Respiratory System

- Functions:
  - Gas exchange
  - Regulation of blood pH
  - Protection
  - Vocalization

Structure of the Respiratory System

- Conducting Zone
  - Mouth, nose, pharynx, larynx, trachea, bronchi, bronchioles
  - Brings air up to body temp and high humidity
  - Debris, pathogens caught in mucous and macrophages

- Respiratory Zone
  - Bronchioles, lungs, alveolar sacs
  - Lungs are lobed, surrounded by pleurae
Physical Properties of the Lungs Affect Ventilation

(c) External anatomy of lungs

Right lung is divided into three lobes.
Left lung is divided into two lobes.

(c) Sectional view of chest. Each lung is enclosed in two pleural membranes. The esophagus and aorta pass through the thorax between the pleural sacs.
Properties of the Lung

- Elasticity vs. Compliance (what's the difference?)
- Fibers in the lungs are compliant, but ___________ makes it harder to stretch
- Surface tension increases the work needed to stretch the air-filled lung
- Remember the cause of surface tension?

- ___________ decrease T and increase compliance because they disrupt the cohesive forces between water molecules
- Law of LaPlace: the inward pressure tending to collapse a bubble depends on surface tension and the radius of the bubble
- Respiratory Distress Syndrome

(a) The two bubbles shown have the same surface tension (T). According to the Law of LaPlace, pressure is greater in the smaller bubble.

Law of LaPlace

\[ P = \frac{2T}{r} \]

- Pressure (P)
- Surface tension (T)
- Radius (r)

According to the law of LaPlace, if two bubbles have the same surface tension, the smaller bubble will have higher pressure.

Why would this be a bad thing?
Respiratory distress syndrome of the newborn

Law of Laplace

\[ P = 2 \pi r T \]

- \( P \) = pressure
- \( T \) = surface tension
- \( r \) = radius

According to the law of Laplace, if two bubbles have the same surface tension, the smaller bubble will have higher pressure.

(a) Surfactant (\( \theta \)) reduces surface tension (\( T \)). In the lungs, smaller alveoli have more surfactant, which equalizes the pressure between large and small alveoli.
Properties of the Lung

- Question: What happens if you get a knife through the thoracic cavity and it penetrates the lung?
- Does the lung explode?
- Does the lung collapse?
- Does the lung remain the same?

Properties of the Lung

- Intrathoracic pressure is always negative (so what?)
- Negative pressure created by:
  - Surface tension of alveolar fluid
  - Elasticity of lungs
  - Elasticity of the thoracic wall

![Diagram of the thoracic cavity and lung](image)

Intrapleural pressure is always negative (so what?)
Physical Properties of Airways

- Flow $\propto \Delta P / R$
- Trachea and bronchi are cartilaginous but bronchiole diameters are adjustable

### Factors That Affect Airway Resistance

<table>
<thead>
<tr>
<th>Factor</th>
<th>Affected by</th>
<th>Mediated by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the system</td>
<td>Constant, not a factor</td>
<td></td>
</tr>
<tr>
<td>Viscosity of air</td>
<td>Usually constant, humidity and altitude may alter slightly</td>
<td></td>
</tr>
<tr>
<td>Diameter of airways</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper airways</td>
<td>Physical obstruction</td>
<td>Mucus and other factors</td>
</tr>
<tr>
<td>Bronchioles</td>
<td>Bronchus obstruction</td>
<td>Pharyngeal nerve (bronchial receptors), histamine, leukotrienes</td>
</tr>
<tr>
<td></td>
<td>Bronchiolisation</td>
<td>Carbon dioxide, epinephrine (β2 receptors)</td>
</tr>
</tbody>
</table>
Alveoli

- One cell layer thick
- Three types of alveolar cells:
  - Type I = simple squamous epithelia
  - Type II = surfactant secreting cells
  - Alveolar Macrophages remove debris and pathogens
Gas Laws and Respiration

Air flow is similar to blood flow

Pressure and Volume Relationships

- Gasses move from areas of high pressure to areas of low pressure until equilibrium is reached
- Boyle’s Law: Pressure of a gas is inversely proportional to its volume
  \[ P_1 V_1 = P_2 V_2 \]

Robert Boyle from Ireland (1622 - 1691)
Began college at age 8
He was already fluent in Latin, Greek and French
Boyle’s Law: \( P_1V_1 = P_2V_2 \)
Decreasing volume increases collisions and increases pressure.

0.5 atm  
1.0 atm  
1.5 atm

Mechanics of Breathing: Application of Boyle’s Law
ambient pressure = 1.0 atm

Mechanics of Breathing

- What causes the intrapulmonary pressure to change?
- There's a difference between WHAT YOU DO and WHAT HAPPENS
- (True in all things, not just respiration!)
Mechanics of Breathing

- Quiet Inhalation:
  - Diaphragm contracts and flattens
  - External intercostals and scalene contract to elevate ribs and push sternum anteriorly
  - What happens to thoracic volume? Which direction will air move?

- Quiet Exhalation:
  - Diaphragm relaxes, external intercostals relax. This is passive.
  - What happens to thoracic volume? Which way will air move?
Deep Breathing

- **Deep Inhalation:**
  - Forceful contraction of diaphragm and external intercostals
  - Also, sternocleidomastoid and scalenes contract, lifting the ribs higher
- **Deep Exhalation:**
  - Contraction of internal and external intercostals, external oblique, rectus abdominis, transverse abdominis, internal oblique

Respirometry

Lab: tidal volume, residual volume, vital capacity, etc.
How Much Gas?

Dalton’s Law

- The pressure due to each gas in an air sample is called partial pressure, designated $P$.
- Dalton’s Law: Total pressure of a gaseous mixture = sum of individual gas (partial pressures)
- Partial pressure = $P_{\text{atm}} \times \%$ of gas in atm
  - Ex: $P_{O_2} = 760\text{mm Hg} \times 21\%$

<table>
<thead>
<tr>
<th>Normal Ventilation Values in Pulmonary Medicine</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pulmonary ventilation</td>
<td>6 L/min</td>
</tr>
<tr>
<td>Total alveolar ventilation</td>
<td>4.2 L/min</td>
</tr>
<tr>
<td>Maximum voluntary ventilation</td>
<td>125–170 L/min</td>
</tr>
<tr>
<td>Respiration rate</td>
<td>12–20 breaths/min</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Partial Pressures ($P_{atm}$) of Atmospheric Gases at 760 mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAS AND ITS PERCENTAGE IN AIR</td>
</tr>
<tr>
<td>--------------------------------</td>
</tr>
<tr>
<td>Nitrogen (N₂) 78%</td>
</tr>
<tr>
<td>Oxygen (O₂) 21%</td>
</tr>
<tr>
<td>Carbon dioxide (CO₂) 0.033%</td>
</tr>
<tr>
<td>Water vapor</td>
</tr>
</tbody>
</table>
How Much Gas Will Dissolve in the Blood?

- Henry's Law: the volume of a gas that will dissolve in a liquid is dependent on:
  - 1. Solubility of the gas in the fluid
  - 2. Fluid temperature
  - 3. Partial pressure of the gas

In the body, what varies?

Respiratory Physiology II
Gas Exchange and Gas Transport
Gas Exchange

- Rate of diffusion is proportional to:
  - Distance
  - Surface area
  - Thickness of membrane

**Oxygen solubility**

(a) Initial state: $\text{O}_2$ in solution

(b) Oxygen dissolution

(c) Oxygen equilibration

$P_O = 100 \text{ mm Hg}$

**Carbon dioxide solubility**

(d) When $P_CO_2$ is in equilibrium at the same portal pressure ($100 \text{ mm Hg}$), more $CO_2$ dissolves.
Oxygen Transport in the Blood

- Normal blood: \([\text{Oxygen in plasma}] = 0.3\) ml \(O_2\) / 100 ml blood
- Where’s the oxygen???
Hemoglobin = Taxi

Hemoglobin and Oxygen Transport

- What determines the behavior of a taxi driver?
- (What determines whether a taxi will load or unload passengers?)
What determines which direction the reaction goes?

$$\text{Hb} + \text{O}_2 \leftrightarrow \text{HbO}_2$$

dehemoglobin \hspace{1cm} \text{oxyhemoglobin}

- $P_{O_2}$ of environment
- $O_2$ affinity (driver's mood; lots of things affect mood!)

Hb - $O_2$ Dissociation Curve
There are three ways CO\(_2\) moves from the cells to the lungs.
- as a dissolved gas (depends on P\(_{CO_2}\))
  (about 7% of CO\(_2\))
- \(\text{Hb} \) (accounts for about 23% of the CO\(_2\))

70% of the CO\(_2\) is converted to carbonic acid (H\(_2\)CO\(_3\)) when it comes into contact with water:
\[
\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-
\]
Regulation of Breathing

- Involuntary; controlled by rhythmicity centers in the medulla oblongata and the pons.
- Activity of inspiration and expiration neurons are cyclic.
- Chemoreceptors in the periphery taste the blood.
  - What are they tasting for? (What is most important?)
  - What happens if the breathing rate is incorrect?
Respiratory Diseases

- Inflammatory lung disease is characterized by a high neutrophil count
  - cystic fibrosis, emphysema, chronic obstructive pulmonary disease or acute respiratory distress syndrome
- Obstructive lung disease occurs when the bronchial tubes are narrowed
  - chronic obstructive pulmonary disease
  - asthma

Respiratory Diseases

- Restrictive lung diseases are due to reduced lung compliance, such as Infant Respiratory Distress Syndrome
- Respiratory Infections
  - Upper: a cold, sinusitis, tonsillitis, pharyngitis, laryngitis
  - Lower: pneumonia most common

Respiratory Diseases

- Lung tumors (benign or malignant)
- Pleural cavity diseases (emphysema, pleurisy, pneumothorax)
- Pleural diseases (pulmonary embolism, pulmonary arterial hypertension, pulmonary edema)
Smoking and Death: Statistics from the CDC

Smoking causes death.
- The health effects from cigarette smoking account for an estimated 443,000 deaths, or nearly 1/5 deaths each year in the US.
- More deaths are caused each year by tobacco use than by all deaths from HIV, illegal drug use, alcohol use, motor vehicle injuries, suicides, and murders combined.
- Smoking causes 90% of all lung cancer deaths in men and 80% of all lung cancer deaths in women.
- An estimated 90% of all deaths from chronic obstructive lung disease are caused by smoking.

Smoking and Increased Health Risks

Compared with nonsmokers, smoking increases the risk of:
- coronary heart disease by 2 to 4 times
- stroke by 2 to 4 times
- men developing lung cancer by 23 times
- women developing lung cancer by 13 times, and
- dying from chronic obstructive lung diseases (such as chronic bronchitis and emphysema) by 12 to 13 times.

Smoking and Cardiovascular Disease

- Smoking causes coronary heart disease, the leading cause of death in the United States.
- Cigarette smoking causes narrowing of the arteries and puts smokers at risk of developing peripheral vascular disease (i.e., obstruction of the large arteries in the arms and legs that can cause a range of problems from pain to tissue loss or gangrene).
- Smoking causes abdominal aortic aneurysm (a swelling or weakening of the abdominal aorta).

Smoking and Respiratory Disease

- Smoking causes lung cancer.
- Smoking causes lung diseases (e.g., emphysema, bronchitis, chronic airway obstruction) by damaging the airways and alveoli.

Smoking causes the following cancers:
- Acute myeloid leukemia
- Bladder cancer
- Cervical cancer
- Esophageal cancer
- Renal cancer
- Cancer of the larynx (voice box)
- Lung cancer
- Cancer of the oral cavity (mouth)
- Cancer of the pharynx (throat)
- Stomach cancer
- Uterine cancer

Smoking and Other Health Effects

Smoking is associated with the following adverse health effects:
- infertility
- preterm delivery
- stillbirth
- low birth weight
- sudden infant death syndrome (SIDS)