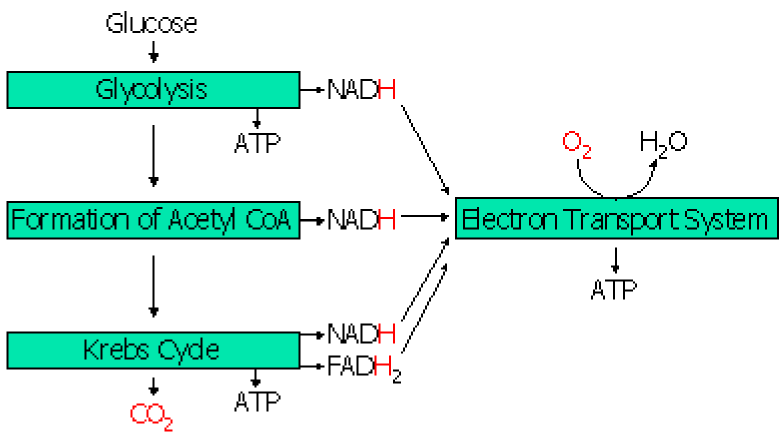
Lecture 9 - Respiratory System

Introduction

Oxygen is needed by aerobic organisms because it is the final electron acceptor during cellular respiration. The diagram below shows that Cellular respiration is a process in which electrons are removed from glucose in a series of steps. The electrons are carried by NADH and FADH2 to the electron transport system. The electron transport system uses the energy in the electrons to synthesize ATP. The remaining carbon atoms in the glucose molecule are released as CO_2, a waste product. The equation for the complete breakdown of glucose by aerobic eukaryotes is:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36\ ATP$$



Atmosphere

78% N_2, 21% O_2, 1% argon, noble gases, CO_2

Some Properties of Gases

Diffusion refers to movement of molecules from an area of higher concentration to an area of lower concentration.

Partial pressure is the pressure exerted by one gas in a mixture.

Total atmospheric pressure at sea level = 760 mm Hg.

Partial pressure O_2 = 760 X .21 = 160 mm Hg.

Diffusion is movement from an area of higher partial pressure to an area of lower partial pressure.

Respiratory Surfaces

All animals need to take in O_2 and eliminate CO_2. ***Lungs*** are membranous structures designed for gas exchange in a terrestrial environment. ***Gills*** are designed for gas exchange in an aquatic environment.

Oxygen must be dissolved in water before animals can take it up. Therefore, the respiratory surfaces of animals (gills, lungs, etc.) must always be moist. This is true of all animals.

Very small organisms don't need respiratory surfaces because they have a high surface:volume ratio.

Skin

The skin can be used as a respiratory surface but it does not have much surface area compared to lungs or gills. Animals that rely on their skin as a respiratory organ are small and either have low metabolic rates or they also have lungs or gills.

Like all respiratory surfaces, the skin must remain moist to function in gas exchange.

Amphibians, most annelids, some mollusks, and some arthropods use their skin as a respiratory organ.

Gills

Gills provide a large surface area for gas exchange in aquatic organisms.

It is difficult to circulate water past gills because water is dense and the O_2 concentration in water is low. There is 5% as much oxygen in water as there is in air. To circulate water past the gills, amphibian larvae physically move their gills, mollusks pump water into mantle cavity which contains the gills, and some crustacean gills are attached to branches of the walking legs.

The flow of blood in the gills of fish is in the opposite direction that water passes over the gills. This arrangement (called ***countercurrent flow***) enables fish to extract more oxygen from the water than if blood moved in the same direction as the passing water.

Gills cannot be used in air because they lack structural support; they would collapse. Their use in air would also result in too much water loss by evaporation.

Tracheal System

Insects, centipedes, and some mites and spiders have a tracheal respiratory system.

Tracheae are a network of tubules that bring oxygen directly to the tissues and allow carbon dioxide to escape. The openings to the outside, called ***spiracles***, are located on the side of the abdomen.

Trachea and lungs are internal to reduce water loss.

Vertebrate Lungs

Simple lungs evolved 450 million years ago in fish.

Some evolved into swim bladders.

Others evolved into more complex lungs.

Paired lungs are the respiratory surfaces in all reptiles, birds, and mammals.

Amphibians

lung is a simple convoluted sac

have small lungs but obtain much O_2 by diffusion across moist skin

ventilate lungs by ***positive pressure***; (reptiles, birds and mammals use negative pressure)

Reptiles

watertight skin; not used as a respiratory surface

lungs possess alveoli

all diffusion occurs across alveolar surface

Birds and Mammals

lungs are more branched with smaller, more numerous alveoli

Bird

Respiratory System

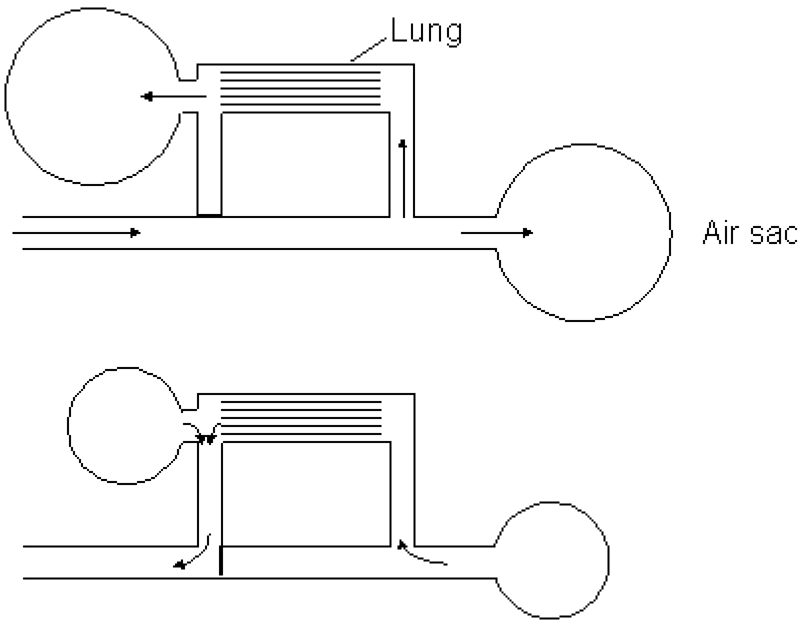
Birds have one-way flow of air in their lungs. As a result, the lungs receive fresh air during inhalation and again during exhalation.

advantages of one-way flow:

no residual volume; all old (stale) air leaves with each breath

crosscurrent flow (crosscurrent = 90° ; countercurrent = 180°; crosscurrent is not as efficient but is still more efficient than mammalian lung)

One-way flow is accomplished by the use of air sacs as illustrated below. During inspiration, the air sacs fill. During expiration, they empty.



Human Respiratory System

Surface area of human lung is 60 to 80 sq. meters

Structures

pharynx $\rightarrow$ epiglottis (open space is the glottis) $\rightarrow$ larynx with vocal cords $\rightarrow$ trachea $\rightarrow$ bronchi $\rightarrow$ bronchioles $\rightarrow$ alveoli

Nasal Cavities

hair and cilia filter dust and particles.

Blood vessels warm air and mucus moistens air.

Ventilation

To inhale, the diaphragm contracts and flattens.

Muscles move the rib cage which also contributes to expanding the chest cavity.

To exhale, the muscles relax and elastic lung tissue recoils.

The Heimlich Maneuver

Choking results when food enters the trachea instead of the esophagus.

The Heimlich maneuver can force air out of the lungs to dislodge the obstruction.

Respiratory pigments

Hemoglobin

Hemoglobin is a protein that carries oxygen and is found in the blood of most animals.

It is synthesized by and is contained within erythrocytes (red blood cells).

Oxygen is bound reversibly to the iron portion.

Hemoglobin increases the oxygen-carry capacity of the blood by 70 times. 95% of the oxygen is transported by hemoglobin, 5% in blood plasma.

The bright red color occurs when it is bound with oxygen.

Hemocyanin

Hemocyanin is a carrier protein found in many invertebrates

It uses copper instead of iron.

It does not occur within blood cells; it exists free in the blood. (Their blood is called hemolymph.)

It is bright blue when bound with oxygen.

Gas Exchange and Transport

Gas Exchange in humans occurs in alveoli. Gasses must diffuse across the alveolar wall, a thin film of interstitial fluid, and the capillary wall.

Partial pressures

	LUNGS	**TISSUES**
OXYGEN	high	low
CO_2	low	high

The partial pressure of CO_2 is higher in the tissues because respiring tissues produce CO_2 as a result of the breakdown of glucose ($C_6H_{12}O_6$) during cellular respiration.

Oxygen Transport

1 hemoglobin molecule + 4 oxygen molecules $\rightarrow$ oxyhemoglobin.

The amount of oxygen that combines depends upon the partial pressure. More oxygen is loaded at higher partial pressures of oxygen.

Hemoglobin does not necessarily release (unload) all of its oxygen as it passes through the body tissues. Oxyhemoglobin releases its oxygen when:

the partial pressure of O_2 is low.

the partial pressure of CO_2 is high. High CO_2 causes the shape of the hemoglobin molecule to change and this augments the unloading of oxygen.

the temperature is high.

the pH is low.

Active tissues need more oxygen and all of the conditions listed above are characteristic of actively metabolizing tissues. Therefore, these tissues receive more oxygen from hemoglobin than less active tissues.

CO (carbon monoxide) binds to hemoglobin 200 times faster than O_2 and does not readily dissociate from the hemoglobin. Small amounts of CO can cause respiratory failure.

Carbon Dioxide Transport

Carbon dioxide is transported to the lungs by one of the following ways:

dissolved CO_2

bound to hemoglobin ($HbCO_2$)

HCO_3^- (bicarbonate ions).

Most is transported as bicarbonate ions because...

$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+$

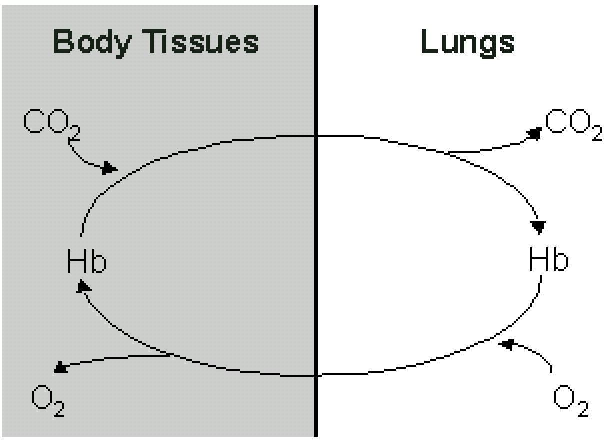
← low partial pressure high partial pressure →
← lungs tissues →

The equation above moves toward the right when the partial pressure of CO_2 is high. When the partial pressure of CO_2 is low, it moves to the left and CO_2 comes out of solution.

In the active tissues, the CO_2 partial pressure is high, so CO_2 becomes dissolved in water, forming H_2CO_3, which then forms HCO_3^- and H^+. In the lungs, the partial pressure of CO_2 is low because the concentration of CO_2 in the atmosphere is low. As blood passes through the lungs, HCO_3^- + H^+ form H_2CO_3 which then forms $CO_2 + H_2O$.

Carbonic anhydrase (in red blood cells) speeds up this reaction 150 times.

HCO_3^- tends to diffuse out of the red blood cells into the plasma.



Control of breathing rate

Eliminating CO_2 is usually a bigger problem for terrestrial vertebrates than obtaining O_2. The body is therefore more sensitive to high CO_2 concentration than low O_2 concentration.

Aquatic vertebrates are more sensitive to low O_2 because O_2 is more limited in aquatic environments.

Neural Control Mechanisms in terrestrial vertebrates

During inhalation, the diaphragm and intercostal muscles are stimulated. Other neurons inhibit these when exhaling.

Respiration is not under voluntary control.

Monitoring H^+ and CO_2

Chemoreceptors in the respiratory control center of the brain (medulla oblongata) detect changes in CO_2 by monitoring pH of cerebrospinal fluid. High CO_2 lowers the pH (an acid is a solution with a high H^+ concentration).

$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+$

Chemoreceptors in the aorta and carotid artery are also sensitive to pH and to greatly reduced amounts of O_2.

Bronchiole diameter

The primary bronchus branches extensively into bronchioles. Terminal bronchioles are surrounded by smooth muscle.

The diameter of the bronchioles (and blood vessels) increases or decreases in response to needs. It is adjusted by smooth muscle under the control of the nervous system. The parasympathetic nervous system (discussed in the chapter on nervous systems) stimulates these muscles to contract, reducing the diameter of the airways. This is advantageous when the body is relaxing and breathing is shallow. Narrow bronchioles result in less air remaining within the lungs after each exhalation.

The sympathetic nervous system relaxes these muscles as a response to stressful situations. This allows a more rapid rate of intake and expulsion of air.

Allergens trigger histamine release which constricts muscles.

Narrower bronchioles result in decreased ventilation of the lungs.

Severe attacks may be life-threatening.

Defense Mechanisms in the Respiratory Tract

Large particles are filtered out by the nose.

Small particles are filtered out by cilia lining the bronchi and bronchioles.

Bronchitis

Bronchitis is an inflammation of the airways that causes mucous to accumulate. The normal cleansing activity of cilia is reduced and not sufficient to remove the mucous. Coughing attempts to clear the mucus.

Smoking and other irritants increase mucus secretion and diminish cilia function.

Emphysema

Emphysema occurs when the alveolar walls lose their elasticity. Damage to the walls also reduces the amount of surface available for gas exchange.

Emphysema is associated with environmental conditions, diet, infections, and genetics. It can result from chronic bronchitis when the airways become clogged with mucous and air becomes trapped within the alveoli.

Effects of Cigarette Smoke

Cigarette smoke prevents the cilia from beating and stimulates mucus secretion.

Coughing is necessary to expel excess mucous but it contributes to bronchitis and emphysema.

Cigarette smoke also kills phagocytic cells in respiratory epithelium. These cells normally help rid the lungs of foreign particles and bacteria.

Cigarette smoke contains compounds that are modified in the body to form carcinogens.

Smoking causes 80% of lung cancer deaths.