The Respiratory System

The function of the respiratory system is to supply the body with oxygen and dispose of carbon dioxide. This is accomplished by four processes:

- Pulmonary ventilation, the movement of air into and out of the lungs.
- External respiration, the movement of O_2 from the lungs to the blood and the movement of CO_2 from the blood to the lungs.
- Transport in the blood of O_2 from the lungs to the body tissues and CO_2 from the body tissues to the lungs.
- Internal respiration, the movement of O_2 from the blood to the tissue cells and of CO_2 from the tissue cells to the blood.

Gross Anatomy

The nose serves as a passageway for inspired air. It moistens, warms and filters the air. The outside entry ways are called the nares. The nasal cavity is divided by the nasal septum and lined with the nasal or respiratory mucosa. Extending medially from each of the lateral walls of the nasal cavity are the superior, middle and inferior nasal conchae. The groove inferior to each of these is the superior, middle and inferior meatus. These conchae greatly increase the surface area of the mucosa and effectively trap many particulates entering the nose. They also cause a turbulence warming and moistening the air. The pharynx begins in the posterior of the nasal cavity and is divided into three parts:

- nasopharynx lies superior to the soft palate. During swallowing the soft palate and uvula move superiorly closing the nasopharynx to food. At the back is the pharyngeal tonsil (adenoid), a mass of lymphoid tissue that traps and destroys pathogens. The Eustacian tubes connect the nasopharynx to the middle ear.
- oropharynx can be seen in the back of the mouth. It lies inferior to the nasopharynx and is connected to the mouth through an opening called the fauces. It contains two kinds of tonsils: the paired palatine tonsil are embedded in the lateral walls and the lingual tonsil which lies at the base of the tongue.
- Laryngopharynx is posterior to the epiglottis and extends to the larynx, where the respiratory and digestive pathways diverge.

The larynx (voicebox) lies between the laryngopharynx and the trachea and functions in voice production. It consists of nine cartilages held together by ligaments.

- The large, anterior thyroid cartilage (Adam's apple), larger in males than females after puberty.
- Between the thyroid cartilage and the trachea is the ring-shaped cricoid cartilage.
- Three small pairs of cartilages, the cuneiforms, the tiny corniculates, and the arytenoids form the lateral and posterior walls of the larynx. The arytenoids anchor the vocal cords.
- The epiglottis extends from the back of the tongue to the rim of the thyroid cartilage. The large spoon-shaped portion of the epiglottis projects upward during breathing. During swallowing, it is deflected over the trachea closing the air passage and allowing food to pass to the esophagous.

Within the larynx are two sets of mucosal folds. The true vocal cords vibrate as air rushes around them producing sound. Between them is a slit-like opening, the glottis, that allows air to enter the trachea. Superior to the true vocal cords are the false vocal cords which do not produce sound but help close the glottis during swallowing. The longer and thicker the true vocal cords, the deeper the pitch. By stretching the cords they become tenser. The more tense, the faster they vibrate resulting in a higher pitch. Loudness depends on the force of the air across the vocal cords.

The trachea (windpipe) descends from the larynx into the mediastinum where it divides into the right and left primary bronchi. The mucosal lining contains goblet cells among a ciliated pseudostratified epithelium. This ciliary escalator continually moves particles (such as bacteria) trapped in mucus up and out of the respiratory tract. Too much mucus will initiate the cough reflex. Cartilaginous C-shaped rings help keep the trachea open. The open part of the "C" at the posterior allows for the passage of the bolus of food in the esophagous. The carina is a sensitive ridge of innervated cartilage located between the primary bronchi. If a foreign object touches the carina, it initiates violent coughing.

Each bronchus enters a depressed area of the lung called the hilus. The primary bronchi then divide into secondary bronchi which supply each lobe of the lung (total of 5). Both primary and secondary bronchi have catilagenous C-shaped rings. The secondary bronchi branch into tertiary bronchi and these branch again and again into smaller and smaller parts of the respiratory tree. Tertiary bronchi have cartilarge plates instead of rings. Branches of less than 1mm are called branchioles and contain no cartilage. As the branches become smaller the smooth muscle surrounding them increases. The terminal branchioles lead into respiratory branchioles protruding from which are scattered alveoli. They end with clusters of alveolar sacs. The alveolus is composed of simple squamous epithelium. Each alveolus is surrounded by a network of capillaries. Also septal cells produce surfactant which keeps the alveolus from collapsing. Alveolar pores connect adjacent alveoli equalizing pressure throughout the lung. Fixed macrophages inhabit the alveoli keeping them sterile.

Respiratory Distress Syndrome in premature infants is due to lack of surfactant causing alveolar collapse.

Asthma is a chronic inflammation of the small branchioles of the lung. In allergic asthma, allergens trigger constriction of bronchiolar smooth muscle making it difficult to breath. Sometimes permanent damage can be inflicted. Over the past 20 years, asthma in the U.S. has increased 75%. As this disease occurs most frequently in developed, industrialized countries, many air pollutants have been blamed. The observation that an increase in all allergies is correlated with the decrease in childhood diseases has led to the hygiene hypothesis – being raised under "too clean" conditions stimulates the immune system to release excessive amounts of histamine. People with parasitic diseases rarely get asthma or allergies of any type.

The apex of each lung lies deep to the clavicle; the base rests on the diaphragm. The left lung is two-lobed, upper and lower. A concavity called the cardiac notch of the left lung accommodates the heart. The right lung is divided into the upper, middle and lower lobes. Lungs consist largely of air spaces. The balance of the tissue is mostly elastic connective tissue. The parietal and visceral pleurae enclose the lungs in the pleural cavity. Between these two membranes is pleural fluid.

A pneumothorax is the presence of air in the intrapleural space. This puts pressure on the lung making it difficult to breathe. The chest may have to be punctured to allow the air to escape.

Respiratory Physiology

Pulmonary ventilation consists of inspiration and expiration and depends on the difference between intrapulmonary pressure (the air pressure in the alveoli) and the atmospheric pressure (the air pressure outside the body). Boyle's law states that (at constant temperature) the pressure and the volume of a gas are inversely related – as pressure decreases, the volume increases. When the inspiratory muscles contract, the diaphragm moves inferiorly and the external intercostals elevate the rib cage. This results in an increase in lung volume, reducing the intrapulmonary pressure. Because the atmospheric pressure is now greater, air rushes into the lung until the pressure is equalized. The opposite occurs during expiration.

Dalton's law states that a gas goes from an area of greater partial pressure (concentration) to lower partial pressure regardless of the movement of other gases. This allows for the movement of O_2 from the alveoli to the capillaries and the movement of CO_2 from the capillaries to the alveoli in the process of external respiration. Internal respiration occurs similarly.

Transportation of O_2 in the blood depends on the binding of O_2 with hemoglobin forming oxyhemoglobin. If all available sites on the hemoglobin are carrying O_2, then hemoglobin is fully saturated. A number of factors may influence the relationship between O_2 and hemoglobin:

- the partial pressure (concentration) of O_2 in the atmosphere may not be enough for O_2 to bind
- the lower the pH, the more readily hemoglobin gives up O_2. Lactic acid in fatigued muscles will cause O_2 to be given up more readily.
- as the temperature rises, O_2 is given up more easily. Working muscles produce heat, causing O_2 to be given up more readily.
- Fetal hemoglobin attracts O_2 more than adult hemoglobin.

Hypoxia occurs when the tissues are starved for oxygen. There are several causes of hypoxia:

- Hypoxic hypoxia occurs when there is not enough available O_2 (for example at high altitudes).

- Anemic hypoxia occurs when there is not enough available hemoglobin to transport the O_2 (for example, there are too few RBC's or CO is bound to available hemoglobin).
- Stagnant hypoxia occurs when the blood is not circulating fast enough to deliver the O_2 (for example in congestive heart failure)
- Histotoxic hypoxia occurs when there is a problem with the cells so they are unable to utilize the O_2 (for example, cyanide poisoning interferes with enzymes used in the electron transport system).

Carbon Dioxide is transported to the lungs in three forms:
- dissolved in plasma (7-10%)
- chemically bound to hemoglobin as carbaminohemoglobin (20-23%)
- as bicarbonate ion in the plasma (70%)

$$CO_2 + H_2O \Leftrightarrow H^+ + HCO_3^-$$

Respiratory Volumes

The <u>tidal volume</u> is the amount of air that goes in or out with normal breathing (approximately 500 ml). Some of this air does not get into the alveoli to participate in gas exchange. This is air that is trapped in respiratory pathways (about 150ml) and is called dead space. Dead space is included in the tidal volume.

The <u>inspiratory reserve volume</u> is the amount of air that can be forcibly inspired beyond the tidal volume (about 3100ml).

The <u>expiratory reserve volume</u> is the amount of air that can be forcibly expelled from the lungs after tidal expiration (about 1200ml).

The <u>residual volume</u> is the amount of air left in the lungs even after the most exerted expiration (about 1200ml). The residual volume helps keep the alveoli open.

The <u>vital capacity</u> is the inspiratory reserve volume + tidal volume + expiratory reserve volume (about 4800ml).

<u>Total lung capacity</u> is equal to the tidal volume + inspiratory reserve volume + expiratory reserve volume + residual volume (approximately 6000ml).

Respiratory Diseases

Chronic Obstructive Pulmonary Disease (COPD) is often found in smokers and is manifested by labored breathing, coughing, frequent pulmonary infections and sometimes respiratory failure.

Obstructive emphysema is distinguished by permanent enlargement of the alveoli, accompanied by deterioration of the alveolar wall. Chronic inflammation leads to a loss of elasticity. When this happens, the airways collapse during exhalation and trap a large volume of air necessitating the use of accessory muscles to expel the air.

Tuberculosis (TB) is an infectious disease caused by the bacteria *Mycobacterium tuberculosis*. It is usually airborne and usually affects the lungs although other organs can be affected. Some of these bacteria survive and multiply inside macrophages. Other macrophages are attracted to the area and eventually a tubercle is formed. Tubercles rupture the bronchiole wall and spread throughout the lungs. A hundred years ago tuberculosis was the leading cause of death in the U.S. Today there is a worldwide resurgence of the disease due to drug resistant forms of the bacillus.

Control of Respiration
The brain medulla is critically important in respiration.
The pneumotaxic center of the pons (pontine respiratory group) modifies the activity of the medullary respiratory neurons and smoothes the transition between inspiration and expiration. Conscious control of breathing by the brain cortex is also possible.

As CO_2 increases in the blood, so to does H^+. A very sensitive homeostatic mechanism involving the medulla keeps CO_2 levels fairly constant. As the H^+ diffuses into the CSF chemoreceptors in the medulla may be stimulated to induce deeper and more rapid breathing called hyperventilation which quickly eliminates excess CO_2.

Chemoreceptors sensitive to arterial O_2 levels are found in the aortic bodies of the aortic arch and in the carotid bodies at the branching of the common carotid arteries. If deprived of O_2 these bodies stimulate the respiratory centers to induce rapid breathing.