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What is Mechanical Ventilation?

Delivery of Ventilation and Supplemental Oxygen with a Mechanical Ventilator to Support a Patient Experiencing Respiratory Failure.
Indications for Mechanical Ventilation:

Respiratory Failure:

Hypoxemic Failure:
- V/Q Mismatch vs. Shunt vs. Hypoventilation
  - PaO2<60mmHg on 100% NRB
    - Pneumonia
    - ARDS
    - Congestive Heart Failure
    - Pulmonary Embolism

Ventilatory Failure:
- Altered Respiratory Mechanics
  - Acute ↑pCO2 with Resp. Acidosis
    - COPD/Asthma
    - Acute Intoxication
    - Neuromuscular Disease
    - Sepsis
    - Obesity Hypoventilation
Recognizing Respiratory Failure:

1) Arterial Blood Gas Abnormalities:

- Hypoxemia: PaO2<60mmHg or O2 sat < 90% on 100% NRB

- Hypercapnea:
  - Acute: pHΔ0.08 for pCO2Δ10mmHg
  - Chronic: pHΔ0.03 for pCO2Δ10mmHg

2) Clinical Impression:

- Use of Accessory Muscles
- Inability to Speak in Full Sentences
- Paradoxical Respirations
- Altered Mentation
- Cardiopulmonary Arrest: When Respirations and Pulse Cease
How to Begin Mechanical Ventilation:

Need a Conduit:

- Endotracheal Tube: Invasive Mechanical Ventilation
- Face Mask: Noninvasive Mechanical Ventilation (NPPV)

2. Deliver Cyclical Positive-Pressure ‘Breaths’.


Placement of an Endotracheal Tube:

Figure 69.—Continued. B. Forward fixation of larynx with left hand, by holding tongue forward with gauze-covered fingers. With the right hand, the catheter is rapidly advanced through the nares and past the glottis as the patient inspires deeply. If he is comatose, a mouth gag is used, and the epiglottis is picked up with the left forefinger. The catheter is then guided through the larynx. C. Advancement of catheter into trachea by intermittent suction over Y-tube. Once it is in trachea, it is moved back and forth to stimulate coughing.
Non-invasive Ventilation Mask:
How to Begin Invasive Mechanical Ventilation: Settings

Options (for invasive ventilation):

- **Mode**: Assist-Control (A/C), Intermittent Mandatory Ventilation (IMV), Pressure Support Ventilation (PS), Others.
- **FiO2**: 21%-100%
- **Rate**: 0-35
- **Tidal Volume**: 4cc/kg to 10cc/kg
- **Inspiratory Flow Rate**: 60L/min to 120L/min
Modes of Invasive Mechanical Ventilation:

- **Assist/Control**

  - I:E- Ratio of Time Spent in Each Phase
  - Tidal Volume for Each Breath is Constant at Set TV
  - Minute Ventilation: Rate (breaths/min) x Tidal Volume
  - Additional Breaths Above Set Rate Are at Set TV.

Source: T. Sisson
Modes of Invasive Mechanical Ventilation:

**Intermittent Mandatory Ventilation**

- **Tidal Volume**: Varies between Set Volume and Spontaneous.
- **Minute Ventilation**: Rate (breaths/min) x Tidal Volume.
- **Additional Breaths Above Set Rate Are What Patient Generates.**
Pressure Support Ventilation

- **Minute Ventilation**: Rate (breaths/min) x Tidal Volume.
- **No Set Rate with Pressure Support**.

Source: T. Sisson
Choosing the Mode of Invasive Mechanical Ventilation:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Rate</th>
<th>TV</th>
<th>Pressure</th>
<th>Flexibility</th>
<th>Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/C</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>++++</td>
<td>+</td>
</tr>
<tr>
<td>IMV</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>PS</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>+</td>
<td>++++</td>
</tr>
</tbody>
</table>
What is Meant By Flexibility?

Minute Ventilation = TV \times RR \quad \text{Determined by Metabolic State} = \text{CO2 Production}

**Example:** 55 year old woman admitted with toxic shock from lower extremity cellulitis. Intubated for respiratory distress. Initial minute ventilation is 10 L/min. Ventilator rate is set at 20 breaths/min with a TV of .500 L.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Rate$_{set}$</th>
<th>TV$_{set}$</th>
<th>TV$_{sp}$</th>
<th>Rate$_{sp}$</th>
<th>MV</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/C</td>
<td>20</td>
<td>.500 L</td>
<td>-</td>
<td>0</td>
<td>10L/min</td>
</tr>
<tr>
<td>IMV</td>
<td>20</td>
<td>.500 L</td>
<td>-</td>
<td>0</td>
<td>10L/min</td>
</tr>
</tbody>
</table>

**Example:** Over the next several hours the patient becomes increasingly unstable with a low blood pressure (70/50) and fevers (temp-102.5F). The minute ventilation also increases to 15 L/min.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Rate$_{set}$</th>
<th>TV$_{set}$</th>
<th>TV$_{sp}$</th>
<th>Rate$_{sp}$</th>
<th>MV</th>
<th>Rate$_{total}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/C</td>
<td>20</td>
<td>.500 L</td>
<td>.500 L</td>
<td>10</td>
<td>15 L/min</td>
<td>30</td>
</tr>
<tr>
<td>IMV</td>
<td>20</td>
<td>.500 L</td>
<td>.250 L</td>
<td>20</td>
<td>15 L/min</td>
<td>40</td>
</tr>
</tbody>
</table>
Getting Started on Invasive Mechanical Ventilation

- Pick a Mode: A/C in Medical Intensive Care Unit Secondary to Flexibility.

- Pick a Volume
  - 8-10 ml/kg body mass as starting point

- Pick a Rate
  - 10-12 is Reasonable in an Adult
  - Rates are Higher in Children and Infants

- Pick an FiO₂
  - Start at 100%.

10:10:10 Rule: 10 breaths/min: 10 cc/kg: 100% FiO₂
The Relationship Between Volume and Pressure

Assist/Control

A= Assist
S= Spontaneous

Tidal Volume
Pressure

Volume

Time
The Relationship Between Volume and Pressure

Intermittent Mandatory Ventilation

A = Assist
S = Spontaneous

Tidal Volume (set)
Tidal Volume (sp)
Tidal Volume (sp)
Compliance: Volume and Pressure Relationship

Compliance = \( \frac{\Delta V}{\Delta P} \)

- Alveolar Over-inflation
- Alveolar Recruitment

\[ X = 500 \text{ ml} \]
\[ Y = 20 \text{ cmH}_2\text{O} \]

Compliance = 25
Compliance: Volume and Pressure Relationship

- Volume vs. Pressure graph with lines A and B.

- Patient A and Patient B graphs showing pressure, volume, and time.

- TV indication in each graph.
Pressure Also Influenced by Airway Resistance

- Pressure\textsubscript{Peak}:
  Determined by Airway Resistance and Lung Compliance.

- Pressure\textsubscript{Plateau}:
  Determined only by Lung Compliance.

Why Do We Care About Lung Pressures?

\[ \Delta \]

Airway Resistance

TV

Stop Flow

Pressure

Volume

Pressure

Volume
Other Ventilator Functions:

- Synchronizing with Patient’s Respirations (Both A/C and IMV).

- Trigger Requires only -2-3 cmH2O Pressure

- Allows Fatigued Muscles to Rest While Providing Some Work
Other Ventilator Functions:

- Positive End Expiratory Pressure (PEEP)

Ventilator Never Lets Circuit Pressures Fall Below Chosen Pressure:
- Prevents At-Risk Alveoli From Collapsing During Exhalation.
- 5 cm H₂O a Common Starting Point.
- Can Significantly Improve Oxygenation by Recruiting Alveoli for Gas Exchange and Thereby Correcting V/Q Mismatch.
Complications of Mechanical Ventilation
Complications of Invasive Mechanical Ventilation:

- **Auto-PEEP (Intrinsic PEEP)**
  - **End Expiratory Pressure Does Not Return to Zero (or Set PEEP):**
    - Typically a Complication of Obstructive Lung Disease.
    - Results From an Inadequate Expiratory Time.
    - Patients with Asthma and COPD Need Prolonged Expiratory Phase to Empty Previous Breath.
Complications of Invasive Mechanical Ventilation:

- **Auto-PEEP (Intrinsic PEEP)**

  - **Problem:** If Thoracic Pressure > Central Venous Pressure then Impairment in Venous Return Resulting in Hypotension.

  - **Management:** Prolong Exhalation (Change I:E Ratio)
    - Fewer Breaths/Minute (Increase Tidal Volume)
    - Shorter Inspiratory Time (Increase Inspiratory Flow Rate)

*Example:* Back to Our Patient with a Tidal Volume of .500 L with Respiratory Rate of 30/minute to Meet a Minute Ventilation of 15 L/minute. Over Time, She Develops a PEEPi of 15 cmH2O with a Decrease in Blood Pressure.

If TV is Increased to .750 L, the Respiratory Rate Will Fall Giving More Time for Exhalation.

\[
\begin{align*}
0.500 \text{ L} \times 30 \text{ breaths/minute} &= 15 \text{ L}.
\end{align*}
\]

\[
\begin{align*}
0.750 \text{ L} \times ? \text{ breaths/minute} &= 15 \text{ L}. \\
? &= 20 \text{ breaths/minute}
\end{align*}
\]

\[
\begin{align*}
0.750 \text{ L} \text{ Comes with a Cost of Increasing Pressure in Lung.}
\end{align*}
\]
Complications of Invasive Mechanical Ventilation:

**High Pressures:**

- Problem: Barotrauma vs. Volutrauma (see ARDS lecture)
  - Large Tidal Volumes ± High Lung Pressures Lead to Lung Injury.
  - Improved Outcome in Acute Respiratory Distress Syndrome by Limiting Tidal Volumes.
  - Barotrauma Can also Manifest as Pneumothorax.

**Causes:**

- High Peak/Normal Plateau
  - Increase in Airways Resistance
  - Worsening Airway Obstruction (Asthma/COPD)
  - Endotracheal Tube Obstruction
  - Biting Tube
  - Mucus Plugging

- High Peak/High Plateau
  - Decrease in Lung Compliance
  - Worsening Disease (ARDS/CHF)
  - Pneumothorax
  - Right Mainstem Intubation
Complications of Invasive Mechanical Ventilation:

- **High Pressures:**
- **Management:**
  - Dependent on Cause, So Try to Determine Etiology.
  - If Due to Low Lung Compliance, Decrease Tidal Volume (see ARDS).
  - Can Consider Pressure Cycled Ventilation.
  - If Due to Increased Airway Resistance, Less of a Problem: Suctioning Bronchodilators, etc.
Complications of Invasive Mechanical Ventilation:

*Over-Ventilation:*

- When Minute Ventilation Is Greater Than Patient Needs:
  - Patient Will Make No Spontaneous Efforts.
  - Suspect Over-ventilation When Patient Sits on Back-up Rate.
  - Also Can Be Detected with an Arterial Blood Gas.

**Example:** 70 year old man is initiated on mechanical ventilation for a COPD exacerbation. Blood Gas just prior to starting mechanical ventilation reveals: pH- 7.24, pCO2-60. After starting mechanical ventilation with A/C, rate of 20, TV of 600, the patient is noted to be breathing at rate of 20 (no efforts above back-up rate). Blood Gas reveals pH-7.48 and pCO2 of 30.

*Management:*

- Decrease Minute Ventilation (↓ TV or ↓ Respiratory Rate).
- For A/C, Set Back-up Rate ~4 Breaths Below Total Respiratory Rate.
Complications of Invasive Mechanical Ventilation:

- **High FiO2:**
  - **Problem:** High Levels of Oxygen Are Toxic to Patient’s Lungs.
    - Exact Level that Is Safe Has Not Been Determined.
    - ≤ 50% FIO2 Is Goal.
    - However, FIO2 Is not Decreased if it Results in Inadequate Oxygenation (Sat > 90% or pO2 > 60 mmHg).

- **Management:** (see ARDS Lecture)
  - PEEP.
  - Prone Positioning.
  - Inhaled Nitric Oxide.
Complications of Invasive Mechanical Ventilation:

🟦 Patient-Ventilator Dysynchrony:

- **Problem:** Patient Discomfort and Anxiety, Impaired Oxygenation/Ventilation.

- **Management:**
  - Sedation: Benzodiazepines and Narcotic Analgesics
  - Change Ventilator Mode.
  - Paralysis: Increases Risk for ICU Myopathy.

🟦 Ventilator Associated Pneumonia:

- **Problem:** Interruption of Upper Airway Defenses.
  - Cough, Gag, Mucus Clearance.
  - Colonization of the Airway/Upper GI Track with Pathogenic Bacteria.

- **Management:**
  - No Fool Proof Method to Prevent Vent-associated Pneumonia.
  - Elevate Head of Bed to 30-45 degrees.
Monitoring Patients on Mechanical Ventilation
Daily Assessments of Invasive Mechanical Ventilation:

- Pressures: (Peak and Plateau).
- Arterial Blood Gas: (Ventilation, Oxygenation)
- Chest X-ray: Position of Endotracheal Tube
- Auto-PEEP: Especially in Patient with Obstruction.
- Patient Comfort and Position of Head.
- Weaning Candidacy.
Weaning From Invasive Mechanical Ventilation

When?
- Underlying Condition Has Improved:
  FIO2 ≤ 40%
  Minute Ventilation ≤ 10 L
  Mental Status Allows Patient to Follow Commands.

Pre-Weaning Assessment: Parameters
- Patient is Taken Off Support Briefly
- Several Parameters are Assessed: MV, TV, RR, Negative Inspiratory Force, Vital Capacity
- No Perfect Predictor for Success in Coming Off Ventilator.
- Rapid Shallow Breathing Index Commonly Used: RR/TV (Liters). < 105 Suggests Likely Success.
Weaning From Invasive Mechanical Ventilation

How?
- If Parameters Suggest that Patient is Ready, Begin Weaning Trial:
  Spontaneous Trial: Patient Breaths on Own.
  IMV Wean: Back-up Rate is Slowly Decreased So that Patient Progressively Takes Over Load.
  Pressure Support Wean: Level of Pressure is Slowly Decreased So that Patient Takes Over Load.

Duration of Spontaneous Trial: Depends on Circumstance ~ 2 Hours.

If Spontaneous Trial is Successful, Endotracheal Tube is Removed.
Non-Invasive Mechanical Ventilation

- **CPAP**: Continuous positive airway pressure

- **BiPAP**: Similar to Pressure Support Where Each Inspiration Is Supported by a Set Pressure. An Expiratory Pressure Is Also Set (Typical Settings 12/5 cmH2O).

- **Why Non-Invasive Ventilation?**
  - Avoids Complications of Invasive Ventilation
  - Particularly Beneficial (Decreased Mortality) For Management of COPD and CHF if Invasive Mechanical Ventilation Can Be Avoided.
Key Points to Understand:

• Indications for Invasive Mechanical Ventilation.

• Settings for Invasive Ventilation and How to Adjust:
  – $\text{FiO}_2$
  – Modes
  – Rate
  – Tidal volume
  – Airway pressures
  – PEEP

• Complications of Invasive Mechanical Ventilation.

• Weaning From Invasive Mechanical Ventilation.
Additional Source Information
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