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
- _______ 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
- 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
• \( P \) – 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 upon 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

**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

**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 \( P_{\text{gas}} \): total pressure of a gas mixture is sum of partial pressures of all its component gases

\[
\text{PN}_2 + \text{PO}_2 + \text{PCO}_2 + \text{Pothers} = \text{Atmospheric pressure (760 mm Hg)}
\]

\[
\text{PN}_2 = 0.78 \times 760 = 593 \text{ mm Hg}
\]

\[
\text{PO}_2 = 0.21 \times 760 = 160 \text{ mm Hg}
\]

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
    - 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)

**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 $O_2$ 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 (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 PO$_2$ in tissue is low
  - Tissues produce large quantities of PCO$_2$ 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

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**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

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**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