The Respiratory System

Respiration is the exchange of gases between the atmosphere, blood, and body tissue cells. The respiratory and circulatory systems work together to supply the body with oxygen and remove carbon dioxide.

Four processes are involved in respiration:

1. **pulmonary ventilation** or breathing - It is the movement of air into and out of the lungs.

2. **external respiration** - It is the exchange of gases between the air sacs or alveoli of the lungs and the blood.

3. **transport of respiratory gases** - Oxygen and carbon dioxide are transported to and from the lungs and body tissue cells by the blood.

4. **internal respiration** - It is the exchange of gases between the blood and the body tissue cells.

The organs and structures of the respiratory system are the nose, pharynx, larynx, trachea, bronchi, and lungs.

**Nose**

**Functions**

1. Filters, warms, and moistens the incoming air.

2. Contains *olfactory receptors* for the sense of smell.

3. Serves as resonating chamber for speech.

The internal structure of the nose consists of a nasal cavity which is divided by a vertical partition called the nasal septum. The anterior portion of the septum is made up of *hyaline cartilage* and the posterior portion is formed by the vomer bone and the perpendicular plate of the ethmoid bone.

The part of the nasal cavity superior to the nostrils, or external nares, is called the vestibule. The vestibule is lined with skin containing sebaceous and sudoriferous glands and hairs called vibrissae. The vibrissae filter out dust and large particles from the inspired air.

From the lateral walls of the nasal cavity there are three mucosa-covered projections known as the superior, middle, and inferior nasal conchae. The conchae reach almost to the nasal septum and divide each side of the nasal cavity into a series of passageways which allows for the circulation of the inspired air.
The area above the superior nasal conchae is the olfactory region. It is lined with olfactory mucosa and contains the olfactory receptors. Below the olfactory region is the respiratory region which is lined with respiratory mucosa. The respiratory mucosa consists of pseudostratified ciliated columnar epithelium which contains goblet cells that secrete mucus, and serous glands that secrete a watery fluid containing antibacterial enzymes called lysozymes. The mucus traps bacteria and they are destroyed by the lysozymes. The cilia move the mucus and trapped bacteria toward the pharynx where it is swallowed and digested in the stomach.

Surrounding the nasal cavity are the paranasal sinuses. The sinuses are located in the frontal, sphenoid, ethmoid, and maxillary bones. The paranasal sinuses function as resonating chambers for speech and they moisten and warm the inspired air. The mucus produced by the mucosal membranes lining the sinuses drains into the nasal cavity and traps bacteria.

Pharynx (throat)

The nasal cavity opens into the pharynx through the internal nares.

The pharynx connects the nasal cavity to the larynx, and the oral cavity to the esophagus. The wall of the pharynx is composed of skeletal muscle and lined with a mucous membrane. It functions as a passageway for air and food and as a resonating chamber for speech.

The pharynx is divided into three regions:

1. nasopharynx - It is the upper portion and it functions as a passageway for air. It is located posterior to the nasal cavity and extends to the soft palate. On the inferior portion of the soft palate there is a projection called the uvula. When swallowing, the uvula curves backwards and upwards and prevents food from entering the nasopharynx. The walls of the nasopharynx are lined with pseudostratified ciliated columnar epithelium. The posterior wall of the nasopharynx contains the pharyngeal tonsils, and the lateral walls contain the openings to the auditory or eustachian tubes which are surrounded by the tubal tonsils.

2. oropharynx - It is the middle portion and it functions as a passageway for both air and food. It is located posterior to the oral cavity and extends from the soft palate to the epiglottis at about the level of the hyoid bone. The oropharynx is lined with stratified squamous epithelium and the walls contain the palatine and lingual tonsils.

3. laryngopharynx - It is the lower portion and it functions as a passageway for both air and food. It is located posterior to the epiglottis and extends from the hyoid bone to the larynx on the anterior side, and to the esophagus on the posterior side. Air passes to the larynx and food passes to the esophagus. The laryngopharynx is lined with stratified squamous epithelium.
Larynx (voice box)

The larynx extends from the laryngopharynx to the trachea and it has three functions.

1. Passageway for air
2. Prevents food from entering the trachea.
3. Contains the vocal cords for voice production.

The larynx consists of nine cartilages connected by membranes and ligaments. Eight of the cartilages are composed of hyaline cartilage and one is composed of elastic cartilage.

The first cartilage is the thyroid cartilage which consists of two plates of hyaline cartilage fused on the anterior side forming a ridge known as the laryngeal prominence or Adam's apple.

Below the thyroid cartilage is the cricoid cartilage which forms the inferior ring of the larynx and is attached to the first ring of hyaline cartilage of the trachea.

Three pairs of hyaline cartilage form the lateral and posterior portions of the larynx.

The ninth cartilage is the epiglottis which is composed of elastic cartilage. The epiglottis is a flaplike structure which extends upward from the anterior rim of the thyroid cartilage. It allows air to enter the larynx during inspiration. When swallowing, the larynx moves upward and the epiglottis moves downward to cover a space called the glottis located between the larynx and the vocal cords. Food is prevented from entering the larynx and is routed to the esophagus.

The mucous membrane of the larynx is arranged into two pairs of horizontal folds. The upper pair of folds are the vestibular folds or false vocal cords. They do not function in sound production and they are composed of skeletal muscle fibers which contract and bring the folds together to close off the larynx when swallowing. The lower pair of folds are the vocal folds or true vocal cords. They contain elastic fibers attached to skeletal muscle and they produce vocal sounds when air is forced between them which causes the muscle fibers to contract and the vocal cords to vibrate.

Trachea (windpipe)

The trachea is a flexible tube located anterior to the esophagus and extends from the larynx into the mediastinum of the thoracic cavity where it divides to form the right and left primary bronchi.

The trachea functions as a passageway for air and it filters, warms, and moistens the incoming air. The trachea consists of 16 to 20 c-shaped rings of hyaline cartilage stacked one on top of the other. The open ends of the rings face the posterior portion of the trachea and the ends are connected by smooth muscle and
connective tissue. The muscle and connective tissue allow the esophagus, located posterior to the trachea, to expand when food is swallowed. The hyaline cartilage rings prevent the trachea from collapsing due to pressure changes during breathing. The walls of the trachea are lined with pseudostratified ciliated columnar epithelium which contains goblet cells.

Bronchi

The bronchi and their branches function as a passageway for air from the trachea to the alveoli of the lungs and to filter, warm, and moisten the incoming air.

The trachea divides into the right and left primary bronchi at the sternal angle. The right primary bronchus is shorter, wider, and more vertical than the left. As a result, foreign objects that are accidentally inhaled, commonly become lodged in the right primary bronchus. The walls consist of rings of hyaline cartilage similar to the trachea, a small amount of smooth muscle, and they are lined with pseudostratified ciliated columnar epithelium (PCCG).

When the primary bronchi enter the lungs, they divide to form smaller secondary or lobar bronchi which extend to each lobe of the lung. The walls consist of fewer rings of hyaline cartilage, more smooth muscle, and they are lined with PCCG.

The lobar bronchi branch to form smaller tertiary or segmental bronchi in which the walls contain plates of hyaline cartilage, an increased amount of smooth muscle and they are lined with simple columnar epithelium.

The segmental bronchi divide repeatedly to form smaller and smaller branches called bronchioles in which the walls contain no hyaline cartilage and they contain smooth muscle and are lined with simple columnar epithelium.

The bronchioles branch to form terminal bronchioles which are composed of smooth muscle and simple cuboidal epithelium.

The terminal bronchioles branch to form respiratory bronchioles which then branch to form alveolar ducts. The wall of the respiratory bronchioles near the terminal bronchioles consists of smooth muscle and they are lined with simple cuboidal epithelium. Near the alveolar ducts the walls of the respiratory bronchioles are lined with simple squamous epithelium.

The alveolar ducts lead to the alveolar sacs which have cup-shaped expansions in their walls called alveoli. The walls of the alveolar ducts, alveolar sacs, and alveoli are composed of simple squamous epithelium.

The alveoli contain dust cells or alveolar macrophages which remove dust, bacteria, and other foreign particles from the incoming air by phagocytosis. Within the simple squamous epithelium of the alveoli are specialized cells which secrete a fluid of lipoprotein called surfactant. The surfactant covers the inner surface of the alveoli and functions in reducing the surface tension of water and other fluid molecules. It allows the lungs to expand with less energy during inspiration, and prevents the alveoli from collapsing during expiration.
The simple squamous epithelium of the alveoli and the walls of the pulmonary capillaries which surround the alveoli form the respiratory membrane. Gas exchange occurs across the respiratory membrane by simple diffusion. Oxygen moves from the alveoli to the blood of the pulmonary capillaries and carbon dioxide leaves the blood of the pulmonary capillaries and enters the alveoli.

**Lungs**

The lungs are located in the thoracic cavity and they are surrounded and protected by two layers of serous membranes collectively called the pleural membrane.

1. **parietal pleura** - It is the outer layer which lines the pleural cavity.

2. **visceral or pulmonary pleura** - It is the inner layer which lies over and covers the surface of the lungs.

Between the parietal and visceral pleura is the pleural cavity which contains pleural fluid that functions in reducing friction between the serous membranes during breathing.

The **right lung** is larger than the left and is divided into three lobes by an oblique fissure and a horizontal fissure. The **left lung** is divided into two lobes by an oblique fissure.

Internally, the lobes contain the respiratory tree which consists of the continuous branching of the lobar and segmental bronchi, bronchioles, terminal and respiratory bronchioles, alveolar ducts and sacs, and alveoli. Within the lobes there are pyramid-shaped areas of tissue called bronchopulmonary segments. Each segment has an artery and a vein, and it receives air from a tertiary or segmental bronchus.

**Mechanics of Breathing**

Breathing, or pulmonary ventilation, is the exchange of gases between the atmosphere and the alveoli and consists of two phases:

1. inspiration or inhalation
2. expiration or exhalation

The movement of air into and out of the lungs depends on pressure changes. Inspiration occurs when the pressure within the alveoli, or intrapulmonary pressure falls below the atmospheric pressure. Contraction of the diaphragm and the muscles between the ribs, or external intercostal muscles, increase the size of the thoracic cavity, which decreases the pressure within the pleural
cavity, or intrapleural pressure. The result is expansion of the lungs. Expansion of the lungs decreases intrapulmonary pressure and the air moves along the pressure gradient from the atmosphere into the lungs.

Expiration is basically a passive process. It occurs when the intrapulmonary pressure is higher than the atmospheric pressure. Relaxation of the diaphragm and external intercostal muscles increases intrapleural pressure, decreases lung volume, and as the lungs recoil, intrapulmonary pressure increases so that air moves from the lungs to the atmosphere.

Pulmonary ventilation is influenced by four physical factors:

1. respiratory passageway resistance - The walls of the respiratory passages, especially the bronchi and bronchioles, offer some resistance to the normal flow of air into the lungs due to friction.

2. lung compliance - it is the distensibility or expandability of the lungs or the ease with which the lungs can be expanded during inspiration.

3. lung elasticity - it is the distension or expansion allowed by elastic fibers in the lungs during normal inspiration and recoil necessary for normal expiration.

4. alveolar surface tension - it is the attraction of liquid molecules to one another which is reduced by the presence of surfactant.

Lung compliance is related to elasticity and surface tension. The presence of elastic fibers in lung tissue results in high compliance. If surface tension within the alveoli were high, the tissues would resist expansion, but surfactant lowers the surface tension and increases compliance.

During inspiration and expiration gas exchange between the blood, lungs, and body tissues occurs by the diffusion of gases through tissues and the flow of gases and solutions of gases in the blood.

There are two ideal gas laws involved in the exchange of gases:

1. Dalton's Law of Partial Pressure - The total pressure exerted by a mixture of gases is the sum of the pressure exerted independently (partial pressure) by each gas in the mixture. Each gas moves from an area of higher partial pressure to an area of lower partial pressure.
2. **Henry's Law** - When a mixture of gases comes into contact with a liquid, each gas will dissolve or go into solution in the liquid in proportion to its partial pressure. The greater the concentration of a particular gas, the more and faster it will dissolve or go into solution in the liquid.

**External respiration**, or pulmonary gas exchange, is the exchange of gases between the alveoli of the lungs and the pulmonary blood capillaries. Oxygen enters the blood of the pulmonary capillaries and carbon dioxide leaves the blood of the pulmonary capillaries and enters the alveoli. Movement occurs because of a partial pressure gradient.

External respiration is influenced by four factors:

1. partial pressure gradients
2. respiratory membrane thickness
3. alveolar surface area
4. ventilation-perfusion coupling - **Ventilation** is the amount of gas reaching the alveoli. **Perfusion** is the volume of blood flow in the pulmonary capillaries.

The higher the pressure gradient, the thinner the membrane, the greater the alveolar surface area, and the greater the ventilation-perfusion coupling, the greater and faster the diffusion of gases.

During **internal respiration** gas exchange occurs between the blood in the tissue capillaries and the body tissues. As oxygen is used by tissue cells for their metabolic activities, oxygen leaves the blood of the tissue capillaries and enters the tissues and carbon dioxide enters the blood of the tissue capillaries from the tissues due to partial pressure gradients.

Transport of respiratory gases between the alveoli of the lungs and the body tissues is a function of the blood. **Oxygen** is either transported by hemoglobin as oxyhemoglobin in the erythrocytes or it is transported in blood plasma. The **partial pressure of oxygen** is high in the pulmonary capillaries and oxygen combines with the hemoglobin. In the tissue capillaries the partial pressure of oxygen is low and the oxygen is released from the hemoglobin and diffuses into the tissue cells.

**Carbon dioxide** may be carried by hemoglobin as carbaminohemoglobin, dissolved in the plasma, or as the bicarbonate ion. In the capillaries of the tissues, the **partial pressure of**
carbon dioxide is relatively high, resulting in the formation of carbaminohemoglobin. In the pulmonary capillaries, the partial pressure of carbon dioxide is low and the carbon dioxide splits from the hemoglobin and enters the alveoli by diffusion.

Control of Respiration

Normal breathing is rhythmic and involuntary. The respiratory centers are located in the medulla and pons.

There are two respiratory centers of the medulla:

1. inspiratory center or dorsal respiratory group (DRG) - it has an intrinsic excitability and is responsible for basic rhythmic breathing.
2. expiratory center or ventral respiratory group (VRG) - it increases inspiratory and expiratory movements during forceful breathing.

The respiratory centers of the pons are the:

1. pneumotaxic center
2. apneustic center

The pneumotaxic and apneustic centers coordinate and regulate inspiration and expiration. The pneumotaxic center sends inhibitory impulses to the inspiratory center of the medulla to prevent the lungs from overinflating during inspiration. The apneustic center sends impulses to the inspiratory center to promote prolonged inspiration. The pneumotaxic center usually overrides the apneustic center.

Factors Influencing the Rate and Depth of Breathing

1. Hering-Breuer Reflex or Inflation Reflex - It is a protective mechanism which prevents overinflation of the lungs. In the walls of the bronchi and bronchioles are stretch receptors. When they are stimulated, impulses are sent along the vagus nerve to the inspiratory and apneustic centers. Both areas are inhibited from activating further inspiration and expiration occurs. As air leaves the lungs, the stretch receptors are no longer stimulated and the inspiratory and apneustic centers are no longer inhibited and inspiration occurs.
2. **Irritant Reflexes** - The lungs contain receptors in the bronchioles which respond to the accumulation of mucus, dust, noxious fumes, cigarette smoke, and other irritants that are inhaled. The bronchioles constrict and impulses are sent to the respiratory centers by way of the vagus nerve resulting in coughing or sneezing.

3. **Higher Brain Centers** - Stimulation of the sympathetic centers in the hypothalamus by strong emotions or pain sends impulses to the respiratory centers and the rate and depth of breathing is altered. The cerebral cortex allows for voluntary control of breathing by bypassing the centers in the medulla and sending impulses directly to motor neurons that control the respiratory muscles. Breathing is consciously altered during singing, whistling, and speaking.

4. **Chemical Factors** - Chemoreceptors which respond to changing levels of carbon dioxide, oxygen, and hydrogen ion concentration in the blood of arteries are located in the medulla, aorta, and carotid arteries. Increase in the carbon dioxide level and decrease in the oxygen level in the blood of the arteries stimulates the peripheral chemoreceptors which are located in the aorta and carotid arteries. The increased carbon dioxide in the blood also increases the level of carbon dioxide and hydrogen ions in the cerebrospinal fluid and stimulates the central chemoreceptors in the medulla. Impulses from the peripheral and central chemoreceptors are sent to the respiratory centers in the medulla and the rate and depth of breathing is increased to remove the excess carbon dioxide.