21.1 Overview of the Respiratory System

- Classified anatomically into upper and lower tracts:
  - __________ – passageways from nasal cavity to larynx
  - __________ – passageways from trachea alveoli
    - __________ – tiny air sacs, site of gas exchange
    - __________ – 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**:
  - __________ zone - pathway air travels
    - Air is filtered, warmed, and moistened
    - Includes structures from nose and nasal cavity to bronchioles
  - __________ zone – where gas exchange occurs; alveoli

- **Respiration** – process that provides body cells with oxygen and removes waste product carbon dioxide:
  1. **Pulmonary ventilation** –
  2. **Pulmonary gas exchange** – movement of gases between ________ and __________
  3. **Gas transport** – movement of gases through blood
4. **Tissue gas exchange** – movement of gases between ___________ and ______________

- Other functions – serve to maintain homeostasis:
  1. 
  2. 
  3. Assist with defecation, urination, and childbirth by increasing pressure in thoracic cavity
  4. Assist with flow of venous blood and lymph
  5. Maintaining acid-base balance
  6. Produces angiotensin-II

→ **21.2 Anatomy of the Respiratory System**

**The Nose and Nasal Cavity**

- Nose and nasal cavity are entryway into respiratory system; serve following functions:
  1. 
  2. Filter debris from inhaled air and secrete antibacterial substances
  3. 
  4. Resonates of voice

- Anatomy of nasal cavity:
  1. ________________ – divided into left and right portions by nasal septum from nostrils (anterior nares) to posterior nares
  2. ___________ – contain bristle-like hairs
  3. **Superior, inferior, and middle conchae** create turbulence
4. ______________ – hollow cavities found within frontal, ethmoid, sphenoid, and maxillary bones
   o Warm and humidify air; also enhance voice resonance and reduce weight of skull

• Histology of nasal cavity:
  1. **Vestibule** is lined with ___________________; resists mechanical stress
  2. Most of nasal cavity is lined with mucosa composed of _____________ and goblet cells
     o Traps foreign particles in mucus → ciliated cells move it toward posterior nasal cavity and pharynx

**The Pharynx**

• **Pharynx** (throat) – three divisions:
  1. ______________ – 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 ______________
• Composed of nine pieces of cartilage
  ▪ _______ cartilage – largest of three unpaired sections (“Adam’s apple”)
  ▪ _______ cartilage – inferior to thyroid cartilage
  ▪ _______________ – posterior to thyroid cartilage

Remaining six found in _____________:
  ▪ 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

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

• **Primary bronchi** (enters the left or right lung at hilum)
  ▪ ___________ primary bronchus – wider, shorter, and straighter than left
  ▪ **Secondary bronchi** once inside each lung; three on right and two on left
  ▪ **Tertiary bronchi** continue to branch smaller and smaller
  ▪ ___________ – smallest airways
  ▪ **Terminal bronchioles → Respiratory bronchioles**
  ▪ As airways divide and get smaller:
    ▪ Epithelium gradually changes from _________ to ________ cells with cilia
    ▪ Amount of smooth muscle increases

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 ______________ are mobile phagocytes
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 - ________ lobes; left lung - ________ lobes

- Each lung is found within a **pleural cavity**
  - ______________ – outer layer of serous membrane
  - ______________ 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 **high** pressure to areas of **low** pressure
• _____________ – pressure and volume of a gas are _____________ 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
  ▪ Inspiration:
    • _______________ – main inspiratory muscle
    • ________________ – muscles found between ribs
      • These muscles increase thoracic cavity volume along with lung volume
    • Maximal inspiration aided by contraction of ________________, ________________, and _______________ muscles
  • 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 _______________ and _______________ 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 _______________

  • **Intrapulmonary pressure** – rises and falls with inspiration and expiration

  • **Intrapleural pressure** – rises and falls with inspiration and expiration; always ____________ intrapulmonary pressure

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**Infant Respiratory Distress Syndrome**

• Inadequate _____________ 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

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**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. Thickness of respiratory membrane
  4. 
  • ____________ of partial pressures – each gas in a mixture exerts its own pressure, called its partial pressure ($P_{gas}$); total pressure of a gas mixture is sum of partial pressures of all its component gases

\[
PN_2 + PO_2 + PCO_2 + Pothers = \text{Atmospheric pressure (760 mm Hg)}
\]

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

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

Partial pressure of a gas in a mixture determines where gas diffuses
Pulmonary Gas Exchange

• Pulmonary gas exchange (respiration) is diffusion of gases between alveoli and blood;
  
  ▪ Carbon dioxide simultaneously diffuses in opposite direction
    o Blood has a low $\text{PO}_2$ (40 mm Hg) while $\text{PO}_2$ in air is 104 mm Hg
    o Blood has a high $\text{CO}_2$ (45 mm Hg) compared to alveoli air (40 mm Hg)

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 $\text{O}_2$ 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
• **Blood carbon dioxide level** – 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 (ventilation) and amount of blood flow (perfusion) in pulmonary capillaries
  
  - Ventilation/perfusion ratio (V/Q) – measurement that describes this match; when affected by disease, called a ____________

**Tissue Gas Exchange**

• Tissue gas exchange (______________ respiration) is oxygen and carbon dioxide between blood and tissues
  
  - Cells use oxygen constantly for cellular respiration so PO₂ in tissue is low
  
  - Tissues produce large quantities of PCO₂ so partial pressure is high

**Factors affecting efficiency of tissue gas exchange include:**

- ____________ 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

- ____________ of tissue – greater blood supply results in more efficient gas exchange
21.5 Gas Transport through the Blood

Gas Transport

• Only _______ of inspired oxygen is ___________ in blood plasma due to its poor solubility; majority of oxygen is transported in blood plasma by hemoglobin

• There are three ways that carbon dioxide is transported

Oxygen Transport

• Oxygen transport is facilitated by hemoglobin (Hb)

  ▪ Hemoglobin is a protein found in erythrocytes

  ▪ 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)

• Effect of affinity on hemoglobin saturation is determined by four factors:
  1. Lower blood PO₂; unloading reaction is favored as fewer O₂ molecules are available to bind to Hb
  2. PCO₂ 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.
  2. _____________________ - CO₂ binds to Hb’s protein component (not heme group that oxygen binds) - **carbaminohemoglobin**
  3.
    - 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 shift**; chloride ions move into erythrocytes as bicarbonate ions move out to balance charges

- 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

- 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

→ 21.7 **Neural Control of Ventilation**

**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.
  - High PCO₂ or H⁺ concentration triggers hyperventilation.
  - Low PCO₂ or H⁺ concentration triggers hypoventilation.
  - Most sensitive to PO₂ in arterial blood.

- ________________ – neurons in medullary reticular formation.
  - Detects changes in both CO₂ and H⁺ concentrations CSF.

High-Altitude Acclimatization

- High-altitude acclimatization allows peripheral chemoreceptors to stimulate an increase in ventilation, permitting body to maintain acceptable blood PO₂ levels, if elevation is gradually increased over period of days (rather than hours).

- Requires days because sensitivity of chemoreceptors for low PO₂ increases with prolonged exposure; the longer they are exposed to a low PO₂, the more they stimulate an increase in ventilation.
• Allows experienced climbers to reach great elevations without supplemental oxygen