Learning Objectives

• Describe the pathophysiology of acute, chronic, and postoperative respiratory failure
• Identify the pathophysiology of sepsis
• Explain common documentation deficiencies and appropriate instances for querying physicians

Pulmonary System Functions

• Ventilate the alveoli
• Diffuse gases (oxygen and carbon dioxide) in and out of the blood
• Perfuse the lungs
• Purpose: Provide oxygen-rich blood to organs and tissues

Yes SIRS, No SIRS, Deep Cleansing Breaths: Sepsis and Respiratory Failure

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Neurochemical control of ventilation (respiratory center, central and peripheral chemoreceptors)

Functional Components of the Respiratory System

- Neurochemical control of ventilation (respiratory center, central and peripheral chemoreceptors)
- Mechanics of breathing (major and accessory muscles, lung elasticity, airway resistance, alveolar surface tension, work of breathing)
- Gas transport (distribution of ventilation and perfusion, O2 transport, CO2 transport)
- Control of pulmonary circulation (distribution of pulmonary blood flow)

Pulmonary Capillary Bed

- Functions
  - Gas exchange
  - Filter emboli
  - Metabolize vasoactive hormones
- Passive vessels – go with the flow
- Vasoconstriction due to low PAO2
  - No air – why send blood?

**Gas Transport**

- Ventilation
- Diffusion of O₂ in lungs
- Perfusion of systemic capillaries
- Diffusion at tissue level
- CO₂ diffusion/transport is reverse

**Ventilation**

- Ventilation = RR × TV
- Measured by PaCO₂
- Influenced by:
  - Lung volumes
  - Capacities
  - Elastance
  - Airway resistance

**Perfusion**

- Flow = pressure/resistance
  - Actual perfusion occurs in capillaries
- Normal CO = 4–8 L/min
- Factors that can limit perfusion:
  - Gravity
  - Lung zones
  - CO
  - PVR

**Lung Zones**

- Alveolus
- Arteriole
- Capillary
- Venule
Diffusion

- Gas moves from higher to lower $P_D$
- Fick's law:

$$\text{Diffusion} = \frac{\text{Surface area} \times \text{driving pressure} \times \text{solubility}}{\text{Tissue thickness} \times \text{molecular weight}}$$

Oxygen Pressure Gradient

- 104 mmHg
- 64 mmHg gradient
- 40 mmHg
- 104 mmHg

Arterial circulation 95 mmHg

Movement of $O_2$ and $CO_2$ Due to Partial Pressures

- Alveolus oxygenated
- Cell

Diffusion Factors

- Membrane thickness
- Surface area
- Gas solubility
- Gas molecular weight
- Driving pressure
Alveolar Cell

- Alveolar – Arterial Oxygen Gradient
  - A-a gradient = diffusion
  - PAO₂: alveolar oxygen
  - PaO₂: arterial oxygen
  - Normal A-a: 10–20 mmHg + age
  - A-a > normal: lung dysfunction
  - PaO₂/FiO₂ or (P/F) ratio

Oxyhemoglobin Curve

- Increased Affinity
  - ↓ pCO₂
  - ↓ levels 2,3 DPG
- Decreased Affinity
  - Acute acidosis
  - ↑ levels 2,3 DPG

Alveolar Air

- 100% humidity
- CO₂ = 40 mmHg
- 104 mmHg

\[
PAO₂ = P_{O₂} - (PCO₂ + 0.8) \\
P_{O₂} = F_{O₂} (PB - 47)
\]

47 = water vapor pressure

P_{O₂} = inspired oxygen pressure
0.8 = assumed respiratory quotient
Cont.

A-a gradient = PAO₂ - PaO₂ =

\[F_{i}O_{2}(P_{b} - 47) - (PaCO₂ ÷ 0.8)] - PaO₂

A-a Gradient and Age

Normal Arterial Blood Gases

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>PaO₂ (mm Hg)</th>
<th>PaCO₂ (mm Hg)</th>
<th>A-a PO₂ (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>84-95</td>
<td>33-47</td>
<td>4-17</td>
</tr>
<tr>
<td>30</td>
<td>61-92</td>
<td>34-47</td>
<td>5-21</td>
</tr>
<tr>
<td>40</td>
<td>76-90</td>
<td>34-47</td>
<td>10-24</td>
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<tr>
<td>50</td>
<td>75-87</td>
<td>34-47</td>
<td>14-27</td>
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<tr>
<td>60</td>
<td>72-84</td>
<td>34-47</td>
<td>17-31</td>
</tr>
<tr>
<td>70</td>
<td>70-81</td>
<td>34-47</td>
<td>21-34</td>
</tr>
<tr>
<td>80</td>
<td>67-79</td>
<td>34-47</td>
<td>25-38</td>
</tr>
</tbody>
</table>

All values pertain to room air breathing at sea level.


Altitude Affects Attitude (and PaO₂!!!)

P/F Ratio

- \(PaO₂/FiO₂\)
- **Normal** > 380 mmHg
- **ALI**
  - \(PaO₂/FiO₂ ≤ 300\) mmHg
- **ARDS**
  - \(PaO₂/FiO₂ ≤ 200\) mmHg
  - \(PaWP ≤ 18\) mmHg
Example

pH 7.4  PaO₂ 90  PaCO₂ 40  RA

\[ \frac{21}{760 - 47} - \frac{40}{8} \] - 90
\[ .21(713) - 50 - 90 \]
150 - 50 - 90
A-a = 10
PaO₂/FiO₂ = 90/.21 = 428

Causes of Hypoxemia

- Decreased oxygen content of inspired gas
- Alveolar hypoventilation
- Diffusion abnormalities
- V/Q mismatch – most common
- Pulmonary right-to-left shunt

Alveolar Hypoventilation

- ↓ PAO₂  → ↑ PaCO₂
  - Chest trauma
  - CNS depression
  - CNS disorders
  - Neuromuscular disorders
- A-a may be normal
- Correct ventilation
Ventilation/Perfusion

Low V/Q – Shunt

- Common cause for hypoxemia
- A-a gradient is most common measure
- Unoxygenated blood goes from right to left heart
  - Asthma from bronchoconstriction
  - Pulmonary edema
  - Pneumonia
- Hypercapnia generally not a problem
- Severe shunt (ARDS): O₂ refractory

Respiratory Failure

- Defined as inadequate gas exchange
- Hypoxemic: PaO₂ < 60 mmHg
  - Most common
- Hypercapnic: PaCO₂ > 50 mmHg
- Other clinical indicators:
  - Increased work of breathing
  - Intercostal retractions
  - Respiratory rate >28
  - Unable to speak in full sentences
- Acute or chronic

Types of Respiratory Failure

- Type I: Acute hypoxemic respiratory failure
- Type II: Alveolar hypoventilation
- Type III: Due to lung atelectasis
  Also called perioperative respiratory failure
- Type IV: Results from hypoperfusion of respiratory muscles
Respiratory Failure: Common Causes

- **Hypoxemic**
  - COPD
  - Pneumonia
  - Pulmonary edema
  - Pulmonary fibrosis
  - Pneumothorax
  - PE
  - Pulmonary hypertension
  - ARDS
  - Obesity
  - Fat embolism syndrome

  **Treatment:** Treat underlying cause, high flow O2, maximize V/Q match

- **Hypercapnic**
  - COPD
  - Severe asthma
  - Drug overdose
  - Poisonings
  - Myasthenia gravis
  - Polynueropathy
  - Head injury
  - Obesity hypoventilation syndrome
  - Alveolar hypoventilation

Postoperative Respiratory Failure

- **Clinical indicators:** same as respiratory failure
  - Atelectasis, pneumonia, pulmonary edema, PE

- **Risk factors:**
  - Anesthesia
  - Smoking
  - Underlying lung disease
  - Period of hypotension during surgery

- **Treatment:**
  - Incentive spirometry, turning, O2, humidification

Chronic Respiratory Failure

- **Develops over time;**
- **Hypercapnic and hypoxemic**
- **Allows for renal compensation**

- Clinical markers of chronic hypoxemia
  - Polycythemia, cor pulmonale, continuous O2 support
  - Muscle wasting, chronic dyspnea, dyspnea at rest

Chronic Respiratory Failure

- **Chronic hypoxemic resp fail**
  - COPD
  - Pulmonary fibrosis
  - Asthma
  - Pulmonary arterial HTN
  - Granulomatous lung diseases
  - Bronchiectasis
  - Obesity

- **Chronic hypercapnic resp fail**
  - COPD
  - Severe asthma
  - Myasthenia gravis
  - Polynueropathy
  - Polio
  - Head, cervical spine injuries
  - Obesity hypoventilation syndrome

- **Treatment:** oxygen, bronchodilators, corticosteroids, adequate nutrition, lung transplant
Improving Documentation

• Clinically credible queries
• Include: clinical indicators, risk factors, treatment
• Differentiate between acute and chronic respiratory failure
• Respiratory documentation processes
• Capturing mechanical ventilation
• Respiratory failure cannot be used as PDx with sepsis, postpartum embolism, poisoning, or HIV/AIDS

Inflammation

• Inflammation is the most important pathological process, comprising the majority of the results of disease …

It is impossible to give a strictly accurate and complete definition of inflammation … which is essentially beneficial in its nature or purpose but may sometimes do harm.

- Robert Muir, 1909

Severe Sepsis: A Healthcare Challenge

• Major cause of morbidity and mortality worldwide
• > 750,000 cases/yr of severe sepsis in the U.S.
• > 500 patients die of severe sepsis daily
**IIR – Inflammatory/Immune Response**

- **Purpose**
  - Protect body from invading pathogens
  - Limit extent of injury
  - Promote rapid healing
- **One of the body’s most complicated homeostatic mechanisms**
  - Humoral
  - Cellular
  - Biochemical

**Defense Lines**

- **External**
  - Intact epithelial barriers – skin, GI, resp, GU, ear
  - Surface secretions – Zasloff’s frogs
  - Body chemicals
  - Neuro reflexes, flushing mechanisms
- **Inflammation**
- **Specific immune response**
  - Cell-mediated immunity – B cells and T cells

**Neuroendocrine Response to Stress**

**Stressor**

- **Sympathetic NS**
  - Adrenal medulla
    - Epinephrine
    - Norepinephrine
  - Renin
  - AT I to AT II
  - Pharyngeal gland
  - Adrenal cortex
  - Cortisol

- **HPA axis**
  - Pituitary gland
  - Vasopressin
  - Aldosterone

**Inflammation**

- **Goal:** move nutrients and IIR cells to injured site
- **Initiated by any cellular injury**
  - Burns, trauma, abscess, ischemic/necrotic tissue, DIC, MI, endotoxin release, global/regional perfusion deficits
- **Following injury:** interlocking plasma cascades, cells and mediator release produce rapid, highly amplified, nonspecific response to varying triggers
Mast cell degranulation

Vascular permeability (edema)

Vasodilation (redness, heat)

Cellular injury

Activation of plasma systems

Complement clotting (psus)

Stimulation of nerve endings (pain)

Release of cellular components

Stimulation of plasma systems

Complement clotting

Vascular permeability

Stimulation of nerve endings

Release of cellular components

The Infection Continuum

Where does your patient fit on the infection continuum?

The Infection Continuum: Clinical Indicators

- Carefully consider whether your patient meets the criteria for sepsis
- Sepsis is a systemic inflammatory response to an infection and may manifest with:

<table>
<thead>
<tr>
<th>Temp</th>
<th>Pulse</th>
<th>Resp</th>
<th>WBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;96.8</td>
<td>&gt;90</td>
<td>&gt;20</td>
<td>&gt;12K or &lt;4K or &gt;10 Bands</td>
</tr>
</tbody>
</table>

SIRS criteria:

- 2 or more
- Temp: <97 (36°C) or >100.4 (38°C)
- Resp: >20 breaths/min
- Pulse: >90 bpm
- WBC: >12K or <4K or Bands >10%

Key points
- Sepsis and septicemia are not synonymous
- Sepsis is defined as an infection that causes systemic inflammation in the host—does not necessarily manifest if symptoms are present
- Sepsis is defined as systemic disease that is due to the presence of pathogens/microorganisms or toxins in the blood
- implies generally a high risk of mortality
- presence of systemic inflammatory response syndrome due to infection

Sepsis = SIRS due to infection

Examples
- Persistent infection
- CDS with new infiltrates
- Abscess
- Bacterial or viral endocarditis
- Evidence of infected mechanical hardware
- Device present—Foley catheter, PD catheter, IV line
- Endocarditis
- Metapneumonia
- Bone/joint infection
- Endocarditis

Severe sepsis = sepsis + organ dysfunction

Examples
- Brain—acute mental status change
- Lung—acute respiratory distress syndrome (ARDS)
- Heart—acute myocardial ischemia
- Liver—jaundice, variable glucose
- Kidney—acute oliguria, increasing creatinine
- Coagulopathy—bleeding, thrombocytopenia

Septic shock = severe sepsis + hypotension

References:
- Coding Clinic 4Q 2007 p 344
- Coding Clinic 2Q 2000 p 3-4
- Bone et al: 1992 Definitions for sepsis and organ failure and guidelines for the new use of innovative therapies in sepsis. The ACCP/SCCM. Chart 20; 1644-2655

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Relationship of Infection, SIRS, Sepsis, and Severe Sepsis

Sepsis

Severe sepsis

Infection

Other

Pancreatitis

Trauma

Burns

SIRS


Identifying Acute Organ Dysfunction as a Marker of Severe Sepsis

Altered consciousness

Confusion

Psychosis

Tachypnea

PaO₂ <70 mmHg

SVO₂ <60%

PaO₂/FIO₂ <300

Tachycardia

Hypotension

Altered CVP

Altered PAOP

Oliguria

Anuria

Creatinine

Jaundice

Enzymes

Abnormal PT

Platelets

PT/PTT

Protein C

D-dimer

Adapted from Solberg WA, Crit Care Med 2000; 28:S27–42.

Sepsis: Risk Factors

- Age extremes
- Compromised immune system
  - Malignancy
  - DM
  - Malnutrition
  - Cytotoxic chemotherapy
- Increased use of Invasive Procedures
- Increased antibiotic resistant organisms

Sepsis: Clinical Picture

- Perfusion imbalance
  - Vasodilation, ↓ SVR
  - ↑ Capillary permeability, hypovolemia
  - Anaerobic metabolism
  - Tissue edema, vasoconstriction, microthrombi
  - Organ and tissue hypoperfusion
  - Coagulopathy

Adapted from Solberg WA, Crit Care Med 2000; 28:S27–42.
Clinical Picture

- **Myocardial alterations**
  - Depressed myocardial performance
  - Impaired contractility, ↓ EF
  - ↓ responsiveness to catecholamines
- **Pulmonary alterations**
  - Initial bronchoconstriction: pulm HTN, WOB
  - Vascular permeability: hypoxemia, risk for ARDS
  - PAO$_2$/FiO$_2$ < 250

Patient Management

- **Primary goal:** Maximize oxygen delivery above the cellular oxygen consumption requirements
- **Prevention, early identification of infectious and inflammatory stimuli**
  - Hand washing
  - Meticulous wound, IV, line care
  - Maintain gut and skin integrity
- **Antibiotics**

Arterial Volume Resuscitation

- MAP, UO, HR
- Oxygen
- Volume
- Pressors: Dopamine, Levo, Epi, Neosynephrine
- Arterial pH vs. base deficit and lactate
  - Base deficit: calculated
  - Normal: 0 ± 2    Mild -3 to -5
  - Moderate -6 to -9    Severe -10

Compliance Documentation

- **Consider entire clinical picture**
- **SIRS:** systemic indicators vs. other etiology
- **Sepsis syndrome**
- **Ensure medical documentation supports medical diagnoses of sepsis (clinical indicators, risk factors, treatment)**
Thank you. Questions?

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