Centre of Excellence for Clinical Management of COVID-19
All India Institute of Medical Sciences, Bhopal

PRINCIPLES OF MECHANICAL VENTILATION
Initiation of Mechanical Ventilation

• Indications
  • Indications for Ventilatory Support
    • Acute Respiratory Failure
    • Prophylactic Ventilatory Support
    • Hyperventilation Therapy
Initiation of Mechanical Ventilation

• Indications
  • Acute Respiratory Failure (ARF)
    • Respiratory activity is inadequate or is insufficient to maintain adequate oxygen uptake and carbon dioxide clearance.
    • Inability of a patient to maintain arterial PaO2, PaCO2, and pH acceptable levels
    • PaO2 < 70 on an O2 >0.6 (PaO2/FiO2 <200)
    • PaCO2 > 55 mm Hg and rising
    • pH 7.25 and lower
Initiation of Mechanical Ventilation

• **Indications**
  
  • Acute Respiratory Failure (ARF)
    
    • *Hypoxic lung failure (Type I)*
      
      • Ventilation/perfusion mismatch
      • Diffusion defect
      • Right-to-left shunt
      • Alveolar hypoventilation
      • Decreased inspired oxygen
    
    • Acute life-threatening or vital organ-threatening tissue hypoxia
Initiation of Mechanical Ventilation

• Indications
  • Acute Respiratory Failure (ARF)
    • *Clinical Presentation of Severe Hypoxemia*
      • Tachypnea
      • Dyspnea
      • Central cyanosis
      • Tachycardia
      • Hypertension
      • Irritability, confusion
      • Loss of consciousness
      • Coma
Initiation of Mechanical Ventilation

- Indications
  - Acute Respiratory Failure (ARF)
    - Acute Hypercapnic Respiratory Failure (Type II)
  - CNS Disorders
    - Reduced Drive To Breathe: depressant drugs, brain or brainstem lesions (stroke, trauma, tumors), hypothyroidism
    - Increased Drive to Breathe: increased metabolic rate (≡CO2 production), metabolic acidosis, anxiety associated with dyspnea
Initiation of Mechanical Ventilation

- Indications
  - Acute Respiratory Failure (ARF)
    - Acute Hypercapnic Respiratory Failure (Type II)
  - Neuromuscular Disorders
    - Paralytic Disorders: Myasthenia Gravis, Guillain-Barre, ALS, poliomyelitis, etc.
    - Paralytic Drugs: Curare, nerve gas, succinylcholine, insecticides
    - Drugs that affect neuromuscular transmission; calcium channel blockers, long-term adenocorticosteroids, etc.
  - Impaired Muscle Function: electrolyte imbalance, malnutrition, chronic pulmonary disease, etc.
Initiation of Mechanical Ventilation

- **Indications**
  - Acute Respiratory Failure (ARF)
    - *Acute Hypercapnic Respiratory Failure*
  - Increased Work of Breathing
    - *Pleural Occupying Lesions:* pleural effusions, hemothorax, empyema, pneumothorax
    - *Chest Wall Deformities:* flail chest, kyphoscoliosis, obesity
    - *Increased Airway Resistance:* secretions, mucosal edema, bronchoconstriction, foreign body
    - *Lung Tissue Involvement:* interstitial pulmonary fibrotic diseases
Initiation of Mechanical Ventilation

• Indications
  • Acute Respiratory Failure (ARF)
    • *Acute Hypercapnic Respiratory Failure*
    • Increased Work of Breathing (cont.)
      • *Lung Tissue Involvement:* interstitial pulmonary fibrotic diseases, aspiration, ARDS, cardiogenic PE, drug induced PE
      • *Pulmonary Vascular Problems:* pulmonary thromboembolism, pulmonary vascular damage
      • *Dynamic Hyperinflation* (air trapping)
      • *Postoperative Pulmonary Complications*
Initiation of Mechanical Ventilation

• Indications
  • Acute Respiratory Failure (ARF)
    • Clinical Presentation of Hypercapnia
      • Tachypnea
      • Dyspnea
      • Tachycardia
      • Hypertension
      • Headache (hallucinations when severe)
      • Confusion (loss of consciousness, even coma when severe)
      • Sweating
Initiation of Mechanical Ventilation

• Prophylactic Ventilatory Support
  • Clinical conditions in which there is a high risk of future respiratory failure
    • Examples: Brain injury, heart muscle injury, major surgery, prolonged shock, smoke injury

• Ventilatory support is instituted to:
  • Decrease the WOB
  • Minimize O2 consumption and hypoxemia
  • Reduce cardiopulmonary stress
  • Control airway with sedation
Initiation of Mechanical Ventilation

• Hyperventilation Therapy
  • Ventilatory support is instituted to control and manipulate PaCO2 to lower than normal levels
    • Acute head injury
Initiation of Mechanical Ventilation

• Contraindications
  • Untreated pneumothorax

• Relative Contraindications
  • Patient’s informed consent
  • Medical futility
  • Reduction or termination of patient pain and suffering
7 Factors to be tuned finely

- Mode of Ventilation
- Minute Ventilation
- Respiratory Rate
- Tidal Volume
- I:E Ratio

- Rate of Flow of gas & Flow Pattern
- FiO$_2$
Initiation of Mechanical Ventilation

- **Initial Ventilator Settings**
  - **Mode**
    - **Full Ventilatory Support (FVS)**
      - Assumes essentially all the work of breathing
      - Majority initially require FVS
      - Assist Control (A/C)
      - SIMV if rate is 12 BPM or higher (Chang)
  - **Partial Ventilatory Support (PVS)**
    - Provides less than total amount of work of breathing
    - Common during weaning
    - SIMV at lower rates (usually <8 -10 BPM)
    - PSV
    - Bi-PAP
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Minute Ventilation
    • The primary goal of volume ventilation ($V_T - V_{a} + V_{d}$) achieve a desired minute ventilation ($\dot{V}_{E}$) that matches the patient’s metabolic needs and accomplishes adequate gas exchange.
    • Ventilators manufactured in the United States commonly have controls for $V_T$ and $f$ used to set the $\dot{V}_{E}$, so it is uncommon to see a know specifically for $\dot{V}_{E}$ in a U.S. manufactured machine.
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Minute Ventilation
    • Metabolic rate is directly related to body surface area (BSA)
      • is approximately 4 times $V_B$ BSA

Males: $= 4 \times BSA$
Females: $= 3.5 \times BSA$
Initiation of Mechanical Ventilation

- **Initial Ventilator Settings**
  - Minute Ventilation based on BSA
    - **Example:**
      Female patient with an estimated BSA of 2.0 m²
      
      \[
      V_B \text{, } B = 3.5 \times 2.0 \text{ m}^2
      \]
      
      \[
      V_B = 7.0 \text{ L/min}
      \]

    - A patient’s \( V_B \) requirements increase by 9% for every 1 °C increase on body temperature
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Tidal Volume
    • Spontaneous VT for an adult is 5 – 7 ml/kg of IBW

Determining VT for Ventilated Patients

• A range of 6 – 12 ml/kg IBW is used for adults
  • 10 – 12 ml/kg IBW (normal lung function)
  • 8 – 10 ml/kg IBW (obstructive lung disease)
  • 6 – 8 ml/kg IBW (ARDS) – can be as low as 4 ml/kg

• A range of 5 – 10 ml/kg IBW is used for infants and children (Pilbeam)
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Ideal Body Weight Calculation

**Male IBW in lb:** \[106 + [6 \times (\text{height in inches} - 60)]\]

**Female IBW in lb:** \[105 + [5 \times (\text{height in inches} - 60)]\]

*Ideally, a tidal volume should be chosen that maintains a \( P_{\text{plat}} < 30 \text{ cm H}_{2}\text{O} \)*
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Respiratory Rate
    • Normal respiratory rate is 12-18 breaths/min.

Determining Respiratory Rate for Ventilated Patients

• A range of 8 – 12 breaths per minute (BPM)

Rates should be adjusted to try and minimize auto-PEEP
Initiation of Mechanical Ventilation

- Initial Ventilator Settings
  - Minute Ventilation
    - Respiratory rate is chosen in conjunction with tidal volume to provide an acceptable minute ventilation
      \[ V_{\text{E}} = \text{VT} \times f \]
    - Normal minute ventilation is 5-10 L/min
    - Estimated by using 100 mL/kg IBW
  - ABG needed to assess effectiveness of initial settings
    - If PaCO2 > 45 (≥ minute ventilation via f or VT)
    - If PaCO2 < 35 (≤ minute ventilation via f or VT)
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Relationship of VT, Flow, TCT and I:E Ration
    • Total Cycle Time equals inspiratory time plus expiratory time ($T_I + T_E = T_{CT}$)

\[
2 \text{ sec } (T_I) + 4 \text{ sec } (T_E) = 6 \text{ sec } (T_{CT})
\]

• Respiratory Rate ($f$) equals 1 min (60 sec) divided by total cycle time

\[
f = \frac{1 \text{ min}}{60 \text{ sec}} \div \frac{T_{CT}}{6 \text{ sec}} = 10 \text{ breaths/min}
\]
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Relationship of VT, Flow, TCT and I:E Ration
    • Calculating $T_I$ from a percentage of TCT ($T_I \%$)

If set $f$ is 10, then TCT equals 6 sec.

If $T_I \%$ is set at 33% or 1/3 of TCT

$T_I = 0.33 \times 6 \text{ sec.} = 2 \text{ sec.}$

Note: $TCT - T_I = T_E$
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Relationship of VT, Flow, TCT and I:E Ratio
    • I:E Ratio equals $T_I$ divided by $T_E$

\[ I:E = \frac{T_I}{T_E} \]

e.g., 
\[ \frac{2 \text{ sec. (}T_I\text{)}}{4 \text{ sec. (}T_E\text{)}} = 1:2 \text{ (I:E Ratio)} \]

*I:E ratios are usually set at 1:1.5 – 1:4 to help prevent air-trapping (auto-PEEP)*
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Relationship of VT, Flow, TCT and I:E Ration
    • I:E Ratio are usually expressed so that $T_I$ equals 1

To reduce the I:E ration to its simplest form, divide the numerator and the denominator by $T_I$

\[
I:E = \frac{T_I}{T_E} \quad \text{e.g.,} \quad \frac{0.7 \text{ sec}}{0.7 \text{ sec}} = 1:4
\]

\[
\frac{T_E}{T_I} \quad \text{e.g.,} \quad \frac{2.8 \text{ sec}}{0.7 \text{ sec}}.
\]
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Relationship of VT, Flow, TCT and I:E Ration
    • Calculating $T_i$ from VT and Flow (square wave)

\[
T_i = \frac{\text{VT}}{\text{Flow}} \quad \text{e.g.,} \quad \frac{1 \text{ L}}{1 \text{ L/sec}} = 1 \text{ sec} (T_i)
\]

The flow control on adult ventilators is calibrated in L/min., so flow needs to be converted to L/sec. as follows:

If flow is 60 L/min, it is equal to \( \frac{60 \text{ L/min}}{60 \text{ sec}} = 1 \text{ L/sec} \)
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Adjusting I:E Ratio

  - $\dot{V}_1 \equiv \dot{V}_T \equiv T_I \equiv$ smaller I:E ratio
  - $\dot{V}_1 \equiv \dot{V}_T \equiv T_I \equiv$ larger I:E ratio

  - $V_T \equiv V_T \equiv T_I \equiv$ larger I:E ratio
  - $V_T \equiv V_T \equiv T_I \equiv$ smaller I:E ratio

  - $f \equiv RR \equiv T_E \equiv$ larger I:E ratio
  - $f \equiv RR \equiv T_E \equiv$ smaller I:E ratio

  - $T_I \% \equiv T_I \% \equiv$ larger I:E ratio
    - e.g., = $T_I \%$ of 20% = 1:4, $T_I \%$ of 25% = 1:3
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Inspiratory Flow
    • Rate of Gas Flow
      • As a beginning point, flow is normal set to deliver inspiration in about 1 second (range 0.8 to 1.2 sec.), producing an I:E ratio of approximately 1:2 or less (usually about 1:4)

      • This can be achieved with an initial peak flow of about 60 L/min (range of 40 to 80 L/min)

Most importantly, flows are set to meet a patient’s inspiratory demand
Adequate Flow During Volume Ventilation

\[ P_{aw} \text{ cmH}_2\text{O} \]

Time (s)

Adequate flow
Inadequate Flow During Volume Ventilation

Adequate flow

Flow set too low

\( P_{aw} \) cmH\(_2\)O

Time (s)
The Patient Outbreathing the Set Flow

- \( P_{aw} \) (cmH\(_2\)O)
- Time (Sec)

Air Starvation
**Expiratory Flow Pattern**

- **Inspiration**
  - Beginning of expiration
  - Exhalation valve opens

- **Expiration**
  - Expiratory time $T_E$
  - Duration of expiratory flow

- **Flow (L/min)**
- **Time (sec)**

- **Peak Expiratory Flow Rate (PEFR)**
Inadequate Inspiratory Flow

Active Inspiration or Asynchrony

Patient's effort

Flow (L/min)

Normal
Abnormal

Time (sec)
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Flow Patterns
    • Selection of flow pattern and flow rate may depend on the patient’s lung condition, e.g.,
      • Post-operative patient recovering from anesthesia may have very modest flow demands
      • Young adult with pneumonia and a strong hypoxemic drive would have very strong flow demands
Initiation of Mechanical Ventilation

- **Initial Ventilator Settings**
  - **Flow Pattern**
    - **Constant Flow (rectangular or square waveform)**
      - Generally provides the shortest TI
      - Some clinician choose to use a constant (square) flow pattern initially because it enables them to obtain baseline measurements of lung compliance and airway resistance (Oakes’ Ventilation Management; ch.5)
Initiation of Mechanical Ventilation

- Initial Ventilator Settings
  - Flow Pattern
    - Sine Flow
      - May contribute to a more even distribution of gas in the lungs
      - Peak pressures are mean airway pressure are about the same for sine and square wave patterns
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Flow Pattern
    • Descending (decelerating) Ramp
      • Improves distribution of ventilation, results in a longer TI, decreased peak pressure, and increased mean airway pressure (which increases oxygenation)
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • Flow Patterns
    • In Terms of Patient Lung Disorders
      • Normal lungs: Not of key importance

      • Low compliance, hypoxemia: Descending flow pattern may be beneficial by keeping peak pressures low and mean airway pressure high, and improving gas distribution

      • High Raw: Descending flow pattern more likely to deliver a set VT at a lower pressure and provide for better distribution of air through the lung than a constant flow
Initiation of Mechanical Ventilation

• **Initial Ventilator Settings**
  • **Positive End Expiratory Pressure (PEEP)**
    • Initially set at 3 – 5 cm H2O
      • Restores FRC and physiological PEEP that existed prior to intubation
      • Subsequent changes are based on ABG results
    • Useful to treat refractory hypoxemia
  • Contraindications for therapeutic PEEP (>5 cm H2O)
    • Hypotension
    • Elevated ICP
    • Uncontrolled pneumothorax
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • FiO2
    • Initially 100%
      • Severe hypoxemia
      • Abnormal cardiopulmonary functions
        • Post-resuscitation
        • Smoke inhalation
        • ARDS

  • After stabilization, attempt to keep FiO2 <50%
    • Avoids oxygen-induced lung injuries
      • Absorption atelectasis
      • Oxygen toxicity
Initiation of Mechanical Ventilation

• Initial Ventilator Settings
  • FiO2
    • Patients with mild hypoxemia or normal cardiopulmonary function
      • Drug overdose
      • Uncomplicated postoperative recovery
        • FiO2 of 40%
        • Same FiO2 prior to mechanical ventilation
Initiation of Mechanical Ventilation

• Initial Ventilator Settings For PCV

  • Rate, T₁, and I:E ration are set in PCV as they are in VV

  • The pressure gradient (PIP-PEEP) is adjusted to establish volume delivery

*Remember:* Volume delivery changes as lung characteristics change and can vary breath to breath
Initiation of Mechanical Ventilation

- **Initial Ventilator Settings For PCV**
  - **Initial Pressure Setting**
    1. Set at $P_{plat}$ during VV – adjust to achieve desired VT
      
      or

    2. Use PIP during VV minus 5 cm H2O (PIP – 5) as a starting point – adjust to achieve desired VT
      
      or

    3. If volume readings not available, initiate pressure at 10 – 15 cm H2O – adjust to achieve desired VT

  *In PCV* $P_{alv}$ *cannot go higher than set pressure, therefore keeping PIP <30 cm H2O can helps avoid alveolar overinflation*
Initiation of Mechanical Ventilation

- Initial Ventilator Settings For PCV
  - Flow Pattern
    - PCV provides a descending ramp waveform

*Note: The patient can vary the inspiratory flow on demand*
Initiation of Mechanical Ventilation

• **Active Inspiration with PCV**
  • The patient can vary inspiratory flow on demand
  • The dashed lines represent active inspiration
  • Note the flow and volume difference during active inspiration
Initiation of Mechanical Ventilation

• **Initial Ventilator Settings For PCV**
  • **Rise Time (slope, flow acceleration)**
    • Rise time is the amount of $T_i$ it takes for the ventilator to reach the set pressure at the beginning of inspiration
  
  • Inspiratory flow delivery during PCV can be adjusted with an inspiratory rise time control (aka: slope control)
  
  • Ventilator graphics can be used to set the rise time
Initiation of Mechanical Ventilation

• **Initial Ventilator Settings For PCV**
  • **Rise Time (slope, flow acceleration)**
    • Ventilator graphics can be used to set the rise time

A. Appropriate sensitivity setting
B. (solid line) Rapid rise in pressure
  B1. Overshoot – too rapid rise time
  B2. (dashed line) Increase to set pressure has been tapered
C. Set pressure
D.1. Active exhalation – TI too long
D.2. ATC assisting exhalation
Initiation of Mechanical Ventilation

• Ventilator Alarm Settings
  • High Minute Ventilation
    • Set at 2 L/min or 10%-15% above baseline minute ventilation
      • Patient is becoming tachypneic (respiratory distress)
      • Ventilator is self-triggering

• High Respiratory Rate Alarm
  • Set 10 – 15 BPM over observed respiratory rate
    • Patient is becoming tachypneic (respiratory distress)
    • Ventilator self-triggering
Initiation of Mechanical Ventilation

• **Ventilator Alarm Settings**
  - **Low Exhaled Tidal Volume Alarm**
    - Set 100 ml or 10%-15% lower than expired mechanical tidal volume
    - Causes
      - System leak
      - Circuit disconnection
      - ET Tube cuff leak
  
  - **Low Exhaled Minute Ventilation Alarm**
    - Set at 2 L/min or 10%-15% below average minute volume
    - Causes
      - System leak
      - Circuit disconnection
      - ET Tube cuff leak
Initiation of Mechanical Ventilation

• Ventilator Alarm Settings
  • High Inspiratory Pressure Alarm
    • Set 10 – 15 cm H2O above PIP
    • Inspiration is terminated when triggered
  • Common causes:
    • Water in circuit
    • Kinking or biting of ET Tube
    • Secretions in the airway
    • Bronchospasm
    • Tension pneumothorax
    • Decrease in lung compliance
    • Increase in airway resistance
    • Coughing
Initiation of Mechanical Ventilation

• **Ventilator Alarm Settings**
  - **Low Inspiratory Pressure Alarm**
    - Set 10 – 15 cm H2O below observed PIP
    - **Causes**
      - System leak
      - Circuit disconnection
      - ET Tube cuff leak
  
  • **High/Low PEEP/CPAP Alarm (baseline alarm)**
    - **High**: Set 3-5 cm H2O above PEEP
      - Circuit or exhalation manifold obstruction
      - Auto – PEEP
    - **Low**: Set 2-5 cm H2O below PEEP
      - Circuit disconnect
Initiation of Mechanical Ventilation

- **Ventilator Alarm Settings**
  - High/Low FiO2 Alarm
    - High: 5% over the analyzed FiO2
    - Low: 5% below the analyzed FiO2
  - High/Low Temperature Alarm
    - Heated humidification
      - High: No higher than 37°C
      - Low: No lower than 30°C
Initiation of Mechanical Ventilation

• Ventilator Alarm Settings
  • Apnea Alarm
    • Set with a 15 – 20 second time delay
    • In some ventilators, this triggers an apnea ventilation mode

• Apnea Ventilation Settings
  • Provide full ventilatory support if the patient become apneic
  • VT 8 – 12 mL/kg ideal body weight
  • Rate 10 – 12 breaths/min
  • FiO2 100%
Thank You