I. Respiratory system
   A. Functions of the respiratory system
      1. Exchange of carbon dioxide and oxygen.
      2. Help maintain the pH of body fluids.
      3. Help maintain the body temperature.
   B. Primary organs of the respiratory system
      1. The **nasal cavity**
         a. External portion consists of bone and hyaline cartilage covered by skin.
         b. Lined internally with mucous membrane.
         c. Contains the **superior, middle and inferior nasal conchae**.
            i. Three bony shelves covered by vascular mucous membrane to increase the surface area within the nasal cavities.
            ii. Help to warm and moisten the air.
            iii. The superior conchae and uppermost nasal septum contain the olfactory receptors.
      2. Paranasal sinuses
         a. Spaces within bones adjacent to the nasal cavity.
         b. Filled with air and lined by mucous membrane.
         c. Drain through the lateral walls of the nasal cavity.
         d. Lighten the bones of the skull and act as resonance chambers for speech.
      3. **Pharynx** (throat)
         a. Wall composed of skeletal muscle and lined by mucous membrane.
         b. Nasopharynx
            i. Located posterior to the nasal cavities.
            ii. Houses the **pharyngeal tonsils**.
            iii. Has two openings for the **Eustachian (auditory) tubes**.
         c. Oropharynx
            i. Located between the soft palate and the level of the hyoid bone.
            ii. Houses the **palatine** and **lingual tonsils**.
            iii. Common passage for food and air.
         d. Laryngopharynx
            i. Begins at the level of the hyoid bone and extends to the openings of the larynx and esophagus.
      4. **Larynx** (voicebox)
         a. Supported by 9 cartilages held together by muscle and elastic connective tissue.
         b. Lined by mucous membrane.
         c. Contains the **epiglottis**.
            i. Composed of elastic cartilage covered by epithelial tissue.
            ii. During swallowing the epiglottis moves down to cover the opening to the larynx, preventing food or liquids from entering the airway below.
         d. Contains the **vocal folds (cords**).
            i. **Vocalis muscles** run anterior to posterior across the larynx.
            ii. Are covered in mucous membrane to form the **vocal folds**.
            iii. Sound production occurs when breathing forces air against the vocal folds, pushing them apart.

(a) When the folds snap back it causes them to vibrate creating a buzzing sound.
(b) Increasing the pressure of the air stream makes the folds open wider and snap more powerfully, creating a louder sound.

5. **Trachea** (windpipe)
    a. Extends from the larynx to the 5^{th} thoracic vertebrae.
    b. Wall supported by 16-20 hyaline cartilage supports shaped like horseshoes, opening on the dorsal side.
        i. The opening on the dorsal side is to facilitate the movement of food down the esophagus.
    c. Lined by mucous membrane with pseudostratified ciliated columnar epithelium.
6. **Bronchi** and **bronchioles**
    a. The trachea divides into the right and left primary bronchi.
        i. These primary bronchi continue to be supported by hyaline cartilage and lined by a mucous membrane.
        ii. The right primary bronchus divides into three secondary bronchi to supply the three lobes of the right lung.
        iii. The left primary bronchus divides into two secondary bronchi to supply the two lobes of the left lung.
        iv. The bronchi continue to branch and decrease in size until they reach 1mm in diameter at which point they are referred to as bronchioles (23 total levels of branching).
7. **Alveoli**
    a. Where the exchange of oxygen (O_2) and carbon dioxide (CO_2) occurs.
    b. Microscopic sacs with walls composed of simple squamous epithelial tissue.
    c. The inside of the alveoli is coated with **surfactant**.
        i. Produced by special cells within the alveoli.
        ii. Reduces the surface tension between water molecules to prevent the alveoli from collapsing during expiration.
        iii. **Infant respiratory distress symptom** is caused by too little surfactant being produced within the infant's alveoli at birth.
    d. A thin layer of connective tissue containing a lot of elastic fibers supports the simple squamous tissue of the alveoli.
    e. A capillary network surrounds the alveoli.

C. The lungs as a whole
1. Cone shaped organs with the point (**apex**) located superiorly.
2. Are covered by the pleural (serous) membrane.
    a. The **visceral pleura** adheres to the surface of the lung.
    b. The **parietal pleura** lines the inside of the thoracic cavity.
    c. The pleural layers are separated by the **pleural cavity** containing serous fluid for lubrication.
    d. **Pleurisy** is an inflammation of the pleural layers that causes friction of the layers during breathing.

D. Secondary organs of the respiratory system
1. **Diaphram**
    a. Skeletal muscle that separates the thoracic and abdominal cavities.

b. Contraction of the diaphragm causes it to flatten and move inferiorly, increasing the size of the thoracic cavity.
c. Relaxation of the diaphragm causes it to move superiorly, decreasing the size of the thoracic cavity.

2. External intercostals

a. Skeletal muscles that insert onto the ribs.
b. Contraction of the external intercostals elevates the ribs and increases the size of the thoracic cavity.
c. Relaxation of the external intercostals depresses the ribs and decreases the size of the thoracic cavity.

3. Internal intercostals

a. Skeletal muscles that insert onto the ribs.
b. Contraction of the internal intercostals depresses the ribs even more, decreasing the size of the thoracic cavity during forced exhalation.

4. Rectus abdominus

a. Skeletal muscles that contract and compress the abdomen to aid in forced exhalation.

E. Ventilation

1. Normal inspiration (inhalation)
   a. Starts with contraction of the diaphragm and external intercostals.
   b. Contraction of these muscles increases the size of the thoracic cavity causing the **intrapleural pressure** (pressure in the space around the lungs) to decrease.
   c. This drop in pressure around the lungs causes the greater pressure inside the lungs to expand the size of each lung, decreasing the **intrapulmonary pressure** (pressure within the lungs).
   d. Once the pressure within the lungs is less than the atmospheric pressure of the outside air, air enters the lungs.
2. Normal expiration (exhalation)
   a. Only requires relaxation of the diaphragm and the external intercostals.
   b. Relaxation of these muscles decreases the size of the thoracic cavity, causing the **intrapleural pressure** to increase.
   c. The greater pressure around the lungs compresses the lungs causing them to get smaller, thereby increasing **intrapulmonary pressure**.
   d. Once the pressure within the lungs is greater than the atmospheric pressure of the outside air, air exits the lungs.
3. Forced inspiration
   a. In addition to the diaphragm and external intercostals, the sternocleidomastoid muscles and scalene muscles contract to increase the size of the thoracic cavity even more than normal.
   b. The greater the increase in the size of the thoracic cavity, the greater the intake of air.
4. Forced expiration
   a. Involves contraction of the internal intercostals muscles and rectus abdominus muscles to decrease the size of the thoracic cavity even more than normal.
   b. The greater the decrease in the size of the thoracic cavity, the greater the amount of air that exits the lungs.

F. Lung volumes and capacities
    1. **Tidal volume**
        a. The volume of air moved in one normal breath.
        b. Is about 500 mL.
    2. **Expiratory reserve volume**
        a. The volume of air that can still be exhaled after a normal expiration.
        b. Is about 1000 mL.
    3. **Inspiratory reserve volume**
        a. The volume of air that can still be inhaled after a normal inspiration.
        b. Is about 3000 mL.
    4. **Residual air**
        a. The amount of air left in the lungs after forcefully exhaling all that can be exhaled.
        b. Is about 1500 mL.
    5. **Vital capacity**
        a. The total volume of air that can be voluntarily moved into and out of the lungs.
        b. Is equivalent to tidal volume + expiratory reserve volume + inspiratory reserve volume.
    6. **Total lung capacity**
        a. Is the vital capacity + the residual air volume.
    7. **Dead space**
        a. The sum of all the spaces in the lungs where no exchange of gases occurs, i.e. the respiratory passageways.

G. Exchange and transport of respiratory gasses
    1. Partial pressure
        a. Air is a mixture of numerous gasses (nitrogen, oxygen, carbon dioxide, etc.)
        b. The pressure of a single gas in a mixture of gasses is referred to as a **partial pressure**.
        c. For example, the pressure of all the gasses that make up air combined is approximately 760mmHg. However, the partial pressure of oxygen looks at how much of that pressure is produced by only the oxygen gas, which is 158mmHg.
        d. Gasses want to diffuse from where their partial pressure is **higher** to where their partial pressure is **lower**.
    2. Exchange of oxygen and carbon dioxide
        a. At the lungs oxygen diffuses from the alveoli, where the partial pressure of oxygen is higher, into the deoxygenated blood in the capillaries where the partial pressure of oxygen is lower.
        b. At the lungs carbon dioxide diffuses from the blood in the capillaries, where the partial pressure is greater, into the alveoli where the partial pressure of carbon dioxide is lower.
        c. At the tissues, the oxygen leaves the blood, where the partial pressure of oxygen is higher, and enters the tissues where the partial pressure of oxygen is less.
        d. At the tissues, the carbon dioxide leaves the tissue, where the partial pressure of carbon dioxide is higher, and enters the blood in the capillaries where the partial pressure of carbon dioxide is less.
    3. The transport of oxygen in the blood occurs in 2 ways:

a. The majority of the oxygen (98.5%) is transported in the blood attached to hemoglobin molecules within red blood cells as **oxyhemoglobin** (**HbO_2**).
b. The other 1.5% of the oxygen is dissolved within the blood plasma.

4. The transport of carbon dioxide in the blood occurs in 3 ways:
   a. Approximately 9% of the carbon dioxide is dissolved within the blood plasma.
   b. About 13% of the carbon dioxide is transported attached to hemoglobin molecules within red blood cells as **carbaminohemoglobin** (**$HbCO_2$**).
   c. The other 78% will be transported as **bicarbonate ions** (**HCO_3^-**).
      i. The bicarbonate is formed by the combination of water (H_20) and carbon dioxide (CO_2) molecules, forming carbonic acid (H_2CO_3). The carbonic acid then dissociates into a hydrogen ion (H^+) and a bicarbonate ion (HCO_3^-).
      ii. This reaction occurs both within the plasma of the blood and within red blood cells.
         (a) Within red blood cells this reaction is assisted by the enzyme **carbonic anhydrase**.
      iii. The complete reaction:

$$H_20 + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

      iv. When the reaction occurs within the plasma the bicarbonate remains within the plasma of the blood.
      v. If the reaction occurs within the red blood cell the bicarbonate formed within the cells is transported out of the cell into the plasma to be transported to the lungs.
         (a) As the negatively charged bicarbonate ions are transported out of the cells a negatively charged chloride ion is transported into the cell in order to replace the bicarbonate.
         (b) This is known as the **chloride shift**.
         (c) It prevents the formation of a charge difference between the inside of the red blood cells and the plasma due to the shifting ions.

H. The control of respiration
   1. The basic rhythm of respiration is controlled by the **medullary rhythmicity center** within the **medulla oblongata**.
      a. This includes both an **inspiratory center** and an **expiratory center**.
      b. There is also a back-up respiratory center (the **apneustic** and **pneumotaxic centers**) within the **pons** that help control the transition between inspiration and expiration.
   2. While the inspiratory center is active it sends nerve impulses to the diaphragm (via the phrenic nerve) and external intercostal muscles (via the intercostal nerves) to stimulate their contraction, resulting in inspiration.
      a. Simultaneously, the inspiratory center sends inhibitory messages to the expiratory center inhibiting its activity.
      b. At the end of two seconds the inspiratory center begins to fatigue, no longer inhibiting the expiratory center.
      c. When no longer inhibited, the expiratory center sends inhibitory impulses to the inspiratory center.

        i. This prevents the inspiratory center from continuing to send impulses to the diaphragm and external intercostal muscles, allowing their relaxation and exhalation.

I. Factors influencing the respiratory rate.
    1. **Chemoreceptors** within the aorta and carotid arteries monitoring carbon dioxide, oxygen and hydrogen ion levels.
        a. Higher levels of carbon dioxide (and hydrogen ions) detected by the chemoreceptors, such as with breath holding or exercise, causes increased stimulation of the inspiratory center and an increased respiratory rate.
            i. Increasing the respiratory rate allows for the exhalation of more carbon dioxide, bringing levels back down to homeostatic.
        b. Lower levels of carbon dioxide (and hydrogen ions) detected by the chemoreceptors, such as with **hyperventilation**, causes decreased stimulation of the inspiratory center and a decreased respiratory rate.
            i. Decreasing the respiratory rate allows for the build-up of carbon dioxide in the blood, bringing levels back up to homeostatic.
        c. Low oxygen levels can also stimulate the chemoreceptors to cause an increase in the respiratory rate. However, only if the level drops to half the normal oxygen level or lower (ex. at elevations 10,000 feet above sea level).
    2. Limbic system stimulation such as with anxiety (thinking about work or an exam).
    3. Movement sensed by proprioceptors in joints can increase the rate and depth of breathing.
    4. Temperature increases, such as with exercise, can increase the rate of breathing.
    5. Pain
    6. The **Hering Breuer reflex**
        a. During inspiration, the inflating lungs ultimately stimulate stretch receptors in the pleura.
        b. Impulses generated by the stretch receptors travel to the medulla oblongata, inhibiting the inspiratory center and stimulating the expiratory center to initiate exhalation.
        c. An important reflex to keep the lungs from over expanding.

J. The respiratory system and maintaining pH.
    1. Breathing plays an important role in controlling pH.
    2. The more carbon dioxide you exhale, the more carbonic acid is eliminated from your blood raising the pH of the blood.
    3. By altering the rate and depth of breathing the pH of arterial blood can be changed within minutes.