Mechanical Ventilation

University of Florida
Department of Anesthesiology
Anesthesiology / Critical Care Clerkship
Basic Physiology—Part 1

- Respiratory Cycle
- Oxygenation
- Ventilation
- Static lung volumes
Respiratory Cycle

- Inhalation & Exhalation
- Ingress & Egress
- But...
- Oxygenation & Ventilation
  - This Division has the Greatest utility
    - Breaking down problems
    - Implementing interventions
  - Any time there is uncertainty start here
Oxygenation

• How can we ascertain success?
  – Arterial Blood Gas (Abg)
    • PaO2
    • Reveals blood that enters trachea and diffuses into blood
  • Alveolar Gas Equation
    – P(A)O2 = FiO2 (Patm – Ph2o) – PCO2/RQ
      » Alveolar gas = Ingress (O2) – Egress (CO2)
      » Respiratory Quotient (RQ)
        • CO2 produced per O2 metabolized = 0.8
        • Depends on diet and metabolism
    – (A-a)gradient tells you oxygenating capability
Alveolar Gas Equation

\[ P_{AO_2} = P_{I_02} - \frac{P_{aCO_2}}{R} \]

\[ P_{AO_2} = F_iO_2(P_{atm} - P_{H_2O}) - \frac{P_{aCO_2}}{0.8} \]
Oxygenation

• Can we tell success with SpO2?
  – Only if patient is on Room Air
  – For example
    • 100% FiO2 could give you an PAO2 of 760mmHg if perfect
    • SpO2 is 100% so all looks good
      – Actual ABG PaO2 reveals 95-100mmHg
      – Thus (A-a) Gradient = 660mmHg
    • This is a limitation of pulse oximetry assessing oxygenation
Ventilation

- Minute Ventilation = Tidal Volume x Respiratory Rate
  - Ve = Vt x RR
- Success is revealed by CO2
  - High CO2 = Hypoventilation
  - Low CO2 = Hyperventilation
  - Respiratory rate?
  - NO...can be tachypnic and hypoventilating
  - Only moving dead space gas
  - Consider breathing through a long snorkel:
    - Only small amount of each breath reaching gas exchange
Static Lung Volumes
Functional Residual Capacity

- Residual Volume + Expiratory Reserve Volume
- Equilibrium of opposing forces
  - Chest Wall (expanding) + Lung Parenchyma (collapsing)
  - Forces are idiosyncratic
    - Chest wall: Obesity, pregnancy, paralysis, body position
    - Lung parenchyma: emphysema, ARDS,
Functional Residual Capacity

Resting lung volumes (FRC) in nonobese lungs with good lung compliance

Reduced resting lung volumes (FRC) in obese lungs due to restriction from surrounding adipose tissue and reduction in lung compliance
Functional Residual Capacity

• Significance...
  – Consider FRC as a Reservoir
  – Normally filled with 21% oxygen and 78% nitrogen
  – Can De-Nitrogenate (i.e. Pre-oxygenate)
    • Now filled with 100% oxygen
    • Creates time for airway instrumentation
    • May manipulate FRC to improve safety profile
Closing Capacity
Closing Capacity (CC)

• CC
  = Residual Volume + Closing Volume

• Alveoli Collapse at the CC
  – Law of Laplace
  – Pressure = 2 x t /r
    • Surface tension (t) reduced by surfactant
    • Radius inversely impacts airway closure
Laplace’s Law

Two bubbles with same surface tension, $T$, but different radii

$$P = \frac{2T}{r}$$

What happens if these two are interconnected?

Pressure Gradient exists between the two---- Flow would occur from small bubble to the larger one
Closing Capacity (CC)

- CC normally less then FRC so alveoli remain open
- Dependent of:
  - Age
  - Body position
  - pathology
Closing Capacity (CC)
# Lung Volumes and Capacities

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Definition</th>
<th>Average Adult Values (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal volume (VT)</td>
<td>Each normal breath</td>
<td>500</td>
</tr>
<tr>
<td>Inspiratory reserve volume (IRV)</td>
<td>Maximal additional volume that can be inspired above VT</td>
<td>3000</td>
</tr>
<tr>
<td>Expiratory reserve volume (ERV)</td>
<td>Maximal volume that can be expired below VT</td>
<td>1100</td>
</tr>
<tr>
<td>Residual volume (RV)</td>
<td>Volume remaining after maximal exhalation</td>
<td>1200</td>
</tr>
<tr>
<td>Total lung capacity (TLC)</td>
<td>RV + ERV + VT + IRV</td>
<td>5800</td>
</tr>
<tr>
<td>Functional residual capacity (FRC)</td>
<td>RV + ERV</td>
<td>2300</td>
</tr>
</tbody>
</table>
Basic Physiology—Part 2

• Indications for Mechanical Ventilation
  – Ventilation Failure
  – Oxygenation Failure

  – A somewhat artificial division
    • One type of failure may involving both
    • But helps to compartmentalize and remember
Ventilation Failure

- Neurologic Disease
- Muscular Disease
- Anatomic Disease
Neurologic pathology

• Central Pathology
  – Sedation
    • Benzodiazepines
    • Opiates
  – Stroke
  – Trauma
    • Traumatic Brain Injury
Neurologic Pathology

- Spinal cord pathology
  - Trauma
  - Virus
  - Stroke
Neurologic Pathology

• Peripheral Nerve pathology
  • Neuromuscular relaxants
  • Guillain-Barre syndrome
Anatomic Pathology

• Chest Wall pathology
  – Flail chest
  – Congenital Diaphragmatic hernia
  – Kyphoscoliosis

• Pleural injury
  – Pneumothorax
  – Hemothorax
  – Pleural effusions
Anatomic Pathology

- Airway Pathology
  - Burn
  - Epiglottis
  - Bronchospasm
  - Foreign body
Oxygenation Failure

- Gas Exchange Problem
  - $V/Q$ Mismatch
  - Diffusion abnormality
  - $VO_2/D_02$ imbalance
  - $FiO2$
Ventilation / Perfusion Mismatch

- Matching is a spectrum
  - Dead space
  - $V / Q = 1:1$
  - Shunt
Dead Space

- Ventilated areas which do not participate in gas exchange

**Total Deadspace = Anatomic + Alveolar + Mechanical**

- **Anatomic Deadspace:** airways leading to the alveoli
- **Alveolar Deadspace:** ventilated areas in the lungs without blood flow
- **Mechanical Deadspace:** artificial airways including ventilator circuits
Dead space equation

\[ \frac{V_d}{V_T} = \frac{P_{ACO_2} - P_{E_{CO_2}}}{P_{ACO_2}} \]

\[ V_d = \frac{P_{a_{CO_2}} - P_{E_{CO_2}}}{P_{a_{CO_2}}} \cdot V_T \]
Shunt

Veno - Arterial Shunt
Classical Principle

Alveoli

Lung vessels

Shunt

\[ Q_{\text{total}} = Q_{\text{v,ve}} + Q_{\text{capillary}} \]

\[ Q_{\text{v,ve}} = (Q_{\text{v,ve}} - C_{aO_2}) + (Q_{\text{capillary}} - C_{cO_2}) \]

\[ Q_{\text{shunt}} / Q_{\text{total}} = (C_{aO_2} - C_{v,ve})/(C_{cO_2} - C_{v,ve}) \]
Shunt

Magnitude of pulmonary shunts

1. Normal shunt = 2-5%
2. Shunt over 5% could indicate problem
3. Shunt over 15% indicates pathological problem
4. Shunt increases with age
V/ Q Matching Spectrum
V / Q Matching : West Zones
Oxygenation Failure

• Gas Exchange Problem
  – V / Q Mismatch
  – Diffusion abnormality
  – VO2/ DO2 imbalance
  – FiO2
Diffusion Abnormality

- Gas Exchange Problem
- Evaluated with DLCO
- Pathology:
  - Emphysema
  - Idiopathic Pulmonary fibrosis
  - Sarcoidosis
  - Pulmonary Hypertension
  - Interstitial Pneumonitis
  - Pulmonary Vasculitis
Oxygenation Failure

• Gas Exchange Problem
  – V / Q Mismatch
  – Diffusion abnormality
  – VO2/ DO2 imbalance
  – FiO2
VO2 / DO2 Imbalance

• Oxygen consumption exceeds Oxygen Delivery

• Causes:
  – Decreases in Cardiac Output
    • Preload
    • Heart rate
    • Contractility
  – Increases in Oxygen Extraction
    • Hypermetabolic states
    • Sepsis
Oxygenation Failure

• Gas Exchange Problem
  – V / Q Mismatch
  – Diffusion abnormality
  – VO2/ DO2 imbalance
  – FiO2
FiO2

- Inadequate oxygen concentration
  - Requires elevated concentration
  - Change Barometric pressure
  - Oxygen displaced by other gases
Mechanical Ventilation

• Volume Controlled (ACV)

• Pressure Controlled (PCV)

• SIMV

• Pressure Support (PS)
Volume Controlled Ventilation

• 2 forms:
  1. Assist-Control Ventilation
  2. Controlled Ventilation

• **Controlled Ventilation**
  – Provider dials in desired tidal volume & respiratory rate
  – Settings delivered regardless of effort (no additional breaths permitted)
  – Gas flows to patient to deliver preset tidal volume
    • May occur despite Peak Airway Pressures
Volume Controlled Ventilation

- **Assist-Controlled Ventilation**
- Vt and RR determined by provider
- Any patient respiratory effort
  - triggers preset tidal volume
  - Defaults to initial settings if no effort attempted
  - Provider selects trigger threshold sensitivity
Controlled Ventilation
Controlled Ventilation

• Previous cartoon (to be reviewed on next slide)
  – Circles represent areas of initiated breaths (assisted)
  – No Effort follows 2 assisted breaths
  – Each Breath exactly same volume delivered
Controlled Ventilation

Diagram showing controlled ventilation with preset flow, preset backup time, patient-triggered breath, time-triggered breath, preset \( V_T \), and PEEP.
Volume Controlled

• Excessive Breaths can lead to “breath-stacking”
  – Also called Auto-PEEP
  – Can obstruct preload or cause pneumothorax
  – Causes increase Work of Breathing
  – Risk of significant Patient-ventilator Dysynchrony
Breath-Stacking

Not Enough time allowed for complete exhalation. Each inspired breath “Stack” on top of the previous breath. Significant risk of hemodynamic changes and barotrauma (Ptx).
Pressure-Controlled Ventilation

• Provider dials in RR and fixed Pressure to deliver breath

• Volume of each Breath varies due to different pulmonary mechanics:
  – Different from person to person
  – Different in same person but different scenarios
    • Patient position, muscle relaxation, abdominal pressures,…
  – Breath delivery
    • Breath filling pressure maintained at same level
    • Decelerating flow wave allows for large tidal volumes
Pressure-Control

• Compare to Volume-Controlled:
  1. Constant pressure level delivered
  2. Volume augmentation
  3. Decelerating gas flow
Pressure-Controlled Ventilation

• Advantages

  – Less likelihood of barotrauma

  – Greater Patient-Ventilator synchrony

  – Larger tidal volumes with smaller Driving pressure
SIMV

• Synchronized-Intermittent Mandatory Ventilation
• Breaths are delivered in a preset RR and volume
• Patient can breath independently between breaths
  – No additional effort is provided for extra breaths
  – Patient maintains some independence in ventilation
  – Used to wean patient from ventilator
    • Progressively dial back mandatory breaths
    • Allow progressively more spontaneous ventilation
**SIMV**

Ovals reveal unsupported additional breaths.  
Squares show preset respiratory rate and tidal volumes.  
Top reveals Controlled ventilation without additional triggering.  
Middle shows additional triggering leading to rapid RR.
SIMV
Can augment spontaneous breaths with pressure support.
Can add PEEP to the system as well to assist oxygenation.
Pressure Support Ventilation

• Patient initiates Every breath
• Ventilator delivers support with preset pressure value
• Patient regulates
  – Own respiratory rate
  – Own tidal volume
• Changes in Pulmonary Mechanics or patient effort
  – Affects tidal volume and RR
Pressure Support Ventilation

Increasing effort or Pressure support will increase delivered volume.
Decreasing effort or Pressure support will decrease delivered volume.
PEEP—Oxygenation Tool

- Positive End-Expiratory Pressure
- Pressure in the lungs (above Atm) that exists in the lungs after expiration
- Coupled with FiO2 for tools to improve oxygenation
- Amount is dialed in by provider to mitigate atelectasis
  - Improves V / Q matching
  - Can reduce the rapid opening and closing of alveoli
  - ARDS net protocol to help oxygenation in next slide
FiO2 & PEEP to treat ARDS

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<thead>
<tr>
<th>Conservative approach:</th>
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<tbody>
<tr>
<td><strong>FiO2</strong></td>
<td>0.30</td>
</tr>
<tr>
<td><strong>PEEP</strong></td>
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<table>
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<th>Aggressive approach:</th>
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<tr>
<td><strong>FiO2</strong></td>
<td>0.30</td>
</tr>
<tr>
<td><strong>PEEP</strong></td>
<td>12</td>
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</table>
Monitoring Lung Mechanics

• Proximal Airway Pressures
  – Peak Inspiratory Pressure
  – Plateau Pressure

• Thoracic Compliance
  – Chest Wall compliance
  – Lung compliance
Proximal Airway Pressures (peak)

- Peak pressure
  - Pressure in lungs generated during inspiration
  - Combination of
    - Resistance in airway
    - Elastance of lungs
  - Ends with End-inspiration
Peak Airway Pressure

- Increased airway resistance
  - Airway obstruction
  - Bronchospasm
  - Circuit kinking
  - Endotracheal tube obstruction
  - Anaphylaxis
Proximal Airway Pressures (plateau)

- Plateau pressure
- Pressure in the airway without any air movement
  - During inspiratory pause
- Determined by Compliance of lung
  - Inversely proportional to elastance
Plateau Pressure

- Increased Plateau pressure
  - Pneumothorax
  - Pneumonia
  - ARDS
  - Auto-PEEP
  - Obesity
  - Pulmonary fibrosis
Thoracic Compliance

- = Change in Volume/ change in Pressure (V/P)
- Inversely proportional to elastance
- Compliance can involve static or dynamic measurement
  - \( C_{\text{dyn}} = \frac{V_t}{\text{PIP} - \text{PEEP}} \)
    - Compliance measured during gas flow
    - PIP = peak inspiratory pressure
  - \( C_{\text{stat}} = \frac{V_t}{\text{Pplt} - \text{PEEP}} \)
    - Compliance measured without gas flow
    - Pplt = Plateau pressure
Thoracic Compliance

Lung compliance
- Involves lung parenchyma
- Fibrosis vs. Emphysema
- Blood and fluid volumes
- Surfactant deficiency
- Pneumothorax

Chest Wall Compliance
- Involves muscles and fat
- Morbidly obese
- Large breast
- Muscle relaxation
- Positioning
THE END

Coo, man...
Coo.