Chapter 10 Gas Exchange

Objectives

1. Explain how the human respiratory system helps maintain homeostasis.
2. Be able to explain the characteristics of a respiratory surface.
3. Explain the need for a respiratory surface.
4. Why are specialized gas exchange systems necessary for large multicellular organisms?
5. What are the benefits of respiratory pigments in the blood of an organism?
7. Be able to identify the structures of the human lung.
8. Describe the structure and function of each organ in the human respiratory system.
   (Nasal cavity, pharynx, epiglottis, larynx, trachea, bronchi, bronchioles, alveoli, diaphragm)
9. Explain the significance of the following: turbinates, glottis, intercostal muscles, cilia in trachea, pleura, rib cage, rib muscles
9. Explain what occurs during each of the four stages of gas exchange in humans: breathing, external respiration, internal respiration, and cellular respiration.
10. Explain the processes of inhalation and exhalation.
11. Identify how respiratory diseases affect the homeostasis of an organism.
   (investigate disorders: lung cancer, asthma, pneumonia, bronchitis, emphysema)
12. Predict the impact of environmental factors, such as allergens, on homeostasis, within an organism.
   (Cigarette smoke, allergens (dust, mold, food) and petrochemicals fumes/perfumes)

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Adaptations for Gas Exchange

Gas exchange is the physical method that organisms use to obtain oxygen from their surroundings and remove carbon dioxide. The respiratory surface is the physical location of gas exchange in the organism.

Requirements of a Respiratory Surface

1. The surface must be thin. Diffusion occurs faster through a thin surface, therefore in order to meet the needs of the organism, the respiratory surface should be as thin as possible to allow the maximum rate of diffusion.
2. The surface must be moist. The respiratory gases (O2 and CO2) must be dissolved in a liquid before they can diffuse.
3. The surface must be in contact with a supply of O2 in the surroundings. The surroundings must have a supply of needed O2 and be able to remove CO2 for the organism.
4. In most multicellular organisms, the respiratory surface must be in contact with a transport system. Not all the cells are in contact with the outside environment. Therefore a transport system is needed to deliver O2 and remove CO2.

Respiratory pigments are colored substances in the blood of many multicellular organisms which carry oxygen and carbon dioxide.

e.g. Hemoglobin in the red blood cells allow blood to hold more respiratory gases than plain water.

Human Gas Exchange

Structures involved:

- lung - organ of breathing and gas exchange found in the chest cavity of all vertebrates
- diaphragm -> a thin muscle which forms the floor of the chest cavity and is involved in breathing
- ribs - a part of the skeletal system which protects the chest cavity which along with intercostal muscles are involved in breathing
pleura - a two layered membrane which completely encloses the lung
   -one layer covers the lung, the other is in contact with the diaphragm and other chest cavity organs
air passage -> a pathway through which air flows to and from the environment and the respiratory surface
during breathing

Parts of the Air Passage
1) nose - Air enters the nose through 2 nostrils. Hair is present to remove particles from the air (dust, pollen).

2) nasal cavity ( sinuses, nasal passages)- The walls of the nasal passages and the rest of the air passage are lined with mucous membranes. Some cells secrete mucus and others have cilia to moisten the air and trap foreign material such as bacteria, dust and other particles. There are many capillaries present to warm the air as it flows through. This prevents damage to lung tissue by the cold air.

3) pharynx - Air passes into the throat from the nasal cavity. There are other “openings” found here: Eustachian tubes, oral cavity, esophagus, trachea.

4) trachea - a.k.a. windpipe The trachea is a tube with “U” shaped cartilage rings in its wall to keep it open. It measures 12 cm long by 2.5 cm wide. It has a ciliated mucous membrane which will move mucus and trapped debris up and out into the pharynx. Tobacco smoke (just one cigarette) will stop the cilia for 20 minutes and increase the amount of mucus present. This causes coughing and a greater risk of respiratory infection.

5) larynx - voice box The larynx is found at the top of the trachea. It is made mainly of cartilage and some small bones. A pair of membranes (vocal cords) stretch across the larynx which vibrate as air flows over them. By controlling the amount of air and the vibrations of the vocal cords humans can control the loudness and pitch of their voice. The epiglottis is present at the top of the larynx which prevents food from entering during swallowing.

6) bronchi - The trachea divides in the middle of the chest into two smaller cartilage ringed tubes called bronchi. Each leads into one of the lungs. The bronchi are lined with a ciliated mucous membrane.

7) bronchial tubes - Inside the lung, each bronchi divides into a tree-like network of smaller and thinner tubes called bronchial tubes.

8) bronchioles - The bronchial tubes divide to form even smaller and thinner tubes called bronchioles.

9) alveoli - At the end of each bronchiole, there is a grape-like cluster of cavities called alveoli (300 million with a surface area of 70 m^2 = size of classroom). Each alveolus is surrounded by a network of capillaries. This is the respiratory surface.

4 Stages of Gas Exchange
1. Breathing
   Breathing is the movement of air into and out of the lungs which consists of 2 phases. The lungs contain a lot of elastic tissue for expansion and retraction but no muscle tissue to cause it. The chest cavity is a vacuum (no air pressure at all) which relies on pressure created by the ribs, rib muscles (intercostals) and diaphragm to cause the lungs to expand and retract.
Inhalation

Inhalation is the active part of breathing in which energy is used to cause the diaphragm to contract and move downward. While this happens, the intercostal muscles contract to pull the ribs up and out. As a result of these two movements, the chest cavity expands which decreases the pressure (negative pressure) in the chest cavity. Thus the lungs expand and air is sucked in through the air passage into the lungs.

Exhalation

Exhalation is the passive part of breathing in which the diaphragm relaxes and moves upward and the intercostals relax and allow the ribs to move down and in. As a result, the chest cavity decreases in volume which increases the pressure (positive pressure) on the lungs. Thus air is squeezed out of the lungs.

Control of Breathing

The normal rate of breathing is 12-25 breaths per minute. This can be controlled somewhat but is generally under involuntary control by the respiratory center in the brain. Several of the larger arteries (including the aorta) have chemoreceptors which measure the amount of O2 and CO2 in the blood and relay messages to the respiratory center in the brain. High CO2 in the blood causes the brain to send signals which increase breathing rate. High O2 levels in the blood cause the brain to send signals to decrease breathing rate. The presence of lactic acid in the blood (due to exercise) will also increase breathing rate.

2. External Respiration

After inhalation, the concentration of oxygen is high in the alveoli and the concentration of carbon dioxide is high in the capillaries around them. Diffusion occurs between the air and blood which will exchange these two gases. Oxygen will move from the air in the alveoli to the blood in the capillaries. Carbon dioxide will move from the blood in the capillaries to air in the alveoli. Exhalation removes the carbon dioxide from the alveoli.

3. Internal Respiration

As blood leaves the lungs and is sent to other parts of the body (a different set of capillaries) the blood has a high concentration of oxygen and the body cells have a high concentration of carbon dioxide. Diffusion occurs between the blood and body cells to exchange these two gases. Oxygen leaves the blood and goes to the body cells through capillaries and intercellular fluid. Carbon dioxide leaves the body cells and goes to the blood through capillaries and intercellular fluid. Blood is then pumped back to the lungs.

4. Transport

Oxygen

Most of the O2 is bound to hemoglobin (Hb) in the capillaries around the alveoli forming a complex called oxyhemoglobin (HbO2). Oxyhemoglobin gives blood its bright red color. When the blood reaches the body tissues, the oxyhemoglobin complex will break apart to release the oxygen to the body cells. A very small amount of oxygen will travel dissolved in the plasma of the blood.

Carbon dioxide

About 70% of CO2 from the body cells will react with the H2O in the blood to produce carbonic acid (H2CO3) which immediately breaks down to the hydrogen ion (H+) and the bicarbonate ion (HCO3-). The carbon dioxide will travel through the blood to the lungs in the form of the bicarbonate ion. When the bicarbonate ion reaches the lungs, carbonic acid is reformed and the CO2 is released from the molecule. These reactions are performed quickly by enzymes in the blood.

About 20% of the CO2 will combine with hemoglobin in the red blood cells to form carboxyhemoglobin (HbCO2). When carboxyhemoglobin reaches the lungs, the CO2 is removed from the hemoglobin.
Only about 10% of the CO2 will dissolve in the plasma to travel to the lungs. During the incomplete burning of any organic material (e.g. cigarettes), carbon monoxide gas is released and inhaled. Hemoglobin will bind to carbon monoxide much easier than to oxygen, therefore limiting the amount of oxygen which can enter the blood and be delivered to the body cells.

Diseases

1) **asthma** - A severe allergic reaction which causes the bronchioles to go into spasms. This results in the squeezing of air passages and therefore wheezing, coughing, and breathing difficulties.

2) **bronchitis** - Irritation or infection of the lining of the bronchial tubes results in swelling and severe coughing. This is due to the build up of mucus and blocked air passages to the alveoli.

3) **emphysema** - The alveoli become damaged due to exposure to smoke and pollution particles. This causes macrophages to digest particles and damaged tissue. Scar tissue develops which decreases the size of the respiratory surface as well as its elasticity. This is permanent damage which can not be undone or repaired.

4) **pneumonia** - The alveoli become filled with fluid which does not permit gas exchange. This is often due to a viral or bacterial infection.

5) **lung cancer** - The irregular and uncontrolled cell growth in the lung tissue is lung cancer. There has been a definite connection to smoking and the additives to cigarettes to cancer.