Blood Gas Homeostasis

- Ventilation – alveolar ventilation to keep gas composition at alveolar:pulmonary capillary respiratory membrane constant
- Diffusion – move respiratory gasses across alveolar:pulmonary capillary (respiratory membrane) and systemic capillary: (ISF) tissue membrane
- Transport – how O₂ and CO₂ are carried in blood
  - Dissolved in liquid
  - Attached to Hemoglobin
- Regulation – what variables are “monitored”; how are monitored variables fixed when not in normal range

Respiration

- General function of system is not “respiraration” but keeping blood gasses within homeostatic range of normal
  - Maintain constant arterial PO₂ and PCO₂

SYMBOLS TO KNOW

\[ P = \text{partial pressure}* \text{ of a gas in a mixture mmHg} \]
\[ A = \text{alveolar} \quad P_AO_2 \quad P_ACO_2 = P_{\text{alveolar}O_2} \quad P_{\text{alveolar}CO_2} \]
\[ a = \text{arterial} \quad P_aO_2 \quad P_aCO_2 = P_{\text{arterial}O_2} \quad P_{\text{arterial}CO_2} \]
\[ v = \text{venous} \quad P_vO_2 \quad P_vCO_2 = P_{\text{venous}O_2} \quad P_{\text{venous}CO_2} \]

*partial pressure = % gas in mixture x atmospheric pressure measured in millimeters of mercury (mmHg)
Pressure exerted by atmospheric air above Earth's surface.

Mercury (Hg) at sea level:
- 760 mm
- 29.9 inch
- 2.49 feet

Pressure at sea level:
- Mercury (Hg)
- Vacuum

Fig. 12-7, p. 350
Homeostatic values for respiratory gases at sea level (760 mmHg)

- $P_{\text{ATM}} \text{O}_2 = 159 \text{ mmHg}$
- $P_a \text{O}_2 = 100-104 \text{ mmHg}$
- $PaO_2 = 100-95 \text{ mmHg}$
- $PvO_2 = 40 \text{ mmHg}$

- $P_{\text{ATM}} \text{CO}_2 = .228 \text{ mmHg}$
- $P_a \text{CO}_2 = 40 \text{ mmHg}$
- $PaCO_2 = 40 \text{ mmHg}$
- $PvCO_2 = 46 \text{ mmHg}$

O\text{2} = 20.93%  
CO\text{2} = 0.03%  
N\text{2} = 79.04%  
all else ignored in atmosphere  
in body, H\text{2}O is a gas in mixture

760 x 20.93% = 159.07 mmHg  
230 x 20.93% = 48.15 mm Hg
CONDUCTING ZONE

F = \Delta PR
Warm
Clean
Humidify
Lecture

Exchange Zone
Diffusion by individual P_{gas}
Flux = (SAx \Delta P x K_p)/SAxDist

Ficks Law of Diffusion

<table>
<thead>
<tr>
<th>Name of branches</th>
<th>Number of tubes in branch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trachea</td>
<td>1</td>
</tr>
<tr>
<td>Bronchi</td>
<td>2</td>
</tr>
<tr>
<td>Bronchioles</td>
<td>4</td>
</tr>
<tr>
<td>Bronchioles</td>
<td>8</td>
</tr>
<tr>
<td>Terminal bronchioles</td>
<td>16</td>
</tr>
<tr>
<td>Terminal bronchioles</td>
<td>32</td>
</tr>
<tr>
<td>Respiratory bronchioles</td>
<td>32</td>
</tr>
<tr>
<td>Alveolar ducts</td>
<td>5 x 10^5</td>
</tr>
<tr>
<td>Alveolar ducts</td>
<td>8 x 10^5</td>
</tr>
</tbody>
</table>
Respiratory Airways

- Trachea and larger bronchi
  - Fairly rigid, nonmuscular tubes
  - Rings of cartilage prevent collapse
- Bronchioles: important in AIRWAY RESISTANCE
  - No cartilage to hold them open
  - Walls contain smooth muscle innervated by autonomic nervous system
  - Affected by circulating hormones and local chemicals

Alveoli

- Thin-walled inflatable sacs
- Function in gas exchange
- Walls consist of a single layer of flattened Type I alveolar cells
- Pulmonary capillaries encircle each alveolus
- Type II alveolar cells secrete pulmonary surfactant
- Alveolar macrophages guard lumen
- Pores of Kohn permit airflow between adjacent alveoli (collateral ventilation)
Blood Gas Homeostasis

- Ventilation – alveolar ventilation to keep gas composition of alveoli constant
- Diffusion – respiratory gasses across respiratory and tissue membranes
- Transport – how O2 and CO2 are carried in blood
- Regulation – what variables are “monitored”; how are monitored variables fixed when not in normal range
Bulk Flow of Air to/from alveoli

Air Flow = Pressure Difference/Airway Resistance

- **Inspiration (inhalation):** Contraction of skeletal muscles alters dimensions of thoracic cavity to create area of lower (than atmospheric) pressure in the body; air flows in

- **Expiration (exhalation):** Passive recoil of thoracic cavity creates an area of higher (than atmospheric) pressure in body; air flows out

- All air is a mixture of gases
Lung Volumes and Capacities
Active Inspiration and Expiration: Bigger volumes than quiet resting ventilation or faster volumes than quiet resting ventilation require additional muscular contraction and increase the work of breathing.

### Oxygen Cost of Ventilation
- **Rest**: 0.5 ml O₂/liter air, 6L/min
- **Moderate**: 0.8 ml O₂/liter air, ~50L/min
- **Heavy**: 2.0 ml O₂/liter air, ~100L/min

Maximal Voluntary Ventilation: Uffda

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**Slow Lung Volumes are related primarily to body size**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Typical Value*</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Respiratory Volumes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidal volume (TV)</td>
<td>500 mL</td>
<td>Amount of air inhaled or exhaled in one breath</td>
</tr>
<tr>
<td>Inspiratory reserve volume (IRV)</td>
<td>3600 mL</td>
<td>Amount of air in excess of tidal inspiration that can be inhaled with maximum effort</td>
</tr>
<tr>
<td>Expiratory reserve volume (ERV)</td>
<td>1200 mL</td>
<td>Amount of air in excess of tidal expiration that can be exhaled with maximum effort</td>
</tr>
<tr>
<td>Residual volume (RV)</td>
<td>1200 mL</td>
<td>Amount of air remaining in the lungs after maximum expiration; keeps alveoli inflated between breaths and mixes with fresh air on next inspiration</td>
</tr>
<tr>
<td><strong>Respiratory Capacities</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vital capacity (VC)</td>
<td>4700 mL</td>
<td>Amount of air that can be exhaled with maximum effort after maximum inspiration (ERV + TV + IRV); used to assess strength of thoracic muscles as well as pulmonary function</td>
</tr>
<tr>
<td>Inspiratory capacity (IC)</td>
<td>3500 mL</td>
<td>Maximum amount of air that can be inhaled after a normal tidal expiration (TV + IRV)</td>
</tr>
<tr>
<td>Functional residual capacity (FRC)</td>
<td>2400 mL</td>
<td>Amount of air remaining in the lungs after a normal tidal expiration (RV + ERV)</td>
</tr>
<tr>
<td>Total lung capacity (TLC)</td>
<td>5900 mL</td>
<td>Maximum amount of air the lungs can contain (RV + VC)</td>
</tr>
</tbody>
</table>

*Typical value at rest
Slow Lung Volumes are related primarily to body size

<table>
<thead>
<tr>
<th>Volume Type</th>
<th>Value (mL/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal volume</td>
<td>7</td>
</tr>
<tr>
<td>Vital capacity</td>
<td>60</td>
</tr>
<tr>
<td>Functional residual capacity</td>
<td>35</td>
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<tr>
<td>Breaths/min</td>
<td>12</td>
</tr>
<tr>
<td>Dead space</td>
<td>2</td>
</tr>
<tr>
<td>Alveolar ventilation</td>
<td>60</td>
</tr>
</tbody>
</table>

Dynamic (Timed) Lung Volumes are used to assess status of ventilatory function
Flow Volume Loop

Properties of Lung Tissue Influence Ventilation Process

- Compliance
- Airway Resistance
Compliance: ΔVolume/ΔPressure

Lung Compliance: Elastic Fibers

This balloon, which is made of stiffer rubber, is more difficult to inflate; thus, the balloon has low compliance. Low lung compliance occurs in some pathological conditions, such as fibrosis, in which increasing amounts of less flexible connective tissue develop.

Click either person to repeat the demonstration.

Lung Compliance: Surfactant from Type II Alveolar Cells increases compliance by decreasing tendency of alveoli to collapse due to surface tension (attraction between water molecules)
• Compliance also varies within the lung according to the degree of inflation and “level” of lung
  – Best compliance in the mid-expansion range.
  – Poor compliance is seen at low volumes (because of difficulty with initial lung inflation)
  – Poor compliance at high volumes (because of the limit of chest wall expansion)
Properties of Lung Tissue Influence Ventilation Process

• Summary:
  – Compliance: increased compliance makes ventilation easier as lung pressure for a given volume

• Airway Resistance
  – Air flow through upper airways by bulk flow
  Flow = Pressure Difference/Resistance
  = \Delta P/R
  – AIRWAY RESISTANCE IS NORMALLY VERY LOW

Flow = \Delta P/Resistance
• Cardiac Output:
  5 liters = 93MAP/18TPR
  20 liters = 100MAP/5TPR
• Ventilation
  6 liters = 2mm\Delta P/.33 RU
  100 liters = 4mm\Delta P/.04 RU

AIRWAY RESISTANCE IS NORMALLY VERY LOW
INCREASED AIRWAY RESISTANCE = DISEASE

- NASAL CONGESTION (COLD)
- BRONCHOSPASM
- (REACTIVE AIRWAY DISEASE)
- CHRONIC OBSTRUCTIVE AIRWAY DISEASE
  - BRONCHITIS
- ASTHMA: abnormal airway response to some “triggerS” inflammation in the airways.
  Smooth muscles surrounding the airways contract, the lining of the air passages swells
  - Animals (pet hair or dander)
  - Dust
  - Changes in weather (most often cold weather)
  - Chemicals in the air or in food
  - Exercise
  - Mold
  - Pollen
  - Respiratory infections, such as the common cold
  - Strong emotions (stress)
  - Tobacco smoke
  - Aspirin and other nonsteroidal anti-inflammatory drugs (NSAIDs)

SUMMARY

- Muscle activity causes changes in the volume of the thoracic cavity during breathing.
- Changing the thoracic cavity volume causes intrapulmonary and intrapleural pressure changes, which allow air to move from high pressure to low pressure regions.
- Lung compliance is normally high due to the lung’s abundant elastic tissue and surfactant’s ability to lower the surface tension of the alveolar fluid.
- Airway resistance is normally low, but nervous stimulation and chemical factors can change the diameter of bronchioles, thereby altering resistance and airflow.