Unit 2 Lecture 5

THE RESPIRATORY SYSTEM

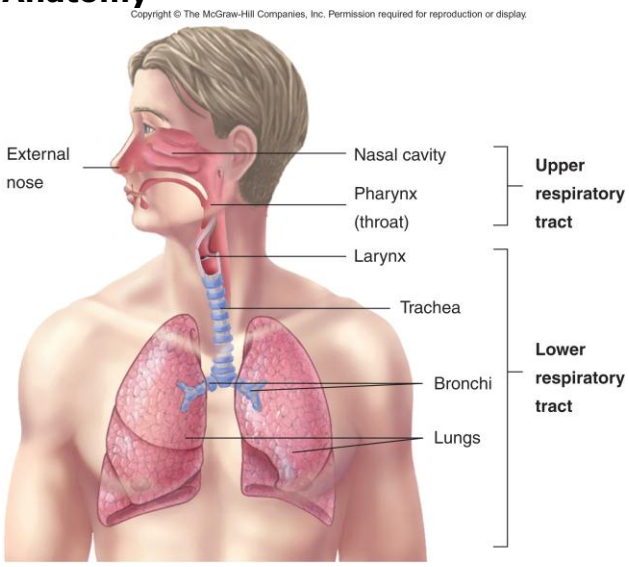
Cellular metabolism requires O_2 to produce energy. As a result of intracellular metabolism, CO_2 is produced. Excessive CO_2 produces acidity which is toxic to cells and must be removed. Two systems supply O_2 and remove CO_2, the cardiovascular system and respiratory system. The urinary system also plays a role in the removal of CO_2. Failure of either system causes a disruption of homeostasis and rapid cell death due to O_2 starvation and buildup of waste products.

Functions of the Respiratory system

- Exchange of gases between the atmosphere and the blood.
- Homeostatic regulation of body pH.
- Protection from inhaled pathogens.
- Vocalization.
- Olfaction.

Respiration is the exchange of gases between the atmosphere, blood and cells. Pulmonary ventilation (breathing) is the inspiration and expiration of air between the atmosphere and lungs. External (pulmonary) respiration is the exchange of gases between lungs and blood. Whereas internal (tissue) respiration is the exchange of gases between blood and cells.

Anatomy



The respiratory tract can be divided into the upper and lower tract. The upper respiratory tract contains the nose and pharynx (throat). The lower respiratory tract is comprised of the larynx, trachea, bronchi, and lungs. Except for some bones in the nose and pharynx, the skeleton of the respiratory tract is mostly cartilage down to the bronchioles where it is replaced by smooth muscle.

Nose

The nasal cavity is inside both the internal and external portion of the nose. A nasal septum separates the nasal cavity into a left and right side. Three nasal conchae (superior, middle and inferior) divide the nasal cavity into passageways (nasal meatuses) that allow air to flow through. Incoming air is filtered, moistened and warmed. Olfactory

stimuli are received by receptors on olfactory epithelium in the superior conchae. Hollow resonating chambers modify speech sounds. Mucous membranes trap dust and with the aid of cilia, move the debris to the throat for elimination by swallowing or spitting.

Pharynx (Throat)

The pharynx starts at the internal nares and ends at the cricoid cartilage. It lies posterior to nasal cavity, oral cavity and larynx and is composed of the nasopharynx, oropharynx and laryngopharynx, respectively. The pharynx functions in the passage of air, food and drink.

Larynx
The larynx connects the laryngopharynx with the trachea. It is composed of pieces of cartilage. The thyroid cartilage (Adam's apple) is the large piece that gives it a triangular shape. The epiglottis is a leaf-shaped cartilage that closes to prevent food and drink from entering the airway. Cricoid cartilage is a ring of cartilage at the bottom of the larynx. Arytenoid cartilage is most important for influencing vocal cords. Corniculate (support the epiglottis) and cuneiform (support the vocal folds) pairs of cartilage are also present. Two pairs of folds extend inward from the laryngeal walls. The ventricular folds are the upper pair and are called the false vocal cords because they do not produce sounds. The space between them is called *rima vestibuli*. The vocal folds (lower pair) are the true vocal cords. The space between is called rima glottides. Movement of vocal folds produces sound. Tension and the length of the folds affect the pitch of sound.

Trachea and Bronchi

The windpipe is a passageway for air. It extends from the larynx to bronchi. The trachea is shaped like incomplete rings or "C" held together by the trachealis muscle. The cartilage provides support. The open part of "C" faces the esophagus which allows the esophagus to expand into trachea during swallowing. At the bronchi, there is an internal ridge called the carina. The mucous membrane of the carina has a very sensitive mucous membrane associated with a cough reflex.

The trachea branches into the right and left primary bronchi. The tracheobronchial tree consists of the trachea, primary bronchi (2) (to each lung), secondary bronchi (5) (to each lobe), tertiary bronchi (10) (to each bronchopulmonary segment), bronchioles and terminal bronchioles. They comprise the first 16 branches of the 25 total branches. This is considered the conduction portion because its primary function is to conduct air into and out of the lungs. It is also here where air is warmed to body temperature, moistened so that the epithelial cells do not dry out, and filtered so that foreign material doesn’t enter the lungs. Bronchial branches are numbered 0-16. Gases move by bulk flow from outside the body down through the terminal bronchioles. In the respiratory portion, branches 17-23, gas

diffusion is the predominant process. It is here that the exchange of gases occurs in the alveoli and alveolar sacs.

Lungs

The lungs are a pair of cone-shaped organs that lie in the thoracic cavity. They are composed of a light, spongy tissue whose volume is mostly filled with air. The lungs lie in the pleural cavity. A very thin layer of pleural fluid surrounds the lungs and holds the lungs tight against the thoracic wall. Gross anatomy reveals a base, the bottom of lung that fits over diaphragm. The apex is the top point. The costal surface lies against the ribs. The mediastinal surface contains the hilum, an area through which bronchi, blood vessels, lymph vessels and nerves enter and exit lung. The cardiac notch is an area in left lung where heart lies. In the right lung there are three lobes (superior, middle, and inferior) and 2 fissures (horizontal and oblique). The left lung has only two lobes (superior and inferior) separated by 1 fissure (oblique).

Each bronchopulmonary segment has many lobules that are wrapped in connective tissue that contains blood vessels and lymphatic vessel. The terminal bronchioles divide into respiratory bronchioles (branches 17-19) which divide into alveolar ducts (branches 20-25). With each generation of branching, cross-sectional area of airways increases such that by the end there are @ 70-100 m^2 of area for gas exchange in the lungs. The alveolus is a cup shaped out pouching on the alveolar ducts; there are an estimated 300 million alveoli 0.3 mm in diameter in each lung. In the conduction portion of the lungs, the capillaries service the smooth musculature. There are 250-300 billion pulmonary capillaries in the lung or @ 1000 per alveoli. They are so interconnected they offer a sheet of blood to the alveolar wall for gas exchange.

There are three cell types found in the alveoli. Through Type I alveolar cells gases are exchanged. Type II alveolar cells release surfactant which lowers surface tension allowing the alveoli to remain inflated. The last cell is an alveolar macrophage that removes dust and other debris from the alveoli.

RESPIRATION

The purpose of respiration is to supply cells of the body with O_2 and to remove excess CO_2. In pulmonary ventilation (breathing), gases are exchanged between the atmosphere and alveoli as a result of differences in pressure gradients. Air moves into the lungs by bulk flow when pressure inside the lungs is less than atmospheric pressure and out when pressure is greater in the lung than out in the atmosphere. For air to move into the lungs, the pressure inside the lungs must decrease. Breathing or inspiration (inhalation) is achieved by increasing the size of the lungs. Inspiration occurs when alveolar pressure decreases. The steps in lung expansion are:

- contraction of the diaphragm and external intercostals and scalene muscles;

- contraction of diaphragm causes it to flatten, lowering its dome moving it 1-10 cm. Contraction of the intercostals and scalene muscles pulls the ribs upward and out;
- this accounts for @ 75% of air entering the lungs;

Expiration (exhalation) starts when inspiratory muscles relax and alveolar pressure exceeds atmospheric pressure. It is basically a passive process since muscles are relaxing and not contracting (although it does use some muscles with forced expiration). Factors involved include the recoil of elastic fibers that were stretched out during inspiration and the inward pull of surface tension due to film of alveolar fluid.

Compliance is the ease with which the lungs and thoracic cavity walls expand. In high compliance the lungs easily expand. In low compliance the lungs resist expansion ("stiff" lungs, hard to inflate). Compliance is related to elasticity and surface tension. When conditions exist that destroy lung tissue, (such as emphysema), lungs become filled with fluid (pneumonia), a deficiency in surfactant, or impedance of lung expansion a decrease in compliance is the result.

Airway resistance

Two factors must be overcome to move air into and out of the lung; elastic forces and resistance (the most important factor of the two). Some resistance is found in airway walls chiefly at the medium sized bronchi. The least resistance is found in terminal bronchiole. An increase in resistance is due to obstruction (mucous, tumor, foreign bodies) and thus more pressure needed to get air into lungs. Bronchoconstriction increases resistance to air flow and decreases the amount of fresh air that reaches the alveoli. Histamine is a strong bronchoconstrictor. Three diseases; asthma, chronic bronchitis and emphysema are examples of conditions that obstruct the flow of air into and out of the lungs.

The obstructive disease asthma causes a narrowing of the airways due to a spasm of the smooth muscles, bronchial wall edema, or increased mucous production results in air being trapped in lungs. This will:

- ⇧ functional residual (reserve) capacity;
- ⇧ residual volume;
- ⇧ total lung capacity;
- ⇩ vital capacity.

Restrictive lung disease (pulmonary fibrosis) increase the 'stiffness of the lung' causing decreased lung compliance and increased lung recoil; the lungs cannot expand normally. This will:

- ⇩ vital capacity;
- ⇩ total lung capacity;

- ⇩ functional residual (reserve) capacity;
- ⇩ residual volume.

Pulmonary Air Volumes & Capacities (sum of $\geq$ 2 volumes) aid in differentiating between two major types of lung disorders, obstructive and restrictive, and in quantifying the extent of the abnormality. They differ with ages, gender, and body type and are measured by using spirometer or respirometer.

- tidal volume: 500 ml of air inspired or expired during a respiratory cycle;
- anatomic dead space: that area that holds @ 150 ml of air that is not exchanged;
- inspiratory reserve volume: @3000 ml, additional inspired air achieved by taking deep breath;
- expiratory reserve volume: @1100 ml, additional expired air forced from lungs;
- residual volume: 1200 ml: since lungs do not empty completely on exhalation, this is the air that remains in the non-collapsible air passages after maximal expiration;
- minimal volume: tool used to determine whether or not infant was a stillborn;
- Inspiratory capacity: 3500 ml, tidal volume and inspiratory reserve;
- Functional reserve capacity: 2300 ml, resting volume of lungs, residual volume and expiratory reserve volume;
- Vital capacity: 4600 ml is the maximum volume of air that can be exhaled after maximum inspiration and is the sum of inspiratory and expiratory reserve volumes and tidal volume;
- Total capacity: 5800 ml, sum of all volumes or total volume of air in lungs when they are maximally inflated.

Physiology of External (Pulmonary) Respiration

External respiration (ER) is the exchange of O_2 and CO_2 between the alveoli of the lungs and the pulmonary capillaries by diffusion. ER converts deoxygenated blood into oxygenated blood. The amount of oxygen that enters the alveoli with each breath is roughly equal to the amount of oxygen that enters the blood. One factor involved is the **partial pressure** difference. Alveolar pO_2 is higher than pO_2 of systemic veins causing O_2 to diffuse from alveoli into blood. A second factor is the surface area for gas exchange. A decrease in the area of alveoli and there will be a decrease rate of external respiration (emphysema). A third factor that affects pulmonary respiration is the diffusion distances. Normally it takes <1 second for O_2-CO_2 to cross the membrane which is only 0.5um thick. Anything that increases the distance (pneumonia) decreases rate of external respiration. Slowing of breathing rate or shallowness of breath due to outside factors (drugs) can also decrease rate of external respiration.

Physiology of Internal (Tissue) Respiration

Internal respiration is the exchange of O_2 and CO_2 between tissue cells and tissue capillaries. Blood leaving the heart via the aorta is fully oxygenated. Blood returning to the heart is not fully oxygenated. Only about 25% of available O_2 enters tissue cells leaving a lot of O_2 in the blood. Differences in the pressure gradients cause diffusion of O_2 and CO_2 between cells and capillary blood.

Transport of oxygen and carbon dioxide is a function of blood. 98.5% of oxygen is bound to hemoglobin (Hgb) in red blood cells. In 100 ml of oxygenated blood there is 20 ml of O_2. Each Hgb molecule has 4 heme groups which can bind one molecule of O_2 each. The following equation shows this.

$$O_2 + Hgb \leftrightarrows HgbO_2 \text{ (oxyhemoglobin)}$$

The pO_2 is the most important factor that determines how much O_2 will combine with Hgb. As pO_2 increases more O_2 combines with Hgb. In active tissues the pO_2 of the tissue may ⇩ to <40 mm Hg. This difference causes O_2 in the blood to be released more easily from blood to the tissue. Other factors that influence the amount of O_2 that will combine with Hgb: acidity, pCO_2, temperature, and the amount of biphosphoglycerate in blood.

Hypoxia occurs when there is an O_2 deficiency at the tissue level. Hypoxic hypoxia is low pO_2 in arterial blood resulting from high altitude, obstruction of air passages or fluid in lung. Anemia hypoxia is too little Hgb in blood and results from hemorrhagic anemia or CO poisoning. Stagnant hypoxia is the inability of blood to carry O_2 to tissue quickly enough; results from heart failure or circulatory shock. Histotoxic hypoxia occurs when O_2 delivered but tissues prevented from using it such as in cyanide poisoning.

Carbon Dioxide

There are five ml CO_2 in 100 ml of deoxygenated blood. CO_2 is carried in three forms: dissolved in plasma 7%, carbaminohemoglobin 23 %, and bicarbonate ions 70% transported in plasma. In the first equation, hemoglobin combines with carbon dioxide to form carbaminohemoglobin. This reaction is influenced by pCO_2. In the second equation, carbon dioxide combines with water through the action of the enzyme carbonic anhydrase (CA) to form carbonic acid which readily disassociates into hydrogen ions and bicarbonate. Both reactions are reversible.

$$\mathbf{Hgb + CO_2 \leftrightarrows HgbCO_2}$$

$$\mathbf{CO_2 + H_2O} \quad \leftrightarrows \quad \mathbf{H_2CO_3} \text{ (carbonic acid)} \quad \leftrightarrows \quad \mathbf{H^+ + HCO_3^-}$$

Summary of gas exchange in lungs and tissue

- Deoxygenated blood returning to lungs contains

CO_2 + $HgbCO_2$ + HCO_3^- + H^+ + HHgb.
CO_2 in plasma + carbaminohemoglobin + bicarbonate ions + buffering of H^+ by Hgb

- The CO_2 in the plasma diffuses into the alveoli and is exhaled.
- The $HgbCO_2$ splits; CO_2 diffuses into alveoli and is exhaled.
- The H^+ + HCO_3^- combine to form H_2O and CO_2 which diffuses into the alveoli and is exhaled.

To maintain electrical balance as HCO_3^- declines in RBC and enters plasma, bicarbonate ions are exchanged for Cl^- (chloride shift) as the Cl^- ions move from the plasma into the RBC. CO_2 diffuses out of RBC and is exhaled. At the same time O_2 is being inhaled and diffusing from alveoli into RBC.

Control of Respiration

Nervous control regulates the respiratory effort. Sensors detect the gases. Messages are sent to the controllers in the respiratory center. Effectors are the muscles that carry out respiration. The respiratory center (in brain stem) is found in three areas. The medullary rhythmycity area is in the medulla. It controls basic rhythm of respiration; (inspiration @ 2 seconds, expiration @ 3 seconds). The pneumotaxic area in the upper pons helps coordinate the transition between inspiration and expiration; helps limit inspiration and facilitate expiration so that lungs don't overfill with air. The apneustic area in the lower pons receives impulses that prolong inspiration and inhibit expiration when pneumotaxic area is inactive.

Regulation of Respiratory center Activity

Cortical influences enable alteration of breathing, are protective so that we don't inhale gases or liquids, and make it impossible to kill self by holding ones breath. The inflation reflex refers to stretch receptors in walls of bronchi and bronchioles that when stimulated cause expiration. In chemical regulation the goal is to maintain proper levels of CO_2 and O_2. Chemoreceptors in blood (carotid and aortic bodies) sense changes in levels of CO_2, O_2 and H^+.

Definitions which are useful to know:

- Eupnea is normal quiet breathing and includes shallow, deep or both
- Costal breathing is shallow chest breathing, causing upward and outward movement of chest.

- Deep breathing is the outward movement of abdomen as a result of contraction and descent of diaphragm
- Hypercapnia is an increase of pCO_2 in the blood
- Hypocapnia is decrease in arterial pCO_2
- Hyperventilation is a rapid and deep breathing (allows an increased level of CO_2 to be expelled.
- Hypoventilation is slow and shallow breathing.
- Dyspnea is difficulty in breathing.
- Apnea is cessation of breathing.
- Atelectasis (collapsed lung or a portion of the lung) is prevented by surfactant (substance released by Type II cells) which decreases surface tension.