I. Anatomy of the Respiratory System

A. Upper Airway Anatomy

1. The Nasal Cavity
   a. Septum – cartilage wall that separates the right and left nasal cavities.
   b. Nares – the nostrils
   c. The entire nasal cavity is lined with a mucous membrane.
      (1) Covered with mucus and is very vascular.
      (2) Helps to trap inhaled particles.
      (3) Warms and humidifies the inhaled air.
   d. Cilia (hairlike fibers) also line the nasal cavity and propel the trapped particles to the back of
      the pharynx where they are swallowed and exit the body by way of the digestive tract.
   e. Structures that connect with the nasal cavity:
      (1) Sinuses
         (a) Air-filled cavities inside certain bones of the skull.
         (b) Reduce the overall weight of the skull.
         (c) Help to warm, purify, and humidify inhaled air.
         (d) Help to make the voice more resonant.
      (2) Eustachian Tubes
         (a) Connect the ear with the nasal cavity.
         (b) Helps equalize the pressure on each side of the eardrum.
      (3) Nasolacrimal Ducts
         (a) Tubes from the inside corners of the eyes to the nasal cavity.
         (b) Drain tears and debris from the eyes into the nasal cavity.

2. The Oral Cavity
   a. Also called the mouth.
   b. Formed by:
      (1) Cheeks
      (2) Hard palate (anteriorly) and soft palate (posteriorly)
      (3) Tongue
         (a) The most common airway obstruction.
         (b) Large muscle that is attached to the mandible and hyoid bone.

3. The Pharynx
   a. Nasopharynx
      (1) The area directly behind the nasal cavity.
      (2) Extends from the back of the nasal cavity down to the level of the soft palate.
   b. Oropharynx
      (1) The area directly behind the oral cavity.
      (2) Extends from the level of the soft palate to the hyoid bone.
   c. Laryngopharynx
      (1) Also called the hypopharynx.
      (2) Extends from the hyoid bone to the opening of the esophagus and larynx.
      (3) Epiglottis
         (a) Leaf-shaped cartilage that covers the opening of the larynx when swallowing.
         (b) Vallecula – the notch just above the epiglottis.
The Respiratory System

4. The Larynx
   a. Also called the voice box.
   b. The most prominent cartilage of the larynx is the thyroid cartilage (also called the Adam’s apple).
   c. Glottis (Glottic opening)
      (1) The opening between the vocal cords.
      (2) The narrowest part of the adult trachea.
   d. Cricoid cartilage
      (1) The cartilage ring just below the thyroid cartilage.
      (2) Forms the inferior border of the larynx.
      (3) Sellick’s Maneuver
         (a) Pressure applied to the cricoid cartilage to occlude the esophagus and prevent aspiration.
         (b) Also called “crike pressure”.
      (4) Cricothyroid Membrane
         (a) Fibrous membrane that connects the thyroid cartilage with the cricoid cartilage.
         (b) This is the site for needle or surgical airways.

B. Lower Airway Anatomy
   1. The Trachea
      a. 10-12 cm long tube that connects the larynx to the mainstem bronchi.
      b. Contains C-shaped cartilage rings.
      c. Lined with mucus and cilia.
      d. Bifurcates (divides) at the carina.
   2. The Bronchi
      a. Tubes from the trachea to each lung.
      b. Right and Left mainstem bronchi.
         (1) Right mainstem bronchus is almost straight.
            (a) Aspirated material often enters this bronchus.
         (2) Left mainstem bronchus angles more acutely to the left.
      c. The right and left mainstem bronchi branch into secondary bronchi which branch into tertiary bronchi which branch into even smaller passages called bronchioles, the smallest of which are called respiratory bronchioles.
      d. As the passages become smaller, the amount of cartilage in their walls decreases and the amount of smooth muscle increases.
      e. Because of this, beta 2 receptors (which are in the smooth muscle) have their greatest effect on the diameter of the bronchioles.
      f. The respiratory bronchioles divide into microscopic alveolar ducts, which terminate into the alveoli.
3. The Alveoli
   a. Balloon-like clusters.
   b. Also called alveolar sacs.
   c. Gas exchange takes place across the alveolar and capillary membranes.
   d. Surfactant
      (1) Chemical that decreases the surface tension of the alveoli which prevents their collapse as air is expired and makes it easier for them to expand when air is inhaled.
      (2) Atelectasis
         (a) Alveolar collapse.
         (b) Can be caused by a lack of surfactant.
         (c) Can also be caused by any condition that prevents inspiration.
         (d) No gas exchange can take place in collapsed alveoli.

4. The Lung Parenchyma (Parenchyma = essential parts of an organ)
   a. Right and Left Lung
      (1) The left lung is smaller because it shares space with the heart.
      (2) Hilum
         (a) Where the mainstem bronchi, blood vessels, and nerves enter the lungs.
         (b) This is the only point of attachment for each lung.
   b. Lobes
      (1) Each lung is further divided into lobes.
      (2) Each lobe has its own secondary bronchus and blood supply.
      (3) Lobes of Right Lung
         (a) Upper
         (b) Middle
         (c) Lower
      (4) Lobes of Left Lung
         (a) Upper
         (b) Lower

5. The Pleura
   a. A double layered membrane that surrounds each lung.
   b. The Two Layers:
      (1) Visceral Pleura
         (a) Attached to the outside surface of the lung.
         (b) Does not contain nerve endings.
      (2) Parietal Pleura
         (a) Lines the wall of the thoracic cavity.
         (b) Does contain nerve endings.
   c. Pleural Space (also called the Pleural Cavity)
      (1) The space between the two layers.
      (2) Contains a thin film of fluid that acts as a lubricant to reduce friction as the two layers slide against each other.
   d. Pleurisy (also called Pleuritis)
      (1) An inflammation of the pleura.
      (2) Causes significant pain with respiration.
C. The Pediatric Airway
   1. Airway is smaller in all aspects.
   2. The jaw is smaller and the tongue is relatively larger.
   3. The epiglottis is rounder and floppier.
   4. The dental ridge and teeth are softer and more fragile.
   5. The larynx is funnel shaped and the trachea is more narrow.
      a. Even a very small foreign body can become wedged in place and be life threatening.
      b. Even a limited amount of swelling can cause serious problems.
   6. The trachea is softer and more flexible and can collapse if the neck and head are hyperextended.
   7. Children will normally rely more on their diaphragm for breathing.

II. Physiology of the Respiratory System

A. Respiration and Ventilation
   1. Respiration = the exchange of gases between a living organism and its environment.
   2. Ventilation = the mechanical process that moves air into and out of the lungs.
   3. The Respiratory Cycle
      a. Inspiration (Inhalation)
         (1) The respiratory centers in the brain send a message (by the phrenic nerve) to the diaphragm telling it to contract, causing it to flatten.
         (2) At the same time, the intercostal muscles contract drawing the rib cage upward and outward.
         (3) All of this causes the size of the chest cavity (thorax) to increase.
         (4) Outside (atmospheric) air rushes in to fill the larger space.
         (5) As the alveoli inflate, they stretch and become thinner, allowing O\textsubscript{2} and CO\textsubscript{2} to diffuse across their membranes.
         (6) When the pressure in the chest cavity (intrathoracic pressure) is equal to atmospheric pressure, the alveoli are maximally inflated.
         (7) Stretch receptors in the bronchi and bronchioles send messages (by the vagus nerve) to the brain telling it to stop inspiration.
      b.Expiration (Exhalation)
         (1) All of the respiratory muscles relax.
         (2) The size of the chest cavity decreases.
         (3) Air is forced out until intrathoracic pressure is equal to atmospheric pressure again.
   4. Pulmonary Circulation
      a. Pulmonary Artery
         (1) Immediately branches into the left and right pulmonary arteries after leaving the right ventricle.
         (2) Carries deoxygenated blood to the left and right lungs.
      b. Pulmonary Veins
         (1) Carry oxygenated blood from each lung back to the heart.
         (2) The blood enters the left atrium, then travels to the left ventricle, and is pumped out through the aorta.
   B. Measuring Oxygen and Carbon Dioxide Levels
      1. Partial Pressure
         a. The pressure exerted by each component of a gas mixture.
b. Determined by multiplying the percentage of the gas in the mixture times the mixture’s total pressure.
c. Partial Pressure of O₂ (PaO₂ or PO₂) in arterial blood usually = 80 to 100 torr
d. Partial Pressure of CO₂ (PaCO₂ or PCO₂) in arterial blood = 35 to 45 torr

2. Diffusion of Gases
   a. In the Lungs
      (1) The amount of O₂ is higher in the alveoli than in the pulmonary capillaries, so it defuses across the capillary membrane into the blood.
      (2) The amount of CO₂ is higher in the pulmonary capillaries, so it defuses across the capillary membrane into the lungs.
   b. In the Peripheral Tissues
      (1) The amount of O₂ is higher in the blood than in the tissues, so it diffuses across the capillary membrane into the tissues.
      (2) The amount of CO₂ is higher in the tissues, so it diffuses across the capillary membrane into the blood.

3. Oxygen Concentration in the Blood
   a. Most of the oxygen that diffuses into the blood combines with hemoglobin in the red blood cells and is measured as oxygen saturation (SaO₂).
   b. The remainder of the oxygen in the blood is dissolved in the plasma and is measured as the partial pressure of oxygen (PO₂).
   c. Oxygen Saturation (SaO₂)
      (1) The amount of hemoglobin that is saturated with oxygen.
      (2) Normally, when PO₂ reaches 90 to 100 torr, almost 100% of the hemoglobin will be saturated with oxygen.
   d. Factors Affecting O₂ Concentration in the Blood:
      (1) Not enough hemoglobin (anemia, hemorrhage).
      (2) Carbon monoxide attached to the hemoglobin.
      (3) Not enough O₂ in the alveoli
         (a) Not enough O₂ in the atmosphere (confined space, high altitude, etc.)
         (b) Foreign body airway obstruction
         (c) Asthma, emphysema, etc.
         (d) Pneumothorax, hemothorax (or combination of the two)
      (4) Problems with diffusion across the pulmonary membrane
         (a) Fluid in the lungs
         (b) Atelectasis
      (5) Pulmonary embolism - when blood is prevented from reaching the capillaries in the lungs because of a blood clot in the pulmonary artery system.
   e. Actions to Correct Problems with O₂ Concentration in the Blood:
      (1) Assist ventilations or provide artificial ventilation.
      (2) Administer supplemental oxygen.
         (a) Increases the concentration of inspired oxygen.
         (b) FiO₂ (fractional concentration of oxygen) = the concentration of inspired oxygen.
      (3) Administer drugs to correct the underlying problem.
         (a) Albuterol for asthma.
         (b) Epinephrine for anaphylaxis.
      (4) Treat traumatic injuries such as tension pneumothorax, flail segment,
4. Carbon Dioxide Concentrations in the Blood
   a. Blood Transportation of CO$_2$
      (1) 70% is in the form of bicarbonate ions in the red blood cells.
      (2) 23% is attached to hemoglobin in the red blood cells.
      (3) 7% is dissolved in the plasma.
   b. Factors Affecting CO$_2$ Concentration in the Blood:
      (1) Hyperventilation (lowers CO$_2$ levels in the blood)
      (2) Increased levels of CO$_2$ in the blood (Hypercarbia)
         (a) Increased CO$_2$ Production:
            i) Fever
            ii) Muscle exertion
            iii) Shivering
            iv) Increase in metabolic acids
         (b) Decreased CO$_2$ Elimination - results from any condition that interferes with respiration.

C. Regulation of Respiration
   1. Respiratory Rate
      a. The number of times a person breathes in one minute.
      b. Voluntary and involuntary nervous system mechanisms control it.
   2. Nervous Impulses from the Respiratory Center
      a. The main respiratory center is in the medulla oblongata (or just medulla) in the brainstem. Another respiratory center that is located in the pons (also in the brain stem, just above the medulla) assists in respiration.
      b. The impulses that control respiration travel from the medulla to the respiratory muscles via the phrenic nerve and intercostal nerves.
   3. Stretch Receptors
      a. Located mainly in the bronchi and bronchioles.
      b. The more they stretch, the more rapidly they send impulses to the medulla which inhibit inspiratory neurons.
      c. This is called the Hering-Breuer Reflex.
   4. Chemoreceptors
      a. Central Chemoreceptors (located in the medulla):
         (1) Primarily sensitive to the pH of CSF.
         (2) The pH of CSF responds very quickly to changes in the level of carbon dioxide in arterial blood (PCO$_2$).
         (3) When PCO$_2$ increases, pH of CSF drops. This stimulates the chemoreceptors in the medulla to increase respiratory rate and depth.
         (4) When PCO$_2$ decreases, pH of CSF goes up. This decreases chemoreceptor stimulation, decreasing the rate and depth of breathing.
         (5) In normal individuals, chemoreceptors in the medulla are not sensitive to changes in oxygen level.
      b. Peripheral Chemoreceptors (located in the aorta and carotid arteries):
         (1) Primarily sensitive to pH of arterial blood.
         (2) Are also sensitive to changes in oxygen levels.
         (3) In normal individuals, a decrease in oxygen level is not usually a
strong stimulus for breathing.

4. An exception to this is when oxygen levels are low and CO\textsubscript{2} levels are also low. Examples include exposure to high altitudes and rapid onset of shock.

5. **Hypoxic Drive**
   a. A default mechanism that uses the level of PO\textsubscript{2}, not PCO\textsubscript{2} and pH levels, to stimulate or inhibit respiration.
   b. This occurs in people with chronically elevated PCO\textsubscript{2} levels because the chemoreceptors become accustomed to the high levels of carbon dioxide.
   c. This is most often seen in patients with chronic respiratory diseases such as emphysema and chronic bronchitis.
   d. High-flow oxygen can raise the level of PO\textsubscript{2} so high that the chemoreceptors stop stimulating the respiratory centers, causing the patient to stop breathing.
   e. However, this usually takes a relatively long period of time to occur and you should NEVER withhold oxygen from a patient who needs it.

D. **Measures of Respiratory Function**

1. **Total Lung Capacity (TLC)**
   a. Maximum lung capacity.
   b. The total amount of air contained in the lung at the end of a maximum inspiration.
   c. Approximately 6 liters (6000 ml)

2. **Tidal Volume (V\textsubscript{T})**
   a. The amount of air inhaled or exhaled during normal quite breathing.
   b. Approximately 500 ml

3. **Dead Space Volume (V\textsubscript{D})**
   a. Amount of tidal volume that remains in air passageways (the trachea, bronchi, and bronchioles).
   b. This air is not available for gas exchange because it is not in the alveoli.
   c. Approximately 150 ml

4. **Alveolar Volume (V\textsubscript{A})**
   a. Amount of tidal volume that reaches the alveoli.
   b. Approximately 350 ml
   c. \( V\textsubscript{A} = V\textsubscript{T} - V\textsubscript{D} \)

5. **Minute Volume (V\textsubscript{min})**
   a. Amount of air moved in and out in one minute.
   b. \( V\textsubscript{min} = V\textsubscript{T} \times \text{respiratory rate} \)

6. **Inspiratory Reserve Volume (IRV)**
   a. Amount of air that can be forcefully inhaled after a normal inspiration.
   b. Approximately 3100 ml

7. **Expiratory Reserve Volume (ERV)**
   a. Amount of air that can be forcefully exhaled after a normal expiration.
   b. Approximately 1200 ml

8. **Residual Volume (RV)**
   a. Amount of air that remains in the lungs at the end of a maximum expiration.
   b. Approximately 1200 ml

9. **Functional Residual Capacity**
   a. Amount of air that remains in the lungs at the end of a normal expiration.
b. Approximately 2400 ml