Objectives: Mechanical Ventilation

- Discuss indications for Mechanical Ventilation (MV) and the Basic Modes of Invasive MV.
- Identify Waveforms
- Discuss discontinuation (Extubation Criteria) and Basic Troubleshooting.

Indications for MV

- Inadequate alveolar ventilation to maintain arterial pH
- Inadequate oxygenation
- Excessive work of breathing
- Circulatory failure/shock
- Inability to protect one’s airway (GCS < 8)

Types of Ventilation

- Negative pressure ventilation
  - Generation of negative pressure outside the thorax translates to negative pressure within the thorax facilitating movement of gas from high to low pressure.
  - Classically known as the “Iron Lung”
    - 1927: Philip Drinker & Louis Agassiz Shaw
      - iron box plus a bed and two vacuum cleaners
    - 1928: Modified by Warren Collins and inaugurated at the Children’s Hospital in Boston for childhood polio

- Positive Pressure Ventilation
  - Tidal breaths generated by gas flow controlled entirely by the ventilator and/or interactive with patient efforts
  - Non-invasive or invasive
Ventilator Induced Lung Injury and ARDS
Sherstin T. Lommatzsch, MD

Invasive Mechanical Ventilation
- Basic Components of the Ventilator

Breath Characteristics: Vocabulary
- Mode
  - Target of gas movement (volume or pressure)
- Trigger
  - Why does the ventilator fire
- Cycle
  - What ends the breath
  - (transition or cycle from expiration to inspiration)
- PEEP (Positive-End Expiratory Pressure)
- Auto PEEP

Breath Characteristics: Mode
- Mode (Why does the gas flow)
  - Volume
    - Practitioner selects how much air the patient’s lungs receive
    - Maximal pulmonary pressure varies based on lung compliance
  - Pressure
    - Practitioner determines the maximal pulmonary pressure
    - Volume varies based on lung compliance

Breath Characteristics: Trigger
- Why does the ventilator give a breath (fire)
  - Time (Controlled Breath)
    - Practitioner selects the Respiratory Rate
  - Flow (L/min) -> Patient Effort (Assisted Breath)
    - Flow sensor "senses" negative pressure (air movement)
    - Different from Flow Rate set in Assist Control
      - Pressure (cmH2O)
        - Ventilator senses a decrease in baseline pressure

Invasive Positive Pressure MV

Breath Characteristics: Vocabulary
- Peak Inspiratory Pressure (PIP)
- Plateau Pressure (Pplat)
- FiO2 (Fraction of Inspired Oxygen)
- Flow Rate (L/min)/Inspiratory Time (s)
  - How quickly the breath is placed into the lungs
- Respiratory Rate (RR)
  - Set in breaths per minute
- Tidal Volume (TV)
  - Volume of air delivered with each breath
Breath Characteristics: Cycle

- What ends the breath?
  - Volume
    - Ventilator completes delivery of a predetermined volume
  - Pressure
    - Ventilator senses the predetermined pulmonary pressure (cm H2O) is reached
  - Flow
    - Speed passing flow sensor slows
  - Time
    - RR = number of breaths per minute

Breath Characteristics: PEEP

- Prevents end-expiratory alveolar collapse.
- Initial applied PEEP is 5 cmH2O.
- Much higher values are often needed for patients undergoing low tidal volume ventilation for Acute Respiratory Distress Syndrome (ARDS)

Breath Characteristics: auto-PEEP

- Etiology
  - Inadequate expiration
  - Ventilator dyssynchrony
  - Breath Stacking:
    - Exhalation time is too short and pt initiations another breath prior to termination of preceding cycle -> results in an increase in end-expiratory pressure, also called auto-PEEP
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**Breath Characteristics: PIP & Pplat**
- Inspiratory Hold
  - Peak Inspiratory Pressure
  - Pulmonary Compliance

**Breath Characteristics: FIO\textsubscript{2}**
- Goal: lowest FIO\textsubscript{2} to meet oxygenation needs
  - Decrease adverse consequences of supplemental oxygen
    - absorption atelectasis
    - Tissue injury (free radicals)

**Flow Rate/Inspiratory Time**
- Maximum flow (L/min) delivered during inspiration (ACVC)
  - Begin with rate of 60 L/minute
    - higher rates are frequently necessary
  - Ratio of inspiratory time to expiratory time (ACPC)
    - I to E ratio
    - Insufficient peak flow rate:
      - Dyspnea

**Inspiratory Time: Expiratory Time Relationship (I:E Ratio)**
- Spontaneous Breathing: I:E ratio is 1:2 (-3)
  - Exhalation is twice as long as inhalation
- Patient pathology guides changes to I:E ratio
  - ARDS → lengthen inspiratory time → improves oxygenation (theoretically)
  - Inverse Ratio
  - COPD/Asthma → lengthening exhalation time → improves ventilation

**Breath Characteristics: RR**
- No optimal method for setting RR has been established
- Begin an initial rate of 12 - 20 breaths per minute
**Breath Characteristics: TV**

- Volume of air delivered with each breath
  - Initial TV is dependent upon
    1. Ideal body weight (predicted body weight)
      - Male: IBW = 50 kg + [2.3 kg * (Height (in) - 60)]
      - Female: IBW = 45.5 kg + [2.3 kg * (Height (in) - 60)]
    2. Disease for which the patient requires MV
      - The same in volume assist control
      - Varies in pressure assist control

**Breath Characteristics: Summary**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Volume</th>
<th>Target</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>Time &gt; RR (control)</td>
<td>flow</td>
<td>Volume</td>
</tr>
<tr>
<td>Effort (assist)</td>
<td>Time &gt; RR (control)</td>
<td>flow</td>
<td>Volume</td>
</tr>
<tr>
<td>Pressure</td>
<td>Time &gt; RR (control)</td>
<td>Pi</td>
<td>Time</td>
</tr>
<tr>
<td>Effort (assist)</td>
<td>Pressure (control)</td>
<td>Pi</td>
<td>Time</td>
</tr>
<tr>
<td>Effort (support)</td>
<td>Pressure (control)</td>
<td>Pi</td>
<td>Flow</td>
</tr>
</tbody>
</table>

**Pressure Support Ventilation**

- The patient controls the RR and exerts a major influence on the duration of inspiration, inspiratory flow rate and tidal volume
- Provides pressure support to overcome the increased work of breathing imposed by the disease process, endotracheal tube, inspiratory valves and other mechanical aspects of ventilatory support.

**Other Modes of Ventilation**

- **Synchronized Intermittent Mandatory Ventilation (SIMV)**
  - Hybrid mode combining ventilator delivered breaths with spontaneous unsupported breaths
  - May be volume controlled or pressure controlled
  - Non-mechanical cycled breaths pressure-supported
  - Associated with greater work of breathing than AC ventilation and therefore is less frequently used (especially as the initial ventilator mode)
  - If strong enough, patient negative inspiratory pressure generated by spontaneous breathing leads to increased venous return, which theoretically may help cardiac output and function.
Other Modes of Ventilation

- **Airway pressure release ventilation (APRV, Bi-Level)**
  - Used in spontaneously breathing patients with acute respiratory failure
  - CPAP is applied over a set time followed by a brief depressurization cycle
  - Alveoli are maintained in an inflated state throughout the respiratory cycle
  - Not prospectively studied or validated

- **High Frequency Oscillation and Volume Diffusive Ventilation**
  - Application of very small tidal volume breaths at frequencies of 500-3000 cycles per minute
  - Able to maintain low peak pressures and relative high end expiratory pressures
  - Has unclear role in adults as a lung protective ventilator strategy to date

Advantages of Each Mode

<table>
<thead>
<tr>
<th>Mode</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assist Control Ventilation (AC)</td>
<td>Reduced work of breathing compared to spontaneous breathing</td>
</tr>
<tr>
<td>AC Volume Ventilation</td>
<td>Guarantees delivery of set tidal volume</td>
</tr>
<tr>
<td>AC Pressure Control Ventilation</td>
<td>Allows limitation of peak inspiratory pressures</td>
</tr>
<tr>
<td>Pressure Support Ventilation (PSV)</td>
<td>Patient comfort, improved patient-ventilator interaction</td>
</tr>
<tr>
<td>Synchronized Intermittent Mandatory Ventilation (SIMV)</td>
<td>Less interference with normal cardiovascular function</td>
</tr>
</tbody>
</table>

Disadvantages of Each Mode

<table>
<thead>
<tr>
<th>Mode</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assist Control Ventilation (AC)</td>
<td>Potential adverse hemodynamic effects, may lead to inappropriate hyperventilation</td>
</tr>
<tr>
<td>AC Volume Ventilation</td>
<td>May lead to excessive inspiratory pressures</td>
</tr>
<tr>
<td>AC Pressure Control Ventilation</td>
<td>Potential hyper- or hypoventilation with lung resistance/compliance changes</td>
</tr>
<tr>
<td>Pressure Support Ventilation (PSV)</td>
<td>Apnea alarm is only back-up, variable patient tolerance</td>
</tr>
<tr>
<td>Synchronized Intermittent Mandatory Ventilation (SIMV)</td>
<td>Increased work of breathing compared to AC</td>
</tr>
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Breath: Waveforms (Who Am I?)

![Breath Waveforms Image](image-url)

Modes of Ventilation: Who Am I?

![Modes of Ventilation Image](image-url)
Modes of Ventilation: Who Am I?

Extubation Criteria

1. Reason for intubation is significantly improved or reversed
2. Awake and Alert (GCS > 8)
3. + Cough and Gag
4. Minimal Secretions
5. PaO2/FiO2 > 200
6. ETT cuff leak present
7. Rapid Shallow Breathing Index (RSBI) ≤ 105

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6. Cuff-Leak Present
7. Rapid Shallow Breathing Index (RSBI) ≤ 105
   \[ \text{RSBI} = \frac{\text{RR}}{TV} \]  

**Spontaneous Breathing Trial**

- T-Piece (or PSV 5cmH2O)
- RR > 35 / min for 5 minutes or longer
- SaO2 < 90 %
- HR > 140 / min sustained changes in HR > 20% of baseline
- sys BP > 180 or >20% increase from baseline

**Spontaneous Breathing Trial**

- T-Piece (or PSV 5cmH2O)
- RR > 35 / min for 5 minutes or longer
- SaO2 < 90 %
- HR > 140 / min sustained changes in HR > 20% of baseline
- sys BP > 180 or >20% increase from baseline

**Objectives: ARDS**

- Definition
- Identification
- Etiology (and mimics)
- Management

**ARDS: Definition**

- Berlin Criteria
  - Begins within 7 days of known cause
  - Bilateral opacities on CXR or CT chest
  - Severity Scale
    - Mild: PaO2/FiO2, 201 to 300 mm Hg; mortality, 27% (95% CI, 24–30)
    - Moderate: PaO2/FiO2, 101 to 200 mm Hg; mortality, 32% (95% CI, 29–34)
    - Severe: PaO2/FiO2, ≤ 100 mm Hg; mortality, 45% (95% CI, 42–48)
  - The above observed at a minimum PEEP (CPAP) = 5cm H2O

**ARDS: Definition**

- Differences from prior definitions:
  - “Acute Lung Injury” (ALI) is replaced by Mild ARDS (PF ratio = 200–300)
  - Removed pulmonary capillary wedge pressure (PCWP) < 18 cm H2O from definition
  - Broadened definition of bilateral opacities

Ferguson ND, et al J Intens Care Med 2012
ARDS: Identification
- High level of suspicion
- ABG
- CXR or CT chest

ARDS: Etiology
- Direct Pulmonary Parenchymal Insult
  - Pneumonia (bacterial, viral, or fungal)
  - Aspiration of gastric contents
  - Pulmonary contusion
  - Inhalation injury
  - Near drowning
- Indirect Pulmonary Parenchymal Insult
  - Sepsis (non-pulmonary source)
  - Nonthoracic trauma
  - Pancreatitis
  - Major burn injury
  - Drug overdose
  - Transfusion of blood products
  - Cardiopulmonary bypass
  - Repersusion edema after lung transplantation
  - Embolectomy

ARDS: Mimics
- Congestive heart failure
- Interstitial lung disease
- Connective-tissue diseases
- Diffuse alveolar hemorrhage
- Drug-induced lung diseases
  - (bleomycin or amiodarone), vascular leak syndrome from immunotherapy
- Cancer (T-cell or B-cell lymphomas or metastatic carcinoma)
- Endobronchial tuberculosis

ARDS: Management
- Lung Protective Mechanical Ventilation
- Sedation
- Paralysis
- Prone Positioning
- Conservative Fluid Management
- TV 6cc/Kg/IBW
- May be achieved with EITHER Volume or Pressure
- Plateau Pressure ≤ 30 cmH₂O
- Use ARDSnet high or low PEEP protocol to reduce FIO₂
ARDS: Management

Which measurements are required to calculate a person’s ideal body weight

a. Weight
b. Height
c. Both

d. None of the above

d. a, b or c

ARDS: Management

Which formula for ideal body weight was used in the ARDSnet trials?

a. Lorentz
b. Robinson
c. Devine
d. a, b or c
e. None of the above

ARDS/ALI: Management

Lung Protective Mechanical Ventilation

- TV, 6cc/Kg/IBW
  - May be achieved with EITHER Volume or Pressure
  - Reduce to 4cc/Kg/IBW (if possible)
  - Permissive Hypercapnia
    - Respiratory Acidosis (pH < 7.2)
    - The lower the RR the better (gatonini)
    - Plateau Pressure ≤ 30 cmH₂O
    - Use ARDSnet high or low PEEP protocol to reduce FIO₂

ARDS: Management

Which formula for ideal body weight was used in the ARDSnet trials?

a. Lorentz
b. Robinson
c. Devine
d. a, b or c
e. None of the above
**ARDS: Management**

- **Lung Protective Mechanical Ventilation**
  - Overdistention
    - Volutrauma
    - Atelectrauma
    - Biotrauma

- **Atelectrauma**
  - Repetitive opening & closing of alveoli
  - Not related to RR

- **Biotrauma**
  - Due to epithelial injury
  - Release of cytokines leading to systemic inflammation

**ARDS: Management**

- What are some complications when elevating PEEP?
  - a. Lowering Blood Pressure
  - b. Decreased Venous Return
ARDS: Management

- Lung Protective Mechanical Ventilation
- Sedation
- Paralysis
  - Add to sedation in moderate to severe ARDS (P/F < 150 mm Hg)
- Prone Positioning
- Conservative Fluid Management
- Nutrition

Papazian L et al. NEJM 2010

ARDS: Management

- Lung Protective Mechanical Ventilation
- Sedation
- Paralysis
- Prone Positioning
- Conservative Fluid Management
- Nutrition

ARDS: Management

- Prone Positioning
  - Used in moderate to severe ARDS (P/F < 120)

ARDS: Management

- Conservative Fluid Management
  - FACT Trial

  - shortened the duration of mechanical ventilation
  - avoidance of fluid administration after correction of shock,49
  - diuretics and albumin improve oxygenation and may shorten mechanical ventilation, but may not reduce mortality,50,51,52
  - NOTE: Albumin may be harmful in patients with traumatic brain injury,53

ARDS: Management

- Conservative Fluid Management
  - FACT Trial
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ARDS: Management
- Lung Protective Mechanical Ventilation
- Sedation
- Paralysis
- Prone Positioning
- Conservative Fluid Management
- Nutrition

ARDS: Management
- Nutrition
  - trophic and early full-calorie enteral nutrition are equivalent with regard to mortality,54
  - aggressive early parenteral nutrition may be harmful.55

Case #1
A 32 female is admitted sepsis due to UTI. A critical care consult is requested for hypotension management. She receives 30cc/kg of NS in addition to appropriate antibiotics. Hypotension persists and she is transferred to the ICU for vasopressor therapy.
- She develops mild to moderate respiratory distress and remains hypotensive. ABG shows a pH 7.4, pCO2 40, HCO3 24 and SaO2 of 95% on room air. CXR is unremarkable. The next appropriate step is to:
  a. Place her on 100% NRB
  b. Monitor the patient and consider another ABG and CXR in 30-60 minutes to decide further course of action
  c. Intubate and initiate mechanical ventilation immediately

Case #1
- She develops worsening respiratory distress with progressive hypoxemia thus a decision is made to intubate and provide mechanical ventilation.
- Which of the following modes of mechanical ventilation will not be appropriate for her?
  a. ACVC
  b. SIMV
  c. PSV/CPAP
  d. ACPC

Case #1
- She weighs 100 kg and is 5'6" tall. The recommended tidal volume for her is:
  a. 1000 cc
  b. 750 cc
  c. 600 cc
  d. 360 cc
  e. None of the above.

Case #1
- She is placed on AC with a Vt of 360 cc, RR = 20, PEEP of 12 and FiO2 of 1. CXR shows ETT 3 cm above carina and no pneumothorax. Her SaO2 is 72%
- What is the next step?
Case #1
- She is placed on AC with a VT of 360 cc, RR = 20, PEEP of 12 and FiO2 of 100%. CXR shows ETT 3 cm above carina and no pneumothorax. Her SaO2 is 72%
- What is the next step?
  - Adjust PEEP


Case #1
- Appropriate changes in PEEP are made. SaO2 has now come up to 78% and the patient appears uncomfortable
- What next?

Case #1
- Patient sedation is increased. SaO2 has gone up to 82%
- What do you do next?

Case #1
- Two hours later, her BP is 110/75, HR 98, RR 30/minute, her plateau pressure is 29, her peak airway pressure is 35, SaO2 is 94% but the ABGs show a pH of 7.25 with a pure respiratory acidosis. The next step is to:
  a. Increase tidal volume
  b. Decrease tidal volume
  c. Decrease rate
  d. Start an IV bicarbonate infusion to maintain a pH 7.35-7.45
  e. Do nothing at this point

Case #1
- Now her SaO2 is 94% but the plateau pressure is 45. CXR shows bilateral diffuse infiltrates. The next step is to:
  a. Increase PEEP
  b. Increase tidal volume
  c. Decrease tidal volume
  d. Increase respiratory rate
  e. Make no changes

Case #1
- Later you are called regarding high ventilator pressure alarms and decreased SaO2. You notice an obviously awake patient in distress. The immediate next steps will include all except:
  a. Order a stat CXR and wait for results before taking the next step
  b. Remove patient from the ventilator and “manually bag the patient”
  c. Sedate the patient to prevent asynchronous breathing and straining
  d. Auscultate and percuss for symmetry
  e. Check plateau pressure
  f. Note position of ET tube to look for migration
Case #1

Later you are called regarding high ventilator pressure alarms and decreased SaO2. You notice an obviously awake patient in distress. The immediate next steps will include all except:

a. Order a stat CXR and wait for the CXR before taking the next step
b. Remove patient from the ventilator and “manually bag the patient”
   - Note the ease or difficulty when bagging the patient

Case #1

Later in the day the nurse calls you because of high pressure alarms on the ventilator and decreased SaO2. You notice an obviously awake patient in distress. The immediate next steps will include all except:

a. Order a stat CXR and wait for the CXR before taking the next step
b. Remove patient from the ventilator and “manually bag the patient”

Ventilator pressure alarms and decreased SaO2 are concerning signs. It is important to act quickly to identify and address the underlying cause to prevent further deterioration of the patient's condition.

Possible causes for high ventilator pressure and decreased SaO2 include:

- ETT migration/blockage
- Acute bronchospasm
- Abdominal compartment syndrome
- Pneumothorax
- Worsening ARDS

Case #1

Two hours later the nurse notifies you that the peak pressure is 55 and the plateau pressure is 27. Possible causes for this change include (more than one can be correct):

- ETT migration/blockage
- Acute bronchospasm
- Abdominal compartment syndrome
- Pneumothorax
- Worsening ARDS

Increased ventilator pressure may indicate issues with the tubing, filters or the patient's respiratory status. It is essential to promptly investigate and address these factors to prevent further complications.

Case #1

Appropriate measures are taken and the pressures return to a peak of 35 and plateau of 27. Next AM the peak pressure is 45 and plateau pressure is 39. Possible causes for this change include (more than one can be corrected):

- ETT migration/blockage
- Acute bronchospasm
- Smaller difference between PIP and Plateau thus cause is more likely to be 2/2 to decrease in pulmonary compliance
- Abdominal compartment syndrome
- Pneumothorax
- Worsening ARDS

Monitoring and managing ventilator pressures are crucial in maintaining patient stability. Identifying and managing potential etiologies ensures the best possible outcome for the patient.
Trouble Shooting the Vent

- High PIP differential:

<table>
<thead>
<tr>
<th>Mucus Plug</th>
<th>ARDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bronchospasm</td>
<td>Pulmonary Edema</td>
</tr>
<tr>
<td>ET tube blockage</td>
<td>Pneumothorax</td>
</tr>
<tr>
<td>Patient Biting the ETT</td>
<td>ET tube migration to a single bronchus</td>
</tr>
<tr>
<td>Effusion</td>
<td></td>
</tr>
</tbody>
</table>

Modified from "Basics of Mechanical Ventilation": University of CA, Irvine

Case #1

- On the fifth ICU day she is afebrile, awake and appears comfortable. She is on ceftriaxone, low-molecular weight heparin, famotidine, norepinephrine (10mcg/min), and fentanyl. Ventilator settings include: AC/VC, Vt 360cc, PEEP 5, FiO2 .35, RR 16/min. Weaning parameters show a NIF of -65 and RSBi of 45.

- Should this patient be extubated?
  - a. Yes
  - b. No

Questions?

Citations