Ventilation, Perfusion, Diffusion, and More:

Making Complex Concepts Clear and Clinically Applicable

NTI 2009
Class Code 262
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Silence
Cell
Phones
Please!

Swimmers never take a breath for granted!

Nurses never take a life for granted!
Opening Questions

- Your patient’s O₂ saturation is 82%. He does not improve with 100% non rebreather mask. Why not?
- Your patient’s O₂ saturation is 95%. Does this assure his tissues are receiving adequate oxygen? Why or why not?
- Your patient’s peak inspiratory pressure is high but his plateau pressure is normal. What are some possible causes?

Opening Questions

- Your patient is on a 50% venti mask and his PaO₂ on blood gas is 90 mmHg. What do you conclude about his oxygenation status?
- Your patient’s PCO₂ on blood gas is 55 mmHg. His PaO₂ is 55 mmHg. His pH is 7.27. What treatment do you anticipate?
Pulmonary Physiology

Physiology of Pulmonary System

- Ventilation and Perfusion
- Diffusion
- Relationship of Oxygen to Hemoglobin
- Oxygen Delivery to the Tissues
- Cellular Respiration
Ventilation

- **Definition:** The movement of air between the atmosphere and alveoli and the distribution of air within the lungs to maintain appropriate concentrations of oxygen and carbon dioxide in the blood.

- Process of ventilation occurs through inspiration and expiration.
Ventilation

- Pressure difference between airway opening and alveoli
  - Contraction of inspiratory muscles
  - Lowers intrathoracic pressure
  - Creates a distending pressure
  - Alveoli expand
  - Alveolar pressure is lowered
  - Inspiration occurs
  - Result: Negative pressure breathing

Ventilation

- Minute ventilation ($V_e$) = Total volume of air expired in one minute
  - Respiratory rate x tidal volume
  - Normal minute ventilation = $12 \times 500\, \text{ml} = 6000\, \text{ml}$
  - Note: (hypoventilation can occur with normal or even high respiratory rate)
Alveolar Ventilation ($V_A$)

- $V_A = V_T -$ anatomical dead space
- Approximately 350 ml per breath

**Anatomical dead space:**
Walls are too thick for diffusion
Mixed venous blood not present

*Approximately 1 cc per ideal pound of body weight*

Respiratory Anatomy

<table>
<thead>
<tr>
<th>Conducting Airways</th>
<th>Gas Exchange Airways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose</td>
<td>Respiratory Bronchioles (transitional zone)</td>
</tr>
<tr>
<td>Pharynx</td>
<td>Alveolar Ducts</td>
</tr>
<tr>
<td>Larynx</td>
<td>Alveoli</td>
</tr>
<tr>
<td>Trachea</td>
<td>$V_A$: Alveolar ventilation</td>
</tr>
<tr>
<td>Right and Left Bronchi</td>
<td></td>
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<tr>
<td>Non-Respiratory Bronchi</td>
<td></td>
</tr>
</tbody>
</table>
Alveolar Cells

- **Type I** *(make up 90% of alveolar surface area)*
  - Squamous epithelium
  - Adapted for gas exchange
  - Prevents fluid from entering alveoli
  - Easily injured

- **Type II**
  - Can generate into Type 1 cells
  - Produces surfactant *(allows alveoli to remain inflated at low distending pressures by decreasing surface tension, decreases work of breathing, detoxifies inhaled gases)*
    - Lipoprotein (phospholipid)
    - Hypoxemia / hypoxia may lead to decreased production or increased destruction
  - Metabolically active
  - Alveolar Macrophages
    - Phagocytosis

Hypoxemia / hypoxia may lead to decreased production or increased destruction.
Lung Volumes

- **INSPIRATORY CAPACITY (IC)**: 3.0 L
- **TOTAL LUNG CAPACITY (TLC)**: 6.0 L
- **FUNCTIONAL RESIDUAL CAPACITY (FRC)**: 3.0 L
- **INSPIRATORY RESERVE VOLUME (IRV)**: 2.5 L
- **TIDAL VOLUME (VT)**: 0.5 L
- **EXPIRATORY RESERVE VOLUME (ERV)**: 1.5 L
- **RESIDUAL VOLUME (RV)**: 1.5 L

- maximal inspiration
- resting volume
- maximal expiration
- no air in lungs
Ventilation

- **Work of Breathing**
  - Affected by:
    - **Compliance** (elastic work of breathing)
      - Lungs distend most easily at low volumes
      - Compliance is opposite of elastic recoil
    - **Airway Resistance** (flow resistance / resistive work of breathing)
      - Total resistance is comprised of tissue (20%) and airway resistance (80%)
      - Directly proportional to viscosity and length of tube / indirectly proportional to radius
      - Small airway resistance offset by numerous small airways (greatest resistance normally in medium bronchi)

Resistive work of breathing greatest during forced expiration.

Assessment of Ventilation

- **Efficiency and effectiveness of ventilation** is measured by PaCO$_2$ (inversely related to V$_A$)
  - PCO2 > 45 mm Hg indicates alveolar hypoventilation *
  - PCO2 < 35 mm Hg indicates alveolar hyperventilation

Note: Only one physiologic reason for increased PaCO$_2$. 
More on Ventilation

- Normal ventilation on room air results in an alveoli with a partial pressure of oxygen of approximately 100 mmHg.

  ![Partial pressure of O2]

  Inspired gas $P_{O_2}$
  149 mm Hg.

Untreated Alveolar Hypoventilation

Untreated alveolar hypoventilation will lead to hypoxemia. The hypoxemia is secondary to uncorrected alveolar hypoventilation.

In acute respiratory failure a blood gas is necessary to assess the $PaCO_2$ to determine if inadequate ventilation contributed to the hypoxemia.
Conditions Altering Ventilation

- **Non Pulmonary Conditions**
- **Pulmonary Conditions**
  - Decreased Compliance
    - Decreased surfactant production
    - Atelectasis
    - Obesity / musculoskeletal disorders (*chest wall compliance*)
    - Restrictive disorders (fibrosis, interstitial lung disease)
    - Pulmonary vascular engorgement
    - Air, blood or excess fluid in pleural space
  - Increased Resistance
    - Narrowing of airways (secretions / bronchospasm)
    - Obstructive Disorders
      - Asthma
      - Emphysema
      - Bronchitis
      - Foreign body causes a fixed obstruction
      - Sleep apnea can be obstructive

Ventilation Review

- What physiological factors affect ventilation?
- What non pulmonary conditions can alter ventilation?
- What pulmonary conditions can impact ventilation?
- How is ventilation assessed? (with and without an ABG?)
- How are ventilatory problems corrected?
Perfusion

- Definition: The movement of blood through though the pulmonary capillaries
Perfusion

Blood supply to lung

- **Pulmonary blood flow**
  - Entire output of right ventricle
  - Mixed venous blood
  - Gas exchange with alveolar air into pulmonary capillaries
- Bronchial blood flow
  - Left ventricle
  - Part of tracheal bronchial tree
  - Systemic arterial blood

Perfusion Fun Facts

- Pulmonary capillaries are slightly smaller than average erythrocyte
- Gas exchange actually starts in smaller pulmonary arterial vessels that are not true capillaries (functional pulmonary capillaries)
- 280 billion capillaries supply 300 million alveoli
- Potential surface area for gas exchange is 50-100 m²
- Alveoli are completely enveloped in pulmonary capillaries
- At rest each red blood cell spends only about 0.75 seconds in the pulmonary capillary. Less time during exercise.
Zones of Perfusion

- Zone 1: May be no blood flow. (alveolar deadspace – no zone 1 in normal breathing)
- Zone 2: Flow during systole.
- Zone 3: Flow during entire cardiac cycle.

Note: Zones are not static.

Pulmonary Vascular Resistance

- Comparison with systemic vascular resistance
  - 1/10 of systemic vascular resistance
  - Pulmonary vascular resistance is evenly distributed between the pulmonary arteries, the pulmonary capillaries, and the pulmonary veins.

- Relationship to pulmonary artery pressures and cardiac output
  - Increase in cardiac output = Increase in PAP = Increased capillary recruitment = Decrease in PVR
  - Increased pulmonary artery pressure may lead to pulmonary edema

- Relationship to lung volumes
  - High lung volumes pull pulmonary vessels open. Results in a decrease PVR.
Pulmonary Vascular Resistance

- During positive pressure mechanical ventilation, both the alveolar and extra-alveolar vessels are compressed during lung inflation and PVR is increased.
- PEEP increases PVR further.

Hypoxic Pulmonary Vasoconstriction

- Diverts blood away from poorly ventilated alveoli
- Also occurs in response to more global hypoxia
  - Increases pulmonary artery pressure and recruits pulmonary capillaries to improve ventilation and perfusion matching
- Has limitations because of small amount of vascular smooth muscle in the pulmonary arteries
- Hypoxic vasoconstriction greatly increases the workload of the right ventricle
Perfusion Review

- Do we directly measure pulmonary perfusion?
- What would be a “pulmonary” disorder that results in decreased pulmonary perfusion?
- What would be a non-pulmonary reason for decrease in pulmonary perfusion?
- What is the impact of increased pulmonary vascular resistance or increased pulmonary pressures on the right heart?
- Does mechanical ventilation increase or decrease the work of the right heart?

Diffusion
Prior to Diffusion

- Ventilation and Perfusion Occur Simultaneously

**Alveolar oxygen**
100 mmHg

Diffusion

- Movement of gases between the alveoli, plasma, and red blood cells
- Net movement of molecules from an area where the particular gas exerts a high partial pressure to an area where it exerts a lower partial pressure
- Different gases each move according to their own partial pressure gradients
  
  *Diffusion of oxygen from alveoli to capillary determines the patient’s oxygenation status*
Determinants of Diffusion

- **Surface Area**: negatively affected by any type of pulmonary resection; tumor, emphysema, pneumothorax

- **Driving pressure**: negatively affected by low inspired fraction of O₂ (smoke inhalation) or by low barometric pressure (high altitudes)
  - Barometric pressure is the sum of the pressures of all the gases it contains

- **Thickness of alveolar capillary membrane (< 1 RBC)**: negatively affected by pulmonary edema, pneumonia, or fibrosis

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Increased FIO₂ and increased PEEP will increase driving pressure of oxygen.
Assessment of Diffusion

- **PaO₂ and oxygen saturation (SaO₂)**

- **Clinical Application:** CO₂ is 20 times more diffusible than O₂ - so a diffusion problem causing hypoxemia does not result in the same problem with CO₂ retention (hypercapnia)

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Diffusion Review

- What are the prerequisites for diffusion?
- Which gas is most adversely impacted by barriers to diffusion?
- How do assess if your patient is adequately diffusing?
- How do you correct a simple diffusion problem?
Ventilation and Perfusion Ratios

Alveoli in upper regions have greater volume and are less compliant. Alveoli in lower parts of lung have a greater change in volume during inspiration and are considered better ventilated.

Ventilation / Perfusion Ratio (V/Q)

- **Ventilation (V)**
  - Alveolar minute ventilation = 4 to 6 L

- **Perfusion (Q)**
  - Normal cardiac output = 5 L

Normal ventilation / perfusion ratio
(V/Q ratio) = 0.8 to 1.2

Ventilation and perfusion must be matched at the alveolar capillary level
Normal VQ Ratio

Decreased ventilation to perfusion ratio
V/Q = 0
(Intrapulmonary Shunting)

In decreased ventilation perfusion ratio

- Alveolar PaO$_2$ will fall
- Alveolar PCO$_2$ will rise
**Increased V/Q Ratio**

(Dead Space)

In increased ventilation perfusion ratio

- Alveolar PaO$_2$ will rise
- Alveolar PaCO$_2$ will fall

**Decreased V/Q Ratio:**

Intrapulmonary Shunting

- Intrapulmonary shunt occurs when there is significant alveolar hypoventilation in relation to normal perfusion (Example: Poorly ventilated alveoli in ARDS)
- V/Q ratio < 0.8

**Result**

- Poorly oxygenated blood returns to left side of heart resulting in low PaO$_2$ and SaO$_2$ (oxygenation problem)
Causes of V/Q Mismatching

- Causes of non uniform ventilation
  - Uneven resistance to airflow
    - Collapsed airways (Emphysema)
    - Bronchoconstriction (Asthma)
    - Inflammation (Bronchitis)
  - Non-uniform compliance throughout the lung
    - Fibrosis
    - Pulmonary vascular congestion
    - Atelectasis

Increased V/Q Ratio: Alveolar Dead Space

- Alveolar dead space: When ventilation is greater than perfusion
- V/Q ratio > 0.8

- Causes of non uniform perfusion:
  - **Pulmonary Emboli**
  - Compression of pulmonary capillaries (high alveolar pressures)
    - Tumors
  - Shock (pulmonary vascular hypotension)
Assessing Oxygenation

- **Clinical Application:** Cannot assess PaO\(_2\) (arterial) without considering alveolar oxygenation content (PAO\(_2\))
  - Increase in FIO\(_2\) will increase PAO\(_2\)
  - Increase in PACO\(_2\) will decrease PAO\(_2\)

**Note:** With normal diffusion the majority of oxygen in the alveoli should diffuse across the alveolar capillary membrane.

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**ALVEOLAR O\(_2\)**

Cannot directly measure the amount of oxygen in the alveoli. It is a calculated value.

**Alveolar Gas Equation:**

\[
PAO_2 = FIO_2 \times (PB - 47) - PaCO_2/0.8
\]

- PAO\(_2\) = partial pressure of alveolar oxygen
- FIO\(_2\) = fraction of inhaled oxygen
- PB = barometric pressure
- 47: PH20 = water vapor pressure
- PaCO\(_2\) = partial pressure of arterial carbon dioxide
- 0.8 = respiratory quotient
Importance of FIO$_2$

*Normal arterial oxygen content of 80 -100 mm Hg is only normal when the FIO$_2$ is .21*

*Expected PaO$_2$ based on FIO$_2$*  
\[(\text{FIO2} \times 6) - \text{PaCO}_2\]

*Example: FIO$_2$ of 100% or 1.0 with PaCO$_2$ 40 mm Hg*  
\[(100 \times 6) - 40 = 560 \text{ mm Hg}\]

PaO$_2$ and FIO$_2$ Ratio

- An assessment and trending tool
- PaO$_2$/ FIO$_2$ ratio:
  - Normal > 300
  - Acute lung injury < 300
  - ARDS< or= 200

PaO$_2$ less than 60 mmHg with an FIO$_2$ of 0.5 (50%) represents a clinically significant shunt.  
(return of poorly oxygenated blood to the left side of the heart).
Linking Knowledge to Practice with PaO2 / FIO2 Ratios

<table>
<thead>
<tr>
<th>PaO2</th>
<th>FIO2</th>
<th>Ratio</th>
<th>Treatment / Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>21%</td>
<td>261</td>
<td>Admit; respiratory distress</td>
</tr>
<tr>
<td>60</td>
<td>100%</td>
<td>60</td>
<td>Worsening; NRB Mask</td>
</tr>
<tr>
<td>210</td>
<td>100%</td>
<td>210</td>
<td>Post intubation ABG, antibiotics</td>
</tr>
<tr>
<td>190</td>
<td>60%</td>
<td>316</td>
<td>Continued treatment, FIO2 decreased</td>
</tr>
<tr>
<td>150</td>
<td>40%</td>
<td>375</td>
<td>Clinical improvement, FIO2 decreased</td>
</tr>
</tbody>
</table>

A – a Gradient

- Provides an index regarding diffusion as cause of hypoxemia.
- Normal A-a Gradient = 5 to 15 mm Hg
- A large A-a gradient generally indicates that the lung is the site of dysfunction.

Normal PaO2 80-100 mm Hg
Critical Thinking Questions Related to Assessment of Hypoxemia

- What if A – a gradient is normal and PaO2 is low?????

- How do you know when hypoxemia is the result of a simple diffusion problem as opposed to a significant intrapulmonary shunt?

Ventilation versus Diffusion

Assessment and Treatment

- **Ventilation problems**
  - Assessed by:
  - Corrected with?

- **Diffusion problems**
  - Assessed by:
  - Corrected with?
Relationship Between Oxygen and Hemoglobin

Oxygen Transportation

- Oxygen is transported both physically dissolved in blood and chemically combined to the hemoglobin in the erythrocytes.

- **Hemoglobin: 97% of oxygen is combined with hemoglobin**
  - Represented by the SaO₂

- **Plasma: 3% of oxygen is dissolved in plasma**
  - Represented by the PaO₂ (measurement of O₂ tension in plasma)

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Oxyhemoglobin Dissociation Curve

- Shows the relationship between PaO$_2$ and SaO$_2$

![Graph showing Oxyhemoglobin Dissociation Curve]

- Horizontal curve shows PaO$_2$ above 60 results in minimal changes in oxygen saturation
  - Protects body – allowing high saturations with large decreases in PaO$_2$
- Vertical curve shows PaO$_2$ below 60 results in significant decreases in oxygen saturation
  - Allows tissues to extract large amounts of O$_2$ with only small decreases in PaO$_2$
Shifts in Oxyhemoglobin Curve

- **Shift to the Left**
  - Easier to pick up at the lung level and more difficult to drop off (unload) at the tissue level
  - Hemoglobin is more saturated for a given PaO2 and less oxygen is unloaded for a given Pao2

- **Shift to the Right**
  - More difficult to pick up at the lung level but easier to drop off (unload) at the tissue level
  - Hemoglobin is less saturated for a given PaO2 and more oxygen is unloaded for a given PaO2

Let’s Practice
Shifts in Oxyhemoglobin Curve

- **Causes of Shift to Left**
  - Hypothermia
  - Decreased 2,3 – DPG
  - Hypocapnia
  - Alkalemia

- **Causes of Shift to Right**
  - Hyperthermia
  - Increased 2,3 – DPG
  - Hypercapnia
  - Acidemia
A Closer Look at 2,3-DPG

- 2,3-Diphosphoglycerate
- Substance in the erythrocyte which affects the affinity of hemoglobin for oxygen (binds to hemoglobin and decreases the affinity of hemoglobin for oxygen)
- Produced by erythrocytes during their normal glycolysis
- Increased
  - Chronic hypoxemia, anemia, hyperthyroidism
- Decreased
  - Massive transfusion of banked blood, hypophosphatemia, hypothyroidism

Alterations in Oxyhemoglobin Curve

\[ \frac{R_{\text{ise}}}{I_{\text{n}}} \]

- 2, 3-DPG
- H+
- Temperature
Hypoxia and Hypoxemia

- **Hypoxemia**
  - Insufficient oxygenation of the blood
  - Mild: PaO2 < 80 mm Hg or SaO2 95%
  - Moderate: PaO2 < 60 or mmHg or SaO2 90%
  - Severe: PaO2 < 40 mmHg or SaO2 75%

- **Hypoxia**
  - Insufficient oxygenation of tissues
  - Determined by cardiac index, Hgb, SaO2, cellular demand, patency of vessels

Oxygen Delivery to Tissues
Transport of Gases in the Blood

**Definition:** movement of oxygen and carbon dioxide through the circulatory system; oxygen being moved from the alveolus to the tissues for utilization and carbon dioxide being moved from the tissues back to the alveolus for exhalation.

Oxygen Delivery To Tissues

- Oxygen delivery measured as $DO_2$: Volume of oxygen delivered to tissues each minute.
  
  - $DO_2 = $ cardiac output $\times$ arterial oxygen content ($\text{hemoglobin} \times \text{arterial oxygen saturation}$)
Formula for Oxygen Delivery

- \( \text{DO}_2 \) formula = \( \text{CO} \times \text{Hgb} \times \text{SaO}_2 \times 13.4 \) (constant)

- Normal \( \text{DO}_2 \) = 900- 1100 ml/min (1000)

- Normal \( \text{DO}_2I \) = 550 – 650 ml/min

Improving Oxygen Delivery

- Oxygen delivery can be improved by increasing cardiac output, hemoglobin or \( \text{SaO}_2 \)

Some interventions more effective in clinical practice; interventions can be performed simultaneously
Oxygen Consumption

- **Measured as VO$_2$**
- **Volume of oxygen consumed by the tissues each minute**
- **Determined by comparing oxygen content in arterial blood to the oxygen content in mixed venous blood**
  - Normal CaO$_2$ is 20 ml/dl and normal CVO$_2$ is 15 ml/dl
- **Normal VO$_2$: 200 – 300 ml / min**
  - (250 ml / min)

Causes of Increased VO$_2$

- Fever per 1 degree C: 10%
- Shivering: 50-100%
- Suctioning: 7-70%
- Sepsis: 5-10%
- Non Family Visitor: 22%
- Position Change: 31%
- Sling Scale Weight: 36%
- Bath: 23%
- CXR: 25%
- Multi Organ Failure: 20-80%
Oxygen Reserve in Venous Blood

- Measured by mixed venous oxygen saturation (SVO$_2$)
- Normal 60-80% (75%)

- Tissues were delivered 1000 ml / min (DO$_2$)
- Tissues uses 250 ml / min (VO$_2$)
- This leaves a 75% reserve in venous blood
- Oxygen Extraction Ratio (O$_2$ER) = 25%

Oxygen Consumption and Oxygen Delivery

- Oxygen delivery and oxygen consumption are independent until a critical point of oxygen delivery is reached

- Tissues will extract the amount of oxygen needed independent of delivery because delivery exceeds need
Relationship of Delivery to Consumption

<table>
<thead>
<tr>
<th>DO₂</th>
<th>VO₂ (extraction is independent of delivery)</th>
<th>SVO₂ (SVO₂ will improve when you increase delivery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 cc</td>
<td>250 cc (25%)</td>
<td>75%</td>
</tr>
<tr>
<td>750 cc</td>
<td>250 cc (33%)</td>
<td>67%</td>
</tr>
<tr>
<td>500 cc</td>
<td>250 cc (50%)</td>
<td>50%</td>
</tr>
</tbody>
</table>

Relation of Delivery to Consumption

- When oxygen delivery reaches a critical level then consumption will depend on delivery
- SVO₂ will not increase with increased delivery while you are in this dependent state
- Anaerobic metabolism occurs here because you have an oxygen deficit
SVO$_2$ Monitoring

- Global indicator between oxygen supply and demand
- Influenced by oxygen delivery and oxygen extraction
- Reflects mixing of venous blood from superior vena cava, inferior vena cava and coronary sinus
- Measured using a pulmonary artery fiberoptic catheter

Significant Changes In SVO$_2$

- SVO$_2$ < 60%
  - Decreased delivery
  - Increased consumption
- SVO$_2$ > 80%
  - Increased delivery
  - Decreased demand
  - Sepsis (tissues cannot extract)
  - Wedged catheter

- Clinically significant change is ±or − 5 to 10% over 3 to 5 minutes
- SVO$_2$ < 40%
  - Represents limits of compensation and lactic acidosis will occur (oxygen demand is greater than oxygen delivery and reserve can be depleted = oxygen debt)
ScVO2

- ScVO2 reflects oxygen saturation of blood returning to right atrium via the superior vena cava.
  - Can be obtained without a pulmonary artery catheter, using a modified central venous catheter with fiberoptic technology.
  - Normal value is > 70%.
  - ScVO2 trends higher than SVO2 but trends with SVO2.

Cellular Respiration

- Definition: Utilization of oxygen by the cell

- Estimated by the amount of carbon dioxide produced and amount of oxygen consumed

- Oxygen is used by the mitochondria in the production of cellular energy – prolonged oxygen deficit can result in lethal cell injury
Oxygen and Ventilator Therapy

Oxygen

Atomic Number: 8
Atomic Mass: 16

Oxygen Therapy

- Cannula: < 40%
- Simple Mask: 40-60%
- Venturi Mask: Up to 40%
- Nonrebreathing mask: 80-100%
- Bag Valve Mask
Low Flow Oxygen Therapy

- Doesn’t provide total inspired gas
- Patient breathes varying amounts of room air
- FIO2 depends on rate and depth of ventilation and fit of device
- Doesn’t have to mean low FIO2
- Nasal cannula is a low flow oxygen delivery system
- Simple face mask is a moderate flow delivery system

High Flow Oxygen Therapy

- Provides entire inspired gas by high flow of gas
- Provides a predictable FIO2
- Doesn’t mean a high FIO2
- 100% non rebreather masks, venturi masks and mechanical ventilators are examples of higher flow oxygen delivery systems
### Guidelines for estimating FIO$_2$ with low flow oxygen devices

<table>
<thead>
<tr>
<th>100% O$_2$ flow rate(L)</th>
<th>FIO$_2$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasal Cannula</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>28</td>
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<td>3</td>
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<td>5</td>
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<td>6</td>
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<tr>
<td>Oxygen Mask</td>
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<td>5-6</td>
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<td>6-7</td>
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<td>7-8</td>
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<tr>
<td>Mask with Reservoir</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>70</td>
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<td>8</td>
<td>80</td>
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<tr>
<td>9</td>
<td>90</td>
</tr>
<tr>
<td>10</td>
<td>99</td>
</tr>
</tbody>
</table>

### Oxygen Toxicity

**Complications of O$_2$**
- Absorption atelectasis
- Decreased hypoxic drive

**Signs and symptoms of oxygen toxicity**
- Dyspnea
- Decreased lung compliance
- Retrosternal pain
- Parasthesia in the extremities

**To reduce risk of oxygen toxicity:**
- 100% no more than 24 hours
- 60% no more than 2-3 days
- Use 40% if therapy for longer term therapy
Mechanical Ventilation

**Indications**
- Respiratory failure.
  - Hypercapnic.
  - Hypoxemic.
- Excessive work of breathing.
  - Tachypnea
  - Accessory muscle use
  - Tachycardia
  - Diaphoresis
- Protection of airway.

**Goals**
- Achieve adequate ventilation.
- Achieve adequate oxygenation.
- Provide decreased work of breathing, patient comfort and synchrony with the ventilator.
- Protect the lungs from further injury.

Non Invasive Positive Pressure Ventilation

- **Continuous Positive Airway Pressure**
  - Continuous pressure throughout breathing cycle
  - Most commonly 10 cm H$_2$O
- **Biphase Positive Airway Pressure**
  - Senses inspiration and delivers higher pressure during inspiration

- Consider as first line strategy
- Consider as alternative to failed weaning
- Decreased VAP
Non Invasive Positive Pressure Ventilation

- Dedicated ventilator or traditional mechanical ventilator
- Note: Single tubing / dual tubing; ported mask or non ported mask
- Contraindications
  - Decreased level of consciousness
  - Increased gastrointestinal bleeding
  - Hemodynamic instability
  - Progressive decline in respiratory status

Intubation and Cuff Pressure

- Cuff pressures should not exceed capillary filling pressures of trachea
  - < 25 cm H2O or < 20 mmHg
- Adequate seal for positive pressure ventilation and PEEP
- Prevents aspiration of large particles but not liquids
- Low pressure / high volume cuffs used
- Leak in cuff or pilot balloon valve requires replacement
- Routine measurement of cuff pressures
Mechanical Ventilation Breaths

- **Volume cycled**: Preset tidal volume
- **Time cycled**: Delivered at constant pressure for preset time
- **Flow cycled**: Pressure support breath. Constant pressure during inspiration.

Modes of Ventilation

- **Assist Control Mode (AC)**
  - Volume targeted (volume cycled)
  - Pressure targeted (time cycled)
- **Synchronized Intermittent Mandatory Ventilation (SIMV)**
  - Same breath options as assist control
- **Adaptive Support Ventilation**
- **Airway Pressure Release Ventilation (APRV)**
  - Open lung strategy
- **High Frequency Oscillator Ventilation**
  - Open lung strategy
Assist Control

- Minimal respiratory rate is set. Set number of breaths delivered at the preset parameters.
- Allows the patient to assist. Maintains control of patient breaths once initiated.
- Differs from (CMV) where no spontaneous breaths are allowed.
- Is effective in decreasing the work of breathing when used with appropriate sedation.
SIMV

- Delivers a set number of ventilator breaths at preset parameters.
- Also allows the patient to initiate breaths above the preset rate.
- Patient initiated breaths in SIMV are patient dependent and not guaranteed to achieve ventilator set parameters.
- Pressure support is often used during spontaneous breaths.
- The primary disadvantage of SIMV is the increased work of breathing in the patient with respiratory distress.

Adaptive Support Ventilation

- Dual control
  - Pressure limited
  - Time cycled
- Breath to breath
- Pressure limit of spontaneous and mandatory breaths continuously adjusted
- Other names based on commercial ventilators
Open Lung Strategies: Focus on Mean Airway Pressure

- APRV
  - Similar to CPAP with release
  - Spontaneous breathing allowed throughout cycle
    - Can also be used with no spontaneous effort
  - Release time allows removal of CO\(_2\)
  - P High (20 - 30 cmH\(_2\)O) and P low (O) (pressure)
  - T high (4-6 seconds) and T low (0.8 seconds) (time)

- Facilitates oxygenation and CO\(_2\) clearance
- Time triggered
- Pressure limited
- Time cycled

Advantages
- Lower peak and plateau pressures for given volume
- Decreased sedation / near elimination of neuromuscular blockade
Open Lung Strategies: Focus on Mean Airway Pressure

- High frequency oscillation
  - Not jet ventilation
  - Constant mean airway pressure
  - TV 1-3ml/kg
  - Delivers and removes gas: 1/3 time delivery in and 2/3 time delivery out
  - Usually set starting at 5 to 6 HZ (60 oscillations / HZ)
  - Chest wiggle
  - JVD: Tamponade effect

Initial Ventilator Settings: Acute Respiratory Failure

- Most common initial mode of ventilation used in critical care for respiratory failure is AC with volume cycled breathes.

  - Tidal volume: (VT): Usually set at 8 – 10 ml/kg of ideal body weight.

  - Respiratory Rate: Usually set at 12-16 breaths per minute.

  - Fraction of Inspired Oxygen (FIO2): Started at 1.0 or 100%. Weaning as quickly as possible to .4 or 40% while maintaining an oxygen saturation of 92-94%.

  - PEEP: Usually started at 5 cm of H2O. PEEP is titrated up as needed to achieve adequate oxygenation. > 15 cm H2O of PEEP is rarely needed.
Adjuncts to Mechanical Ventilation

- PEEP: Positive end expiratory pressure

- PSV: Pressure support ventilation; positive pressure during inspiration; during spontaneous breaths with SIMV or during non invasive mechanical ventilation
More on PEEP

- PEEP is used to improve oxygenation by increasing mean airway pressures and increasing the driving pressure of oxygen across the alveolar capillary membrane.
- Prevents derecruitment, low levels do not recruit
- PEEP and PAOP
- Potential complications:
  - Barotrauma
  - Decreased cardiac output
  - Regional hypoperfusion

Other Ventilator Settings

- Peak Flow (gas flow): speed and method of VT delivery, velocity of air flow in liters per minute
- Sensitivity: determines patient’s effort to initiate an assisted breathe
- I:E ratio (inspiratory to expiratory ratio): Typically set at 1:2 (can be altered to facilitate gas exchange and prevent auto peep)
Measured Parameters

- Mean Airway Pressure: Constant airway opening pressure
  - PEEP
  - CPAP
  - Pressure Support

- I:E Ratio
  - Inspiration time and mean airway pressure
  - Development of auto PEEP

Measured Parameters

- Peak Inspiratory Pressure
  - Accounts for airway resistance and lung compliance

- Inspiratory Plateau Pressure
  - Takes resistance out of equation
Improving Resistance and Compliance

- **Airway Resistance**
  - Effective coughing
  - Bronchodilators (albuterol) or steroids for bronchospasm
  - Repositioning and suctioning to mobilize and aspirate secretions
  - Decrease endotracheal tube resistance.
    - > 8 mm
    - Short tubes

- **Lung / Chest Compliance**
  - Deep breath and hold
  - Incentive spirometry (10 breaths per hour)
  - Prevent abdominal distention / positioning
  - Thoracentesis or chest tube for pleural effusion
  - Diuretics for pulmonary edema
  - Antibiotics for pneumonia
  - CPAP
  - PEP (positive expiratory pressure)

Hemodynamic Effects of Mechanical Ventilation

- Decreased venous return
- Pulmonary capillary compression and increased right ventricular afterload
- Decreased right ventricular stroke volume
- Decreased left ventricular afterload
Hypotension with Mechanical Ventilation

- **Conversion to positive pressure ventilation.**
  - Assure adequate circulating fluid volume.
- **Tension Pneumothorax**
  - Chest tube required.
- **Development of auto PEEP**
  - Increase expiration time.

Complications of Mechanical Ventilation

- **Barotrauma** (caused by excessive pressure)
- **Volutrauma** (caused by excessive volume)
- **Ateletrauma** (caused by low volume resulting in repetitive opening and closing of distal lung units)
- **Biotrauma** (caused by biochemical mediators released in response to mechanical ventilation as opposed to a mechanical complication)
Lung Protective Strategies

- Low tidal volume (6 ml / kg) with permissive hypercapnea
- Maintain plateau pressure $\leq 30$ mm Hg

Benefits of Sedation During Mechanical Ventilation

- Reduce anxiety
- Amnesia, particularly during use of neuromuscular blocking agents
- Prevent recall of unpleasant experience
- Decrease level of stress hormones
- Reduce tissue oxygen consumption
- Improve ventilator synchrony
Neuromuscular Blockade

- **Depolarizing agents**
  - Mimic acetylcholine: produces fasciculation followed by paralysis
  - Example: Succinylcholine

- **Non-depolarizing agents**
  - Prevents action of acetylcholine
  - Example: Vecuronium and Atracurium

- **Complications of neuromuscular blockade.**
  - Deep vein thrombosis, muscle atrophy, and nerve compression syndromes.
  - Acute quadriplegic myopathy syndrome, or critical illness polyneuropathy is a serious complication

- **Assessment with neuromuscular blocking agents.**
  - Peripheral nerve stimulators
  - The most commonly used nerve-muscle combinations
    - Facial nerve and orbicularis oculi
    - Ulnar nerve and adductor pollicis
  - The goal is to have one or two twitches in response to nerve stimulation.
## Sources of Nosocomial Pneumonia during Mechanical Ventilation

<table>
<thead>
<tr>
<th>Exogenous</th>
<th>Endogenous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical ventilatory circuit</td>
<td>Gastric pH and volume</td>
</tr>
<tr>
<td>Heated humidifier</td>
<td>Buccal mucosa and oropharyngeal flora</td>
</tr>
<tr>
<td>Suction catheters</td>
<td>Circulating infectious agents—septicaemia</td>
</tr>
</tbody>
</table>

## Microbiologic causes of Nosocomial Pneumonia

- **Bacteria**
- **Viruses**
- **Fungi**
- **Protozoa** (*Pneumocystis carinii*)
- **Atypical agents** (Legionella)

## Evidenced Based Nursing Practice

### Prevention of VAP

- Hand hygiene
- Oral care, including brushing of teeth, gums, and tongue
- HOB elevated 30 to 40 degrees
- Suction only when necessary (not routine)
- **Routine installation of NS not recommended**
- Cover yankauer catheters when not in use
- Ventilator circuit changes only when soiled, or weekly
- Adequate endotracheal tube cuff pressure
  - Maintain at < 20 mm Hg or < 25 cm H2O to not exceed capillary filling pressure of trachea.
  - Low pressure high volume cuffs typically used.
  - Inflate to assure no or minimal leak during inspiration.
  - Need for increasing air may be due to tracheal dilation or leak in cuff or pilot balloon valve (tube must be replaced if leak present).
  - Cuff pressures measured routinely every 8-12 hours and with any change in tube position.
Prevention of VAP

- Subglottic suctioning prior to repositioning or deflating cuff
- Hold tube feedings if residuals > 150 cc
- Discontinue NG tubes as soon as possible
- Extubate as soon as possible
- Avoid nasal intubation
- Stress ulcer prophylaxis with sucralfate rather than H2 blockers or proton pump inhibitors (potential advantage)
- Avoid overuse of antibiotics

Basic Ventilator Changes: Review

- To Change PaCO₂
  - Change _______
  - Change _______

- To change PaO₂
  - Change _______
  - Change _______

? Problem

? Problem
Ventilator Weaning

- **Spontaneous breathing trial**
  - Short period of time
  - T – Piece with CPAP or CPAP and PSV
  - If patient has not been on ventilator very long
  - Quickly need to extubate if patient tolerates

- **IMV**
  - Decreasing rate
  - Adding pressure support
  - If patient has been on ventilator for several days and has deconditioning of respiratory muscles

Minimum Weaning Parameters

- Spontaneous respiratory rate < 30 breaths per minute
- Spontaneous tidal volume: > 5ml/kg
- Vital capacity: > 10 ml/kg, ideally 15ml/kg
- Minute ventilation: < 10L
- Negative inspiratory pressure: < -25 to -30 cm H2O
- FIO2: < 0.50
- PaO2 / FIO2 ratio > 200
Tracheostomy

**Indications**
- Facilitate removal of secretions
- Decrease dead space
- Bypass upper airway obstruction
- Prevent or limit aspiration with cuffed tube
- Patient comfort for prolonged mechanical ventilation

**Benefits**
- Decrease laryngeal damage, swallowing dysfunction, and glottic trauma
- Decrease in airway resistance
- Improved ability to suction lower airways
- Decreases risk of sinusitis
- Improved patient comfort and mobility

Bedside Respiratory Monitoring: SpO2 (Pulse Oximetry)

- Used to estimate oxyhemoglobin. The SpO2 generally correlates with the SaO2 + or - 2%.
- The goal equal to or greater than 92-94% in most patients.
  - Higher in African Americans
- Requires the presence of a pleth wave detecting an accurate pulse.
  - Patients receiving administration of high fat content such as with propofol or TPN can have a falsely high SpO2.
- Several factors can interfere with the accuracy
  - Hemoglobin < 5 g/dL or hematocrit <15%.
  - Abnormal hemoglobin, such as carboxyhemoglobin or methemoglobin.
  - SpO2 below 70%.
  - State of low blood flow, such as with hypotension or vasoconstriction.
  - IV dyes, fingernail polish, and some skin pigancements
Bedside Respiratory Monitoring:
Patient End Tidal CO2 (PetCO2):

- Expired CO2 can be measured, directly at the patient and ventilator interface.
- Airway adapter should be placed as close to the patients airway as possible.
- End exhalation represents alveolar gas, and under normal circumstances, parallels PaCO2.
- The normal gradient between PaCO2 and PetCO2 is 1-5 mm Hg.
- Several factors can interfere with the correlation
  - Body temperature, pulmonary disease and cardiac status.
- It can be used to detect changes over time and should be considered in patients who are undergoing deep sedation.

Acid –Base Balance
Definitions

- **Acid**: A substance that can give up a H+ ion
- **Acidemia**: A blood pH below 7.35
- **Acidosis**: The condition that causes acidemia
- **Base**: A substance that can accept an H+ ion
- **Alkalemia**: A blood with a pH above 7.45
- **Alkalosis**: The condition that causes the alkalemia

Acid – Base Balance

- **pH**
  - Indirect measurement of hydrogen ion concentration
  - Reflection of balance between carbonic acid and bicarbonate (base)
  - Inversely proportional to hydrogen ion concentration (acids donate H+ ions)
    - ▲H+ concentration = ▼pH, more acid
    - ▼H+ concentration = ▲pH, less acid
    - pH < 6.8 or > 7.8 is incompatible with life
Buffers

- Bicarbonate (the presence of hemoglobin makes this a much more effective buffer)
  - Bicarbonate generated by kidney
  - Aids in elimination of H+
- Phosphate
  - Aids in excretion of H+ ions by the kidneys
- Proteins

Acid - Base Regulation

- Respiratory System
  - Responds within minutes – fast but weak
  - Regulates the excretion or retention of carbonic acid
    - If pH is down: increase rate and depth of respiration to blow off PCO2
    - If pH is up: decrease rate and depth of respiration to retain PCO2
Acid - Base Regulation

- Renal System
  - Responds within 48 hours – slow but powerful
  - Regulates excretion or retention of bicarbonate and the excretion of hydrogen and non-volatile acids
    - If pH is down: kidney retains bicarbonate
    - If pH is up: kidney excretes bicarbonate

ABG Analysis

- Evaluate ventilation: PaCO2
- Evaluate acid-base status: pH
- Evaluate source of abnormal pH: respiratory or metabolic
- Evaluate oxygenation: PaO2, SaO2
ABG Analysis: Parameters

- **pH**
  - Normal 7.35-7.45
  - < 7.35 Acidosis
  - > 7.45 Alkalosis

- **PaCO₂**
  - Normal 35-45 mm Hg
  - < 35 alkalosis or respiratory compensation for metabolic acidosis
  - > 45 acidosis or respiratory compensation for metabolic alkalosis

- **HCO₃**
  - Normal 22-26 mEq/L
  - < 22 metabolic acidosis or metabolic compensation for respiratory alkalosis
  - > 26 metabolic alkalosis or metabolic compensation for respiratory acidosis

- **Base Excess (BE)**
  - Normal +2 to −2
  - < -2 (base deficit) metabolic acidosis or metabolic compensation for respiratory alkalosis
  - > +2 metabolic alkalosis or metabolic compensation for respiratory acidosis
### ABG Analysis: Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal Range</th>
<th>Abnormal Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pao(_2)</strong></td>
<td>80-100 mm Hg</td>
<td>&gt;100 hyperoxemia, &lt; 80 mild hypoxemia, &lt; 60 moderate hypoxemia, &lt; 40 severe hypoxemia</td>
</tr>
<tr>
<td><strong>Sao(_2)</strong></td>
<td>95% or &gt;</td>
<td>&lt; 95% mild desaturation of HGB, &lt; 90% moderate desaturation of HGB, &lt; 75% severe desaturation of HGB</td>
</tr>
</tbody>
</table>

### Compensation

An acidosis or alkolosis for which there has been compensation causes the pH to return to the normal range while leaning toward the initial disorder. The body never overcompensates. A non leaning pH with two abnormal indicators suggests a mixed disorder (one alkalotic and one acidotic process).
Anion Gap

- The anion gap is used to help determine the cause of the patient’s metabolic acidosis.
- **Anion Gap = Na⁺ - [Cl⁻ + HCO₃⁻]**
- A normal anion gap is 12 ± 4 mEq/L.
- An increased anion gap typically indicates an increased concentration of anions other than Cl⁻ and HCO₃⁻.
  - Lactic acidosis
  - Ketoacidosis
  - Renal retention of anions

Common Causes of Respiratory Acidosis

- Depression of respiratory control centers
- Neuromuscular disorders
- Chest wall restriction
- Lung restriction
- Airway obstruction
- Pulmonary parenchymal disease
Common Causes of Respiratory Alkalosis

- Central nervous system disorders
- Drugs
- Hormones
- Bacteremia
- High altitude
- Over mechanical ventilation
- Acute asthma
- Pulmonary embolism

Common Causes of Metabolic Acidosis

- Ingested toxic substances
- Loss of bicarbonate ions
- Lactic acidosis
- Ketoacidosis
- Renal failure
Common Causes of Metabolic Alkalosis

- Loss of hydrogen ions
  - Vomiting
  - Diuretics
  - Steroids
- Excess bicarbonate

Practice ABGs
### ABG Analysis Practice

- **pH**: 7.30
- **PaCO2**: 54
- **HCO3**: 26
- **PaO2**: 64

### ABG Analysis Practice

- **pH**: 7.48
- **PaCO2**: 30
- **HCO3**: 24
- **PaO2**: 96
ABG Analysis Practice

- pH  7.30
- PaCO2  40
- HCO3  18
- PaO2  85

ABG Analysis Practice

- pH  7.50
- PaCO2  40
- HCO3  33
- PaO2  92
### ABG Analysis Practice

- **pH**: 7.35  
- **PaCO2**: 54  
- **HCO3**: 30  
- **PaO2**: 55

### ABG Analysis Practice

- **pH**: 7.21  
- **PaCO2**: 60  
- **HCO3**: 20  
- **PaO2**: 48
ABG Analysis Practice

- pH 7.54
- PaCO2 25
- HCO3 30
- PaO2 95
Acute Respiratory Failure

Failure of the respiratory system to provide for the exchange of oxygen and carbon dioxide between the environment and tissues in quantities sufficient to sustain life

Type I: Hypoxemic Normocapnic
- Low PaO2
- Normal PaCO2
- Widened A-a gradient

Type II: Hypoxemic Hypercapnic
- Low PaO2
- High PaCO2
- Normal A-a gradient
Acute Respiratory Failure: Causes

- Type I (oxygenation failure)
  - Pathophysiology: Decreased V/Q ratio (shunting), diffusion defect
    - Pneumonia
    - Pulmonary edema
    - Pleural effusion
    - ARDS

- Type II (acute ventilatory failure)
  - Pathophysiology: Hypoventilation
    - CNS depressant drugs
    - Spinal cord injury
    - Chest trauma
    - Acute exacerbation of COPD

Oxygen Therapy and PCO$_2$ goals in COPD

COPD

- Disorders of emphysema, chronic bronchitis, and small airway disease.
- Obstructive disease causes resistance to airflow.
- Decreased expiratory airflow is central to COPD.
  - Residual volume, functional residual capacity, and total lung capacity can increase.
  - Increased resistance during forced expiration from dynamic compression.
  - FEV$_1$ (expiratory airflow) 1 / FVC < .80
- Chronic inflammation of all structures of the lungs.
  - Excessive mucous secretion and ciliary dysfunction.
  - Leads to repeated damage and repair of the airways.
- Vascular changes can lead to pulmonary hypertension and subsequent acute cor pulmonale can develop.
Emphysema and Chronic Bronchitis

- **Emphysema**
  - Destruction of alveolar walls and elastic tissue support of small airways
  - Enlargement of air spaces distal to terminal bronchioles
  - **Air trapping**
  - Airway resistance increased; also loss of pulmonary capillaries
  - Decreased surface area for gas exchange
  - V/Q mismatching

- **Chronic bronchitis**
  - Mucous glands hypertrophy
  - Decreased cilia
  - Increased bronchial wall thickness
  - **Chronic inflammation and excessive secretions block airways**
  - Increased resistance – ventilation impairment

COPD: Clinical Manifestations

**Chronic Bronchitis**
- Chronic cough and sputum production daily for minimum of 3 months/year for at least 2 consecutive years
- Can have chronic hypoxemia / right sided heart failure
- Exacerbations related to infection

**Emphysema**
- Increased responsiveness to hypoxemia
- Dyspnea with adequate oxygenation
- Initial dyspnea on exertion
- Dyspnea at rest
COPD: Clinical Manifestations

- Blended symptoms
- Large lung volumes / diminished breath sounds
- Ventilation / perfusion mismatching
- High PaCO$_2$ / low PaO$_2$
- Increase erythropoietin for increased RBCs
- Right sided heart failure

COPD: Treatment

- Smoking cessation
- Bronchodilators
  - Anticholinergics are the first-line medication in maintenance therapy.
    - ipratropium (Atrovent).
  - Beta-agonists can be added
    - Short acting
      - racemic albuterol (Ventolin, Proventil, Accuneb).
      - levalbuterol (Xopenex).
      - metaproterenol (Alupent).
      - pirbuterol (Exirel, Maxair).
    - Long acting
      - salmeterol (Serevent).
      - formoterol (Foradil, Oxeze).
  - Theophylline is a long acting weak bronchodilator.
COPD: Treatment

- **Antibiotics** - acute exacerbations can be caused by bacterial infections.
- **Corticosteroids**: Remains controversial, but they are frequently used in treating exacerbations. Steroids are used as part of chronic treatment in some patients. Corticosteroids can also be combined with other medications.
  - budesonide (Pulmicort)
  - fluticasone and salmeterol (Advair)
- **Expectorants/mucolytics.**

COPD: Treatment

- **Oxygen** (Can improve survival in patients who are hypoxemic)
  - **Criteria**
    - Room air: PaO2 < 55 mm Hg with saturation < 85%.
    - PaO2 56-59 and saturation 86-89%, with a qualifying secondary diagnosis.
    - Goal of oxygen therapy is to obtain PaO2 of 65-80 mm Hg while awake and at rest.
  - Typically delivered at 1-4 L/min, with an increase of 1 L during sleep and exercise.
  - Should be given continuously at least 19 hours of each day.
- **Pneumonia and influenza vaccines**
Case Example

- Patient history: COPD (CO$_2$) retainer
- Initial presentation: Tachypneic with SaO$_2$ of 78%

- Cause of exacerbation?
- Initial interventions?

Case Example

- ABG
  - 7.29
  - PaCO$_2$ 60
  - HCO$_3$ 30
  - PaO$_2$ 48

- Treatment options?
- Goals for ABG values?
Status Asthmaticus

Exacerbation of acute asthma characterized by severe airflow obstruction that is not relieved after 24 hours of maximal doses of traditional therapy

Characterized by expiratory wheezing

Status Asthmaticus: Etiology

- Extrinsic (specific allergy can be related to attack)
  - Pollen
  - Dust
  - Pets
  - Smoke
  - Food
  - Drugs

- Intrinsic (attack is seemingly unrelated to an allergen)
  - Infection
  - Stress
  - Exercise
  - Aspiration
Status Asthmaticus: Pathophysiology

- Trigger (extrinsic or intrinsic)
- Intrinsic trigger causes imbalance of sympathetic and parasympathetic nervous systems
- Extrinsic: IgE released ► histamine and slow-reacting substance of anaphylaxis (SRS-A)
- Histamine ► swelling and inflammation of smooth muscle of large bronchi (and mucous membrane swelling)
- Swelling of smooth muscle of small bronchi and release of prostaglandins (enhance histamine)

Status Asthmaticus: Pathophysiology

- Histamine causes excessive secretion of mucous ► narrows the airway lumen
- Tachypnea increases insensible water loss ► thicker secretions
- Mucous in small airways
- Increased work of breathing (impaired ventilation) (Note: ▲ PaCO2 is late sign)
Status Asthmaticus: Treatment

- Eliminate or treat cause
- Steroids
- Need to ventilate when PaCO$_2$ becomes elevated
- Additional similar treatment as pneumonia

Pulmonary Embolism

- Obstruction of blood flow to one or more arteries of the lung by a thrombus (other emboli – fat, air, amniotic fluid) lodged in a pulmonary vessel
- Lower lobes frequently affected due to increased perfusion
Risk Factors for PE

- Stasis of blood
  - Prolonged immobilization after surgical procedures
  - Plaster casts
  - Venous obstruction
  - Heart failure / Shock / Hypovolemia
  - Varicose veins
  - Obesity
- Hypercoagulability
  - Polycythemia vera
  - Sickle cell disease
  - Malignancy
  - Pregnancy
  - Recent trauma
  - Oral contraceptives
- Injury to the vascular endothelium
  - Central venous and arterial catheters
  - Phlebitis

Pulmonary Embolism: Pathophysiology

- > 90% of thrombus develop in deep veins of iliofemoral system
  - Can also originate in the right side of the heart, pelvic veins, and axillary or subclavian veins.
  - Another source is around indwelling catheters.
- Thrombus formation leads to platelet adhesiveness and release of serotonin (vasoconstrictor).
- Dislodgement of thrombus
  - Intravascular pressure changes (standing, massaging legs, fluid challenge, valsalva maneuver).
  - Natural clot dissolution (7-10 days after development).
Pulmonary Embolism: Pathophysiology

- Clot lodges in pulmonary vessels
- Ventilation continues but perfusion decreases
  - Increase in alveolar dead space
  - Alveolar CO2 decreases (alveolar shrinking). Allows for more inspired air into the perfused alveoli.
- Overperfusion of uninvolved lung results in a decreased V/Q ratio
- Decreased blood flow damages type II pneumocytes, which results in a decrease in surfactant production. (atelectasis)
- Pulmonary edema can develop as secondary complication
- Hypoxemia can occur due to ventilation perfusion mismatching.
- Increased PVR can lead to pulmonary hypertension and potential acute cor pulmonale.
- Cardiogenic shock can occur as the result of right-ventricular failure.

Pulmonary Embolus: Clinical Presentation

- Large to massive when 50% of pulmonary artery bed is occluded
  - Impending doom
  - Hypoxemia
  - Syncope
  - Sign and symptoms of right heart strain or right-ventricular failure
  - Signs of right-ventricular strain on ECG.
  - Sudden shock
  - Pulseless electrical activity

- Medium-sized emboli
  - Dyspnea
  - Substernal chest discomfort/pleuritic chest pain
  - Many non-specific signs
  - Tachypnea
  - Tachycardia
  - Rales
  - Accentuated 2nd heart sound
Pulmonary Infarction

- Pulmonary infarction is infrequent
- More common
  - Large embolus
  - Pre-existing lung disease
- Results in alveoli filling with RBCs and inflammatory cells
- Complicated by infection
  - Abscess

- Signs and Symptoms
  - Pleuritic chest pain
  - Dyspnea
  - Hemoptyisis
  - Cough
  - Pleural friction rub

Signs and Symptoms

- Pleuritic chest pain
- Dyspnea
- Hemoptyisis
- Cough
- Pleural friction rub
Pulmonary Embolus: Treatment

- Prevent thrombus formation
  - Compression stockings that provide a 30-40 mm Hg or higher gradient
  - Low molecular weight heparin
- Fibrinolytic therapy
  - Indicated in patients with hypotension (even if resolved), hypoxemia, or evidence of right-ventricular strain
  - Troponin levels can also be used to guide decision-making in patients with sub-massive PE
- Pulmonary embolectomy is a surgical option when fibrinolytic therapy is contraindicated
- Treatment for Obstructive Shock!
Pulmonary Embolus: Treatment

- Heparin is the treatment of choice for reducing mortality in PE
  - Initiated prior to a confirmed diagnosis
  - Slows or prevents clot progression and decreases risk of further emboli
- Oxygen is indicated, even in the absence of hypoxemia
- Pulmonary vasodilators to help reduce pulmonary vascular resistance
- Treat right-ventricular failure with fluids and inotropes
- Warfarin
  - 3 to 6 months if there is identifiable reversible risk factor
  - Minimum of 6 six months if there is no identifiable risk factor
  - Long term with recurrent PE or in patients with ongoing risk factors
- Surgical interruption of inferior vena cava with a filter
  - Patients with contraindication to anticoagulants.
  - Recurrent thromboembolism despite anticoagulant.
  - Survivor of massive PE

Special Considerations Fat Emboli

- **Risk Factors:**
  - Skeletal Trauma: femur and pelvis
  - Major orthopedic surgery
  - 24 to 72 hours post insult
- **Signs and Symptoms:**
  - Vague chest pain
  - Shortness of breath
  - Sudden restlessness – drowsiness
  - Fever
  - Petechiae (transient – axillary or subconjunctival)
- Release of free fatty acids causes endothelial injury and toxic vasculitis
- Hemorrhage into lungs (**decrease** H&H and platelets)
- CXR pattern similar to ARDS
- Steroids
Special Considerations Air Emboli

- **Risk Factors**
  - Dialysis
  - Pulmonary artery catheters
  - Surgical procedures
  - CABG

- **Symptoms**
  - Dyspnea, chest pain, agitation, confusion, cough

- **Treatment**
  - Prevent
  - 100% oxygen
  - Left lateral / trendelenburg
  - Positive pressure ventilation
  - Aspiration of air

Pulmonary Edema

- **Extra vascular accumulation of fluid in the lungs (cardiac or non cardiac)**
  - Results in **impaired diffusion** of oxygen due to increase in interstitial space
  - Results in **decreased V/Q ratio** due to poorly ventilated fluid filled alveoli
  - Fluid in alveoli also impacts compliance of lungs and therefore ventilation

- Capillary endothelium more permeable to water and solute than alveolar endothelium
- Edema accumulates in the interstitium before the alveoli
Pulmonary Edema

- Fluid in pulmonary interstitium is removed by lymphatic drainage of the lung
- Volume of lymph flow from the lung can increase ten fold in pathological conditions
- Only when this large safety factor is taxed does pulmonary edema occur

Pulmonary Edema: Risk Factors and Treatment

- Loss of integrity of alveolar capillary membrane
  - Infection
  - Inhaled toxins
  - Oxygen toxicity
- Increase in pulmonary capillary hydrostatic pressure
  - Left sided heart failure
  - Excessive fluid administration
  - Occlusion of pulmonary vein

Other: Blockage of lymphatic system

- Cardiac pulmonary edema is treated as acute decompensated heart failure.
- Non cardiac pulmonary edema is treated like ARDS.
Pneumonia

- Acute infection of the lung parenchyma, including alveolar spaces and interstitial space

- Causes:
  - Bacteria (Community acquired versus Hospital acquired)
  - Virus
  - Fungi
  - Parasites
  - Mycoplasma

Risk Factors for Bacterial Pneumonia

- Previous viral respiratory infection
- Gastro esophageal reflux disease (GERD)
- Chronic alcohol abuse
- Cigarette smoking
- Decreased level of consciousness
- Anesthesia
- Intubation
- Lung disease
- Diabetes mellitus
- Use of corticosteroids
- Elderly
Pneumonia: Pathophysiology

- Causative agent is inhaled or enters pharynx via direct contact
- Alveoli become inflamed
- Alveolar spaces fill with exudate and consolidate
- Diffusion of O2 obstructed
  - Hypoxemia.
- Goblet cells are stimulated to increase mucous
  - Increased airway resistance and work of breathing

Pneumonia: Causative Agents

- Common agents in community-acquired pneumonia (younger and healthier population)
  - Streptococcus pneumoniae (most common agent in community acquired pneumonia).
  - Mycoplasma pneumoniae.
  - Chlamydia pneumoniae
  - Viral.
  - Haemophilus influenzae common among smokers
  - Klebsiella pneumoniae in patients with chronic alcoholism
- Agents in the older population commonly include gram negative bacilli
  - Moraxella catarrhalis (particularly common in patients with chronic bronchitis).
  - Staphylococcus aureus (in the setting of post viral influenza).
- Methicillin-resistant Staphylococcus aureus (MRSA) also as a cause of community-acquired pneumonia
Hospital Acquired Pneumonia

Causative agents

- Aerobic gram negative rods
  - Klebsiella sp.
  - Psuedomonas sp.
  - Enterobacter sp.
  - Escherichia coli.
  - Proteus sp
  - Serratia sp.
  - Enterococci.
- *Staphylococcus aureus* (including methicillin-resistant Staphylococcus aureus [MRSA])
- Group B streptococci

- Nosocomial pneumonia is typically caused by bacterial agents that are more resistant to antibiotic therapy.

**Sources**

- Contamination of pharynx and perhaps stomach with bacteria
- Repeated small aspirations of oral pharyngeal secretions.
- Retrograde contamination from GI tract.

Pneumonia: Clinical Presentation

- Flu-like symptoms.
- Pleuritic chest pain.
- Confusion in elderly.
- Tachycardia, tachypnea, fever.
- Crackles and wheezes.
- Productive cough.
- Clinical signs of dehydration.

The clinical presentation in the elderly may be more subtle including confusion, dehydration, and fever.
Diagnosis of Pneumonia

- Sputum gram stain
- Sputum culture
- Blood cultures *(bacteremia not present in most)*
- Leukocytosis / Shift to left of WBCs.
  - Leukocytosis and a left shift is expected in bacterial pneumonia.
  - Failure of the white blood cell count to rise in the presence of a bacterial infection is associated with an increased mortality
- Blood gases/oxygen saturation
- Chest x-ray – produces variable results but infiltrates are frequently seen
  - A chest CT may also be used to aid in the
Complications of Pneumonia

- Abscesses may form and rupture into pleural space leading to pneumothorax and/or empyema
  - Video assisted thoracoscopy with debridement is a treatment option for empyema in the early organizing phase
  - Full thoracotomy with decortication may be necessary in later organizing phases
- Pleural Effusion
- Acute respiratory failure
- ARDS
- Sepsis

*Mortality rates for nosocomial or hospital-acquired pneumonia are higher than those for community acquired pneumonia (particularly in the elderly)*

Pneumonia: Treatment

- **Prevent nosocomial infections**
- Timely Antibiotics
- Hydration (Electrolyte Monitoring)
- Deep breathing / incentive spirometry
- Bronchodilators, expectorants, mucolytics
- Avoid: sedatives and antitussives
- Early activity and mobility (DVT Prophylaxis)
Aspiration

- Vomiting or regurgitation
- Large particles – airway obstruction
- pH of liquid determines injury
  - pH<2.5 or large volume
  - Chemical burns destroy type II cells
  - May induce bronchospasm
  - Increase alveolar capillary membrane permeability
    - Decrease compliance
    - Decrease V/Q ratio

Aspiration

- Non acidic aspiration
  - More transient
- Food stuff / small particles
  - Inflammatory reaction
  - Hemorrhagic pneumonia within 6 hours
- Contaminated material with bacteria can be fatal
Aspiration: Possible Prevention Strategies

- Avoiding sedation.
- Resting prior to meal time.
- Eating slowly.
- Flexing the head slightly to the “chin down” position.
- Determining food viscosity best tolerated (thickening liquids will improve swallowing in some patients).

Acute Respiratory Distress Syndrome

A syndrome of acute respiratory failure characterized by non-cardiac pulmonary edema and manifested by refractory hypoxemia. ARDS does not include mild or early acute lung injury, but rather involves severe and diffused lung injury.
Risk Factors in ARDS

- Sepsis (most common)
- Transfusion
- Aspiration
- Trauma
- Massive transfusion
- Pancreatitis

Acute Respiratory Distress Syndrome: Etiology

- Direct lung injury
  - Chest trauma
  - Near drowning
  - Smoke inhalation
  - Pneumonia
  - Pulmonary embolism
- Indirect lung injury
  - Sepsis
  - Shock
  - Multi system trauma
  - Burns
  - CABG
  - Head injury

Time from injury of alveolar capillary membrane to onset of symptoms is 12-48 hours.
ARDS: Pathophysiology

- Stimulation of inflammatory and immune systems
- Release of toxic substances, causing micro vascular injury
- Pulmonary capillary membranes are damaged
  - Increase in capillary permeability.
- Cells and fluids leak into interstitium and alveolar spaces
  - Pulmonary Edema
- Impaired production and dysfunction of surfactant
  - Alveolar collapse and massive atelectasis.
- Intrapulmonary shunting
- Hypoxic vasoconstriction
- Decreased the compliance of lung
  - High-peak inspiratory pressures to ventilate the lungs.
- Potential development of pulmonary fibrosis in chronic phase.
  - Endothelium, epithelium, interstitial space expand.
  - Protein exudate inside the alveoli produces a hyaline membrane.

Acute Respiratory Distress Syndrome: Diagnosis

- Predisposing condition
- PaO2/FIO2 ratio < 200
- Chest x-ray: Diffuse bilateral infiltrates
  (Chest CT may also be used)
- Decreased static compliance of lungs
- PAOP < 18 mm Hg or no evidence of increased left-atrial pressure
- No evidence of COPD
- No other explanation for above
ARDS: Treatment

- Optimal ventilation / oxygenation
- Avoid over hydration
- No routine use of steroids
- Pulmonary vasodilators

High Mortality Persists so Prevention Remains Key

Drugs Used to Decrease Right Sided Afterload / Treat Pulmonary Hypertension

- Oxygen
- Pulmonary vasodilators
  - NTG
  - Sodium nitroprusside
  - Inhaled nitric oxide
  - See medications used in the treatment of pulmonary artery hypertension
Mechanical Ventilator Management Strategies for ARDS

- Lower tidal volume ventilation
  - Permissive hypercapnia
- Maintain plateau pressure < 30 mmHg

- Uninterrupted PEEP
- Avoidance of auto PEEP

- Airway pressure release ventilation
- High frequency ventilation (Oscillatory)
- Independent lung ventilation
- ECMO

Case Example

- 65 year old female; 85 kg
- Post witnessed cardiac arrest
- Initial PaO₂ / FIO₂ ratio 102

- Initial diagnosis?
Case Example

- Ventilator settings:
  - AC
  - Rate 12
  - TV 700 ml
  - FIO2 80%
  - PEEP 5 cm

- 2nd ABG
  - pH – 7.33
  - PaCO2 – 40 mmHg
  - HCO3 – 14
  - PaO2 - 92

- Ventilator adjustment?

- Other treatment considerations?

Pulmonary Hypertension

- PPH (primary pulmonary hypertension)
- IPAH (idiopathic pulmonary arterial hypertension)
- Rare disease

- Perhaps caused by insult to endothelium in patient with susceptibility to pulmonary vascular injury
  - Vascular scarring
  - Endothelial dysfunction
  - Intimal and medial smooth muscle proliferation
Pathophysiology

- Early: Pulmonary artery pressures continue to increase due to increasing work of right ventricle
- Then: Thrombotic pulmonary arteriopathy
  - In situ thrombosis of small muscular pulmonary arteries
- Later: Plexogenic pulmonary arteriopathy
  - Remodeling of pulmonary vasculature with intimal fibrosis

Associated Conditions

- Portal hypertension
- Connective tissue diseases
  - Associated
- Anorexigens
- Alpha adrenergic stimulants (i.e. cocaine / amphetamines)
- HIV
IPAH has no cure
- Untreated leads to right sided heart failure and death
- New drugs have improved survival rates
  - Prostacyclin analogues
  - Endothelin receptor antagonists

APAH occurs more frequently than IPAH
- 15-20% have familial component

Females are affected more than males
- Women of child bearing age more often affected.

Presentation
- Average time from symptom onset to diagnosis is 2 years
- Most common symptoms in one study:
  - Dyspnea (60%)
  - Weakness (19%)
  - Recurrent syncope (13%)

Possible Physical finding:
- Increased pulmonic component of 2nd heart sound
- Palpable 2nd heart sound
- Murmurs of pulmonic and tricuspid regurgitation
- Right ventricular heave
- JVD
- Large V waves
- Other signs of right heart failure
- Normal lungs
### Treatment

#### General
- Anticoagulation (Warfarin)
- Digoxin
- Diuretics
- Oxygen with hypoxemia
  - May be of no benefit in left to right shunt

#### Conventional Pulmonary Vasodilators
- Calcium channel blockers
  - Nifedipine / diltiazem
  - Only used in patients who are responders to acute vasodilator testing (25%)
  - High doses are used
  - Can have rebound pulmonary hypertension when withdrawn
  - Only in patients without overt right sided heart failure

### Approved Pulmonary Vasodilators for PPH

- **Epoprostenol (Flolan)**
  - IV - Parental
  - Prostacyclin analogue (prostanoid)

- **Treprostinil (Remodulin)**
  - IV / SQ – Parental
  - Prostacyclin analogue (prostanoid)

- **Iloprost (Ventavis)**
  - Nebulized inhalation
  - Prostacyclin analogue (prostanoid)
### Approved Pulmonary Vasodilators for PPH

- **Bosentan (Tracleer)**
  - Oral
  - Endothelin antagonist (ERA)

- **Ambrisentan (Letairis)**
  - Oral
  - Endothelin antagonist (ERA)

- **Sildenafil (Revatio)**
  - Phosphodiesterase (type 5) enzyme inhibitor
  - Oral

### Other Treatment Options

- Single or double lung transplant (cardiac transplant may or may not be needed)
- Atrial septostomy (palliative)
  - Creates right to left shunt
- Cardiopulmonary rehab for mild symptom limited aerobic activity
Closed (Simple) Pneumothorax

- Air enters the intra pleural space through the lung causing partial or total collapse of the lung
  - Between visceral and parietal pleura

Possible etiology

- Primary (no underlying lung disease)
  - Blebs / bullae
  - Smoking
- Secondary (underlying lung disease)
  - Air enters damaged aveoli
  - COPD

- Blunt trauma (lung laceration by rib fracture)
- Positive pressure ventilation (rupture of weak alveoli, bleb or bullous)
- Iatrogenic – from medical procedure

Pathophysiology

- Disruption of normal negative intrapleural pressure
- Lung collapse
  - Decreased vital capacity
- Decreased surface area for gas exchange
- Acute respiratory failure (particularly secondary)

Signs and Symptoms

- Chest pain, dyspnea, cough, tachycardia
- Asymmetrical chest excursion, diminished absent breath sounds on affected side, dramatic increases in peak inspiratory pressures on a mechanical ventilator

Treatment

- Oxygen
- Analgesics
- Observation (asymptomatic, small primary)
- Aspiration (symptomatic small primary)
- Chest Tube Criteria
  - Secondary
**Tension Pneumothorax**

- Accumulation of air into the pleural space without a means of escape causes complete lung collapse and potential mediastinal shift.

**Etiology**
- Blunt trauma
- Positive pressure mechanical ventilation
- Clamped or clotted water seal drainage system
- Airtight dressing on open pneumothorax

**Pathophysiology**
- Air rushes in—cannot escape pleural space
- Creates positive pressure in pleural space
- Ipsalateral lung collapse
- Mediastinal shift $\Rightarrow$ contralateral lung compression $\Rightarrow$ potential tearing of thoracic aorta
- Can also compress heart $\Rightarrow$ decrease RV filling $\Rightarrow$ shock

![Image of heart and lungs]
## Tension Pneumothorax

<table>
<thead>
<tr>
<th>Signs and Symptoms</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similar to closed pneumothorax</td>
<td>Oxygen (100%)</td>
</tr>
</tbody>
</table>
| If mediastinal shift:  
  - Tracheal shift away from affected side  
  - JVD  
  - Hypotension | Emergency decompression  
  - Chest Tube  
  - Other as with closed pneumo |

## Open Pneumothorax

- Air enters the pleural space through the chest wall

**Etiology**
- Penetrating Trauma
Open Pneumothorax

**Pathophysiology and Signs and Symptoms**
- Equilibrium between intrathoracic and atmospheric pressures
- Patient condition depends on size of opening compared to trachea
- The affected lung collapses during inspiration
- May cause a tension pneumothorax
- Subcutaneous emphysema usually present

**Treatment**
- Similar to closed pneumothorax
- Closure of open wound with petroleum jelly gauze
  - End expiration
  - Modification for tension pneumothorax
- Chest tube and water seal drainage

Reflection
Thank you!

Handouts available
www.cardionursing.com