Human Anatomy & Physiology – Dr. Sullivan
Unit VI - Respiratory System – Chapter 22

I. Summary
   a) Cells continuously use oxygen for the production of energy and release carbon dioxide as a waste product of energy production.
   b) The cardiovascular and respiratory system work together to provide cells with the oxygen necessary to survive.
   c) **Respiration:** the process of gas exchange in the body described in three steps

II. **Pulmonary ventilation (**aka breathing**):** the mechanical flow of air into and out of the lungs
   a) **Inspiration:** air flows into the lungs
   b) **Expiration:** air flows out of the lungs

III. **Respiration**
   a) **External respiration**: the gas exchange between the air in the lungs and the blood in the pulmonary capillaries
   b) **Internal Respiration**: the gas exchange between blood in the systemic capillaries and the cells of the body.

IV. **Respiratory Anatomy**
   a) The respiratory system consists of the nose, pharynx (throat), larynx (voice box), trachea, bronchi, and the lungs.
   b) There are two anatomical divisions of the respiratory system
      i) **Upper respiratory system**: includes nose, pharynx, and associated structures within.
      ii) **Lower Respiratory system**: includes the larynx, trachea, bronchi, and lungs.
   c) There are two functional divisions of the respiratory system as well:
      i) **Conducting portion**: the series of cavities and tubes that filters, warms, moistens, and carries air into the lungs.
         (1) nose, pharynx, larynx, trachea, bronchi, bronchioles, and terminal bronchioles.
      ii) **Respiratory Portion**: the tissues within the lungs where gas exchange occurs
         (1) respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli.
         (2) In an average healthy adult, the volume of air that the conducting portion can hold is 150ml.
         (3) In that same adult, the volume of air that the respiratory portion can hold is 5-6 Liters.
   d) **The Nose**
      i) **Nasal Cavity**: the inside of the nose
      ii) **Nasal Septum**: separates the nasal cavity into right and left sides.
      iii) **Vestibule**: the anterior portion of the nasal cavity, just inside the nose
         (1) The vestibule is lined with coarse hairs designed to filter out large dust particles.
      iv) **Nasal Conchae**: three projections (superior, middle, and inferior) within the wall of the nasal cavity that give it a grooved-like appearance.
      v) **Superior, Middle, and Inferior meatuses**: the spaces in between the conchae.
      vi) **Olfactory epithelium** lines the superior nasal conchae and contains olfactory receptors.
   e) **The Pharynx** aka: throat
      i) The pharynx starts just posterior to the nasal cavities (at the beginning of the soft palate) and runs about 5” down to the **cricoid cartilage** (the most inferior portion of the larynx below the adam’s apple)
      ii) Separates into three regions: **Nasopharynx, Oropharynx,** and **Laryngopharynx** based on the anatomical level.
         (1) naso: nose, oro: mouth, laryngo: larynx
         (2) The oropharynx has digestive and respiratory properties because food, drink and air all enter here.
      iii) **Fauces**: the opening that connects the mouth to the oropharynx.
   f) **Larynx:** composed of 9 pieces of cartilage.
      i) Thyroid Cartilage (Adam’s Apple): larger in males

ii) **Glottis**: two pairs of folds of mucous membrane called the **ventricular folds** (aka false vocal cords), the **vocal folds** (aka true vocal cords, and the space between them called the **rima glottidis**.
    (a) The glottis is the opening in the larynx that leads to the trachea (aka wind pipe)
  (2) **Epiglottis**: large piece of elastic cartilage attached at one end to the thyroid cartilage and free to move around at the other end
    (a) During swallowing the larynx and pharynx rise. The elevation of the pharynx widens it and makes it easier to accept food and water.
    (b) As the larynx rises, the epiglottis' free end lowers, covering the glottis and preventing food and/or water from entering the trachea.

g) **The Bronchial Tree**
  i) **Trachea**: the windpipe that leads from the inferior portion of the larynx to where it branches off into the left and right primary bronchus.
  ii) **Carina**: the place where the trachea (still in between the two lungs) splits and branches bilaterally into the lungs
  iii) **Primary Bronchi**: bilateral and plural for bronchus. As soon as the branches from the trachea enter the lungs, they are considered primary bronchi.
    (1) The primary bronchus diverges into smaller, multiple secondary bronchi, which diverge into smaller, multiple tertiary bronchi, which diverge into smaller, multiple bronchioles, which diverge into smaller, multiple terminal bronchioles.

h) **Lungs**
  i) Two cone-shaped organs in the thoracic cavity, separated by the mediastinum.
  ii) **Thoracic Cavity:** the space inside the ribs, superior to the diaphragm, inferior to the bilateral 1^{st} ribs.
  iii) Separated into two distinct chambers to house each lung. Therefore, if in injury causes one lung to collapse, the other can continue to function.
  iv) The lungs are protected by a two-layered membrane called the **pleural membrane**.
    (1) **Parietal Pleura**: The superficial layer lining the inside of the thoracic cavity
    (2) **Visceral Pleura**: the deep layer that covers the lungs themselves
      (a) Between the two layers is the **pleural cavity**, which contains a small amount of lubricating fluid decreasing friction, so the lungs can expand easily.
      (b) **Pleurisy or Pleuritis**: Inflammation of the pleural cavity
      (c) **Pleural Effusion**: excessive fluid in the pleural cavity
  v) **Base of the lungs**: the broad inferior portion of the lungs
  vi) **Apex**: the narrow superior portion of lungs.
  vii) **Hilus**: a region of each lung on the mediastinal (medial) surface where bronchi, pulmonary vessels, lymphatic vessels, and nerves can enter and exit the lung.
  viii) **Cardiac Notch**: the concavity on the mediastinal side of the left lung that the heart sits in.
  ix) **Lobes**:
    (1) Each human lung is separated into lobes: the left lung, into two lobes, the right lung into three.
    (2) Left lung has an **inferior and superior lobe** separated by the **oblique fissure.**
    (3) The right lung has **an inferior, middle, and superior lobe**.
      (a) The **horizontal fissure** separates the superior and middle lobes**.**
      (b) The **oblique fissure** separates the middle and inferior lobes**.**
      (c) **Bronchopulmonary segment:** a section of the lung tissue supplied by one tertiary bronchus
        (i) Within each Bronchopulmonary segment are many **lobules.**
        (ii) Each lobule contains a lymphatic vessel, an arteriole, a venule, and a branch from the terminal bronchiole.
        (iii) Eventually, the terminal bronchioles divide into microscopic branches called **respiratory bronchioles**, which eventually subdivide into several **alveolar ducts**.
        (iv) Respiratory passages from the trachea down to the alveolar ducts divide into branches about 25 times.
        (v) **Alveolus** (pl. alveoli): a cup shaped outpouching surrounding the alveolar duct.

(vi) Air from the alveolar duct enters the alveolus
(vii) Alveoli secrete **alveolar fluid**, which keeps the surface of the alveoli between the cells and the air moist.
1. **Surfactant**: component of alveolar fluid, which the lowers the surface tension and prevents the alveoli from collapsing.

V. **Pulmonary Ventilation (breathing)**
a) The diaphragm separates the abdominal and the thoracic cavity.
b) **Inspiration (inhalation)**
i) When the diaphragm contracts, it flattens out inferiorly toward the abdominal cavity.
ii) This expands the thoracic cavity volume, which decreases the air pressure inside the thoracic cavity. PV=nRT!
iii) The air pressure inside the thoracic cavity becomes less than that of the outside world.
(1) Therefore, if the nose and/or mouth are open, air rushes in from higher pressure (outside) to lower pressure (inside).
c) **Expiration (exhalation)**
i) Normal resting exhalation does not require muscular contraction, it is a result of **elastic recoil**.
(1) Elastic recoil is the springing back of the lungs and chest wall after being expanded.
(2) Caused by elastic properties of the tissues and the inward pull of surface tension.
(3) The pressure inside the lungs becomes greater than the pressure outside
(a) As the diaphragm relaxes, it domes, decreasing the volume in the thoracic cavity, in turn increasing the pressure.
(4) Exhalation becomes an active procedure when forceful breathing is required, such as exercise or playing a wind instrument.
(a) Abdominal contraction forces the ribs downward and the diaphragm upward, forcefully decreasing the volume of the thoracic cavity.
d) **Lung Volumes and measurements**
i) **Respiratory rate (RR)**: number of breaths per minute, avg: 12 breaths/min
ii) **Tidal Volume (TV)**: the volume of air in one normal breath, avg: 500ml
iii) Spirometer: apparatue commonly used to measure tidal volume
iv) **Minute ventilation (MV):** the volume of air inhaled and exhaled in one minute.
(1) TV x RR = MV
v) **Inspiratory Reserve Volume (IRV):** the amount of air in addition to the TV that can be forcefully inhaled. avg: 3100 ml
vi) **Inspiratory Capacity (IC):** the total volume of air that can be inhaled
(1) IC = TV + IRV
vii) **Expiratory Reserve Volume (ERV**): the volume of air in addition to the TV that can be forcefully exhaled. avg. 1200ml
viii) **Residual Volume (RV)**: the volume of air that must remain in the lungs to keep the alveoli inflated at all times. Can not be exhaled and may cause collapsing of the lungs if so.
(1) During a normal breath, ERV and RV remain in the lungs.
(2) These two together is called the **Functional Residual Capacity (FRC)**
(a) **ERV + RV = FRC**
ix) **Vital Capacity (VC)** is the maximum volume of air that can be breathed in and out in one breath. IRV + TV + ERV = VC
x) **Total Lung Capacity (TLC)** is how much air the lungs can hold at one time
(1) TV+IRV+RV+ERV= TLC

VI. **CNS Control of respiration**
a) The basic rhythm of respiration is controlled by neurons in the brainstem.
b) The *respiratory center* is made up of three different areas from the brainstem
c) *The Medullary rhythmicity area* in the medulla oblongata has an inspiratory and expiratory area
i) During normal, quiet breathing, only neurons from the inspiratory area are active, since normal expiration is passive.
ii) During forceful breathing, nerve impulses from the inspiratory area activate the expiratory area causing muscle contraction for forceful exhalation.

d) *The Pneumotaxic area* of the pons functions to stop inhalation before the lungs become too full with air, shortening the duration of inhalation.
   i) When the pneumotaxic area is active, breathing becomes more rapid and shallow.
e) *The Apneustic Area* of the pons sends stimulatory impulses to the inspiratory area of the medulla oblongata, increasing the duration of inhalation to allow for long, deep breaths.
   i) When both are active, the pneumotaxic area overrides the apneustic area.

VII. **Chemoreceptor control of respiration**

a) Chemical stimulate also modulate how quickly and how deeply we breathe.
b) The main function of respiration is to maintain proper levels of oxygen and carbon dioxide and is very responsive to chemical changes in the levels of both of these.
c) *Peripheral Chemoreceptors* for oxygen, hydrogen ions, and carbon dioxide are found in three locations in the circulatory system and monitor these levels in blood.
d) The Carotid bodies in the bilateral carotid arteries and the Aortic bodies in the aorta.
e) *Central Chemoreceptors* for carbon dioxide and hydrogen ions are also located in the medulla oblongata and monitor these levels in the CSF.
f) We can voluntarily control changes in our breathing pattern because the respiratory system has connections with the cerebral cortex. However, there is an involuntary portion that will take over when conditions inside the body demand it.
   i) A buildup of carbon dioxide or hydrogen atoms in the body will be recognized by the chemoreceptors and they will strongly stimulate the inspiratory area sending nerve impulses along the phrenic and intercostal nerves causing a contraction of the diaphragm and intercostal muscles forcing involuntary inhalation.

VIII. Respiration: gas exchange between the blood, the alveoli, and the tissues.

a) Internal: between blood and tissues (sytemic respiration)
b) External: between the alveoli and the blood (pulmonary respiration)
c) Exchange of gasses between air in alveoli and blood in pulmonary capillaries.
   i) Results in conversion of **deoxygenated blood** from the right side of the heart to **oxygenated blood** for return to the left side of the heart.
d) **Partial Pressure**: the pressure of a specific gas in a mixture.
   i) Total pressure is the sum of all partial pressures in a mixture (pressure is measured in the units mmHg (millimeters of mercury)).
e) Gasses diffuse from areas of higher partial pressure to areas of lower partial pressure.
f) Atmospheric air is made up of mostly Nitrogen (78.6%), Oxygen (20.9%), Carbon Dioxide (.04%), Water vapor (.4%), and some other gasses (.06%).
   i) i.e. if the total pressure of air is 760mmHg and the air is 21% oxygen, then the partial pressure of oxygen is 21% of 760. To calculate this multiply 760mmHg times .21. The answer is approximately 160mmHg. This is written as $pO_2 = 160$mmHg.
g) External Respiration (pulmonary respiration)
   i) Exchange of gasses between air in alveoli and blood in pulmonary capillaries.
      (1) Results in conversion of **deoxygenated blood** from the right side of the heart to **oxygenated blood** for return to the left side of the heart.
   ii) **Gas Exchange in the alveoli**
      (1) As the deoxygenated blood enters the arteriole side of the pulmonary capillary, the pO_2 is 40mmHg and the $pCO2_2$ is 45mmHG
      (2) In the alveoli: the pO_2 in the alveoli is 105mmHG and the pCO_2 is 40mmHG.
         (a) Remember that there is a large residual volume of air in the lungs and there is the anatomical dead space. These areas are filled with stale air that has already been respired. So the pO_2 of fresh air drops when it enters the lungs and mixes with the pO_2 of stale air. That's why the breathed air in the alveoli has a pO_2 of only 105mmHg.
         (b) As the capillary passes through the alveoli, the gasses diffuse toward equilibrium and the pO_2 of blood becomes 105mmHG and the pCO_2 becomes 40mmHg in the venule side of the pulmonary capillary. (there is so much oxygen in alveolar air that the rather than the pO_2 diffusing to the average of 40 & 105, the capillary blood can be totally saturated to 105mmH.)

            (i) There is some mixing of oxygenated blood and deoxygenated blood as it enters because some of the blood from the heart does not contact alveoli causing the pO_2 of pulmonary venule blood to be 100mmHg.
        (c) At higher altitudes, the air pressure drops, as does the pO_2. Gas exchange occurs more slowly and may cause symptoms such as lightheadedness, fatigue, headache, insomnia, nausea, and disorientation.
            (i) 100% oxygen is used to increase the pO_2 in these situations for breathing.
            (ii) Exhaled *atmospheric* air is still 16% oxygen and capable of sustaining life. Therefore, CPR works because there is enough oxygen in exhaled air to breathe with.

h) Internal Respiration

- i) Gas exchange between the blood in the systemic capillaries and the interstitial fluid
- ii) The pCO_2 in the arteriole end of the capillary is about 40mmHg and the pCO_2 in the interstitial fluid is about 45mmHg.
    - (1) So, CO_2 diffuses down its partial pressure gradient into the capillary until the venule end of the capillary has a pCO_2 of 45mmHg on it's way back to the right atrium.
        - (a) This is how the blood picks up CO_2 and brings it back to the lungs to be exhaled out.
- iii) The pO_2 in the arteriole end of the capillary is about 100mmHg and the pO_2 in the interstitial fluid is about 40mmHg.
    - (1) So, the O_2 diffuses down its pressure gradient from the capillary blood into the interstitial fluid until the venule end of the capillary blood has a pO_2 of about 40mmHg.
    - (2) This is the way O_2 is delivered to the tissues so the cells can utilize it to make ATP.

IX. Common Pathologies

- a) **Asthma**: 3-5% of the population. It is characterized by chronic airway inflammation, hypersensitivity to stimuli, and airway obstruction.
    - i) Possibly caused by spasm of the smooth muscles of the brochioles, increased mucous secretion, edema of the mucous, and/or damage to the epithelial lining.
- b) **Chronic Obstructive Pulmonary Disorder**: Caused by smoking, air pollution, pulmonary infection, occupational exposure to dusts and gases, and genetics. Two-types:
    - i) **Emphysema**: destruction of the walls of the alveoli, causing large sacs of air that remain filled with expiration. The result is less surface are for gas exchange and more difficulty expelling breathed air from the lungs to make room for fresh air.
        - (1) **most common cause:** cigarette smoking
    - ii) **Chronic Bronchitis**: Excessive bronchial mucous secretion accompanied by a productive cough lasting 3 months/year for 2 consecutive years.
        - (1) **Most common cause**: cigarette smoking