The Respiratory System Goals

- Discuss the general functions of the respiratory system
- Review the anatomy of the respiratory system
- Discuss the concept of ventilation
- Learn about gas exchange and transport
- Review mechanisms related to the control of respiration
- Discuss selected disorders of the respiratory system

Respiratory System Functions

1. **Provide extensive surface area** for gas exchange between the air and blood (alveoli)
2. **Move air** to and from the exchange surfaces via respiratory passageways (ventilation)
3. **Protect** respiratory surfaces from dehydration, temperature changes, and pathogens
4. **Produce sounds** involved in speaking, singing, etc.
5. **Facilitate the detection of olfactory stimuli** with the help of sensory receptors in the nasal cavity
Respiratory Anatomy

- Nasal cavity
- Sphenoidal sinus
- Internal nares
- Nasal conchae
- Tongue
- Pharynx
- Hyoid bone
- Larynx
- Trachea
- Bronchus
- Bronchioles
- Ribs
- Diaphragm
- Frontal sinus
- Esophagus
- Clavicle

- The branching pattern of bronchi in the left lung, simplified
- Trachea
- Cartilage plates
- Left primary bronchus
- Visceral pleura
- Secondary bronchus
- Tertiary bronchi
- Smaller bronchi
- Bronchioles
- Terminal bronchiole
- Respiratory bronchiole
- Alveoli in a pulmonary lobule
- Bronchopulmonary segment
Respiratory Anatomy

• Composed of the structures involved in ventilation (breathing) and gas exchange. Organized into an upper respiratory system and a lower respiratory system.

The **upper respiratory system** consists of the nose, nasal cavity, paranasal sinuses, and the pharynx
  Filters, warms, and humidifies incoming air (necessary to protect the more delicate tissues of the lower respiratory system)
• The **lower respiratory system** consists of the larynx (voice box), trachea, bronchi, bronchioles, and alveoli. The lower respiratory system begins with the larynx.

Respiratory Tract

The **respiratory tract** includes the passageways that carry air to and from the exchange surfaces of the lungs
  **Conducting portion** begins at the entrance to the nasal cavity and extends through the pharynx, larynx, trachea, bronchi, and larger bronchioles
  **Respiratory portion** includes the smallest, most delicate bronchioles and their associated alveoli (air-filled pockets in the lungs that are the site of gas exchange)
Alveoli are organized to allow extremely efficient gas exchange because the distance between blood in an alveolar capillary and the air inside an alveolus is typically ~0.5 µm and the surface area of the lungs devoted to gas exchange is ~35x the surface area of your body!

Respiratory Mucosa

- Because the job of the conducting airways is to filter, warm, and humidify air before it reaches the fragile alveolar surfaces, these passageways are lined by respiratory mucosa, a ciliated pseudostratified columnar epithelial tissue layer, which produces a layer of mucus to capture debris and pathogens.
The Nose

- The nose is the primary passageway for air entering the respiratory system.
- Air normally enters through the **external nares** passing the **nasal vestibule**, home of large hairs to trap large particles (e.g. sand, insects)
- The **nasal septum** divides the **nasal cavity** in half
- **Superior, middle, and inferior nasal conchae** project into the nasal cavity, causing turbulent airflow so further particles will stick to the mucus and to also allow added time for air warming and humidification
- Air also flows into the adjacent **paranasal sinuses** (i.e. maxillary, frontal, ethmoid, sphenoid) which serve to further warm and humidify air
- Note that the superior surfaces of the nasal cavity are lined by **olfactory epithelium**—home of receptors related to your sense of smell
- The nasal cavity connects with the **nasopharynx** (top of the pharynx) by way of the **internal nares.**
The nasal cavity and pharynx, as seen in sagittal section with the nasal septum removed.
Pharynx

• Chamber shared by digestive and respiratory system, extending from the internal nares to the entrances to the larynx and esophagus. Divided into:
  • Nasopharynx
  • Oropharynx
  • Laryngopharynx

• The nasopharynx is lined by the same pseudostratified ciliated columnar epithelium as the nasal cavity.
• Left and right auditory tubes open on either side (reason chewing gum on an airplane helps “pop” your ears).

• The oropharynx extends from the soft palate down to the level of the hyoid bone. Its epithelium is stratified squamous here to allow passage of both food and air. Abrasion from food would destroy pseudostratified ciliated columnar tissue.

• The laryngopharynx is the inferior portion of the pharynx, extending from the level of the hyoid bone to the entrance to the larynx and esophagus. It is also lined with stratified squamous epithelium.

Larynx

• As inhaled air exits the pharynx, it enters the larynx through a narrow opening called the glottis; the larynx is a cartilaginous structure that surrounds and protects the glottis.

• Formed by three large, unpaired cartilages—the epiglottis, the thyroid cartilage, and the cricoid cartilage.
Epiglottis—projects superior to the glottis and forms a lid over it; folds over the glottis during swallowing to prevent entry of liquids/solids into respiratory tract. It is made of elastic cartilage.

Thyroid cartilage (thyroid means “shield-shaped” here)—made of hyaline cartilage, it is U-shaped and incomplete posteriorly (why? Hint—where is the esophagus?)

Anterior surface called the laryngeal prominence (“Adam’s apple”)

Cricoid cartilage—also hyaline cartilage, it protects the glottis and the entrance to the trachea along with the thyroid cartilage

Ligaments attach the cartilages to one another; the vocal ligaments, which are covered by folds of laryngeal epithelium called vocal folds—highly-elastic structures involved in the production of sound (and therefore also called the vocal cords)

The vestibular ligaments, which are superior to the vocal ligaments, are also covered by folds of epithelial tissue called vestibular folds—they don’t have much of a role in speaking and are sometimes called “false vocal cords”—vocal folds are called “true vocal cords”

Sound Production

- As air passes through the glottis, it causes vibration on the vocal folds, which produces sound waves (think about how whistles work)
- The pitch of that sound wave depends on the diameter, length, and tension of the vocal folds—with tension being controlled by voluntary muscles that reposition the cartilages in the larynx relative to one another
- As the distance b/t these cartilages increases, the vocal folds tense up and pitch rises.
- Children have slender, short vocal folds $\rightarrow$ high-pitched voice
- At puberty, the larynx of males enlarges much more than that of females, leading to thicker and longer vocal folds and a lower voice than found in adult females
- Sound production in the larynx is called phonation, but talking also requires articulation (modifications in the tongue, teeth, and lips)
Coughing

- When you swallow, muscles in your neck normally elevate the larynx and bend the epiglottis over the glottis, but in cases where this doesn’t happen and a **bolus** (ball of food you are swallowing) or liquid contacts the vestibular or vocal folds, the **coughing reflex** is triggered:
  - Glottis is kept closed while the chest and abdominal muscles contract, building up pressure
  - When the glottis is then opened suddenly, a blast of air from the trachea (hopefully) ejects the material
**Trachea**

- Tough, flexible tube with a 1” diameter
- Mucosa here resembles that of the nasal cavity (mucus is moved toward the pharynx by cilia for swallowing)
- Contains 15-20 **tracheal cartilages** that stiffen and protect it
  - C-shaped and incomplete on the posterior border—allows esophagus to expand when you swallow large masses of food
- **Trachealis muscle** at the back of each cartilage allows for changes in the diameter of the trachea (under ANS control) to influence airflow
- **Carina cartilage** found at bottom of trachea where it divides in two principal bronchi.

**Lungs**

The **right** and **left lungs** are found within the right and left pleural cavities, respectively
- Each is a blunt cone with an **apex** extending superiorly and a **base** sitting on top of the **diaphragm**
  - The **right lung** has 3 lobes—superior, middle, and inferior, separated by the horizontal and oblique fissure
  - The **left lung** has 2 lobes—superior and inferior, separated by the oblique fissure
- The left lung extends further inferiorly than the right b/c the diaphragm arches up on the right to accommodate the liver
- However, since the heart is slightly off-center, the medial margin of the left lung is indented at the **cardiac notch**.
As the bronchi enter the lungs, they divide into smaller passageways—these branches within the lungs are called *interpulmonary bronchi*.  
• Each primary bronchus divides into **secondary bronchi**—one serves each lobe of each lung.  
• Secondary bronchi then branch into **tertiary bronchi** - supplies air to an individual **bronchopulmonary segment**, an specific region of a lung.  
Walls of each of these bronchi exhibit progressively less cartilage (and more smooth muscle)  
• Tertiary bronchi branch within their associated bronchopulmonary segments divide into many **bronchioles**, which finally branch into the finest conducting airways, the **terminal bronchioles**.  
• As the airways get smaller, the amount of smooth muscle in their walls increases. This smooth muscle allows for increased regulation of airflow by the Autonomic Nervous System.  
  • Sympathetic → bronchodilation  
  • Parasympathetic → bronchoconstriction (can also occur due to allergic reaction)  
• As the airways become further partitioned, they form individual **lobules** that are also supplied by branches of the pulmonary arteries, pulmonary veins, and nerves  
• **Septa**, which are continuous with the **visceral pleura** (lines the lung), separate lobules  
• Each terminal bronchiole supplies a single lobule  
• Terminal bronchioles divide to form **respiratory bronchioles** to deliver air to the alveoli for gas exchange.

Note that smaller bronchial arteries and veins supply oxygen and nutrients to these tissues and remove CO2 and wastes
- Respiratory bronchioles connect to multiple **alveoli** via **alveolar ducts**
- Each lung contains 150,000,000 alveoli
- Alveoli are surrounded by elastic fibers that lead to recoil during exhalation, pushing air out

- Gas exchange occurs across the **respiratory membrane**:  
  - 3 layers:  
    - Squamous epithelial tissue lining alveolus  
    - Endothelial cells lining adjacent capillary  
    - Fused basal laminae b/t the two  
  - ~0.5 μm thick → diffusion across occurs very rapidly (important that O₂ and CO₂ are lipid-soluble)

- Alveoli are surrounded by capillaries
- Roaming **alveolar macrophages** patrol to remove anything that eluded the respiratory defenses  
- **Pneumatocytes type I** are the extremely thin epithelial cells of alveoli
- **Pneumatocytes type II** produce **surfactant**—oily secretion that reduces surface tension in the liquid coating the alveolar surface
- **Surface tension** tends to cause bubbles to collapse (think of water bubbles vs. soapy water bubbles (soap is also surfactant)):

  *alveoli would collapse w/o surfactant*
Blood supply to lungs

- Two circuits nourish the lungs:
  - **Respiratory exchange circuit** receive blood from pulmonary arteries (enter at hilum) → alveoli for exchange → pulmonary veins
    - Note that angiotensin-converting enzyme, which converts angiotensin I to angiotensin II (regulate blood volume and BP) is found in the epithelial cells lining alveolar capillaries
  - **Conducting circuit** supplied by bronchial arteries, which supply oxygen and nutrients to the tissues of the conducting passageways; the bronchial veins empty into the pulmonary vein (and therefore dilute the oxygen-rich blood leaving the alveoli)

Pleural Cavities

- The thoracic cage is composed of two **pleural cavities** separated by the mediastinum (each lung occupies one **pleura**)
- **Parietal layer** covers the inner surfaces of the thoracic wall and extends over the diaphragm and mediastinum
- **Visceral layer** covers the outer surfaces of the lungs (and forms septa)
- While each lung is found in a pleural cavity surrounded by two membranes (parietal and visceral) that allow for independent motion of the lungs and thoracic cage, those two membranes are only separated by a thin film of pleural fluid. Both layers secrete a small amount of **pleural fluid** to (reduce friction between surfaces as we breathe)
Respiration and Ventilation

**Respiration** refers to two processes:
- **External respiration**—exchange of oxygen and carbon dioxide between the body’s interstitial fluids and the external environment
- **Internal respiration**—absorption of oxygen and release of carbon dioxide by cells (cellular respiration)

**External Respiration** involves three steps:
- **Pulmonary ventilation**—breathing
- **Gas diffusion**—movement across the respiratory membrane and across capillary walls at the tissues
- **Transport of $O_2$ and $CO_2$**—importance of hemoglobin

**Pulmonary ventilation** serves to maintain adequate alveolar ventilation by physically moving air into and out of the alveoli to prevent buildup of $CO_2$ and ensure a continuous supply of $O_2$

**Atmospheric Pressure**
- Although you don’t typically notice it, the air above you on Earth has weight and it is constantly pushing down on you (this is why air gets “thinner” as you ascend a mountain) → atmospheric pressure
- Just like we saw with hydrostatic pressure in the circulatory system, gases will move from areas of higher pressure to areas of lower pressure
- Air moves into and out of the lungs as air pressure in the lung cycles between levels below atmospheric pressure (creating a vacuum → inhalation) and above atmospheric pressure (exhalation)
• When your respiratory muscles compress the lungs, pressure inside the lungs increases (> atmospheric pressure)—air forced out—**expiration**
• When these muscles return to their original position, pressure falls (< atmospheric pressure) and air flows in—**inspiration**

• The relaxed diaphragm forms a dome at the base of the thoracic cavity
• When it contracts, it tenses and moves inferiorly and the muscles of the rib cage (external intercostals) contract to move the ribs superiorly → volume of the thoracic cavity (and the lungs) increases, so pressure falls such that \( P_{\text{inside}} < P_{\text{outside}} \)

**Inspiration**

• Notice the greater than/less than sign points in the direction that air will move

• When the diaphragm then relaxes, it returns to its original position and the external intercostals also relax to move the ribs inferiorly → volume of the thoracic cavity (and the lungs) decreases, so pressure rises such that \( P_{\text{inside}} > P_{\text{outside}} \)  

**Expiration**

**Review**

• At the start of a breath, \( P_{\text{inside}} = P_{\text{outside}} \) (no air is moving)
• When the thoracic cavity enlarges, the pleural cavities and the lungs also expand and pressure falls:
  \( P_{\text{inside}} < P_{\text{outside}} \) **(inhalation)**
  • Air will enter the lungs until their volume stops increasing when \( P_{\text{inside}} = P_{\text{outside}} \) once again (e.g. if you increase the volume of the lungs by 50%, inhalation ends when there are 50% more air molecules)
• When the thoracic cavity decreases in volume, pressures rise in the lungs:
  \( P_{\text{inside}} > P_{\text{outside}} \) **(exhalation)**
Other Important Pressures

- **Intrapulmonary pressure**—pressure inside the respiratory tract at the alveoli ($P_{\text{inside}}$ on the previous slides)
  - Direction of airflow is determined by the relationship between intrapulmonary pressure and atmospheric pressure
  - During quiet breathing, $P_{\text{intrapulm}} = 759 \text{ mmHg}$ on inhalation and 761 mmHg on exhalation; $P_{\text{atmospheric}} = 760 \text{ mmHg}$, so the differential is no more than 1 mmHg.

- **Intrapleural pressure** is the pressure in the space between the parietal and visceral pleura
  - Averages about -4 mmHg (always a vacuum)
  - Because the lungs are so elastic, they would collapse to 5% of their normal resting volume if not for the intrapleural pressure, which the elastic fibers in the lung cannot overcome (if you have a wound that pierces both pleura, your lungs will collapse—what would a surgeon need to do to keep you alive?)
  - Since the elastic fibers of the lungs are constantly pulling on the visceral pleura, $P_{\text{intrapleural}}$ normally remains negative, but it does fluctuate with breathing; changes in $P_{\text{intrapleural}}$ are responsible for the respiratory pump that aids venous return
Tidal Volume

- Amount of air you move into or out of your lungs during a single respiratory cycle (directly related to the pressures we have discussed)
- At the start of the respiratory cycle, $P_{\text{intrapulm}} = P_{\text{atmospheric}}$ no air flows
- As pressures in the thoracic cavity fall, air begins to enter
- As air enters, pressure begins to rise until it equals atmospheric pressure and inhalation ends (same pattern seen for exhalation)

Compliance of the Lungs

- **Compliance** affects how easily the lungs fill and empty—it is a measure of the lungs’ expandability—as compliance falls, more force is required to fill and empty the lungs
- **Factors affecting compliance:**
  - *Connective tissue in the lungs*: loss of supporting tissues due to alveolar damage (e.g. emphysema) increases compliance (alveoli expand and capillaries deteriorate); fibrosis of the lungs does the opposite—stiffens alveoli, compliance drops
  - *Surfactant production*: if surfactant production drops (e.g. respiratory distress syndrome) the alveoli collapse on expiration and compliance falls
  - *Mobility of thoracic cage*: disorders like arthritis, which affect the articulations of the ribs or vertebral column, reduce compliance

Resistance also affects air flow—as it increases, air flow falls

Individuals with asthma have both mucus accumulation and histamine release in the bronchioles causing bronchoconstriction—resistance increases, so air flow drops
Inhalation Respiratory Muscles

- Inhalation: **diaphragm** contracts and flattens (responsible for 75% of breathing at rest)
- **External intercostals** elevate ribs (25% of breathing at rest)
- Accessory muscles become active when respiration must increase (all of these muscles increase rib movement):
  - Sternocleidomastoid, serratus anterior, pectoralis minor, scalenes

Exhalation Respiratory Muscles

- Exhalation: when exhalation is passive (as at rest), it involves the **diaphragm** and **external intercostals** simply relaxing
- Accessory muscles become active when respiration must increase:
  - Internal intercostals and transversus thoracis muscles depress the ribs
  - Abdominal muscles compress abdomen and force diaphragm upward (which you may noticed if you’ve done any heavy lifting at the gym)

Types of breathing

- **Quiet breathing** (eupnea): inhalation involves muscular contractions, but exhalation is passive
- **Diaphragmatic breathing** (deep breathing)—contraction of the diaphragm alone provides necessary change in thoracic volume; occurs at minimal levels of activity
- **Costal breathing** (shallow breathing)—breathing occurs solely due to changes in rib cage volume; pregnant women increasingly rely on this as the enlarging uterus pushes the abdominal viscera against the diaphragm.
- **Forced breathing** (hyperpnea): active inspiratory and expiratory movements with the accessory muscles also involved
Respiratory Rates and Volumes

- **Respiratory Rate** is the number of breaths you take per minute (normally 12-18/minute at rest)
- **Respiratory Minute Volume** is the amount of air moved every minute

Minute Volume = Resp. Rate * Tidal Volume

= 12 * 500 mL (at rest)
= 6000 mL/minute

- **Alveolar ventilation**—while you may inhale 500 mL of air at rest, not all of it gets to the alveoli—about 150 mL stays in the conducting passageways and does not participate in gas exchange (anatomical dead space); alveolar ventilation accounts for this:

Alv. Vent. = Resp. Rate * (tidal vol. – anat. dead space)

= 12 * (500 mL – 150 mL)
= 12 * 350 mL
= 4200 mL

This number gives a better approximation of respiratory performance

- Because you can inhale much more vigorously and exhale more completely than you do at rest, we divide the total volume of your lungs into a series of **volumes** and **capacities** (the sum of various volumes)—we use these numbers to diagnose pathologies.
- Note that most of these numbers will be lower in females because the **total lung capacity** (total volume of the lungs) is 6000 mL in males and 4200 mL in females.
- **Resting tidal volume** \( (V_T) \) is the amt. of air moved into and out of the lungs during a single respiratory cycle at rest—\( \sim 500 \text{ mL} \) in males and females

- **Expiratory reserve volume** \( \text{(ERV)} \) is the amt. of air you can voluntarily expel after a normal, quiet respiratory cycle

- **Residual volume** is the amt. of air that remains in the lungs even after maximum exhalation

- **Minimal volume**—component of residual volume—represents the amt. of air that would remain in your lungs if they were allowed to collapse (cannot be measured in healthy person)

- **Inspiratory Reserve Volume** \( \text{(IRV)} \) is the amt. of air that you can take in over and above the tidal volume

- **Inspiratory capacity** is the amount of air you can draw into your lungs after a quiet respiratory breath. \( \text{IRV} + V_T \)

- **Functional residual capacity** \( \text{(FRC)} \) is the amt. of air remaining in your lungs after completing a quiet respiratory cycle \( \text{ERV} + \text{residual volume} \)

- **Vital capacity** is the maximum amt. of air you can move into and out of your lungs in a single respiratory cycle \( \text{ERV} + V_T + \text{IRV} \)

- **Total lung capacity** is the volume of the lungs: Vital capacity + Residual volume
Gas Exchange

- Gases are exchanged between the alveolar air and the blood through diffusion, in response to concentration gradients.
- The **Gas Laws** are the principles that govern the movement and diffusion of gas molecules.
  - Boyle’s Law again stated that *pressure is inversely proportional to volume*.
- The actual amount of gas in solution also depends on its solubility in the particular liquid.
  - CO₂ is highly soluble in body fluids.
  - O₂ is slightly less soluble.
  - N₂ is almost insoluble.

Alveolar Air

- The properties of air begin to change the moment it enters your respiratory tract, as it humidifies, is filtered, and mixes with the air remaining in the alveoli → alveolar air contains more CO₂ and less O₂ than atmospheric air (exhaled air is a mix of alveolar air and inhaled air that stayed in the conducting airways, so those numbers are inbetween inhaled and alveolar levels).

<table>
<thead>
<tr>
<th>Source of Sample</th>
<th>Nitrogen (N)</th>
<th>Oxygen (O)</th>
<th>Carbon Dioxide (C)</th>
<th>Water Vapor (H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhaled air (dry)</td>
<td>597 (78.6%)</td>
<td>159 (20.9%)</td>
<td>0.3 (0.04%)</td>
<td>3.7 (0.5%)</td>
</tr>
<tr>
<td>Alveolar air (saturated)</td>
<td>573 (75.4%)</td>
<td>100 (13.2%)</td>
<td>40 (5.2%)</td>
<td>47 (6.2%)</td>
</tr>
<tr>
<td>Exhaled air (saturated)</td>
<td>569 (74.8%)</td>
<td>116 (15.3%)</td>
<td>28 (3.7%)</td>
<td>47 (6.2%)</td>
</tr>
</tbody>
</table>

Changes due to some absorption and due to the changing properties of the air.

O₂ picked up

CO₂ removed from body

Air humidifies
Gas exchange across the respiratory membrane is efficient because:
1. The differences in partial pressure across the respiratory membrane are substantial, leading to rapid diffusion (this is the reason you get light-headed at high altitudes—\( P_{O_2} \) in the air falls causing this differential to decrease)
2. Distances involved in exchange are short (reason that inflammation or fluid build up, which increases this distance, impairs gas exchange)
3. Gases are lipid soluble
4. Total surface area is large
5. Blood flow and air flow are coordinated (blood flow is highest surrounding alveoli with the highest \( P_{O_2} \))

• Blood arriving in the pulmonary arteries has a lower \( P_{O_2} \) and a higher \( P_{CO_2} \) than the alveolar air, causing diffusion in the pulmonary capillaries—**External Respiration**
  • This diffusion occurs very rapidly (at rest, a RBC moves through the pulm. capillaries in 0.75 s; 0.3 s during exercise and this is usually enough time for \( P_{O_2} \) in the blood to reach 100 mmHg and \( P_{CO_2} \) to fall to 40 mmHg)

• When blood exits the pulmonary capillaries and enters the pulmonary veins, it mixes with blood that had supplied the conducting airways (where exchange did not occur) \( \rightarrow P_{O_2} \) drops to 95 mmHg
• At the tissues (site of **Internal Respiration**), \( P_{O_2} \) is lower than in the blood and \( P_{CO_2} \) is higher—exchange occurs
Gases Transport

- **$O_2$ transport:**
  - 2% dissolved in plasma
  - 98% $HbO_2$ within RBC (oxyhemoglobin).
    
    \[
    Hb + O_2 \rightarrow HbO_2 \quad (\text{lungs})
    \]
    
    \[
    HbO_2 \rightarrow Hb + O_2 \quad (\text{tissues})
    \]
  
  Reversibility is very important here

- The percentage of heme units bound to oxygen at a given time is called **hemoglobin saturation** and it is proportional to the $P_{O_2}$.
  
- Note that the **Hemoglobin Saturation Curve** is not flat—between 80 and 100 mmHg, there is little change in saturation, while below 80 mmHg, there is a steep drop off.

Factors affecting Hb Saturation

- **pH** (and, therefore, $P_{CO_2}$) affects Hb saturation such that as pH drops ($P_{CO_2}$ rises), saturation also drops; opposite occurs as pH rises—**Bohr Effect**
  
  - Active tissues have a lower pH—*further release of $O_2$*
  
- Increases in temperature also decrease saturation
  
  - Active tissues are also warmer—*further release of $O_2$*
• CO₂ transport:
  - 7% dissolved in plasma
  - 23% HbCO₂ within RBC (carbaminohemoglobin)
    - Hb + CO₂ → HbCO₂ (tissues)
    - HbCO₂ → Hb + CO₂
  - 70% HCO₃⁻ within RBC (bicarbonate)
    - H₂O + CO₂ → H₂CO₃ → H⁺ + HCO₃⁻ (tissues)
    - H⁺ + HCO₃⁻ → H₂CO₃ → H₂O + CO₂ (lungs)
  - The protons produced by this reaction bind to Hb and decrease the affinity of Hb for oxygen
    - As large amounts of CO₂ get transported away from cells as bicarbonate, more oxygen is dumped off at the tissues, so tissues producing more carbon dioxide get more oxygen
  - 70% of the CO₂ transported in blood diffuses into RBCs and is converted into carbonic acid by carbonic anhydrase in the RBCs—it then immediately dissociates into a proton and bicarbonate
    - Most of the protons bind to Hb (to buffer pH); bicarbonate moves into the plasma in exchange for Cl⁻ (chloride shift)
    - 23% binds to Hb (carbaminohemoglobin)
    - 7% dissolves directly into plasma
Control of Respiration

- The body can constantly adapt to changes in gas exchange needs by:
  - Modifying blood flow
  - Changing the depth and rate of breathing under control of the brain’s respiratory centers

Local regulation

- When $P_{O_2}$ of a tissue falls or $P_{CO_2}$ rises, the partial pressure differentials increase, automatically leading to greater exchange (like a small rapid vs. a waterfall)
- Rising $P_{CO_2}$ levels also lead to vasodilation (flush out the CO$_2$)
- In the lungs:
  - **Lung perfusion** (blood flow to the alveoli) is modulated due to the fact that alveolar capillaries constrict when $P_{O_2}$ is low—do not send blood to hypoxic alveoli
  - **Alveolar ventilation** (air flow to individual alveoli) is modulated due to the fact that bronchioles dilate when $P_{CO_2}$ is high, to deliver fresh oxygen and flush out carbon dioxide

The basic pattern of breathing is set by the cyclical interaction b/t the DRG and the VRG—there may be pacemaker cells in these structures (not yet found)
Chemoreceptor Reflexes

- Stimulation of chemoreceptors (pH drops, $P_{CO_2}$ rises, $P_{O_2}$ drops) leads to an increase in the depth and rate of respiration—under normal conditions, though, it is $P_{CO_2}$ that is responsible for this regulation (sensitivity to $P_{O_2}$ only begins when it’s below 60 mmHg, while $P_{CO_2}$ only has to rise by 10% to elicit a response)
- Why do we put a bag over the mouth of someone who is hyperventilating? $P_{CO_2}$
- Note that any factors affecting pH will also affect respiratory performance—rise in lactic acid during exercise stimulates respiratory activity

Nervous Control

- Both voluntary and involuntary components
- Involuntary centers in the brain regulate activity of the respiratory muscles and control respiratory minute volume by adjusting both frequency and depth of pulmonary ventilation—all in response to information from sensory receptors along the respiratory tract and throughout the body
- Voluntary control comes from the cerebral cortex that affects the output from lower brain regions (necessary to swim, talk, etc.)
- The respiratory rhythmicity centers of the medulla oblongata are paired centers that set the pace of respiration—each center has a:
  - Dorsal respiratory group (DRG) inspiratory center that controls lower motor neurons innervating the external intercostals and diaphragm—it functions in every respiratory cycle and is active during inspiration
  - Ventral respiratory group (VRG) functions only during forced breathing and includes neurons innervating lower motor neurons controlling accessory respiratory muscles involved in active exhalation (from the expiratory center) and maximal inhalation (from the inspiratory center)
    - Active when you go for a jog, for example
Apneustic and Pneumotaxic Centers

- Paired nuclei found in the pons that adjust the output of the DRG and VRG by modulating resp. rate and depth of breathing in response to sensory stimuli or input from other brain structures
- Each **Apneustic center** (ap NOO stik) stimulates the DRG on that side of the brainstem—it can briefly increase the intensity of inhalation during quiet breathing as necessary and it can increase lung inflation during forced breathing due to input from the vagus nerves regarding lung inflation

- The **Pneumotaxic centers** (noo mo TAKS ic) inhibit the apneustic centers and promote passive or active exhalation (increasing resp. rate by shortening the duration of each inhalation)
- Centers in the hypothalamus and cerebrum can alter activity in the pneumotaxic centers (e.g. hyperventilating due to stress), although relatively normal breathing can continue if the brainstem is severed above the pons; damage affecting the pneumotaxic centers, however, leads to aberrant breathing patterns featuring minimal exhalation

- **Hypercapnia**—high $P_{CO_2}$ in arterial blood
- **Hypocapnia**—low $P_{CO_2}$ in arterial blood

- The activities of the respiratory centers are modulated by sensory information from:
  - Chemoreceptors sensitive to $P_{CO_2}$, pH, or $P_{O_2}$ of the blood or CSF
  - Baroreceptors in the aortic or carotid sinuses sensitive to changes in BP
  - Stretch receptors that respond to changes in lung volume
  - Irritating physical or chemical stimuli in the nasal cavity, larynx, or bronchial tree
  - Pain or changes in body temperature
Respiratory control involves multiple levels of regulation. Most of the regulatory activities occur outside of our awareness.

**Higher Centers**
- Hypothalamus
- Limbic system
- Central nervous system
- Hypothalamus

The pneumotaxic centers inhibit the pneumotaxic centers and thereby promote passive or active exhalation. An increase in the duration of each inhalation; a decrease in pneumotaxic output slows the respiratory rate but increases the depth of respiration, because the pneumotaxic centers are more active.

**Aphymotic and Pneumotaxic Centers**
- Aphymotic (ap-RCO-otic) centers
- The pneumotaxic centers are located in the medulla oblongata and control the output of the respiratory rhythm center.

**Respiratory Rhythm Centers**
- The basic rhythm of respiratory control modulates paradoxical movements in the medulla oblongata. These receptors generate cycles of contraction and relaxation in the diaphragm. The inspiratory center controls the depth of inspiration by adjusting the activities of these pneumotaxic and coordinating the activities of the accessory respiratory muscles. The expiratory center controls the duration of exhalation and the diaphragm, and the expiratory center functions in every respiratory cycle.

**A rise in arterial PCO₂ stimulates chemoreceptors that accelerate breathing cycles at the inspiratory center.** This change increases the respiratory rate, encourages CO₂ loss at the lungs, and lowers arterial PCO₂.

**A drop in arterial PCO₂ inhibits these chemoreceptors.** In the absence of stimulation, the rate of respiration decreases, slowing the rate of CO₂ loss at the lungs, and elevating arterial PCO₂.

**HOMEOSTASIS DISTURBED**
- Increased arterial PCO₂
- Decreased arterial PCO₂ (hypocapnia)

**HOMEOSTASIS RESTORED**
- Normal arterial PCO₂

**Stimulation of arterial chemoreceptors**
- Increased arterial PCO₂
- Decreased arterial PCO₂ (hypocapnia)

**Stimulation of respiratory muscles**
- Decreased PCO₂, increased pH in CSF

**Stimulation of respiratory muscles**
- Increased PCO₂, decreased pH in CSF

**Inhibition of arterial chemoreceptors**
- Reduced stimulation of respiratory muscles

**Inhibition of respiratory muscles**
- Increased respiratory rate with increased elimination of CO₂ at alveoli

**Inhibition of respiratory muscles**
- Decreased respiratory rate with decreased elimination of CO₂ at alveoli

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Hering-Breuer Reflexes

- **Inflation Reflex**—prevents overexpansion of the lungs during forced breathing
  - Stretch receptors in the smooth muscle tissue around the bronchioles are stimulated by lung expansion—info. travels up the vagus nerve to the resp. rhythmicity center; DRG is inhibited, expiratory center of VRG stimulated→ inhalation stops as the lungs near maximum volume and active exhalation starts

- **Deflation Reflex**—inhibits expiratory centers and stimulates inspiratory centers when lungs are deflating
  - Receptors in the alveolar wall near the alveolar capillary network stimulate the reflex as the volume of the lungs drops (normally only during forced exhalation) until exhalation stops and inhalation begins

- Hering-Breuer reflexes prevent you from over-inhaling or over-exhaling

Protective Reflexes

- When you are exposed to toxic vapors, chemical irritants, or mechanical stimulation of the respiratory tract, receptors in the respiratory tract epithelium will cause sneezing, coughing, etc.
  - Irritation of nasal cavity→ sneezing
  - Irritation of larynx, trachea, or bronchi→ coughing
  - Both coughing and sneezing lead to **apnea**—a period when respiration is suspended—followed by a forceful expulsion of air at ~100 mph
  - Laryngeal spasms result from the entry of chemical irritants, foreign objects, or fluids into the area around the glottis—the airway is temporarily closed (this can cause you to pass out and/or die)
Voluntary Control

- Conscious thought processes tied to strong emotions (e.g. rage, fear) stimulate centers in the hypothalamus and can affect resp. rate.
- Emotional states can also affect the sympathetic or parasympathetic divisions of the ANS:
  - Sym—bronchodilation and resp. rate increases
  - Para—bronchoconstriction and resp. rate decreases
- Anticipation of strenuous exercise can automatically increase resp. rate and cardiac output by sympathetic stimulation.
- Conscious control of breathing can completely bypass respiratory centers, using pyramidal fibers innervating the same lower motor neurons as the DRG and VRG.
- This is essential to speaking, singing, and swimming, when we must precisely time resp. activity.
- Higher centers can also inhibit apneustic centers and the DRG and VRG, as when you hold your breath.
- You can only override the respiratory centers to a point, though—you cannot hold your breath and kill yourself, for example—once $P_{CO2}$ rises to critical levels, you are forced to take a breath.

Respiratory Performance Declines with Age
Disorders of the Respiratory System

Respiratory Distress Syndrome—develops in premature infants b/c the infant is not making enough surfactant—surface tension increases and the alveoli collapse during exhalation → over time, respiration becomes more difficult and gas exchange stops

- Synthetic or natural surfactant can be sprayed into the resp. tract

Emphysema—chronic shortness of breath and inability to tolerate physical activity because the respiratory membrane has been damaged, increasing compliance

- Alveoli expand, capillaries degenerate
- Linked to the toxic vapors in cigarette smoke
- Ability to deliver adequate oxygen decreases
- **Heavy smokers usually develop this by age 40**
- once damage is done, it is permanent

Lung cancer—30% of all cancers in USA

- 85-90% of cases due to smoking cigarettes
- Inspired air when smoking is drier and contaminated with carcinogens and particulate matter, which overloads the respiratory defenses and damages the underlying epithelium
- 5-year survival rate is 30%
- Risk increases if you smoke more cigarettes
  
  *Exposure to chronic second-hand smoke increases your lung cancer risk by 30%*

Mesothelioma
Cystic fibrosis—progressive, chronic genetic disease of the exocrine glands—affects both the digestive and respiratory tracts

- Lung tissue elasticity is lost and lungs become rigid. Thick mucus develops along bronchial tree. IRV lower (harder to inflate lungs)
- Caused by a mutant gene that disrupts the cystic fibrosis transmembrane conductance regulator (CFTR) which regulates flow of salt into and out of cells
  - The CFTR’s salt transport is required for the generation of normal mucus and digestive juice—this cannot happen in individuals with the mutant CFTR gene; the abnormal mucus builds up in the respiratory tract and the individual cannot make normal digestive juice (though artificial enzymes can be ingested to help with the latter)

Asthma—tightness in the chest, coughing, wheezing, shortness of breath, fatigue

- Attacks can be triggered by exercise, cold air, smoking, aerosols, stress, infection, laughing
- Caused by mucus production and irritation to bronchial structures (causing swelling); air moving around mucus plugs cause the wheezing sound
- Primatine Mist (Epi) is a nonspecific beta agonist—it stimulates beta-2 receptors on bronchioles leading to bronchodilation (but also stimulates beta-1 receptors → CO and BP increases → can’t use this if you have high BP then)
- Better treatments are selective beta-2 agonists (albuterol) that are frequently prescribed with an expectorant to loosen mucus
The Respiratory System

FOCUS: The respiratory system consists of the nasal cavity, pharynx, larynx, trachea, and lungs. The diaphragm and thoracic wall muscles change the volume of the thoracic cavity, producing pressure gradients responsible for the movement of air into and out of the lungs. Once in the blood, oxygen is mostly transported bound to hemoglobin, and most carbon dioxide is transported as bicarbonate ions. Respiration is controlled by centers in the brain. The most important regulators of resting respiration are blood carbon dioxide and pH levels, although low blood oxygen levels can increase respiration. Respiration during exercise is mostly determined by the cerebral motor cortex and by feedback from proprioceptors.

CONTENT LEARNING ACTIVITY

**Nose and Nasal Cavity**

*Air passing through the nasal cavity is warmed, humidified, and cleaned.*

Match these terms with the correct statement or definition:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conchae</td>
<td>Divides the nasal cavity into right and left parts.</td>
</tr>
<tr>
<td>Epithelium</td>
<td>Forms the floor of the nasal cavity.</td>
</tr>
<tr>
<td>Hard palate</td>
<td>Bony ridges on the lateral walls of the nasal cavity; function to increase surface area.</td>
</tr>
<tr>
<td>Nasal septum</td>
<td>Air-filled spaces within bones that connect to the nasal cavity.</td>
</tr>
<tr>
<td>Paranasal sinuses</td>
<td>Produces mucus that traps debris in the air; moves mucus to the pharynx.</td>
</tr>
</tbody>
</table>

**Pharynx and Larynx**

*Sometimes the pharynx is called the throat and the larynx is called the voice box.*

1. Match these terms with the correct statement or definition:

   - Epiglottis
   - Laryngitis
   - Loudness
   - Pharynx
   - Pitch
   - Thyroid cartilage
   - Vocal cords

   1. Common passageway of the respiratory and digestive systems; connects to the larynx and the esophagus.
   2. Largest part of the larynx, which forms the Adam's apple.
   3. Ligaments that vibrate to produce sounds.
   4. Determined by the force of air moving past the vocal cords.
   5. Determined by the tension of the vocal cords.
   6. Inflammation of the mucous membranes of the vocal cords.
   7. Covers the opening of the larynx, preventing materials from entering the larynx during swallowing.

**The upper respiratory tract consists of the nose, nasal cavity, and pharynx.**

3. Match these terms with the correct parts labeled in Figure 10-1.

   - Bronchus
   - Larynx
   - Lower respiratory tract
   - Nasal cavity
   - Pharynx
   - Trachea
   - Upper respiratory tract

   1. __________
   2. __________
   3. __________
   4. __________
   5. __________
   6. __________
   7. __________
   8. __________
Trachea, Bronchi, and Lungs

"The trachea and bronchi serve as passageways for air between the larynx and lungs; the lungs are the principal organs of respiration."

A. Match these terms with the correct statement or definition:

- Alveoli
- Bronchioles
- Lobes
- Lobules
- Primary bronchi
- Secondary bronchi
- Tertiary bronchi
- Trachea

1. Extends from the larynx and divides to form the primary bronchi; supported by C-shaped cartilages.
2. Sections of lung separated by connective tissue but not visible as surface fissures.
3. Tubes that supply each lobe of the lung.
4. Tubes that supply the lobules of the lungs.
5. Contains smooth muscle that regulates airflow.
6. Place where gas exchange takes place.

B. Match these terms with the correct parts labeled in Figure 15-2:

- Alveoli
- Bronchiole
- Primary bronchus
- Secondary bronchus
- Tertiary bronchus
- Trachea

1.  
2.  
3.  
4.  
5.  
6.
Pleural Cavities

"Each lung is surrounded by a separate pleural cavity."

Match these terms with the correct statement or definition:

- Parietal pleura
- Pleural cavity
- Pleural fluid
- Thoracic cavity
- Visceral pleura

1. Cavity that contains the lungs and the pleural cavities.
2. Cavity formed by membranes; surround the lungs.
3. The part of the pleural membrane that is in contact with the lungs.
4. The pleural cavity contains a thin film of this substance which acts as a lubricant and helps to hold the pleural membranes together.

Pleurisy is an inflammation of the pleural membranes.

Ventilation

"Ventilation, or breathing, is the process of moving air into and out of the lungs."

Using the terms provided, complete the following statements:

- Decreases
- Diaphragm
- Expiration
- External intercostal
- Higher

1. Increases
- Inspiration
- Internal intercostal
- Lower

The phase of ventilation during which air is moving into the lungs is called (1). Two principles govern the movement of air: First, air moves from a (2) to a (3) area of pressure; second, as the volume of a container increases, the pressure within the container (4). The muscle primarily responsible for changing the volume of the thorax is the (5). When this muscle contracts, the volume of the thorax (6), lung volume (7), and pressure within the alveoli (8). Consequently air pressure in the alveoli is (9) than atmospheric air and air moves into the lungs. During quiet expiration the diaphragm relaxes and thorax volume (10), as the thorax returns to its resting position. Consequently air pressure in the alveoli is (11) than atmospheric pressure and air moves out of the lungs. In addition to the diaphragm, the intercostal muscles change thorax volume by moving the ribs. The (12) muscles increase thoracic volume during inspiration, and the (13) muscles decrease thoracic volume during labored breathing.
Understanding Lung Collapse

"Two factors tend to make the lungs collapse, and two factors keep the lungs from collapsing."

Match these terms with the correct statement or definition:

- Elastic recoil of lungs
- Pleural membranes adhere to each other
- Pneumothorax
- Respiratory distress syndrome
- Surface tension of alveolar fluid
- Surfactant

1. Two factors that cause the lungs to collapse.
2. Two factors that keep the lungs from collapsing.
3. Mixture of lipoproteins produced by the epithelium of the alveoli; reduces surface tension.
4. Results when newborns do not manufacture enough surfactant and the lungs tend to collapse.
5. Entry of air into the pleural cavity; causes the lung to collapse.

Pulmonary Volumes

"A spirometer is a device for measuring the volumes of air that move into and out of the lungs."

A. Match these terms with the correct statement or definition:

- Expiratory reserve volume
- Inspiratory reserve volume
- Residual volume
- Tidal volume
- Vital capacity

1. Volume of air inspired or expired by quiet breathing.
2. Volume of air that can be taken in after the inspiration of a normal tidal volume.
3. Volume of air that can be blown out after the expiration of a normal tidal volume.
4. Volume of air in the respiratory passages and lungs after maximum expiration.
5. The sum of the inspiratory reserve volume, tidal volume, and expiratory reserve volume.
6. The volume of air that a person can expel from the respiratory tract after a maximum inspiration.

8. Match these terms with the correct parts labeled in Figure 15-3:

- Expiratory reserve volume
- Inspiratory reserve volume
- Residual volume
- Tidal volume
- Vital capacity

Gas Exchange

"Gas exchange takes place across the respiratory membrane."

A. Match these terms with the correct statement or definition:

- Alveoli
- Blood
- Increases
- Respiratory membrane
- Decreases

1. Structure across which gas exchange between air and blood takes place.
2. Has the highest concentration of oxygen.
3. Effect on gas exchange when the respiratory membrane becomes thicker; an example is pneumonia.
4. Effect on gas exchange when the surface area of the respiratory membrane decreases; an example is emphysema.
B. Match these terms with the correct parts labeled in Figure 15.4:

Alveolar wall
Capillary wall
Fluid with surfactant
Interstitial space
Respiratory membrane

1. 
2. 
3. 
4. 
5. 

Oxygen and Carbon Dioxide Transport in the Blood

Oxygen is transported bound to hemoglobin; carbon dioxide is mostly transported as bicarbonate ion.

Using the terms provided, complete the following statements:

1. Bicarbonate ions
2. Hemoglobin
3. Blood proteins
4. Hydrogen ions
5. Carbonic anhydrase
6. Increases
7. Decreases
8. Plasma

Approximately 97% of oxygen is transported by (1). The remaining 3% of oxygen is transported dissolved in (2). Approximately 8% of carbon dioxide is transported by (3), 20% by (4) (primarily hemoglobin), and 72% as (5). The enzyme (6) inside red blood cells (7) the rate at which carbon dioxide and water react to form (8) and bicarbonate ions. Consequently, when carbon dioxide levels increase, hydrogen ion levels increase, and blood pH (9).

Control of Respiration

Respiration is regulated by the respiratory center in the medulla oblongata and lower pons.

Match these terms with the correct statement or definition:

<table>
<thead>
<tr>
<th>Term</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carotid and aortic bodies</td>
<td>Motor cortex</td>
</tr>
<tr>
<td>Decrease</td>
<td>Proprioceptors</td>
</tr>
<tr>
<td>Increase</td>
<td>Respiratory center</td>
</tr>
<tr>
<td>Medulla oblongata</td>
<td></td>
</tr>
</tbody>
</table>

1. Part of brain that rhythmically stimulates the muscles of inspiration, such as the diaphragm.
2. Chemoreceptors located here are most sensitive to small changes in blood carbon dioxide and pH levels.
3. Chemoreceptors located here primarily respond to low oxygen levels.
4. Change in respiration rate that occurs as a result of a small decrease in blood carbon dioxide.
5. Change in respiration rate that occurs as a result of a small decrease in blood pH.
6. Change in respiration rate that occurs as a result of a large decrease in blood oxygen.
7. Respiratory center is most affected by these two during exercise.

Disorders of the Respiratory System

Knowledge of respiratory disorders is clinically important.

A. Match these terms with the correct statement or definition:

<table>
<thead>
<tr>
<th>Term</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asthma</td>
<td>Paralysis</td>
</tr>
<tr>
<td>Bronchitis</td>
<td>Pulmonary fibrosis</td>
</tr>
<tr>
<td>Emphysema</td>
<td>Sudden infant death (SIDS)</td>
</tr>
<tr>
<td>Lung cancer</td>
<td></td>
</tr>
</tbody>
</table>

1. Inflammation of the bronchi.
2. Results in the destruction of the walls of the alveoli.
3. Contraction of the bronchioles; often caused by allergic reaction.
4. Exposure to asbestos, silica, or coal dust result in the replacement of normal lung tissue with fibrous connective tissue.
5. Tumor arising in the epithelium of the respiratory tract.
6. Causes death when infants stop breathing during sleep.
7. Inability to contract respiratory muscles; caused by trauma to the nervous system or the polio virus.
B. Match these terms with the correct statement or definition:

- Common cold
- Diphtheria
- Flu
- Fungal infections
- Pneumonia
- Strept throat
- Tuberculosis
- Whooping cough

1. Bacterial infection characterized by inflammation of the pharynx and fever; treated effectively with antibiotics.
2. Bacterial infection producing a membrane that blocks the respiratory passages.
3. Viral infection that typically causes sneezing, excessive nasal secretions, and congestion; usually last a week.
4. Bacterial infection that causes a loss of cilia from respiratory epithelial cells; mucus builds up in the respiratory passages.
5. Bacterial infection that produces tubercles in the lungs.
6. General term for many lung infections; caused by many different kinds of microorganisms and characterized by accumulation of fluid in the alveoli.
7. Viral infection characterized by chills, fever, headaches, and muscular aches.
8. Respiratory infection contracted from spores in dust or animal feces.

4. Name the four lung volumes.

5. List two factors that tend to cause the lungs to collapse and two factors that prevent the lungs from collapsing.

6. List the four parts of the respiratory membrane through which gases must diffuse.

7. Rank in order of importance the ways in which oxygen and carbon dioxide are transported.

8. List three chemical factors that influence respiration, the location in the body where the levels of these chemicals are monitored, and the changes of these chemicals that cause an increase in respiration rate.

---

**Mastery Learning Activity**

Place the letter corresponding to the correct answer in the space provided.

1. The nasal cavity
   - a. warms and humidifies air.
   - b. is divided into left and right parts by the hard palate.
   - c. contains the openings to the auditory tubes.
   - d. all of the above

2. The pharynx
   - a. is closed off by the epiglottis when materials are swallowed.
   - b. opens into the oral and nasal cavities.

3. The larynx
   - a. connects the pharynx to the esophagus.
   - b. has C-shaped cartilages.
   - c. contains the vocal cords.
   - d. all of the above
4. Which of the following parts of the respiratory passages is correctly matched with the structure it supplies?
   a. trachea - secondary bronchi
   b. primary bronchi - lobes of the lungs
   c. secondary bronchi - lobules of the lungs
   d. bronchioles - alveoli

5. During an asthma attack, the patient has difficulty breathing because of constriction of the
   a. trachea.
   b. bronchi.
   c. bronchioles.
   d. alveoli.

6. The parietal pleura
   a. covers the surface of the lungs.
   b. lines the inner surface of the thoracic cavity.
   c. separates lobules of the lungs from each other.
   d. is the membrane across which gas exchange occurs.

7. When the diaphragm contracts, the
   a. volume of the thoracic cavity increases.
   b. air pressure in the lungs decreases below atmospheric pressure.
   c. air moves into the lungs.
   d. all of the above

8. The lungs do not normally collapse because of
   a. surfactant.
   b. elastic recoil of lung tissue.
   c. surface tension of alveolar fluid.
   d. all of the above

9. A patient expires normally; then, using forced ventilation, he blows as much air as possible into a spirometer. This would measure the
   a. inspiratory reserve.
   b. expiratory reserve.
   c. residual volume.
   d. tidal volume.
   e. vital capacity.

10. Which of the following layers must gases cross to pass from the air to the blood?
    a. simple squamous epithelium
    b. thin interstitial space
    c. thin layer of alveolar fluid
    d. all of the above

11. Gases diffuse across the respiratory membrane
    a. from areas of higher to areas of lower gas concentration.
    b. more readily when the thickness of the respiratory membrane is increased.
    c. less readily when the surface area of the respiratory membrane is increased.
    d. all of the above

12. Most carbon dioxide is transported in the blood
    a. dissolved in plasma.
    b. bound to blood proteins, primarily hemoglobin.
    c. within bicarbonate ions.
    d. bound to iron.

13. Blood oxygen levels
    a. are more important than carbon dioxide levels in the regulation of respiration.
    b. need to change only slightly to cause a change in respiration.
    c. are monitored primarily by chemoreceptors in the carotid and aortic bodies.
    d. all of the above

14. During exercise, respiration rate and depth increase primarily because of
    a. increased blood carbon dioxide levels.
    b. decreased blood oxygen levels.
    c. decreased blood pH.
    d. input to the respiratory center from the cerebral motor cortex and from proprioceptors.
The Respiratory System: Anatomy Review

1. Fill in the missing organs of the respiratory system:

_________________ (air enters) → nasal cavity → _______________ (both air and food move through) → trachea → _______________ (large tubes leading to both lungs) → lungs.

2. Each lung is surrounded by two layers of serous membrane known as pleurae. These are:

__________ pleura; covers the surface of the lung
__________ pleura; lines the thoracic wall

The space in between is called the ____________ cavity and it is filled with ____________ fluid. This fluid assists breathing movements by acting as a ________________.

3. Bronchial tree:

Air flows from the trachea through the _____________, _____________, and _____________ bronchi to smaller and smaller bronchi. The trachea and bronchi contain ______________ to keep the airways open.

Bronchi branch into _____________, which do not contain ____________ but do contain more ________ muscle. This allows for regulation of airflow.

4. Airways from the nasal cavity through the terminal bronchioles are called the ______________ zone. The function of this zone is to _____________ and ______________ the air.

Is there gas exchange in this zone? ______

5. The respiratory zone contains ____________ where gas is exchanged. This zone consists of the ______________ bronchioles, ___________ ducts and ___________ sacs.

6. The pulmonary __________ carries blood which is (high or low) in oxygen to the lungs.

Pulmonary __________ exchange gases with the alveoli.

Blood leaves the lungs in the pulmonary ____________, which carry _____________ blood back to the heart.

The Respiratory System: Physiology Review

1. Name the three types of cells in the alveolus:

1. _____________; simple squamous epithelium
2. _____________; removes debris and microbes
3. _____________; secretes surfactant.

Surfactant (decreases or increases) surface tension which prevents the alveoli from collapsing.

2. The thin respiratory membrane consists of the ________________ epithelium and the ______________ membrane of both the alveolus and the capillary.

3. In congestive heart failure, there is an accumulation of fluid in the lungs known as _________________. This increases the thickness of the respiratory membrane, resulting in (more or less) gas exchange.

4. When air enters the pleura space causes _________________.

When air enters the pleura space causes _________________.