21.1 OVERVIEW OF THE RESPIRATORY SYSTEM
Classified anatomically into upper and lower tracts:

- **Upper** – passageways from nasal cavity to larynx
- **Lower** – passageways from trachea alveoli
  - **Alveoli** – tiny air sacs, site of gas exchange
  - **Each is a collection of millions of alveoli and their blood vessels embedded in elastic connective tissue**
BASIC FUNCTIONS OF THE RESPIRATORY SYSTEM

- Classified functionally into **conducting** and **respiratory zones**:
  - __________________ - pathway air travels
    - Air is filtered, warmed, and moistened
    - Includes structures from nose and nasal cavity to bronchioles
  - __________________ - where gas exchange occurs; alveoli

![Diagram of the respiratory system](image)
• **Respiration** – process that provides body cells with oxygen and removes waste product carbon dioxide:
  1. **Pulmonary ventilation** – movement of air in and out of lungs
  2. **Pulmonary gas exchange** – movement of gases between lungs and blood
  3. ________________– movement of gases through blood
  4. **Tissue gas exchange** –

• Other functions – serve to maintain homeostasis:
  ▪ Speech and sound production
  ▪ Assist with defecation, urination, and childbirth by increasing pressure in thoracic cavity
  ▪ Assist with flow of venous blood and lymph
  ▪ Maintaining acid-base balance
21.2 Anatomy of the Respiratory System

The Nose and Nasal Cavity

- Nose and nasal cavity are entryway into respiratory system; serve following functions:
  - Filter debris from inhaled air and secrete antibacterial substances
  - Resonates of voice
• Anatomy of nasal cavity:
  - **Nasal cavity** – divided into left and right portions by nasal septum from nostrils (anterior nares) to posterior nares
  - _______________ – contain bristle-like hairs
  - **Superior, inferior, and middle conchae** create turbulence
  - **Paranasal sinuses** – hollow cavities found within frontal, ethmoid, sphenoid, and maxillary bones
    - Warm and humidify air; also enhance voice resonance and reduce weight of skull
• Histology of nasal cavity:
  - **Vestibule** is lined with stratified squamous epithelium; resists mechanical stress
  - Most of nasal cavity is lined with mucosa composed of PSCCE and goblet cells
    - Traps foreign particles in mucus → ciliated cells move it toward posterior nasal cavity and pharynx

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**THE PHARYNX**

• **Pharynx** (throat) – three divisions:
  - ___________ – posterior to nasal cavity; lined with PSCCE
    - Extends from posterior nares to soft palate
  - ___________ – posterior to oral cavity
    - Extends from uvula to hyoid bone
    - stratified squamous epithelium
  - ___________ – **hyoid bone** to **esophagus**
    - stratified squamous epithelium
**THE LARYNX**

- **Larynx** or voice box – houses **vocal cords**
  - Stratified squamous epithelium superior to vocal cords
  - PSCCE found inferior to vocal cords
- Composed of ________ pieces of **cartilage**

The Larynx

- Nasopharynx
- Oropharynx
- Laryngopharynx
- Esophagus
- Nasal cavity
- Oral cavity
- Uvula
- Tongue
- Epiglottis
- Larynx
- Vocal cord
- **Thyroid cartilage** – largest of three unpaired sections ("Adam’s apple")

- _________ cartilage – inferior to thyroid cartilage

- _________ – posterior to thyroid cartilage

Remaining six found pairs:

- **Cuneiform cartilages** – help support epiglottis

- **Arytenoid cartilages** – involved in sound production

- **Corniculate cartilages** – involved in sound production
- **Vestibular folds** (false vocal cords) close off glottis during swallowing; play no role in sound production
- **True vocal cords** and **Vocal ligaments** – elastic bands; vibrate to produce sound when air passes over them

**THE TRACHEA**

- **Trachea (windpipe)** - C shape cartilage rings

- Larynx
- Trachea
- Carina
- Primary bronchi

(a) Trachea and lungs
(b) Cross section through trachea and esophagus
SMOKER’S COUGH

- Deep, rattling cough of a smoker is linked directly to numerous adverse effects of smoke on the respiratory system
- Chemicals in smoke
  - Act as irritants, increasing mucus secretion
  - Partially paralyze and eventually destroy cilia lining tract
- As result, more mucus is present, but cilia are less able to sweep it out of airways
- Cough develops as only way to prevent mucus buildup
- Cilia will reappear within a few months after smoking stops

THE BRONCHIAL TREE

- ________ bronchi (enters the left or right lung at hilum)
  - Right primary bronchus – wider, shorter, and straighter than left
- ________ bronchi once inside each lung; three on right and two on left
- ________ bronchi continue to branch smaller and smaller
- Bronchioles – smallest airways
  - Terminal bronchioles → Respiratory bronchioles
(a) Conducting zone passages and bronchial tree
• As airways divide and get smaller:
  - Epithelium gradually changes from PSCCE to
  - Amount of smooth muscle increases
  - Hyaline cartilage decreases
**ALVEOLI AND THE RESPIRATORY Membrane**

- **Alveolar ducts** → **Alveolar sacs** - grapelike clusters of alveoli (site of gas exchange)

  1. Type I alveolar cells (____________________)
  2. Type II alveolar cells (simple cuboidal cells) produce surfactant
  3. Alveolar macrophages are mobile _________
**THE LUNGS AND PLEURAE**

- Right and left lungs are separated by heart and mediastinum

- Cardiac notch

- __________ – where primary bronchi, blood and lymphatic vessels, and nerves enter and exit lung

- Right lung - three lobes; left lung - two lobes
Each lung is found within a **pleural cavity**

- **________ pleura** – outer layer of serous membrane
- **________ pleura** continuous with surface of lungs

- Pleural membranes secrete a thin layer of **serous fluid** to lubricate surfaces of lungs as they expand and contract
Pleuritis and Pleural Friction Rub

- Many conditions (heart failure to pneumonia) can cause inflammation of the visceral and parietal pleura (pleuritis)
- Pleuritic pain – one of most common symptoms; chest pain with inhalation; results from inflamed pleura rubbing together as lungs expand and contract
- Rubbing can sometimes be heard with stethoscope; termed pleural friction rub; resembles sandpaper rubbing against itself

21.3 Pulmonary Ventilation
THE PRESSURE-VOLUME RELATIONSHIP

- First process of respiration is **pulmonary ventilation**

- The **pressure-volume relationship** provides driving force for pulmonary ventilation
  - Gas molecules move from areas of ________ pressure to areas of ________ pressure

---

- ___________ – pressure and volume of a gas are **inversely** related

  As volume Pressure

  (and vise versa)
# The Process of Pulmonary Ventilation

- Process of pulmonary ventilation consists of **inspiration** and **expiration**

- Volume changes in thoracic cavity and lungs leads to pressure changes and air to move into or out of the lungs

<table>
<thead>
<tr>
<th>Inspiration</th>
<th>Maximal inspiration aided by contraction of sternocleidomastoid, pectoralis minor, and scalenes muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>__________</strong> – main inspiratory muscle</td>
<td><strong>__________</strong> – muscles found between ribs</td>
</tr>
<tr>
<td>External <strong>__________</strong> – muscles found between ribs</td>
<td>These muscles increase thoracic cavity volume along with lung volume</td>
</tr>
</tbody>
</table>
• Expiration is a mostly passive process that does not utilize muscle contraction
  - Diaphragm returns to its original dome shape that pushes up on lungs
  - __________ decrease lung volume and raise intrapulmonary pressure above atmospheric pressure so air flows out of lungs
• Maximum expiration muscles include **internal intercostals** and **abdominal muscles**
  
  ▪ Forcefully decrease size of thoracic cavity; why your abdominal and back muscles are often sore after having a cough

  ▪ **Heimlich maneuver** – delivering abdominal thrusts that push up on diaphragm

• **Nonrespiratory movements**, not intended for ventilation, include yawns, coughs, sighs, sneeze, laughing, hiccups, crying, etc.
• Pressures at work during ventilation:
  - **Atmospheric pressure** – at sea level atmospheric pressure is about 760 mm Hg
  - ______________ pressure – rises and falls with inspiration and expiration
  - **Intrathoracic pressure** – rises and falls with inspiration and expiration; always below intrapulmonary pressure
INFANT RESPIRATORY DISTRESS SYNDROME

• Inadequate surfactant makes alveolar inflation between breaths very difficult

• Surfactant is not produced significantly until last 10–12 weeks of gestation; premature newborns may therefore suffer from infant respiratory distress syndrome (RDS)

• Treatment – delivery of surfactant by inhalation; also positive airway pressure (CPAP); slightly pressurized air prevents alveoli from collapsing during expiration

PULMONARY VOLUMES AND CAPACITIES

• _________ – amount of air inspired or expired during normal quiet ventilation

• _________ – volume of air that can be forcibly inspired after a normal TV inspiration

• _________ – amount of air that can be forcibly expired after a normal tidal expiration (700–1200 ml)

• _________ – air remaining in lungs after forceful expiration
21.4 Gas Exchange
**GAS EXCHANGE**

- Pulmonary ventilation only brings new air into and removes oxygen-poor air from alveoli
- Two processes are involved in gas exchange:
  - ____________ gas exchange involves exchange of gases between alveoli and blood
  - ____________ gas exchange involves exchange of gases between blood in systemic capillaries and body’s cells

**THE BEHAVIOR OF GASES**

- Gas behavior – important factor that affects gas exchange
  1. 
  2. Surface area of respiratory membrane
  3. 
  4. Ventilation-perfusion matching
law of partial pressures – each gas in a mixture exerts its own pressure, called its partial pressure ($P_{\text{gas}}$); total pressure of a gas mixture is sum of partial pressures of all its component gases

$$PN_2 + PO_2 + PO_2 + P_{\text{others}} = \text{Atmospheric pressure (760 mm Hg)}$$

$$PN_2 = 0.78 \times 760 = 593 \text{ mm Hg}$$

$$PO_2 = 0.21 \times 760 = 160 \text{ mm Hg}$$

Partial pressure of a gas in a mixture determines where gas diffuses.

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**PULMONARY GAS EXCHANGE**

Pulmonary gas exchange (external respiration) is diffusion of gases between alveoli and blood;

- Oxygen diffuses from ________ into ________
- Carbon dioxide simultaneously diffuses in opposite direction
  - Blood has a low $PO_2$ (40 mm Hg) while $PO_2$ in air is 104 mm Hg
  - Blood has a high $CO_2$ (45 mm Hg) compared to alveoli air (40 mm Hg)
Oxygen diffusion during gas exchange is

a. from the pulmonary blood into the alveolar air
b. so slow that equilibrium is never reached
c. driven by the gradient between inspired air and alveolar blood
d. less efficient than diffusion of carbon dioxide
**REVIEW**

The efficiency of pulmonary gas exchange is impacted by all of the following EXCEPT

a. Degree of match between air and blood flow
b. Surface area of respiratory membrane
c. Thickness of the respiratory membrane
d. Blood pressure in the pulmonary capillaries

**REVIEW**

The efficiency of pulmonary gas exchange is increased by

a. A mismatch between air and blood flow
b. An increase in respiratory membrane surface area
c. Thickening of the respiratory membrane
d. A decrease in respiratory membrane surface area
**HYPERBARIC OXYGEN THERAPY**

- Person placed in chamber and exposed to *higher than normal partial pressures of oxygen*; increases oxygen levels dissolved in plasma; in turn increases *delivery to tissues*

- Used to treat conditions benefiting from increased oxygen delivery: severe blood loss, crush injuries, anemia (decreased O\textsubscript{2} carrying capacity of blood), chronic wounds, certain infections, burns

- Also used for *decompression sickness* ("bends"); seen in divers who *ascended too rapidly*; caused by dissolved gases in blood coming out of solution and forming bubbles in bloodstream; therapy forces gases *back* into solution, eliminating bubbles

**FACTORS AFFECTING EFFICIENCY OF PULMONARY GAS EXCHANGE**

- *Surface area of respiratory membrane* of both lungs is extremely large (approximately 1000 square feet)
  - Any factor that reduces surface area decreases efficiency of pulmonary gas exchange
  - __________ – low blood oxygen level; sign of severely impaired pulmonary gas exchange
  - __________ – high blood carbon dioxide level; sign of severely impaired pulmonary gas exchange
• **Thickness of respiratory membrane** – distance that a gas must diffuse
  - Thickening of the membrane reduces exchange efficiency (inflammation)

• **Ventilation-perfusion matching** – degree of match between amount of air reaching alveoli (__________) and amount of blood flow (__________) in pulmonary capillaries
  - **Ventilation/perfusion ratio (V/Q)** – measurement that describes this match; when affected by disease, called a mismatch
**Tissue Gas Exchange**

- Tissue gas exchange (internal respiration) is oxygen and carbon dioxide between blood and tissues
  - Cells use oxygen constantly for cellular respiration so __________ in tissue is low
  - Tissues produce large quantities of __________ so partial pressure is high
Factors affecting efficiency of tissue gas exchange include:

- **Surface area available for gas exchange** (of branched systemic capillaries); large enough to allow for gas exchange efficiency

- **Distance over which diffusion must occur**; less distance to diffuse results in more efficient gas exchange

- **Perfusion of tissue** –
21.5 Gas Transport through the Blood

Gas Transport

- Only 1.5% of inspired oxygen is dissolved in blood plasma due to its poor solubility; majority of oxygen is transported in blood plasma by __________
- There are three ways that carbon dioxide is transported
OXYGEN TRANSPORT

• Oxygen transport is facilitated by **hemoglobin (Hb)**
  - _________ carried by Hb
  - Hemoglobin is a protein found in _________
  - Consists of four subunits, each including a **heme group**; each heme contains one iron atom that can bind to one molecule of oxygen

• Hemoglobin binds and releases oxygen
  - Oxygen from alveoli binds to hemoglobin in pulmonary capillaries; **oxyhemoglobin (HbO₂)**
  - Hb in systemic capillaries releases oxygen to cells of tissues
Effect of affinity on hemoglobin saturation is determined by four factors:

1. Lower blood $\text{PO}_2$; unloading reaction is favored as fewer $\text{O}_2$ molecules are available to bind to Hb

2. $\text{PCO}_2$ increase, Hb binds oxygen less strongly so more oxygen is unloaded
3. When pH decreases, Hb binds oxygen less strongly so more oxygen is unloaded.

4. Increasing temperature decreases Hb’s affinity for oxygen; facilitates unloading reaction of oxygen into tissues; reverse also true.
Carbon Dioxide Transport

- Carbon dioxide is transported from tissues to lungs in blood three ways:
  1. Dissolved in plasma (____)
  2. _________ (23%) - CO₂ binds to Hb’s protein component (not heme group that oxygen binds) - carbaminohemoglobin
3. Bicarbonate ions (70%)

- CO₂ quickly diffuses into erythrocytes
- **Carbonic anhydrase (CA)** catalyzes:

- Most HCO₃⁻ diffuses into blood plasma and H⁺ binds to Hb
- HCO₃⁻ carries a negative charge; counteracted by __________ __________; chloride ions move into erythrocytes as bicarbonate ions move out to balance charges

(a) Bicarbonate formation in an erythrocyte in a systemic capillary
The PCO₂ level in blood is determined by the following two factors:

1. _______________ – rate and/or depth of breathing increase; increases amount of CO₂ expired from lungs
   - pH of blood rises; more oxygen may be dissolved in blood as well

2. _______________ – rate and/or depth of breathing decrease; causes retention of CO₂ (increases PCO₂)
   - Blood becomes more acidic; oxygen levels (PO₂) in blood may drop (hypoxemia)
**Carbon Monoxide Poisoning**

- Carbon monoxide (CO) is produced from burning organic compounds; colorless, odorless, tasteless found in smoke from fires, cigarettes, exhaust fumes (from engines, heaters, stoves)

- Binds reversibly with Hb, producing *carboxyhemoglobin*; occupies oxygen binding sites with affinity 200–230 times that of oxygen; small concentrations of CO can therefore cause serious problems

**Carbon Monoxide Poisoning**

- CO binding changes *Hb’s shape*, increasing affinity for oxygen; decreases amount of oxygen released to tissues

- *Symptoms* – confusion, dizziness, nausea; severe cases include seizures, coma, and death

- *Treatment* – 100% oxygen at atmospheric or hyperbaric pressure
1. **Pulmonary ventilation:** Oxygen and carbon dioxide are moved between the air and the alveoli in the lungs (see Figure 21.16).

2. **Pulmonary gas exchange:** Oxygen enters and carbon dioxide exits the blood via the alveoli (see Figure 21.20a).

3. **Gas transport:** Oxygen and carbon dioxide are transported by the blood (see Figures 21.22 and 21.25).

4. **Tissue gas exchange:** Oxygen and carbon dioxide are exchanged between the blood and the tissue cells (see Figure 21.20b).

Oxygen is transported throughout the blood, primarily on hemoglobin.

After tissue gas exchange, most carbon dioxide in the blood is converted to bicarbonate ions and is transported to the lungs to be expired.
21.7 Neural Control of Ventilation

- Breathing usually occurs without conscious thought or control
  - _________ – normal breathing; one of most vital functions body carries out as absence of breathing leads to death
• Control of breathing is by neurons found in brainstem; specialized cells detect and monitor CO₂ levels, H⁺ levels, and O₂ levels in body
• Negative feedback loops and stretch receptors in lungs also ensure oxygen intake and carbon dioxide elimination match metabolic requirements

**CONTROL OF THE BASIC PATTERN OF VENTILATION**

• ___________ controls ventilation; neurons in _________ influence respiratory rhythm
  - **Respiratory rhythm generator (RRG)** – group of neurons that creates basic rhythm for breathing; found within a structure called the **ventral respiratory column**
  - Neurons found in **medullary reticular formation** assist RRG; known as **ventral and dorsal respiratory groups**
- **Ventral respiratory group (VRG)** found in anterior and lateral portion of medulla, contains both inspiratory and expiratory neurons.

  Both nerves also supply certain accessory muscles of inspiration and expiration.

- **Dorsal respiratory group (DRG)** found in posterior medulla; primarily involved in inspiration.
CONTROL OF THE RATE AND DEPTH OF VENTILATION

- ________________ are specialized cells that respond to changes in the concentration of a specific chemical
  - ____PCO₂ or H⁺ concentration triggers hyperventilation
  - ____PCO₂ or H⁺ concentration triggers hypoventilation
  - Most sensitive to PO₂ in arterial blood

- **Central chemoreceptors** – neurons in medullary reticular formation
  - Detects changes in both CO₂ and H⁺ concentrations CSF
(b) Response to decreased arterial $P_{CO_2}$ and/or $H^+$ concentration by a negative feedback loop
### High-Altitude Acclimatization

- **High-altitude acclimatization** allows peripheral chemoreceptors to stimulate an increase in ventilation, permitting body to maintain *acceptable blood PO$_2$ levels*, if elevation is gradually increased over period of days (rather than hours).

  - Requires days because sensitivity of chemoreceptors for low PO$_2$ increases with prolonged exposure; the longer they are exposed to a low PO$_2$, the more they stimulate an increase in ventilation.

  - Allows experienced climbers to reach *great elevations without supplemental oxygen*.

<table>
<thead>
<tr>
<th>STIMULI</th>
<th>CONTROL MECHANISM</th>
<th>EFFECT ON RESPIRATORY CENTERS</th>
<th>EFFECT ON VENTILATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerebral cortex inputs (e.g., emotion)</td>
<td>Voluntary control</td>
<td>+/−</td>
<td>Varied</td>
</tr>
<tr>
<td>Changes in arterial P$_{CO_2}$, H$^+$ concentrations</td>
<td>Central chemoreceptors</td>
<td>+/−</td>
<td>Hyperventilation when P$<em>{CO_2}$ and/or H$^+$ concentrations increase; hypoventilation when P$</em>{CO_2}$ and/or H$^+$ decrease</td>
</tr>
<tr>
<td>Changes in arterial P$_O_2$</td>
<td>Peripheral chemoreceptors</td>
<td>*</td>
<td>Hyperventilation when arterial P$_O_2$ decreases</td>
</tr>
</tbody>
</table>