Mechanical Ventilation: Modes

David Ray Velez, MD
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Table of Contents

Overview

Definitions

- *Minute Ventilation (MV)*: Amount of Air that Enters the Lungs per Minute
  - MV = RR x Vt
- *Respiratory Rate (f/RR)*: Number of Breaths Delivered per Minute
- *Tidal Volume (Vt)*: Volume of Air Delivered with Each Breath
- *Pressure Support (PS)*: Additional Pressure Added to PEEP to Cause Inspiration
  - Also Known as Inspiratory Pressure (PI) or Change in Pressure (ΔP)
- *Positive End Expiratory Pressure (PEEP)*: Positive Pressure Remaining in Airways at the End of Expiration
- *Fraction of Inspired Oxygen (FiO2)*: Percentage of Oxygen in Air Delivered to the Patient
- Breath Types:
  - *Patient-Trigger Breath*: A Breath Initiated by the Patient's Own Respiratory Drive (Can Be Triggered by Pressure Changes, Flow Changes, Volume Changes, or Shape-Signal)
  - *Machine-Triggered Breath*: A Breath Automatically Cycled by the Ventilator without Any Patient Initiation

Modes

- Non-Controlled Ventilation
  - *Continuous Positive Airway Pressure (CPAP)*
  - *Pressure Support Ventilation (PSV)*
  - PSV Variations:
    - *CPAP with PSV (Similar to BPAP)*
    - *Automatic Tube Compensation (ATC)*

        - *Volume Support Ventilation (VSV)*
- Volume-Controlled Ventilation
    - *Controlled Mechanical Ventilation (CMV)*
    - *Assist-Control Ventilation (AC)*
    - *Synchronized Intermittent Mechanical Ventilation (SIMV)*
- Pressure-Controlled Ventilation
    - *Controlled Mechanical Ventilation (CMV)*
    - *Assist-Control Ventilation (AC)*
    - *Synchronized Intermittent Mechanical Ventilation (SIMV)*
- Advanced Modes of Ventilation
    - *Airway Pressure Release Ventilation (APRV)*
    - *High-Frequency Oscillatory Ventilation (HFOV)*
    - *Adaptive Support Ventilation (ASV)*
    - *Neurally Adjusted Ventilatory Assist (NAVA) Ventilation*

Noninvasive Ventilation

- *See Supplemental Oxygenation
- *See Non-Invasive Ventilation (NIV)

Ventilator Management

- *See Mechanical Ventilation: Settings
- *See Mechanical Ventilation: Ventilator Management
- *See Mechanical Ventilation: Airway Pressures
- *See Mechanical Ventilation: Ventilator Liberation

Complications

- *See Mechanical Ventilation: Patient-Ventilator Dyssynchrony
- *See Mechanical Ventilation: Complications

Non-Controlled Ventilation

Continuous Positive Airway Pressure (CPAP)

- Provides a Continuous Pressure Level (Similar to PEEP)
- **No Additional Support** Provided to Patient-Triggered Breaths
- All Breaths are Patient-Triggered – Patient Determines the Rate and Volume
- General Settings:
    - CPAP Pressure: 5-15 cmH2O
    - FiO2: Adjusted as Needed

Pressure Support Ventilation (PSV)

- **Additional Pressure Support** Provided to Patient-Triggered Breaths
- All Breaths are Patient-Triggered – Patient Determines Rate and Volume
- General Settings:
    - Pressure Support: 5-20 cmH2O
    - FiO2: Adjusted as Needed

PSV Variations

- *CPAP with PSV (Similar to BPAP)*
    - Pressure Support is in Addition to PEEP
    - PSV 10/5 Indicates 5 cmH2O of PEEP and 15 cmH2O During Support
- *Automatic Tube Compensation (ATC)*
    - Ventilator Programming Continuously Adjusts Pressure Support to the Level Needed to Overcome the Endotracheal Tube
    - ATC Can Be Used as a Component and Combined with Any Conventional Ventilator Mode
- *Volume Support Ventilation (VSV)/ Volume Targeted Ventilation (VTV)*
    - Continuously Adjusts Pressure Support to the Level Needed to Achieve a Target Tidal Volume
    - Some Evidence Suggests Decreased Weaning Time and Total Ventilation Time [1]
    - Significant Literature Evaluating its Use in Neonates [2,3]

General Use

- Used Primarily for Ventilator Weaning
- Pressure Used to Overcome the Resistance of the Endotracheal Tube
- Disadvantages:
    - Higher Work of Breathing and Can Cause Respiratory Fatigue
    - Can Result in Carbon Dioxide Retention and Acidosis
    - Poor Choice for Full Ventilatory Support

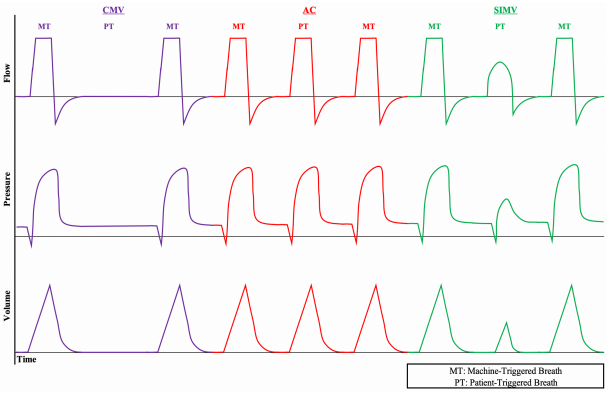
Volume-Controlled Ventilation

Controlled Mechanical Ventilation (CMV)

- Mechanism:
    - Sets a **Controlled** Minute Ventilation (Rate and Volume)
    - Does **Not Allow** Any Patient-Triggered Breaths
- Advantages:
    - **Lowest Work of Breathing**
    - Set Minute Ventilation is Easily Adjusted

- Disadvantages:
  - Less Comfortable
  - May See Ventilator Dyssynchrony with Wasted Effort
  - May Require Deeper Sedation or Paralytics

Assist-Control Ventilation (AC)



Time Graphs of Volume-Controlled Ventilation Modes [5]

- Mechanism:
  - Sets a **Minimum** Minute Ventilation (Rate and Volume)
  - Allows Patient-Triggered Breaths in Addition to Set Minimum Breaths
  - Patient-Triggered Breaths are at the **Set Volume**
- Advantages:
  - Increased Comfort
  - Allows Sedation Weaning
  - Improved Ventilator Synchrony
  - Lower Work of Breathing than SIMV
- Disadvantages:
  - Higher Work of Breathing than CMV
  - Can Hyperventilate with "Breath-Stacking"

Synchronized Intermittent Mechanical Ventilation (SIMV)

- Mechanism:
  - Sets a **Minimum** Minute Ventilation (Rate and Volume)
  - Allows Patient-Triggered Breaths in Addition to Set Minimum Breaths
  - Patient-Triggered Breaths are at a **Patient's Own Volume**
- Advantages:
  - May Allow Exercise of Respiratory Muscles – No Proven Advantage to SIMV [4]
- Disadvantages:
  - Highest Work of Breathing and Can Cause Respiratory **Fatigue**
  - Less Comfortable
  - Can Hyperventilate with "Breath-Stacking"

Pressure-Controlled Ventilation

Mechanism

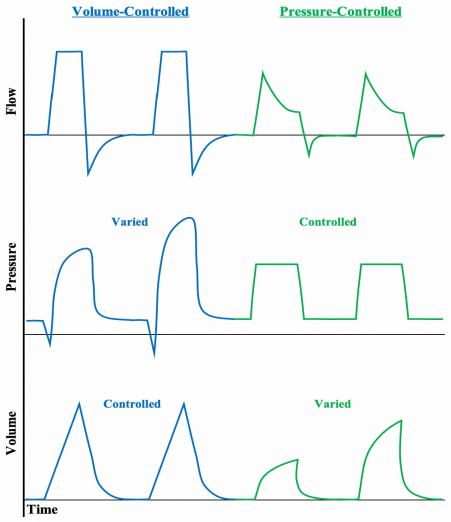
- Provides a Set Airway Pressure for the Given Inspiratory Time
- **Adjusts the Inspiratory Pressure Level** Instead of Tidal Volume

Modes

- Delivered Using Same Modes as Volume-Controlled Ventilation (*See Above)
- *Controlled Mechanical Ventilation (CMV)*
- *Assist-Control Ventilation (AC)*
- *Synchronized Intermittent Mechanical Ventilation (SIMV)*

Use

- Used Much Less Often than Volume-Controlled Ventilation
- Advantages:
  - Peak Inspiratory Pressure (PIP) is Constant (Inspiratory Pressure + PEEP)
    - Decreased Risk for Barotrauma by Lower PIP
    - *See Mechanical Ventilation: Airway Pressures
  - Increased Mean Airway Pressure and Duration of Alveolar Recruitment
  - Increased Comfort and Decreased Work of Breathing
  - May Allows Better Synchrony with the Ventilator
- Disadvantages:
  - Tidal Volume and Minute Ventilation is Variable

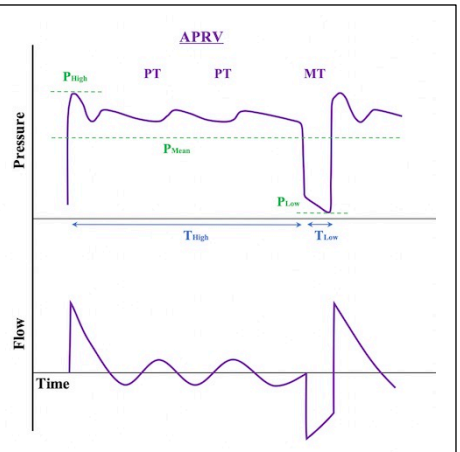


Time Graphs of Volume- vs Pressure-Controlled Ventilation [5]

Advanced Modes of Ventilation

Airway Pressure Release Ventilation (APRV)

- Mechanism:
  - Maintains **High Pressure** (P High) **for an Extended Time** (T High) to Optimize Oxygenation
  - **Pressure Released** (P Low) **for Short Time Period of Time** (T Low) to Allow Ventilation
  - Longer Inspiratory/Expiratory Ratio: 80-95%
  - Spontaneous Breathing is Permitted but Will Have Low Tidal Volumes at the Higher Pressures
- Most Commonly Used for Severe ARDS When Having Difficulty Oxygenating on Other Modes [6,7]
- Settings:
  - P High 25-35 cmH2O
  - T High 4.5-6.0 Seconds
  - P Low 0 cmH2O
  - T Low 0.5-0.8 Seconds
  - FiO2: Adjusted as Needed
  - Keep Automatic Tube Compensation (ATC) on if Spontaneous Breathing

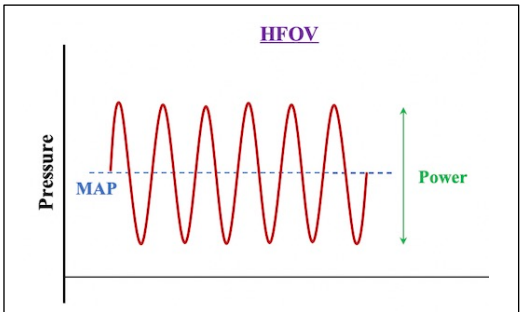


APRV Time Graphs [5]

- Advantages:
  - Maximize Alveolar Recruitment and Oxygenation
  - Lung-Protective (Lower Peak Pressures and Less Barotrauma)
  - More Comfortable than CMV – Allows Decreased Sedation
- Disadvantages:
  - Not Ideal if Requiring Heavy Sedation – Spontaneous Breathing is Important for Ventilation
  - Generally Avoided in Severe Obstructive Airway Disease – Risks Hyperinflation with Increased Pressure and Barotrauma
  - Generally Avoided if Needing High Ventilatory Requirements

High-Frequency Oscillatory Ventilation (HFOV)

- Mechanism:
  - Very High Respiratory Rate (300-900 Breaths per Minute) by a High-Frequency Oscillatory Pump
  - Rate is So Fast That the Airway Pressure Merely Oscillates Around a Constant Mean Airway Pressure
  - Does Not Produce Large Bulk Tidal Volumes but Rather Creates a Relatively Continuous Gas Flow
- Most Commonly Used for Severe ARDS Only When Having Difficulty Oxygenating on Other Modes – Should Not Be Used Routinely (May Actually Increase Mortality) [8,9]



HFOV Pressure-Time Graph [5]

- Settings:
  - Bias Flow: 30-40 L/min
  - Frequency (F): 3-15 Hz (1 Hz is Equivalent to 60 Breaths per Minute)
  - Inspiratory Time: 33% (I:E Ratio of 1:2)
  - Mean Airway Pressure (MAP): 25-35 cmH2O
    - Generally Started at 2-3 cmH2O Above the Prior MAP on CMV
  - Power/Amplitude (Delta P): 30-90 cmH2O
    - Sets the Variation Around the MAP
    - Appropriate Amplitude is Based on “Chest Wiggle”/Vibration
  - FiO2: Adjusted as Needed
- Advantages:
  - Maintains Alveolar Recruitment and Oxygenation
  - Lung-Protective (Lower Peak Pressures and Less Barotrauma)
- Disadvantages:
  - Significant Discomfort and Requires **Heavy Sedation** or Paralysis
  - Decreased Expiratory Time Creates Risk for Hyperinflation with Increased Pressure and Barotrauma
  - High Risk of Hemodynamic Instability Due to High Mean Airway Pressures

Adaptive Support Ventilation (ASV)

- Mechanism:
  - Continual Adjustments are Automatically Made to Respiratory Rate and Inspiratory Pressure to Achieve a Goal Minimum Minute Ventilation (MMV)
    - The Ventilator Calculates Optimal Settings by the "Otis Equation" to Minimize Work of Breathing [10,11]
    - Accounts for Respiratory Mechanics (Resistance, Compliance, Dead Space – Calculated)
  - Patient-Triggered Breaths are Given Pressure Support
  - Machine-Controlled Breaths are Given as Needed to Achieve a Calculated Respiratory Rate
- Settings:
  - Ventilate by Setting a Percentage of Minimum Volume (MinVol) of Desired Minute Ventilation
    - 100% Normal, 120% in ARDS, 90% in Asthma, 110% in Others
    - Add 20% for Fevers > 101.3 F
  - Oxygenate by Setting PEEP and FiO2
- Advantages:
  - Decreased Work of Breathing
  - Attempts Lung Protective Strategies to Prevent Volutrauma, Barotrauma and Auto PEEP
  - May Decrease Ventilator Weaning Time in COPD

$$f = \frac{1 + 2\alpha \times RC \times \frac{\text{Min Vol} - (f \times V_d)}{V_d} - 1}{\alpha \times RC}$$

Otis Equation for Adaptive Support Ventilation [5]

Neurally Adjusted Ventilatory Assist (NAVA) Ventilation

- Mechanism:
  - Catheter Implanted in a Gastric Tube Detects Electrical Discharge in the Diaphragm
  - Diaphragmatic Excitation Triggers a Mechanical Breath
  - The Degree of Assist Varies by the Amplitude of the Electrical Discharge – Tidal Volume Continuously Varies
- Advantages:
  - Neural-Ventilator Coupling (Time Between Spontaneous Breath and Delivered Mechanical Breath) is Faster than Conventional Modes
  - May Increase Ventilator Synchrony
- Disadvantages:
  - Requires Spontaneous Breathing – Unable to Use with Heavy Sedation or Blunted Respiratory Drive

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