th>
<th>0.4</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEEP</td>
<td>5</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>14</td>
<td>14</td>
<td>16</td>
<td>16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FiO\textsubscript{2}</th>
<th>0.5</th>
<th>0.5-0.8</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEEP</td>
<td>18</td>
<td>20</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>24</td>
</tr>
</tbody>
</table>

16
Further Reading

Available free online via the Levy Library website
Good Luck!