Lecture Outline

- Basics of the Respiratory System
  - Functions & functional anatomy
- Gas Laws
- Ventilation
- Diffusion & Solubility
- Gas Exchange
  - Lungs
  - Tissues
- Gas Transport in Blood
- Regulation of Ventilation & Impacts on
  - Gas levels, pH

Basics of the Respiratory System

General Functions

- Exchange of gases
  - Directionality depends on gradients!
    - Atmosphere to blood
    - Blood to tissues
- Regulation of pH
  - Dependent on rate of CO₂ release
- Protection
- Vocalization
- Synthesis

Respiration

- What is respiration?
  - Respiration = the series of exchanges that leads to the uptake of oxygen by the cells, and the release of carbon dioxide to the lungs
    - Step 1 = ventilation
    - Inspiration & expiration
    - Step 2 = exchange between alveoli (lungs) and pulmonary capillaries (blood)
      - Referred to as External Respiration
    - Step 3 = transport of gases in blood
    - Step 4 = exchange between blood and cells
      - Referred to as Internal Respiration
  - Cellular respiration = use of oxygen in ATP synthesis
Basics of the Respiratory System

Functional Anatomy

- What structural aspects must be considered in the process of respiration?
  - The conduction portion
  - The exchange portion
  - The structures involved with ventilation
    - Skeletal & musculature
    - Pleural membranes
    - Neural pathways

- All divided into
  - Upper respiratory tract
    - Entrance to larynx
  - Lower respiratory tract
    - Larynx to alveoli (trachea to lungs)

Basics of the Respiratory System

Functional Anatomy

- Bones, Muscles & Membranes
  - Create and transmit a pressure gradient
    - Relying on
      - the attachments of the muscles to the ribs (and overlying tissues)
      - The attachment of the diaphragm to the base of the lungs and associated pleural membranes
      - The cohesion of the parietal pleural membrane to the visceral pleural membrane
      - Expansion & recoil of the lung and therefore alveoli with the movement of the overlying structures
Basics of the Respiratory System
Functional Anatomy

• Pleural Membrane Detail
  – Cohesion between parietal and visceral layers is due to serous fluid in the pleural cavity
    • Fluid (30 ml of fluid) creates an attraction between the two sheets of membrane
    • As the parietal membrane expands due to expansion of the thoracic cavity it “pulls” the visceral membrane with it
      – And then pulls the underlying structures which expand as well
    • Disruption of the integrity of the pleural membrane will result in a rapid equalization of pressure and loss of ventilation function = collapsed lung or pneumothorax

Basics of the Respiratory System
Functional Anatomy

• The Respiratory Tree
  – connecting the external environment to the exchange portion of the lungs
  – similar to the vascular component
  – larger airway = higher flow & velocity
    • small cross-sectional area
  – smaller airway = lower flow & velocity
    • large cross-sectional area

<table>
<thead>
<tr>
<th>Name</th>
<th>Division</th>
<th>Diameter (mm)</th>
<th>How many?</th>
<th>Gross-sectional area (cm²)</th>
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<td>Conducting system</td>
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<td>Trachea</td>
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<td>Smaller bronchi</td>
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<td>6-11</td>
<td>5-10</td>
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<td>Bronchioles</td>
<td>12-23</td>
<td>0.5-1</td>
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<td>10⁴</td>
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<td>Alveoli</td>
<td>24</td>
<td>0.3</td>
<td>3 x 10⁹</td>
<td>1 x 10⁹</td>
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conductive portion
exchange portion
Basics of the Respiratory System

Functional Anatomy

• What is the function of the upper respiratory tract?
  – Warm
  – Humidify
  – Filter
  – Vocalize

• Characteristics of exchange membrane
  – High volume of blood through huge capillary network results in
    • Fast circulation through lungs
      – Pulmonary circulation = 5L/min through lungs….
      – Systemic circulation = 5L/min through entire body!
    • Blood pressure is low…
      – Means
        » Filtration is not a main theme here, we do not want a net loss of fluid into the lungs as rapidly as the systemic tissues
        » Any excess fluid is still returned via lymphatic system
Basics of the Respiratory System

Functional Anatomy

• Sum-up of functional anatomy
  – Ventilation?
  – Exchange?
  – Vocalization?
  – Protection?

Respiratory Physiology

Gas Laws

• Basic Atmospheric conditions
  – Pressure is typically measured in mm Hg
  – Atmospheric pressure is 760 mm Hg
  – Atmospheric components
    • Nitrogen = 78% of our atmosphere
    • Oxygen = 21% of our atmosphere
    • Carbon Dioxide = .033% of our atmosphere
    • Water vapor, krypton, argon, … Make up the rest

• A few laws to remember
  – Dalton’s law
  – Fick’s Laws of Diffusion
  – Boyle’s Law
  – Ideal Gas Law

Respiratory Physiology

Gas Laws

• Dalton’s Law
  – Law of Partial Pressures
    • “each gas in a mixture of gases will exert a pressure independent of other gases present”
    Or
    • The total pressure of a mixture of gases is equal to the sum of the individual gas pressures.
  – What does this mean in practical application?
    • If we know the total atmospheric pressure (760 mm Hg) and the relative abundances of gases (% of gases)
      – We can calculate individual gas effects!
      – \( P_{\text{gas}} \times \% \text{ of gas in atmosphere} = \text{Partial pressure of any atmospheric gas} \)
        » \( P_{O_2} = 760 \text{mmHg} \times 21\% \times .21 = 160 \text{ mmHg} \)
    • Now that we know the partial pressures we know the gradients that will drive diffusion!

• Fick’s Laws of Diffusion
  – Things that affect rates of diffusion
    • Distance to diffuse ✓
    • Gradient sizes ✓
    • Diffusing molecule sizes ✓
    • Temperature ✓
  – What is constant & therefore out of our realm of concern? ✓
    • So it all comes down to partial pressure gradients of gases… determined by Dalton’s Law!
Respiratory Physiology
Gas Laws

• Boyle’s Law
  – Describes the relationship between pressure and volume
    • “the pressure and volume of a gas in a system are inversely related”
    • $P_1V_1 = P_2V_2$

Respiratory Physiology
Gas Laws

• How does Boyle’s Law work in us?
  – As the thoracic cavity (container) expands the volume must up and pressure goes down
    • If it goes below 760 mm Hg what happens?
  – As the thoracic cavity shrinks the volume must go down and pressure goes up
    • If it goes above 760 mm Hg what happens

Respiratory Physiology
Gas Laws

• Ideal Gas law
  – The pressure and volume of a container of gas is directly related to the temperature of the gas and the number of molecules in the container
  – $PV = nRT$
    • $n =$ moles of gas
    • $T =$ absolute temp
    • $R =$ universal gas constant @ 8.3145 J/mol K
  – Do we care?

Ventilation

• Terminology
  – Inspiration = the movement of air into the respiratory tracts (upper & lower)
  – Expiration = movement of air out of the respiratory tracts
  – Respiratory cycle is one inspiration followed by an expiration

• Cause of Inspiration?
  – Biological answer
    • Contraction of the inspiratory muscles causes an increase in the thoracic cavity size, thus allowing air to enter the respiratory tract
  – Physics answer
    • As the volume in the thoracic cavity increases (due to inspiratory muscle action) the pressure within the respiratory tract drops below atmospheric pressure, creating a pressure gradient which causes molecular movement to favor moving into the respiratory tract
  – Cause ofExpiration?
Ventilation

Besides the diaphragm (only creates about 60-75% of the volume change) what are the muscles of inspiration & expiration?

What is the relationship between alveolar pressure and intrapleural pressure and the volume of air moved?

• What are the different respiratory patterns?
  – Quiet breathing (relaxed)
  – Forced inspirations & expirations

• Respiratory volumes follow these respiratory patterns…
Ventilation

• Inspiration
  – Occurs as alveolar pressure drops below atmospheric pressure
    • For convenience atmospheric pressure = 0 mm Hg
      – A (-) value then indicates pressure below atmospheric P
      – A (+) value indicates pressure above atmospheric P
    • At the start of inspiration (time = 0),
      – atmospheric pressure = alveolar pressure
        » No net movement of gases!
    • At time 0 to 2 seconds
      – Expansion of thoracic cage and corresponding pleural membranes and lung tissue causes alveolar pressure to drop to -1 mm Hg
      – Air enters the lungs down the partial pressure gradient

Ventilation

• Expiration
  – Occurs as alveolar pressure elevates above atmospheric pressure due to a shrinking thoracic cage
    • At time 2-4 seconds
      – Inspiratory muscles relax, elastic tissue of corresponding structures initiates a recoil back to resting state
      – This decreases volume and correspondingly increases alveolar pressure to 1 mm Hg
        » This is above atmospheric pressure, causing…?
    • At time 4 seconds
      – Atmospheric pressure once again equals alveolar pressure and there is no net movement

Ventilation

• Both inspiration and expiration can be modified
  – Forced or active inspiration
  – Forced or active expiration

  – The larger and quicker the expansion of the thoracic cavity, the larger the gradient and
    • The faster air moves down its pressure gradient

Ventilation

• Things to consider
  – surfactant effect
  – airway diameter

  – Minute volume respiration (ventilation rate times tidal volume) & anatomical dead space
    • Leading to a more accurate idea of alveolar ventilation rates

  – Changes in ventilation patterns
Ventilation

- Surfactant is produced by the septal cells
  - Disrupts the surface tension & cohesion of water molecules
  - Impact?
    - Prevents alveoli from sticking together during expiration

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**Ventilation**

- **Airway diameter** & other factors that affect airway resistance?

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<th>FACTOR</th>
<th>AFFECTED BY</th>
<th>MEDIATED BY</th>
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<tr>
<td>Length of the system</td>
<td>Constant; not a factor</td>
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<tr>
<td>Viscosity of air</td>
<td>Usually constant; humidity &amp; alti-</td>
<td>Mucus and other factors</td>
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<tr>
<td>Diameter of airways</td>
<td>tude may alter slightly</td>
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<td>Upper airways</td>
<td>Physical obstruction</td>
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<td>Bronchioles</td>
<td>Bronchoconstriction</td>
<td>Parasympathetic neurons (muscarinic receptors), histamine, leukotrienes</td>
</tr>
<tr>
<td>Bronchodilation</td>
<td>Carbon dioxide, epinephrine (β2 receptors)</td>
<td></td>
</tr>
</tbody>
</table>

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**Next Time…**

- Diffusion and Solubility
  - Gas composition in the alveoli
- Gas exchange
- Gas transport in blood
- Regulation of pulmonary function