Basics of Mechanical Ventilation

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Normal Breathing (Negative Pressure)

Breathing - The process whereby air (gasses) move in and out of the body.

Inspiration:
- Rib cage expands as rib muscles contract
- When pressure in lungs decrease - air rush in
- Diaphragm contracts (moves down)

Expiration:
- Rib cage gets smaller as rib muscles relax
- When pressure in lungs increase - air is pushed out
- Diaphragm relaxes (moves up)
The Ventilator

- Best Invention in history-???? saves lives
- Created the modern ICU

Rules:
- Love your ventilator; listen to what it tells you, its your friend
- Use its lingo
- Beware of your ventilator
- Adjust the ventilator to the patient not patient to ventilator
Ventilator Lingo

• How are you doing (correct)  
  (Flow Triggered, Flow Targeted, Volume Cycled Assist control mode)

  (Flow Triggered, Pressure targeted, Time Cycled Assist Control mode)

• Whad up yo, Howzit (slang)  
  (Volume control) (AC)
  (Pressure control) (PC)
Ventilator Evolution

- 1970: 3 modes of ventilation
- 2014: > 200 modes of ventilation
  > 50 ventilator trade names
Goals of Mechanical Ventilation

- Safety:
  - Oxygenation & Ventilation
  - Avoid Ventilator Induced Lung Injury (volutrauma, barotrauma, atelectrauma, biotrauma, ergotrauma)

- Comfort: Patient ventilator Synchrony, auto-PEEP

- Liberation: Minimize duration of mechanical ventilation
## Indications for Mechanical Ventilation

### Alveolar filling processes
- Pneumonitis - infectious, aspiration
- Noncardiogenic pulmonary edema/ARDS (eg, due to infection, inhalation injury, near drowning, transfusion, contusion, high altitude)
- Cardiogenic pulmonary edema
- Pulmonary hemorrhage
- Tumor (eg, choriocarcinoma)
- Alveolar proteinosis
- Intravascular volume overload of any cause

### Pulmonary vascular disease
- Pulmonary thromboembolism
- Amniotic fluid embolism, tumor emboli

### Diseases causing airways obstruction: central
- Tumor
- Laryngeal angioedema
- Tracheal stenosis

### Diseases causing airways obstruction: distal
- Acute exacerbation of chronic obstructive pulmonary disease
- Acute, severe asthma

### Hypoventilation: decreased central drive
- General anesthesia
- Drug overdose

### Hypoventilation: peripheral nervous system/ respiratory muscle dysfunction
- Amyotrophic lateral sclerosis
- Cervical quadriplegia
- Guillain-Barré syndrome
- Myasthenia gravis
- Tetanus, tick bite, ciguatera poisoning
- Toxins (eg, strychnine)

### Hypoventilation: chest wall and pleural disease
- Kyphoscoliosis
- Trauma (eg, flail chest)
- Massive pleural effusion
- Pneumothorax

### Increased ventilatory demand
- Severe sepsis
- Septic shock
- Severe metabolic acidosis
Respiratory Mechanics

**Airway resistance:** Proportional to length, flow and inversely related to Radius

\[ \frac{P_1 - P_2}{V} \]

**Compliance:** \( \frac{1}{Elastance} \)

How much pressure required to obtain a certain volume

---

**Equation of Motion**

\[ P = P_{resistive} + P_{elastance} \]

\[ P = R \times V + E \times V \]
**Respiratory Mechanics**

*Static Compliance* (ml/cmH2O) = Tidal volume/Plateau pressure - Total PEEP

*Resistance (cmH2O/L/S) =* PIP – Ppl/Flow
Positive Pressure Breath

**Trigger:** How does Inspiration start

**Limit:** Maximum value during Inspiration

**Cycle:** How does inhalation stops and exhalation starts
Modes of Mechanical Ventilation

**WHAT IS A MODE?** A mode of mechanical ventilation has three essential components:
- The control variable
- The breath sequence
- The targeting scheme.

**Mechanical breath description**
Control variable—the mechanical breath goal, ie, a set pressure or a set volume.
Trigger variable—that which starts inspiration, ie, the patient (generating changes in pressure or flow) or a set rate (time between breaths).
Limit variable—the maximum value during inspiration.
Cycle variable—that which ends inspiration.

**Breath sequence**
Continuous mandatory ventilation—all breaths are controlled by the ventilator, so usually they have the same characteristics regardless of the trigger (patient or set rate); no spontaneous breaths are allowed.
Intermittent mandatory ventilation—a set number of mechanical breaths is delivered regardless of the trigger (patient initiation or set rate); spontaneous breaths are allowed between or during mandatory breaths.
Continuous spontaneous ventilation—all breaths are spontaneous with or without assistance.

**Type of control or targeting scheme**
Set point—the ventilator delivers and maintains a set goal, and this goal is constant (eg, in pressure control, the set point is pressure, which will remain constant throughout the breath); to a degree, all modes have some set-point control scheme.
Servo—the ventilator adjusts its output to a given patient variable (ie, in proportional assist ventilation, the inspiratory flow follows and amplifies the patient’s own flow pattern).
Adaptive—the ventilator adjusts a set point to maintain a different operator-selected set point (ie, in pressure-regulated volume control, the inspiratory pressure is adjusted breath to breath to achieve a target tidal volume).
Optimal—the ventilator uses a mathematical model to calculate the set points to achieve a goal (ie, in adaptive support ventilation, the pressure, respiratory rate, and tidal volume are adjusted to achieve a goal minute ventilation).

Society of Mechanical Ventilation
# Modes of Mechanical Ventilation

## Classification of modes of ventilation

<table>
<thead>
<tr>
<th>Control Variable</th>
<th>Breath Sequence</th>
<th>Targeting Scheme</th>
<th>Examples of commercially available modes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volume</strong></td>
<td>Continuous mandatory ventilation</td>
<td>Set point</td>
<td>Volume control, VC-A/C, CMV, (S)CMV, Assist/Control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dual</td>
<td>CMV + pressure limited</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adaptive</td>
<td>Adaptive flow</td>
</tr>
<tr>
<td></td>
<td>Intermittent mandatory ventilation</td>
<td>Set point</td>
<td>SIMV, VC-SIMV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dual</td>
<td>SIMV + pressure limited</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adaptive</td>
<td>AutoMode (VC-VC), mandatory minute volume</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>Continuous mandatory ventilation</td>
<td>Set point</td>
<td>Pressure control, PC-A/C, AC PCV, high-pressure oscillatory ventilation*</td>
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<tr>
<td></td>
<td></td>
<td>Adaptive</td>
<td>Pressure-regulated volume control, <em>VC+AC</em>, <em>AMV+AutoFlow</em></td>
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<tr>
<td></td>
<td>Intermittent mandatory ventilation</td>
<td>Set point</td>
<td>Airway pressure-release ventilation, *SIMV PCV, BiLevel, *PCV+ *</td>
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<tr>
<td></td>
<td></td>
<td>Adaptive</td>
<td>VC+SIMV, V V+SIMV APV SIMV, SIMV+AutoFlow, Automode (PRVC-VC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Optimal</td>
<td>Adaptive support ventilation*</td>
</tr>
<tr>
<td></td>
<td>Continuous spontaneous ventilation</td>
<td>Set point</td>
<td>Continuous positive airway pressure, pressure support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dual</td>
<td>Volume assured pressure support, volume augment</td>
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<tr>
<td></td>
<td></td>
<td>Servo</td>
<td>Proportional assist ventilation, <em>automatic tube compensation</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adaptive</td>
<td>Volume support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intelligent</td>
<td>SmartCare</td>
</tr>
</tbody>
</table>

Alternative modes of mechanical ventilation: A review for the hospitalist
Modes of Mechanical Ventilation

- Same tidal volume every breath
- Same inspiratory flow every breath
- Varying inspiratory pressure (compliance, resistance, Pt’s WOB)
- Easy
- Worsens Dysynchrony
- May worsen Pt’s work of breathing
- Inferior oxygenation (less mean airway pressure)

- Same inspiratory pressure every breath
- Varying inspiratory flow
- Varying tidal volume every breath (compliance, resistance, WOB)
- Little more difficult
- Can result in higher tidal volumes
- Superior synchrony
- Superior oxygenation (Higher mean airway pressure)
- May reduce VILI
**Patient-Ventilator Interaction**

The graph illustrates the interaction between patient work of breathing (WOB) and ventilator WOB for different modes of ventilation. The lines represent:
- Black line: PAV, NAVA
- Red line: PC, PS
- Green line: VC, adaptive PC

As the patient WOB increases, the ventilator WOB increases as well, indicating a direct relationship between the two. The graph helps in understanding how different ventilation modes affect the work load on both the patient and the ventilator.
**PEEP (Positive End Expiratory Pressure)**

Probably most important Parameter to apply and adjust

Many ways to do it (no agreement in literature)
Improves oxygenation

Too low can cause VILI

Too high can cause overdistention & hemodynamic instability
PEEP (Positive End Expiratory Pressure)

**Pressure-Volume Loop Inflection Points**

- **HIP**: Point where the lung reaches TLC, above that: Over distention
- **LIP**: Point where alveoli are recruited, below that: alveolar collapse during exhalation

**Stress Index**

- Stress index < 1
- Stress index = 1
- Stress index > 1

Recruitment  Normal  Overdistension

Ranieri. Anesthesiology 2000
PEEP (Positive End Expiratory Pressure)

Esophageal balloon and Trans-Pulmonary pressure measurement

PEEP-FiO2 table

<table>
<thead>
<tr>
<th>FiO2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.7</th>
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<tr>
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<td>5</td>
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<td>8</td>
<td>8</td>
<td>10</td>
<td>10</td>
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<table>
<thead>
<tr>
<th>FiO2</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>0.9</th>
<th>1.0</th>
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</thead>
<tbody>
<tr>
<td>PEEP</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>16</td>
<td>18-24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FiO2</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>14</td>
<td>14</td>
<td>16</td>
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</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>

Transpulmonary pressure actually 45 cmH₂O
Transpulmonary pressure only 15 cmH₂O
Weaning & Liberation

Weaning & Liberation

Weaning
The process of abruptly or gradually withdrawing ventilatory support

Liberation
The removal of the artificial airway

Weaning & Liberation
Facts

- Mechanical ventilation can be abruptly withdrawn in 75% of patients whose respiratory failure has been improved or resolved
- 25% of patients will need progressive withdrawal of mechanical ventilation
- 40% of time spent on the ventilator is for weaning
- 56% of patients with unplanned extubation did not require reintubation
- Weaning parameters are not good predictors of extubation
- Weaning with high PSV >7 cmH2O is not weaning
- 10% - 15% extubation failure is acceptable
Weaning & Liberation

Weaning

When?

- Respiratory Criteria:
  - PaO$_2$ ≥ 60 mm Hg on FiO$_2$ ≤ 40–50% and PEEP ≤ 5–8 cm H$_2$O
  - PaCO$_2$ normal or baseline (except for permissive hypercapnia).
  - Patient is able to initiate an inspiratory effort.

- Cardiovascular Criteria:
  - No evidence of myocardial ischemia.
  - Heart rate ≤ 140 beats/minute.
  - Blood pressure normal without vasopressors or with minimum vasopressor support (e.g., dopamine < 5 µg/kg/min).

- Adequate Mental Status:
  - Patient is arousable, or Glasgow Coma Score ≥ 13.

- Absence of Correctible Comorbid Conditions:
  - Patient is afebrile.
  - There are no significant electrolyte abnormalities.

Weaning

How?

Spontaneous Breathing Trial (SBT)

- Check respiratory system compliance and resistance before SBT

30 - 120 minutes

- T-piece
- PSV 5-7 CmH$_2$O
- CPAP 5-7 CmH$_2$O
- ATC
- Smart Care
- PAV
Weaning & Liberation

Weaning

Ventilatory Support

Assess Readiness

SBT

success

Fail

Evaluate for extubation

Extubate

Weaning

Underlying indication for mechanical ventilation has resolved or improved

DAILY SCREENING OF THE RESPIRATORY FUNCTION

NOT READY FOR WEANING

READY FOR WEANING

Mechanical ventilation and daily screening

SPONTANEOUS BREATHING TRIAL

T-tube or PSV 7cmH2O

30min is enough

No signs of poor tolerance

SIGNS OF POOR TOLERANCE

EXTUBATION

GRADUAL WITHDRAWAL

Once-daily trial

Pressure support/T-tube

RECOMMENDATION

LEVEL OF EVIDENCE

Grade A

Level [4]

Grade A

Level [3]

Grade A

Level [5]

Grade A

Level [1]

Grade A

Level [2]
Weaning & Liberation

Weaning causes of failed SBT

Factors that can lead to weaning failure due to the imbalance between ventilatory needs and respiratory capacity

Factors that increase the load

<table>
<thead>
<tr>
<th>Increased resistive loads</th>
<th>Increased chest wall elastic loads</th>
<th>Increased lung elastic loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bronchospasm</td>
<td>Pleural effusion</td>
<td>Hyperinflation (auto-PEEP)</td>
</tr>
<tr>
<td>Airway edema, secretions</td>
<td>Pneumothorax</td>
<td>Alveolar edema</td>
</tr>
<tr>
<td>Upper airway obstruction</td>
<td>Flail chest</td>
<td>Infection</td>
</tr>
<tr>
<td>Obstructive sleep apnea</td>
<td>Obesity</td>
<td>Atelectasis</td>
</tr>
<tr>
<td>Endotracheal tube kinking</td>
<td>Ascites</td>
<td>Interstitial inflammation and/or edema</td>
</tr>
</tbody>
</table>

Factors that result in decreased neuromuscular competence

<table>
<thead>
<tr>
<th>Decreased drive</th>
<th>Muscle weakness</th>
<th>Impaired neuromuscular transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drug overdose</td>
<td>Electrolyte derangement</td>
<td>Critical illness polyneuropathy</td>
</tr>
<tr>
<td>Brain-stem lesion</td>
<td>Malnutrition</td>
<td>Neuromuscular blockers</td>
</tr>
<tr>
<td>Sleep deprivation</td>
<td>Myopathy</td>
<td>Aminoglycosides</td>
</tr>
<tr>
<td>Hypothyroidism</td>
<td>Hyperinflation</td>
<td>Guillain–Barré syndrome</td>
</tr>
<tr>
<td>Starvation/malnutrition</td>
<td>Drugs, corticosteroids</td>
<td>Myasthenia gravis</td>
</tr>
<tr>
<td>Metabolic alkalosis</td>
<td>Sepsis</td>
<td>Phrenic nerve injury</td>
</tr>
<tr>
<td>Myotonic dystrophy</td>
<td></td>
<td>Spinal cord injury</td>
</tr>
</tbody>
</table>

Weaning Patients who fail SBT

- Correct underlying reason for failure
- Daily SBT
- At least 24 hours of rest in between trials
Thank You