CHAPTER 22: THE RESPIRATORY SYSTEM

The respiratory system provides a continuous supply of oxygen to the cells of the body via the circulatory vessels and RBCs. The respiratory system consists of organs that exchange gases between the atmosphere and the blood: nose, pharynx, larynx, trachea, bronchi, bronchioles and lungs (including alveoli). It also removes the carbon dioxide produced by the process of cellular respiration (ongoing in every cell of the body). Respiration is the exchange of gases among the atmosphere, blood and cells.

PROCESSES INVOLVED IN RESPIRATION

Pulmonary ventilation is breathing. External respiration is the exchange of gases between alveoli and blood. It is influenced by four factors: (1) partial pressure gradients, (2) respiratory membrane thickness, (3) alveolar surface area and (4) ventilation-perfusion (blood flow volume in pulmonary capillaries) coupling.

The diffusion of gases improves when (1) the partial pressure gradient increases, (2) the respiratory membrane is thinner, (3) the surface area of the alveoli is increased and (4) ventilation-perfusion coupling improves. Internal respiration is the exchange of gases between blood and cells.

The respiratory and cardiovascular systems participate equally in respiration. Failure of either system has the same effect on the body: disruption of homeostasis and rapid death of cells due to oxygen starvation.

FUNCTIONAL ANATOMY OF THE RESPIRATORY SYSTEM

The conducting zone is the region of the respiratory system that consists of all respiratory passageways that serve as rigid conduits by which air reaches the sites of gas exchange. The respiratory zone is the actual site of gas exchange and is composed of the respiratory bronchi, bronchioles, alveolar ducts and alveoli. The structures of the respiratory system include the nose, pharynx, larynx, trachea, bronchi and lungs. The specifics regarding each of these structures include:

(1) Nose

The external portion of the nose consists of a framework of bone and cartilage covered with skin and lined with mucous membranes. The external nose is flexible due to presence of cartilage. Undersurface has two openings called nostrils (external nares).

The internal portion of the nose consists of a large nasal cavity in the skull. It is inferior to cranium, superior to mouth. Anterior end merges with external nose. Interior end merges with the throat through two openings called the internal nares or choanae.

The vestibule is the anterior portion of the nasal cavity just inside the nostrils. It is surrounded by cartilage. The upper nasal cavity is surrounded by bone. The nasal cavity is divided by the nasal septum. The nasal septum divides the inside of the nose into right and left sides. The anterior portion of the septum is composed primarily of hyaline cartilage and the vomer and the perpendicular plate of the ethmoid bone form the remainder.

Four paranasal sinuses (frontal, sphenoidal, maxillary and ethmoidal) open into the internal nares. Nasolacrimal ducts open into the internal nares. Ethmoid and sphenoid bones form the roof of the nasal cavity.
The palate forms floor of the cavity. Hard palate is supported by maxillary processes and palatine bone. Soft palate is the unsupported, muscular posterior portion of the hard palate. It is the location of uvula, which helps close off the nasopharynx during swallowing to help prevent food from entering the nasal cavity. Functions of interior structures of nose include: (1) air processing (warming, moistening and filtering air) and (2) reception of olfactory (odor) stimuli. Resonating chambers receive speech sounds. Hairs help provide defenses as do the linings of mucous membranes.

(2) Pharynx (Throat)

Funnel-shaped tube approximately 13 cm (5 inches) long. Starts at internal nares and lies posterior to nasal cavity and oral cavity. The wall of the pharynx is composed of skeletal muscle and lined with mucous membranes. The throat serves as passageway for air and food. It provides a resonating chamber for speech sounds. Sections of structure include:

- Nasopharynx - auditory tubes (a/k/a Eustachian or pharyngotympanic tubes) and internal nares open into this area, which is the uppermost portion of the pharynx and contains the uvula.
- Oropharynx - posterior to oral cavity. It extends from the soft palate to the epiglottis (in region of the hyoid bone). Opening from mouth located here. It is the common passageway for food and air. It is also the location of palatine and linguinal tonsils.
- Laryngopharynx - becomes continuous with the esophagus posteriorly and the larynx anteriorly.

(3) Larynx

This is the voice box. It is a short passageway (5 cm or 2 inches) that connects the pharynx with the trachea. Passageway for air and helps prevent food from entering trachea. It is located midline of neck anterior to the fourth through sixth cervical vertebrae. Superiorly attaches to the hyoid bone and is continuous with the trachea inferiorly. The larynx is supported by nine pieces of cartilages: (1) three single pieces (epiglottic, thyroid and cricoid) and (2) three double pieces (arytenoid, corniculate and cuneiform).

(4) Trachea (windpipe)

The trachea (windpipe) is 12 cm (4.5 inches) in length and 2.5 cm (1 inch) in diameter and is anterior to the esophagus. The trachea extends from larynx to fifth thoracic vertebrae. The tracheal walls are composed of three layers mucosa, submucosa and adventitia. The mucosa consists of lamina propria and elastic fibers, plus the surface ciliated pseudostratified columnar epithelium.

(5) Bronchi

The trachea terminates in the chest by dividing into the right and left bronchi (bronchus, bronchi). The right bronchus is more vertical, shorter and wider than the left. Therefore more objects are likely to enter the right than the left. Like the trachea the bronchi have incomplete C-rings of cartilage and are lined with ciliated pseudostratified columnar epithelium.

Upon entering the lungs the bronchi divide to form smaller secondary bronchi: one for each lobe of the right lung (with three lobes) and the left lung (with two lobes). Each secondary bronchus subdivides into smaller bronchi, which are termed tertiary bronchi. Tertiary bronchi further subdivide into bronchioles. Bronchioles subdivide into smaller bronchioles called terminal bronchioles. Terminal bronchioles, in turn, branch and become respiratory bronchioles.
The term bronchial tree refers to tree-like appearance of the respiratory tract (turned upside down!). Macrophages (known as dust cells) lurk in alveolar sacs to keep an eye out for potential invaders. We swallow about 2 million dust cells per hour! Two cell types in alveoli (1) type I (squamous cells) and type II (cuboidal/septal cells).

(6) Lungs

The lungs are paired cone-shaped organs located in the thoracic cavity. The right lung is thicker and broader than the left. It is also shorter than the left because the diaphragm is higher on the right side to accommodate the liver. The lungs occupy the entire thoracic cavity except for the mediastinum, which houses the heart, major blood vessels, bronchi, esophagus, trachea and thymus. Each lung is cone-shaped and is suspended in its own pleural cavity. Double-layered pleural membrane encloses and protects each lung. Layers include: (1) parietal, (2) pleural cavity and (3) visceral. Regions of the lung include: (1) root, (2) apex, (3) costal surface, (4) hilus, (5) cardiac notch and (6) base.

The left lung has superior and inferior lobes separated by the oblique fissure. The right lung has superior and inferior lobes that are separated by the oblique fissure. The right lung also has the middle lobe, which is separated by the horizontal fissure as well as a portion of the oblique fissure. Each lobe of each lung receives its own secondary bronchus. Within the substance of each lung the secondary bronchi give rise to tertiary (segmental) bronchi, which are constant in origin and distribution. Each tertiary bronchus supplies air to a region of the lung known as a bronchopulmonary segment. There are 10 bronchopulmonary segments in the right lung and 8 or 9 in the left lung. The segments are separated from one another by CT septae. Since the segments are separated from one another, a diseased segment can be removed without disruption to the other segments. Each bronchopulmonary segment is broken down into small compartments called lobules. Each lobule is wrapped in elastic connective tissue and contains a lymphatic vessel, an arteriole, a venule and a branch from a terminal bronchiole, which subdivide into microscopic respiratory bronchioles, which in turn subdivide to form alveolar ducts.

FACTORS PREVENTING LUNG COLLAPSE

- Surfactant - a phospholipoprotein produced by the septal cells (Type II alveolar cells) that decreases surface tension, thereby preventing the alveoli from sticking together.
- Pleural cavity - cavity between pleural membranes, which is sealed so that the pressure inside the cavity is constant.
- Movement of the diaphragm - degree of motility of the diaphragm and other muscles is limited so they cannot move inward enough to bring the pressure up to 760 mm of Hg.

MECHANICS OF BREATHING

Breathing is called pulmonary ventilation and is the process by which gases are exchanged between the atmosphere and the alveoli of the lungs. Air flows into the lungs because of a simple pressure gradient. Twelve respirations per minute are normal for an adult at rest.

PULMONARY VENTILATION INVOLVES

- Inspiration - occurs when the pressure in lungs is lower than that in atmosphere, air will flow from the atmosphere to the lungs. This involves contraction of specific muscles. During contraction the diaphragm moves down and flattens out, thereby increasing the height of the
chest cavity. During contraction the external intercostals lift the ribcage and pull the sternum forward thereby expanding the chest diameter.

- (2) Expiration - expiration is a passive process that occurs when pressure in the lungs is higher than that in the atmosphere. Process begins when inspiratory muscles relax to their original resting length. The ribcage descends and the lungs then recoil. This decreases the thoracic and the intrapulmonary volumes. Compression of the alveoli follows and the intrapulmonary pressure then increases to over 1 mm Hg, which causes gases to leave lungs. If respiration is forced, then it is no longer passive. It becomes an active process that involves the internal intercostal muscles and the muscles of the abdominal wall.

**MECHANICAL FACTORS THAT REGULATE BREATHING**

Gas exchange in the body occurs by bulk flow of gases, solutions of gases and the diffusion of gases through tissues.

**PRESSURE RELATIONSHIPS**

- Dalton’s Law - each gas in a mixture exerts its own pressure so each exerts a partial pressure as if all the other gases were not present.

- Henry’s Law - the amount of a gas dissolved in a given liquid will vary because the solubility of gases varies and so does their partial pressure in solution. This helps explain decompression sickness (the “bends”) and nitrogen narcosis. “The quantity of a gas that will dissolve in a liquid is proportional to the partial pressure of the gas and its solubility coefficient when temperature remains constant”. As soon as lungs fill with air, oxygen diffuses from the alveoli into the blood, through the interstitial fluid and into the cells. Carbon dioxide diffuses in the opposite direction.

- Boyle’s Law - there is an inverse relationship between pressure and volume of a gas. As the volume decreases, the pressure will increase. As the volume increases, the pressure will decrease.

**INFLUENCING FACTORS**

The influencing factors include: (1) resistance, (2) compliance, (3) lung elasticity and (4) alveolar surface tension.

**RESPIRATORY VOLUMES, CAPACITIES and TESTS**

- Volumes - tidal, inspiratory reserve, expiratory reserve and residual volume.

- Respiratory capacities - inspiratory capacity, functional residual capacity, vital capacity and total lung capacity

Tests performed with the respirometer (spirometer) can distinguish between obstructive pulmonary diseases, which involve increased airway resistance (such as chronic bronchitis and asthma) and restrictive disorders, such as TB or polio.
TRANSPORT OF RESPIRATORY GASES BY THE BLOOD

Oxygen is carried in blood in two ways: (1) bond to hemoglobin and (2) dissolved in plasma. Over 98.5% of all oxygen is bound to hemoglobin. Each hemoglobin molecule can combine with four molecules of oxygen, after which the hemoglobin molecule is called oxyhemoglobin (HbO$_2$). When O$_2$ is released from hemoglobin, the hemoglobin is called deoxyhemoglobin (HHb). The rate of binding/releasing of oxygen to hemoglobin is regulated by several factors: (1) partial pressure of oxygen, (2) temperature, (3) blood pH and (4) partial pressure of CO$_2$. Oxygen dissolves poorly in water. There is only 1.5% found in plasma.

Transportation of CO$_2$ from cells to lungs is accomplished by three methods (1) dissolved in plasma (7-10%), (2) chemically bound to hemoglobin (20-30%) and (3) as bicarbonate ions in plasma (60-70%). CO$_2$ forms carbonic acid (H$_2$CO$_3$) when dissolved in water. This rapidly dissociates into bicarbonate ions (HCO$_3^-$). Equation: CO$_2$ + H$_2$O produces H$_2$CO$_3$ produces H$^+$ + HCO$_3^-$. This reaction also occurs in plasma, but is many times faster when it occurs in RBC’s.

CONTROL OF RESPIRATION

Normal breathing is involuntary and the respiratory centers that regulate the process are in the medulla and the pons. These centers coordinate inspiration and expiration. The medullary centers for respiratory control are: (1) the dorsal respiratory group (inspiratory center) and the (2) ventral respiratory group (expiratory center). The pons centers for respiratory control include: (1) pneumotaxic and (2) apneustic. Rate and depth of breathing is regulated by: (1) Hering-Breur inflation reflex, (2) irritant reflexes, (3) higher brain centers (in the hypothalamus and cerebral cortex) and chemoreceptors.
<table>
<thead>
<tr>
<th>Disorder</th>
<th>Description</th>
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<tbody>
<tr>
<td>Asthma</td>
<td>Inflammation of airways. Causes reduction in airflow. Protein &quot;adipocyte/macrophage binding protein&quot; (aP2) in fat tissue metabolism triggers the inflammation. Heavier you are, the more likely to be asthmatic.</td>
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<tr>
<td>Atelectasis</td>
<td>Chest wound causes lung collapse. Renders lung useless.</td>
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<td>COPD</td>
<td>Chronic obstructive pulmonary diseases. Ex: emphysema.</td>
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<td>Emphysema</td>
<td>Surface area of alveoli reduced when alveolar walls are damaged and broken.</td>
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<td>Hiccups</td>
<td>Repeated, involuntary spasms of the diaphragm. The exact cause is still unknown.</td>
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<td>Hypoxia</td>
<td>Inadequate oxygen delivery. Variety of causes.</td>
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<td>IRDS</td>
<td>Infant respiratory distress syndrome. Too little alveolar surfactant. Common in premature babies.</td>
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<tr>
<td>Laryngitis</td>
<td>Inflammation of the larynx.</td>
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<td>Lung cancer</td>
<td>Most common cause of cancer-related death among women.</td>
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<tr>
<td>Pneumothorax</td>
<td>Presence of air in the intrapleural space. Repair by closing hole and pulling air out of space with tubes.</td>
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<td>Sarcoidosis</td>
<td>Possibly autoimmune. Causes formation of granulomas in body organs. Often associated with lungs.</td>
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<td>Tuberculosis</td>
<td>Mycobacterium tuberculosis is the causative agent.</td>
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<td>Yawning</td>
<td>A long-standing hypothesis is that yawning is caused by an excess of carbon dioxide and lack of oxygen in the blood. The brain stem detects this and triggers the yawn reflex. May also be due to a need to cool the brain.</td>
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