

Transport

Not a life function – why not?

Surface area to volume ratio and west Dorset villages.

Where is it necessary in the five kingdoms.

What is transported? You tell me!

What does the transporting?

Blood (haemolymph), lymph and tissue fluid and specialist fluids like CSF.

Open circulatory system

An open circulatory system is a type of circulatory system in which nutrients and waste are moved through the body with the assistance of a fluid which flows freely through the body cavity, rather than being contained in veins. Many organisms like Arthropods and Molluscs have an open circulatory system, with the exact composition of the circulating fluid varying, depending on the animal species involved.

The Problems of Closed circuits

- All exchanges between blood and cells occur in the capillaries. The force of the pump that pushes blood through the arteries is dissipated as the blood flows through capillaries. Although capillaries are tiny, the total cross-sectional area of all the capillaries supplied by a single artery is much greater than that of the artery itself. Like a rapid, narrowly-confined stream spreading out over a flat plain, the force and velocity of flow diminish quickly.

This creates a problem:

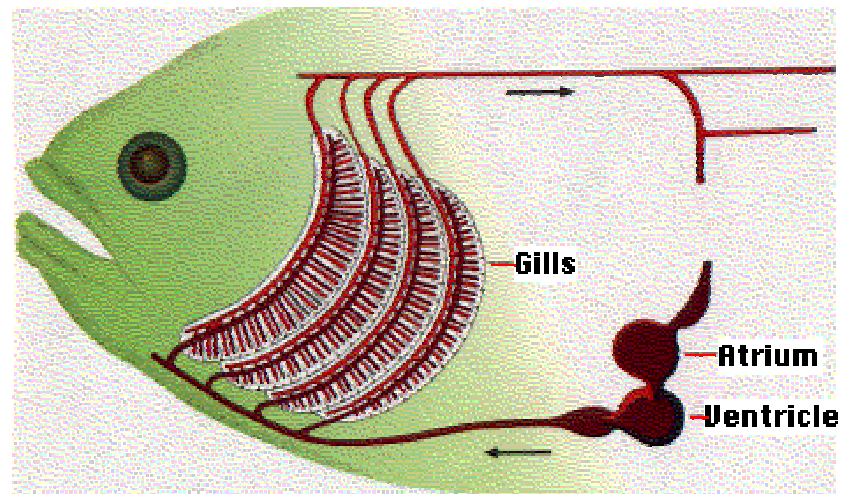
- If the pump is used to deliver blood with force to the gas exchange organ, little force remains to distribute the oxygenated blood to the tissues.
- If the pump is used to deliver blood with force to the tissues, little force remains to send the deoxygenated blood to the gas exchange organ.

The Fish Heart

Blood collected from throughout the fish's body enters a thin-walled receiving chamber, the **atrium**.

- As the heart relaxes, the blood passes through a valve into the thick-walled, muscular **ventricle**.
- Contraction of the ventricle forces the blood into the capillary networks of the **gills** where gas exchange occurs.
- The blood then passes on to the capillary networks that supply the rest of the body where exchanges with the tissues occur.
- Then the blood returns to the atrium.

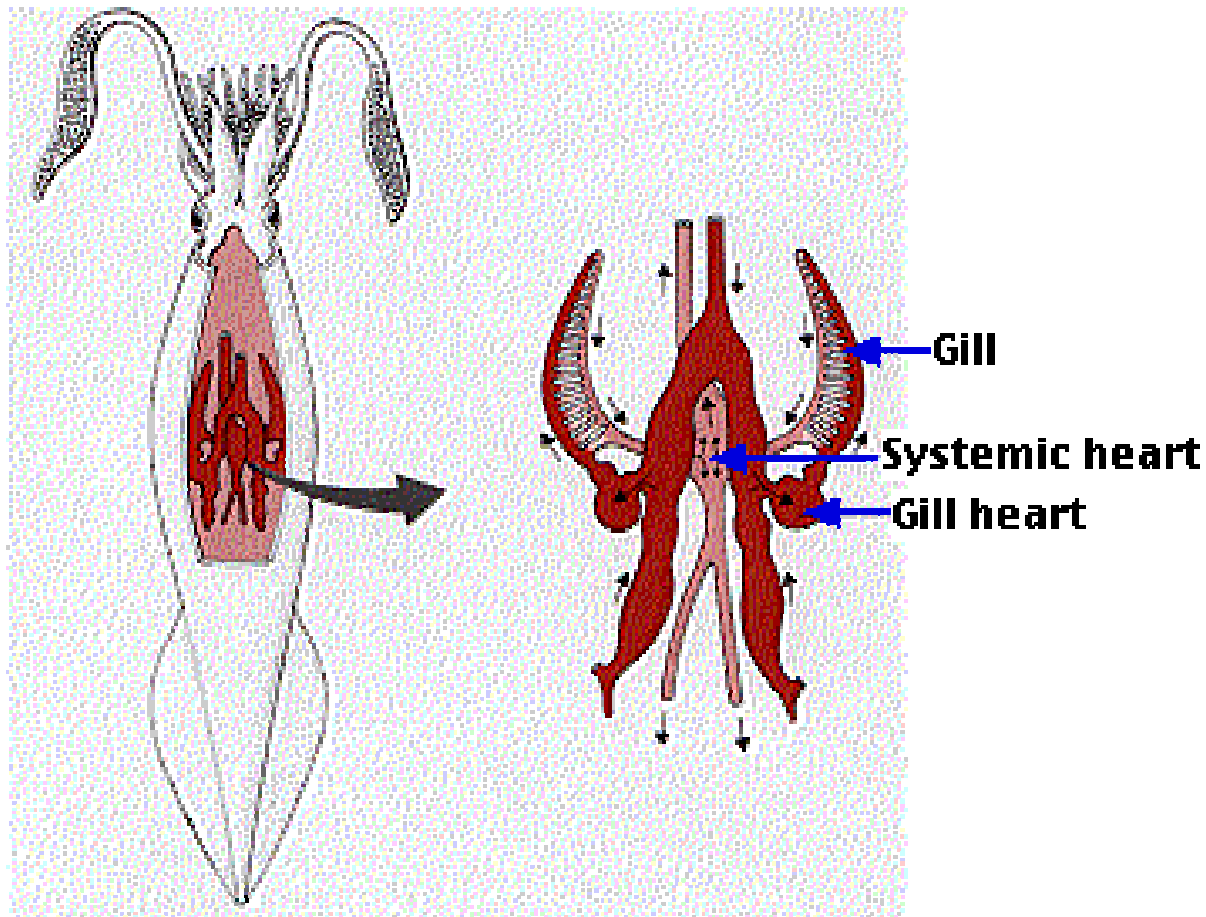
While obviously adequate to the fish's needs, this is not a very efficient system. The pressure generated by contraction of the ventricle is almost entirely dissipated when the blood enters the gills.



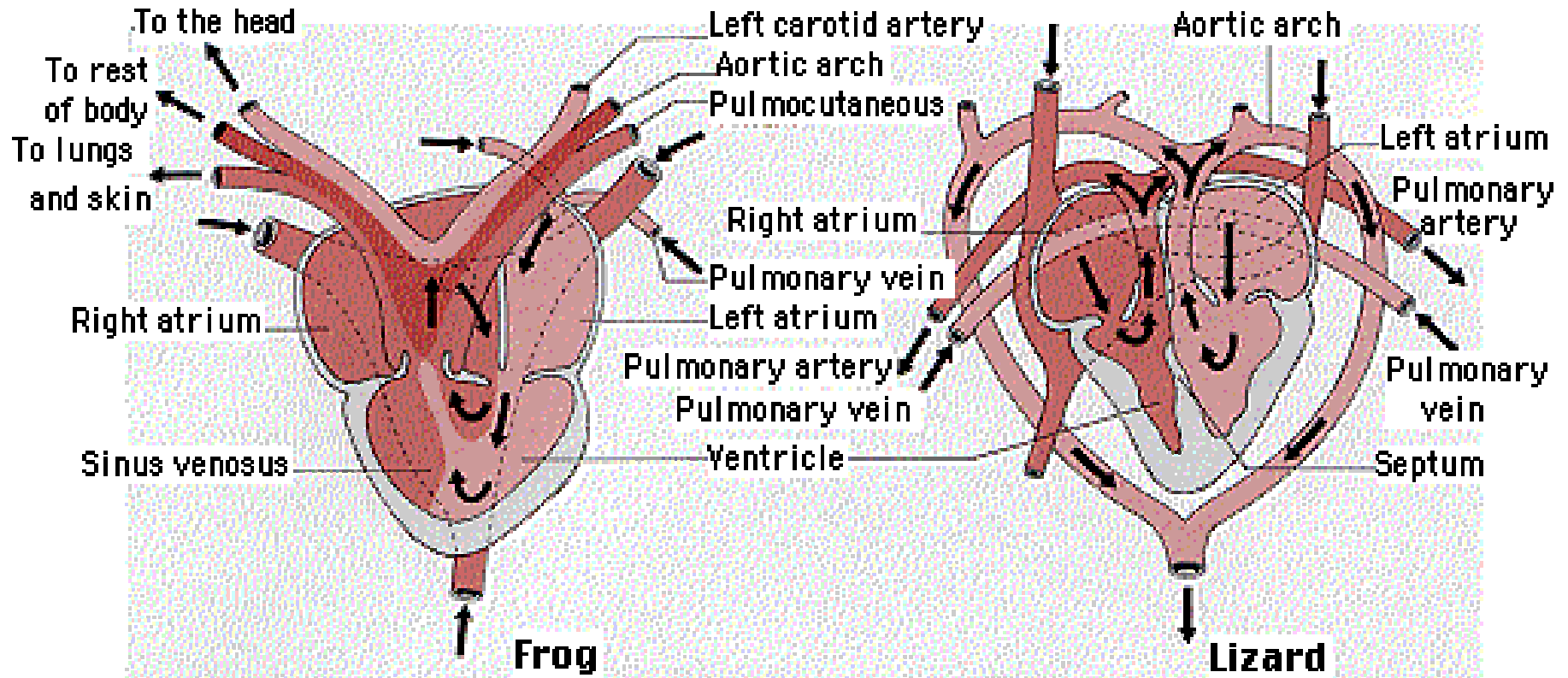
The Squid Hearts

This group has solved the problem by having separate pumps:

- two **gill hearts** to force blood under pressure to the gills and
- a **systemic heart** to force blood under pressure to the rest of the body.



Three Chambers: the Frog and Lizard



The Frog

The Frog Heart

The frog heart has 3 chambers: **two atria** and a single **ventricle**.

- The atrium receives deoxygenated blood from the blood vessels (veins) that drain the various organs of the body.
- The left atrium receives oxygenated blood from the lungs and skin (which also serves as a gas exchange organ in most amphibians).
- Both atria empty into the single ventricle.
- While this might appear to waste the opportunity to keep oxygenated and deoxygenated bloods separate, the ventricle is divided into narrow chambers that reduce the mixing of the two blood.
- So when the ventricle contracts,
 - oxygenated blood from the left atrium is sent, relatively pure, into the **carotid arteries** taking blood to the head (and brain);
 - deoxygenated blood from the right atrium is sent, relatively pure, to the **pulmocutaneous arteries** taking blood to the skin and lungs where fresh oxygen can be picked up.
 - Only the blood passing into the **aortic arches** has been thoroughly mixed, but even so it contains enough oxygen to supply the needs of the rest of the body.
- Note, that in contrast to the fish, both the gas exchange organs and the interior tissues of the body get their blood under full pressure.

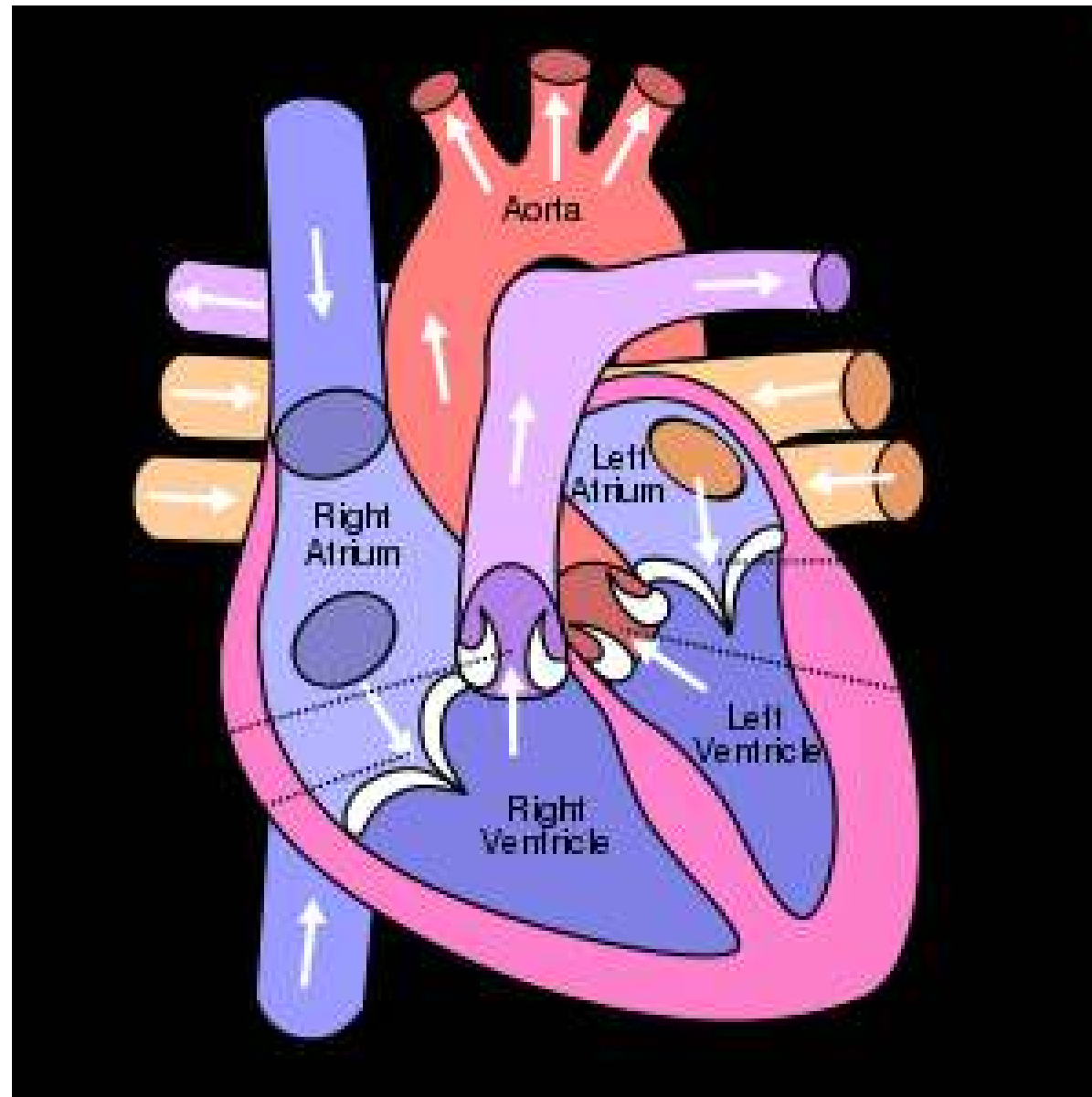
The Lizard

- Lizards have a muscular **septum** which partially divides the ventricle.
- When the ventricle contracts, the opening in the septum closes and the ventricle is momentarily divided into two separate chambers.
- This prevents mixing of the two bloods. The left half of the ventricle pumps oxygenated blood (received from the left atrium) to the body. The right half pumps deoxygenated blood (received from the right atrium) to the lungs.

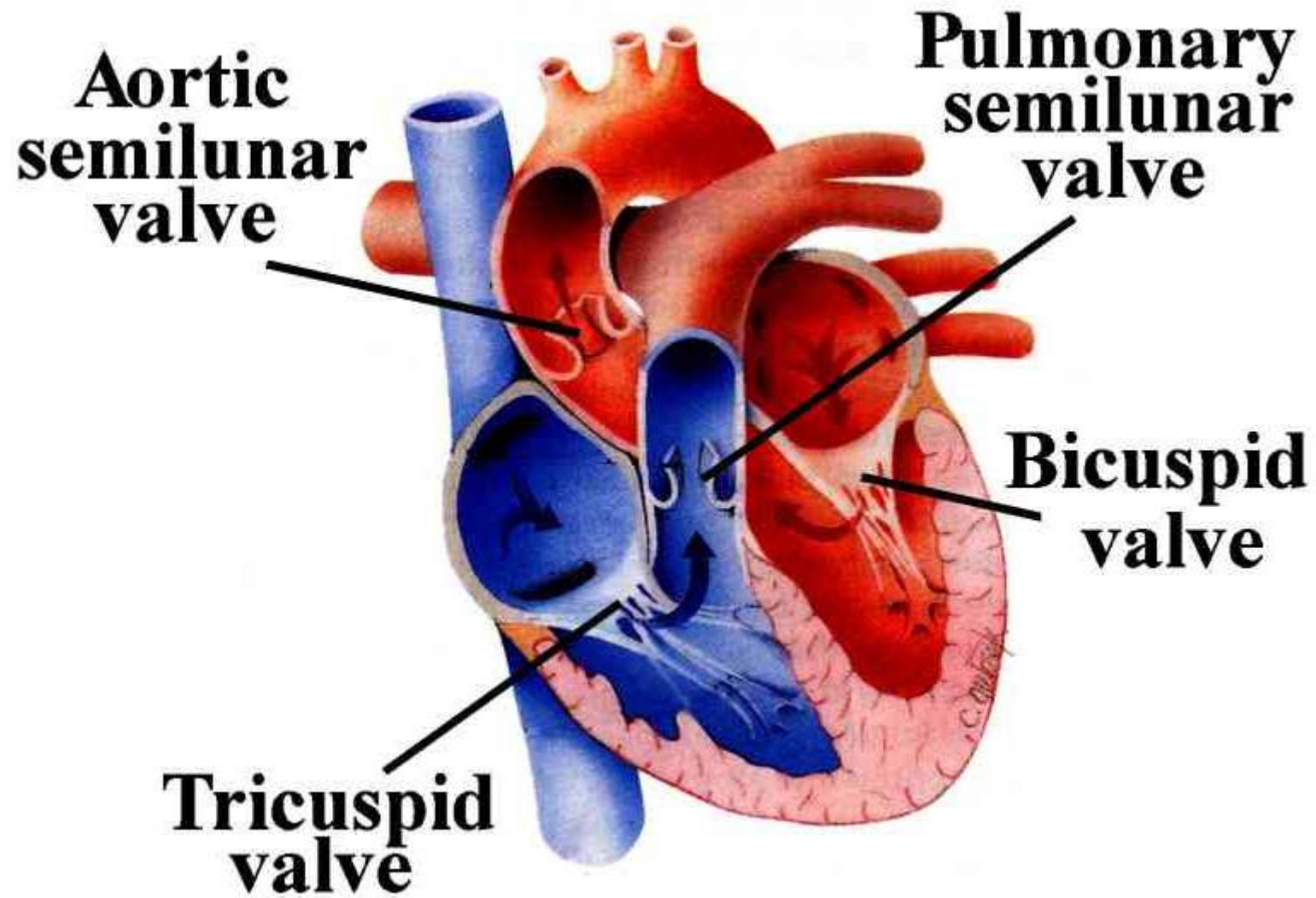
The Lizard

- **Four Chambers: Birds, Crocodiles, and Mammals**
- The septum is complete in the hearts of birds, crocodiles, and mammals providing two separate circulatory systems:
 - Pulmonary for gas exchange with the environment and
 - Systemic for gas exchange (and all other exchange needs) of the rest of the body.
- The efficiency that results makes possible the high rate of metabolism on which the endothermy ("warm-bloodedness") of birds and mammals depends.

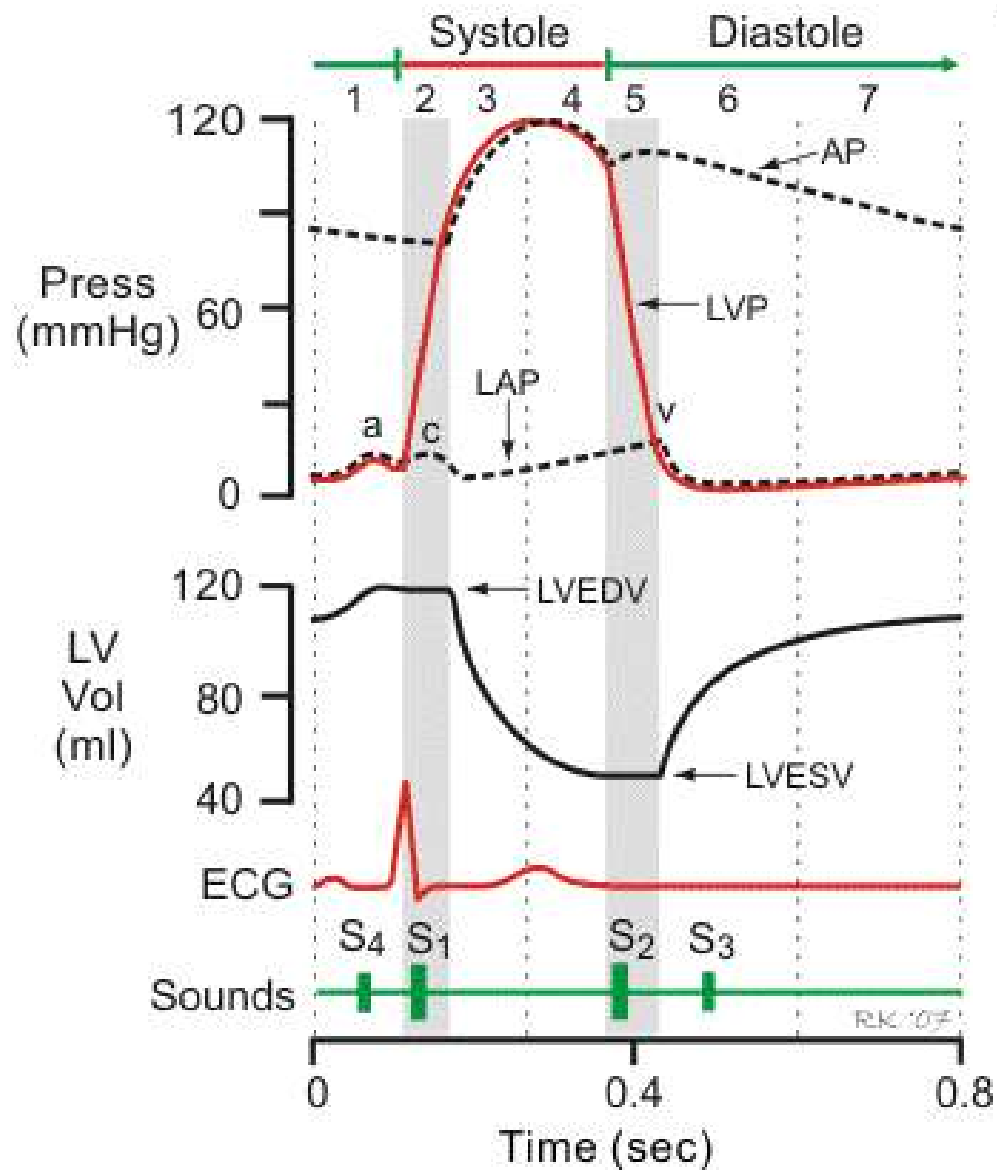
Mammalian Heart



Heart Valves



Cardiac cycle



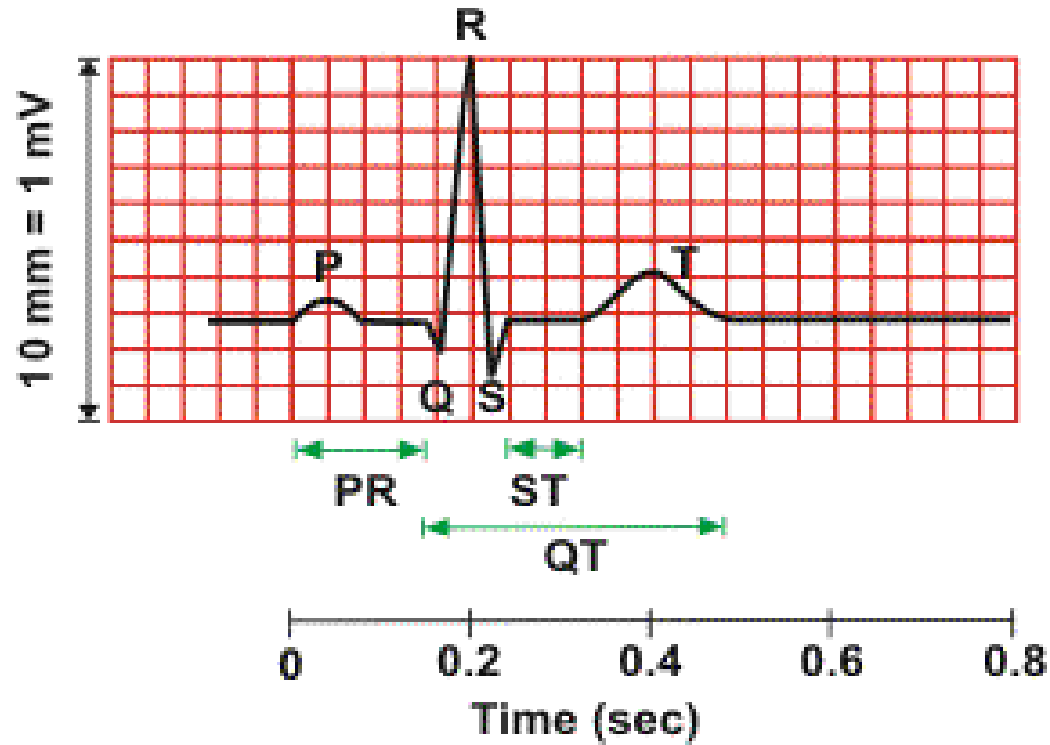
The cardiac cycle diagram shown to the left depicts changes in aortic pressure (AP), left ventricular pressure (LVP), left atrial pressure (LAP), left ventricular volume (LV Vol), and heart sounds during a single cycle of cardiac contraction and relaxation. These changes are related in time to the electrocardiogram.

Cardiac cycle

In humans, the cardiac cycle can be subdivided into two major phases, the systolic phase and the diastolic phase. Systole occurs when the ventricles of the heart contract. Accordingly, systole results in the highest pressures within the systemic and pulmonary circulatory systems. Diastole is the period between ventricular contractions when the right and left ventricles relax and fill.

<http://www.cvphysiology.com/Heart%20Disease/HD002.htm>

ECG



P wave (0.08 - 0.10 s)

QRS (0.06 - 0.10 s)

P-R interval (0.12 - 0.20 s)

Q-T_c interval (≤ 0.44 s)*

$$*QT_c = \frac{QT}{\sqrt{RR}}$$

Atrial Contraction (Phase 1)

- This is the first phase of the cardiac cycle because it is initiated by the p wave ECG, which represents electrical depolarisation of the atria. Atrial depolarisation then causes contraction of the atrial muscles. As the atria contract, the pressure within the atrial chambers increases, which forces more blood flow across the open atrioventricular (AV) valves, leading to a rapid flow of blood into the ventricles. Blood does not flow back into the vena cava because of inertial effects of the venous return and because the wave of contraction through the atria moves toward the AV valve thereby having a "milking effect." However, atrial contraction does produce a small increase in venous pressure that can be noted as the "**a-wave**" of the left atrial pressure (LAP).

Atrial Contraction (Phase 1) cont

- After atrial contraction is complete, the atrial pressure begins to fall causing a pressure gradient reversal across the AV valves. This causes the valves to float upward (pre-position) before closure. At this time, the ventricular volumes are maximal, which is termed the **end-diastolic volume** (EDV).
- A Heart sound is sometimes noted during atrial contraction (**fourth heart sound, S₄**). This sound is caused by vibration of the ventricular wall during atrial contraction.

All valves closed Isovolumetric Contraction (Phase 2)

- The AV valves close as intraventricular pressure exceeds atrial pressure. Ventricular contraction also triggers contraction of the papillary muscles with their attached chordae tendineae that prevent the AV valve leaflets from bulging back into the atria and becoming “leaky” . Closure of the AV valves results in the **first heart sound (S₁)**. During the time period between the closure of the AV valves and the opening of the aortic and pulmonary valves, ventricular pressure rises rapidly without a change in ventricular volume (i.e., no ejection occurs). Ventricular volume does not change because all valves are closed during this phase.

Rapid Ejection (Phase 3)

- This phase represents the initial and rapid ejection of blood into the aorta and pulmonary arteries from the left and right ventricles, respectively. Ejection begins when the intraventricular pressures exceed the pressures within the aorta and pulmonary artery.
- No heart sounds are ordinarily noted during ejection because the opening of healthy valves is silent. The presence of sounds during ejection

Reduced Ejection (Phase 4)

- Approximately 200 msec after the QRS and the beginning of ventricular contraction, ventricular repolarisation occurs as shown by the T-wave of the electrocardiogram. Repolarisation leads to a decline in ventricular activity and therefore the rate of ejection falls.
- Left atrial and right atrial pressures gradually rise due to continued venous return from the lungs and from the systemic circulation, respectively.

Isovolumetric Relaxation (Phase 5)

- When the intraventricular pressures fall sufficiently at the end of phase 4, the aortic and pulmonic valves abruptly close (aortic precedes pulmonic) causing the **second heart sound (S₂)**
- Although ventricular pressures decrease during this phase, volumes remain constant because all valves are closed. The volume of blood that remains in a ventricle is called the end-systolic volume and is ~50 ml in the left ventricle. The difference between the end-diastolic volume and the end-systolic volume is ~70 ml and represents the stroke volume. So what is cardiac output per minute?

Rapid Filling (Phase 6)

- As the ventricles continue to relax at the end of phase 5, the intraventricular pressures will at some point fall below their respective atrial pressures. When this occurs, the AV valves rapidly open and ventricular filling begins. Despite the inflow of blood from the atria, intraventricular pressure continues to briefly fall because the ventricles are still undergoing relaxation. Once the ventricles are completely relaxed, their pressures will slowly rise as they fill with blood from the atria.
- The opening of the mitral valve causes a rapid fall in LAP. The peak of the LAP just before the valve opens is the "**v-wave**." This is followed by the **y-descent** of the LAP. A similar wave and descent are found in the right atrium and in the jugular vein.
- Ventricular filling is normally silent. When a **third heart sound (S₃)** is audible, it may represent tensing of chordae tendineae and AV ring during ventricular relaxation and filling. This heart sound is normal in children but is often pathological in adults.

Reduced Filling (Phase 7)

- As the ventricles continue to fill with blood and expand, they become less compliant and the intraventricular pressures rise. This reduces the pressure gradient across the AV valves so that the rate of filling falls.

- In normal, resting hearts, the ventricle is about 90% filled by the end of this phase. In other words, about 90% of ventricular filling occurs before atrial contraction (phase 1).**

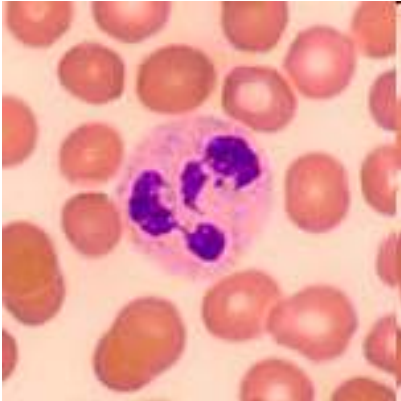
- Aortic pressure and pulmonary arterial pressures continue to fall during this period.

-

Human blood

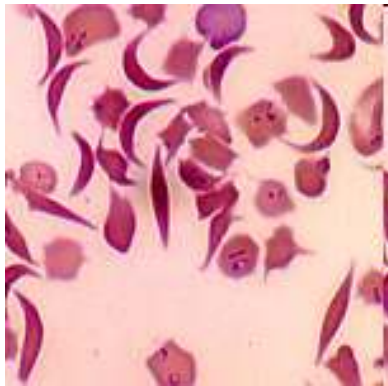
Blood is liquid plasma and cells – lots of different kinds of cells.

ERYTHROCYTES



The background cells in this micrograph are erythrocytes (red blood cells). These cells are non-nucleated, biconcave discs that are filled with haemoglobin. The primary function of these cells is to carry oxygen from the lungs to the body cells.

We usually have ? erythrocytes per cubic millimetre of blood.



Sickle cell anaemia is an inherited condition which results in some erythrocytes being malformed. The gene for this condition causes the haemoglobin to be incorrectly formed, which in turn causes some erythrocytes to take on a crescent shape. These cells are not able to carry adequate amounts of oxygen to cells.

Haemocytometer

Hemocytometer grid:

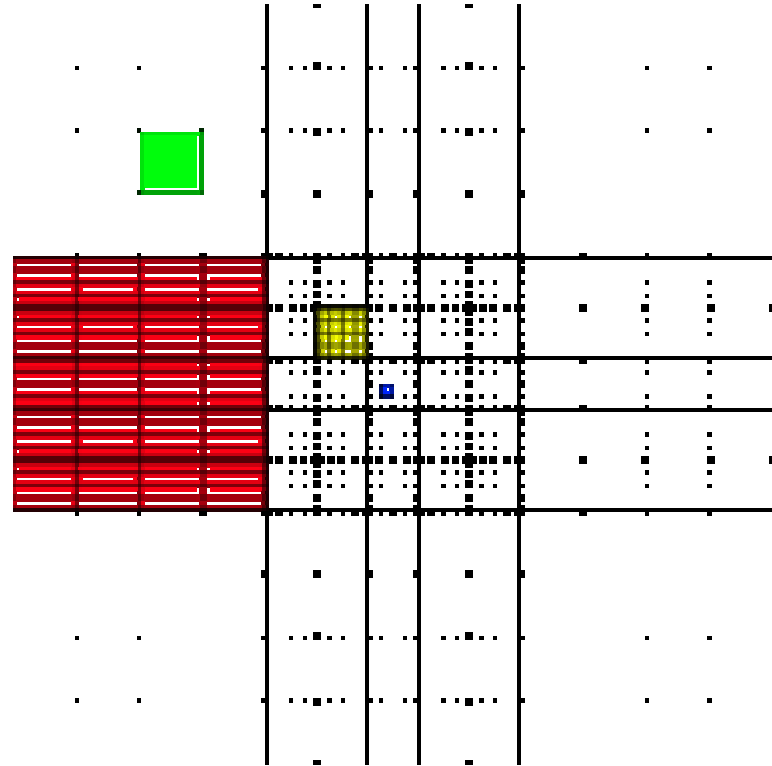
red square = 1 mm^2

green square = 0.0625 mm^2

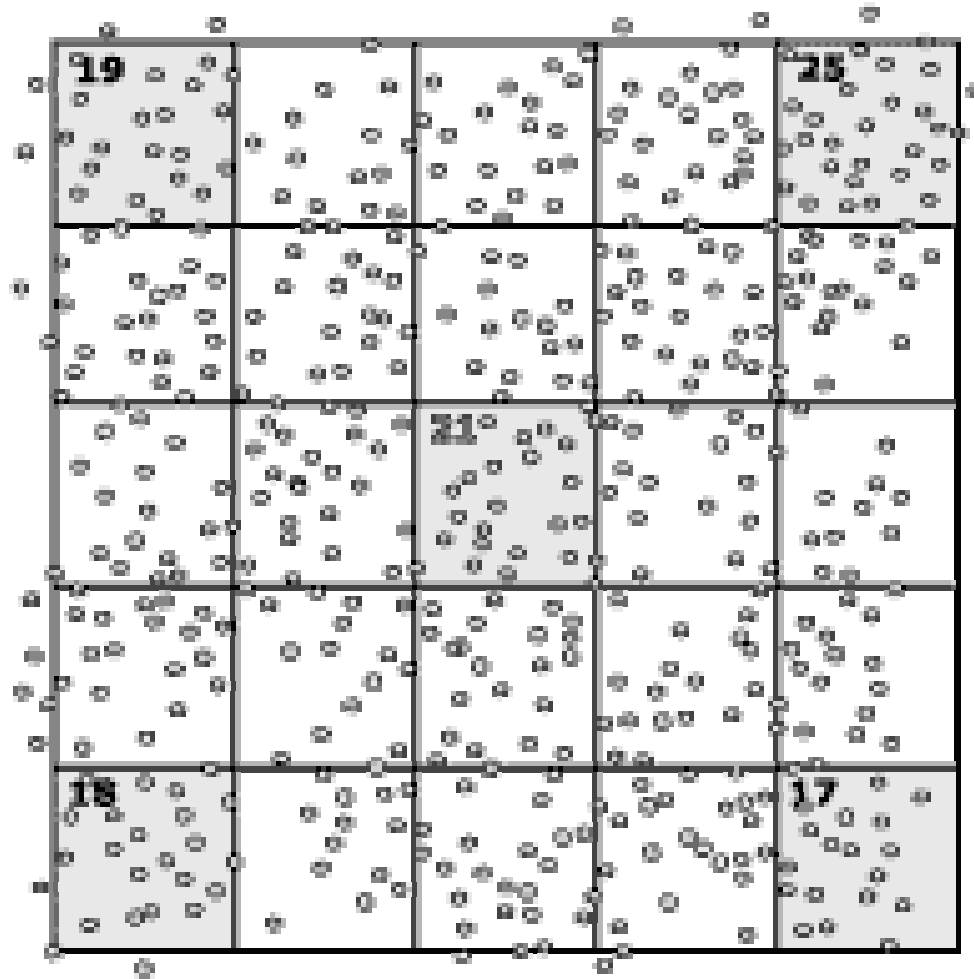
yellow square = 0.04 mm^2 ,

blue square = 0.0025 mm^2 ,

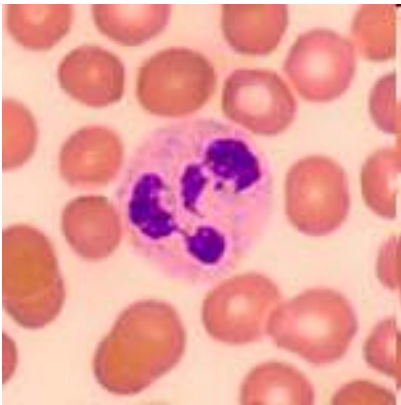
at a depth of 0.1 mm .



Haemocytometer Calculating Erythrocyte concentration



NEUTROPHIL

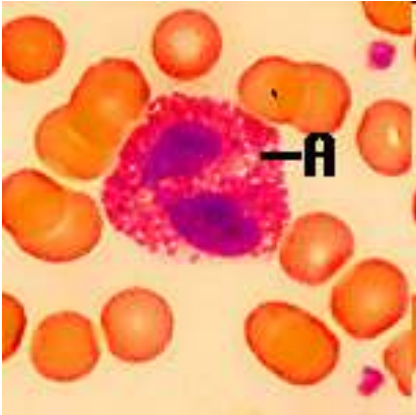


This granulocyte has very tiny light staining granules (the granules are very difficult to see). The nucleus is frequently multi-lobed with lobes connected by thin strands of nuclear material. These cells are capable of phagocytizing foreign cells, toxins, and viruses.

When taking a Differential WBC Count of normal blood, this type of cell would be the most numerous.

Normally, neutrophils account for 50-70% of all leukocytes. If the count exceeds this amount, the cause is usually due to an acute infection such as appendicitis, smallpox or rheumatic fever. If the count is considerably less, it may be due to a viral infection such as influenza, hepatitis, or rubella.

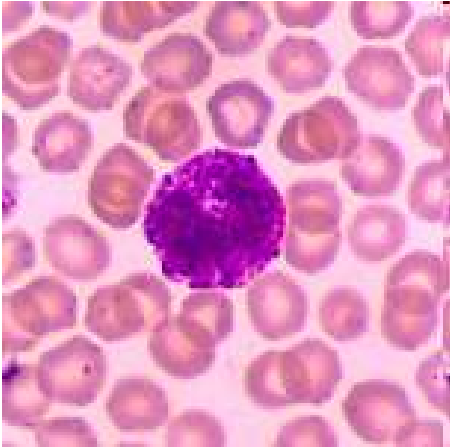
EOSINOPHIL



This granulocyte has large granules (A) and appear pink (or red) in a stained preparation. This micrograph was colour enhanced to illustrate this feature. The nucleus often has two lobes connected by a band of nuclear material. The granules contain digestive enzymes that are particularly effective against parasitic worms in their larval form. These cells also phagocytize antigen - antibody complexes.

These cells account for less than 5% of the WBC's. Increases beyond this amount may be due to parasitic diseases, bronchial asthma or hay fever.

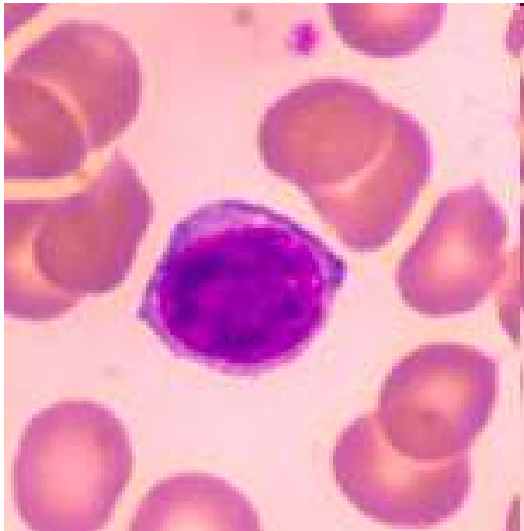
BASOPHIL



The basophilic granules in this cell are large, stain deep blue to purple, and are often so numerous they mask the nucleus. These granules contain histamines (cause vasodilation) and heparin (anticoagulant).

In a Differential WBC Count we rarely see these as they represent less than 1% of all leukocytes.

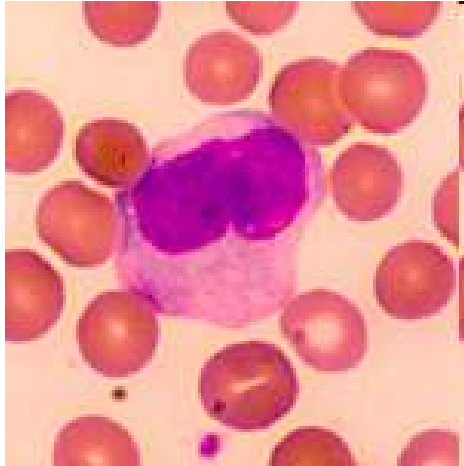
LYMPHOCYTE



The lymphocyte is an agranular cell with very clear cytoplasm which stains pale blue. Its nucleus is very large for the size of the cell and stains dark purple. (Notice that the nucleus almost fills the cell leaving a very thin rim of cytoplasm.) This cell is much smaller than the three granulocytes (which are all about the same size). These cells play an important role in our immune response. The T-lymphocytes act against virus infected cells and tumor cells. The B-lymphocytes produce antibodies.

This is the second most numerous leukocyte, accounting for 25-35% of the cells counted in a Differential WBC Count. When the number of these cells exceeds the normal amount, one would suspect infectious mononucleosis or a chronic infection. Patients with AIDS keep a careful watch on their T-cell level, an indicator of the AIDS virus' activity

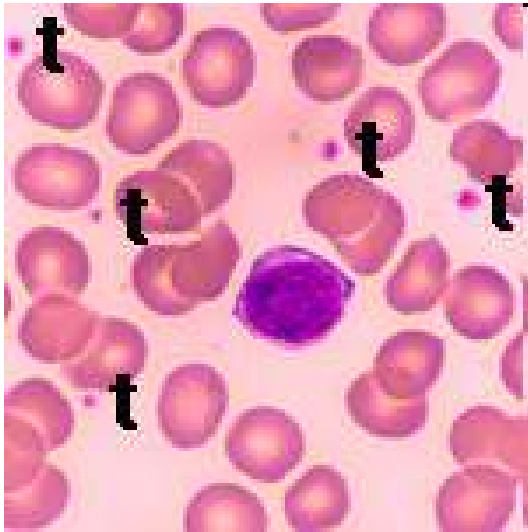
MONOCYTE



This cell is the largest of the leukocytes and is agranular. The nucleus is most often "U" or kidney bean shaped; the cytoplasm is abundant and light blue (more blue than this micrograph illustrates). These cells leave the blood stream (diapedesis) to become macrophages. As a monocyte or macrophage, these cells are phagocytic and defend the body against viruses and bacteria.

These cells account for 3-9% of all leukocytes. In people with malaria, endocarditis, typhoid fever, and Rocky Mountain spotted fever, monocytes increase in number.

THROMBOCYTES - PLATELETS










Platelets, which are cell fragments, are seen next to the "t's" above. (Many of the other micrographs on this page contain them as well.) Platelets are important for proper blood clotting.

Each cubic millimeter of blood should contain 250,000 to 500,000 of these. If the number is too high, spontaneous clotting may occur. If the number is too low, clotting may not occur when necessary.

Blood Cell Summary

Table 14.10 Cellular components of blood (diagrams not drawn to scale).

<i>Component</i>	<i>Origin</i>	<i>Number of cells/mm⁻³</i>	<i>Function</i>	<i>Structure</i>
Erythrocytes	bone marrow	5 000 000	transport of oxygen and some carbon dioxide	
Leucocytes	bone marrow			
<i>(a) Granulocytes (72% of total white blood cell count)</i>				
neutrophils (70%)	bone marrow	4 900	engulf bacteria	
eosinophils (1.5%)		105	anti-histamine properties	
basophils (0.5%)		35	produce histamine and heparin	
<i>(b) Agranulocytes (28%)</i>				
monocytes (4%)	bone marrow	280	engulf bacteria	
lymphocytes (24%)	bone marrow lymphoid tissue spleen	1 680	production of antibodies	
Platelets	bone marrow	250 000	initiate blood-clotting mechanism	

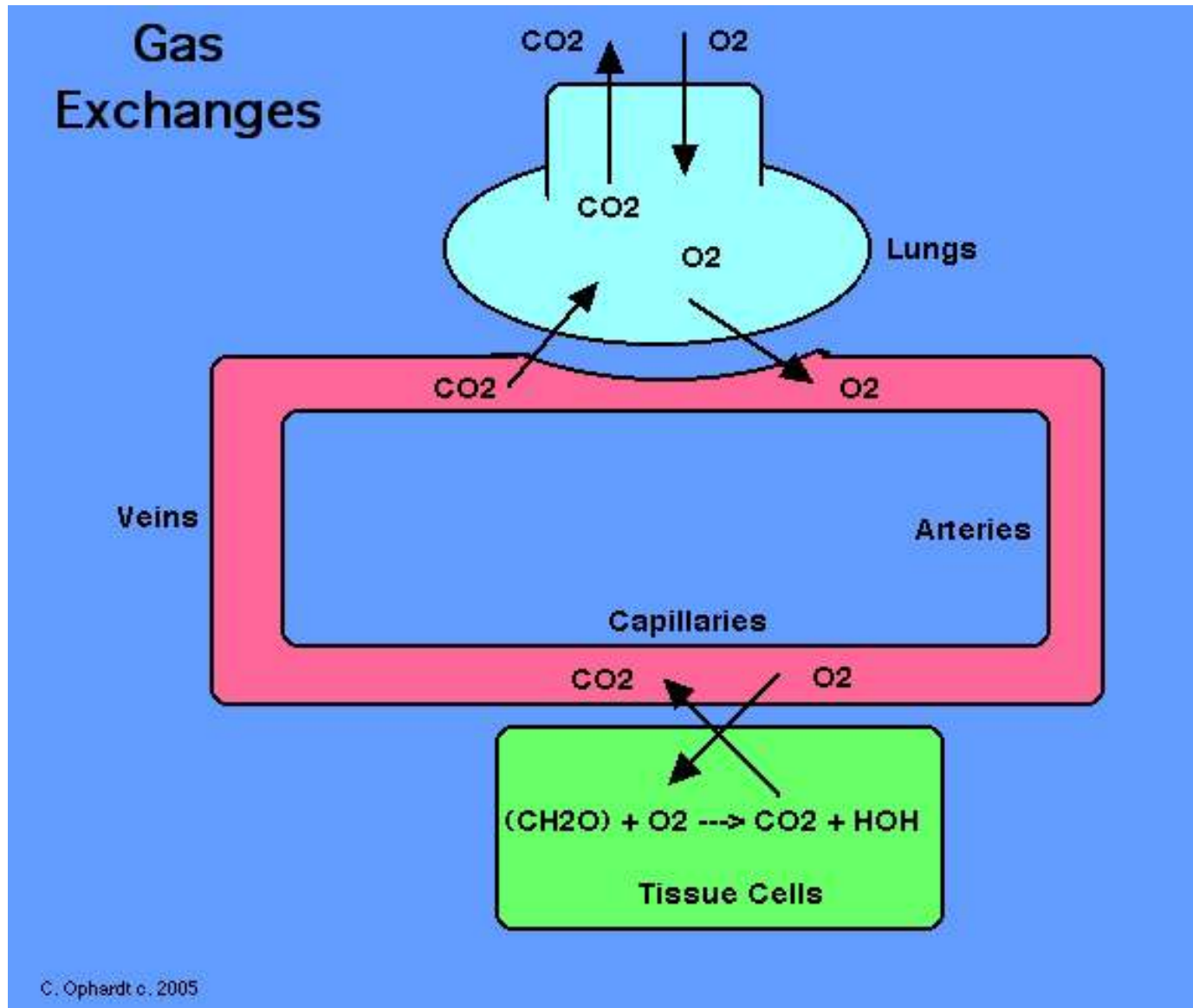
Blood plasma

Blood plasma is the liquid component of whole blood, and makes up approximately 55% of the total blood volume. It is composed primarily of water with small amounts of minerals, salts, ions, nutrients, and proteins in solution. In whole blood, red blood cells, leukocytes, and platelets are suspended within the plasma.

Plasma proteins

Plasma contains a large variety of proteins including albumin, immunoglobulins, and clotting proteins such as fibrinogen. Albumin constitutes about 60% of the total protein in plasma and is present at concentrations between 35 and 55 mg/ml. It is the main contributor to osmotic pressure of the blood and it functions as a carrier molecule for molecules with low water solubility such as lipid soluble hormones, enzymes, fatty acids, metal ions, and pharmaceutical compounds. Albumin is structurally stable due to its seventeen disulfide bonds and unique in that it has the highest water solubility. Due to the structural integrity of albumin it remains stable under conditions where most other proteins denature.

Transport of Gases



Transport of Oxygen 1

Gaseous Diffusion:

Partial pressures are used to designate the concentrations of gases. Dalton's Law of Partial Pressures states that the total pressure of all gases is equal to the sum of the partial pressures of each gas. For example, the total atmospheric pressure of air is 760 mm Hg. In equation form:

$$P(\text{total air}) = P(\text{O}_2) + P(\text{N}_2) + P(\text{CO}_2) + P(\text{HOH})$$

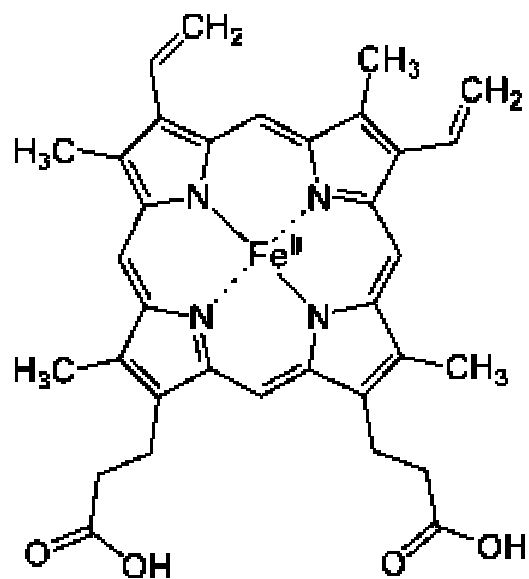
$$760 = 160 + 594.7 + 0.3 + 5.0$$

The partial pressures for oxygen and carbon dioxide in various locations are given in Figure 1. The movement or exchange of gases between the lungs, blood, and tissue cells is controlled by a diffusion process.

A gas diffuses from an area of higher partial pressure to an area of lower partial pressure.

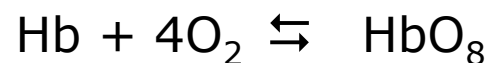
Transport of Oxygen 2

In the lungs, oxygen diffuses from alveolar air into the blood because the venous blood has a lower partial pressure. The oxygen dissolves in the blood. Only a small amount is carried as a physical solution (0.31 ml per 100 ml). The remainder of the oxygen is carried in chemical combination with the haemoglobin in red blood cells (erythrocytes).



Haemoglobin has four haem groups (with Fe) attached to four globular protein chains.

Oxygen attaches to the haem group where the pp of Oxygen is high to produce oxyhaemoglobin.



Plotting Oxygen pp against saturation of haemoglobin with oxygen gives a dissociation S-shaped curve.

Transport of Oxygen 1

The graph is S-shaped because one molecule of Oxygen combined to Haemoglobin changes the shape of the molecule so that subsequent molecules are taken up more easily (with less energy/quicker).



Haemoglobin is also found in deep sea fan worms which have red "plumes"), which extend into the water and absorbs H_2S and O_2 for bacteria, and CO_2 for use as synthetic raw material similar to photosynthetic plants.

Dissociation Curve

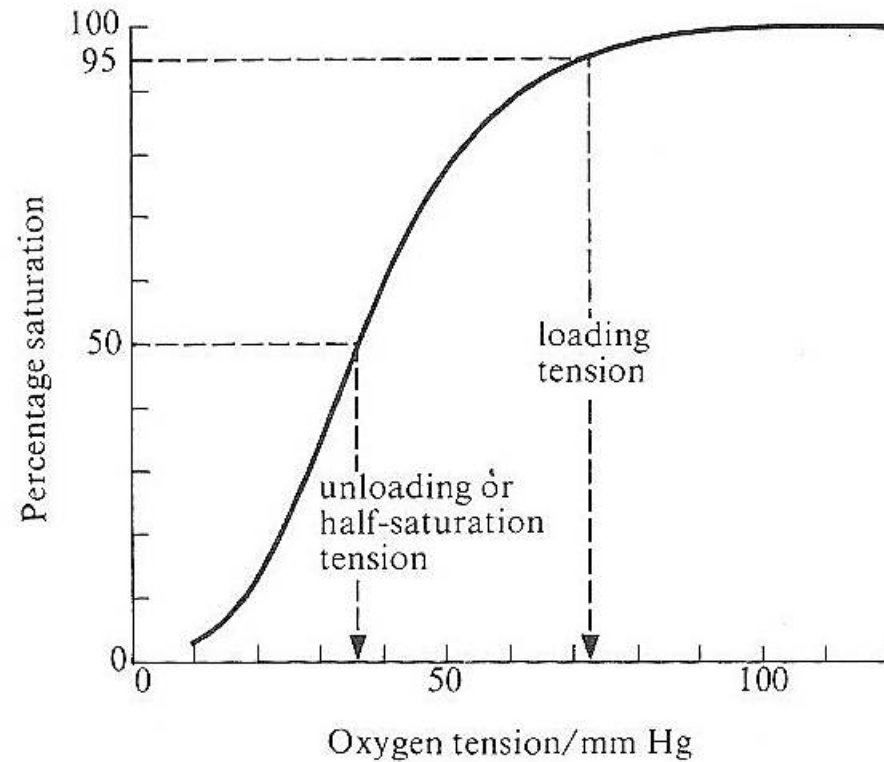
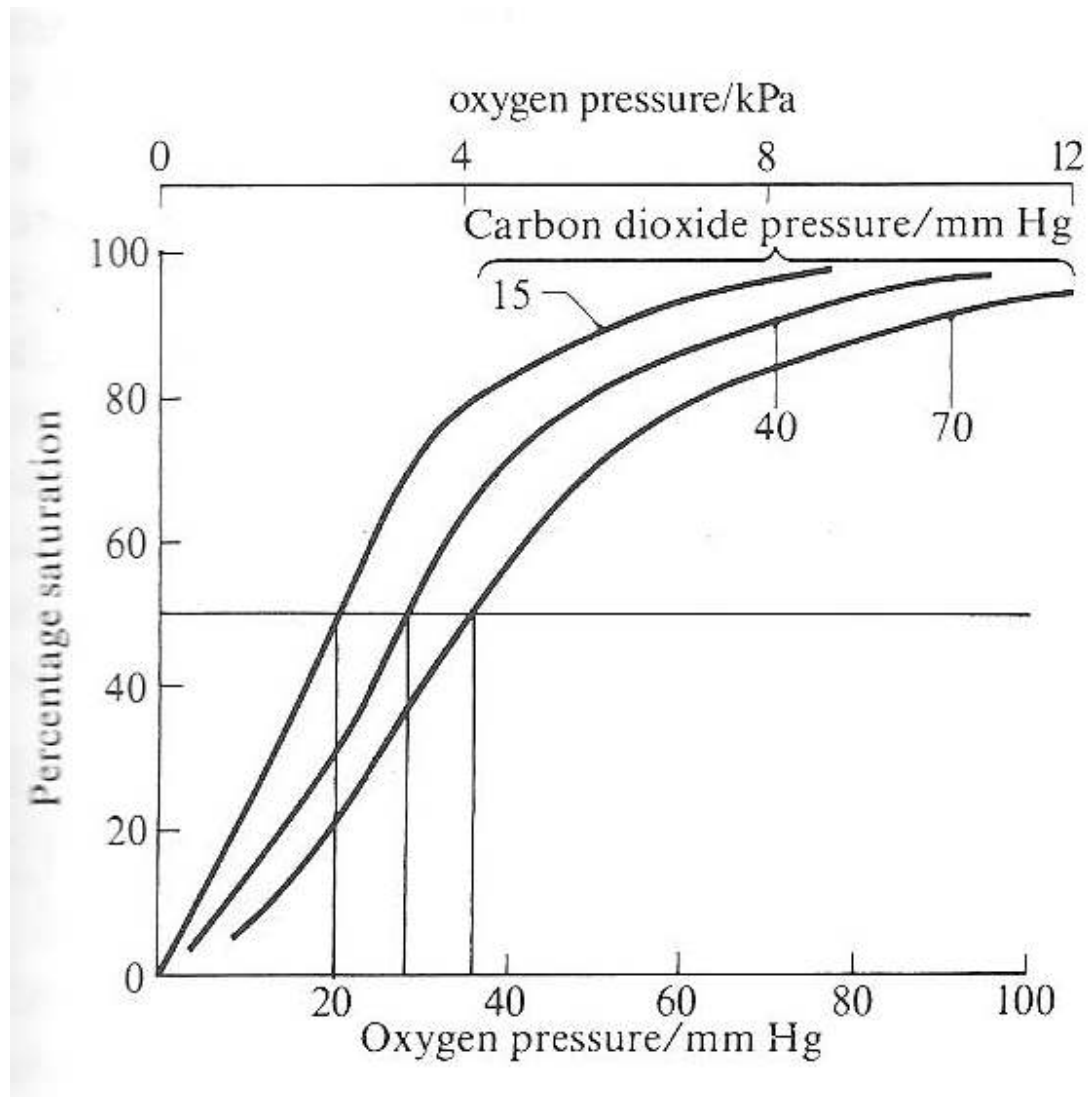
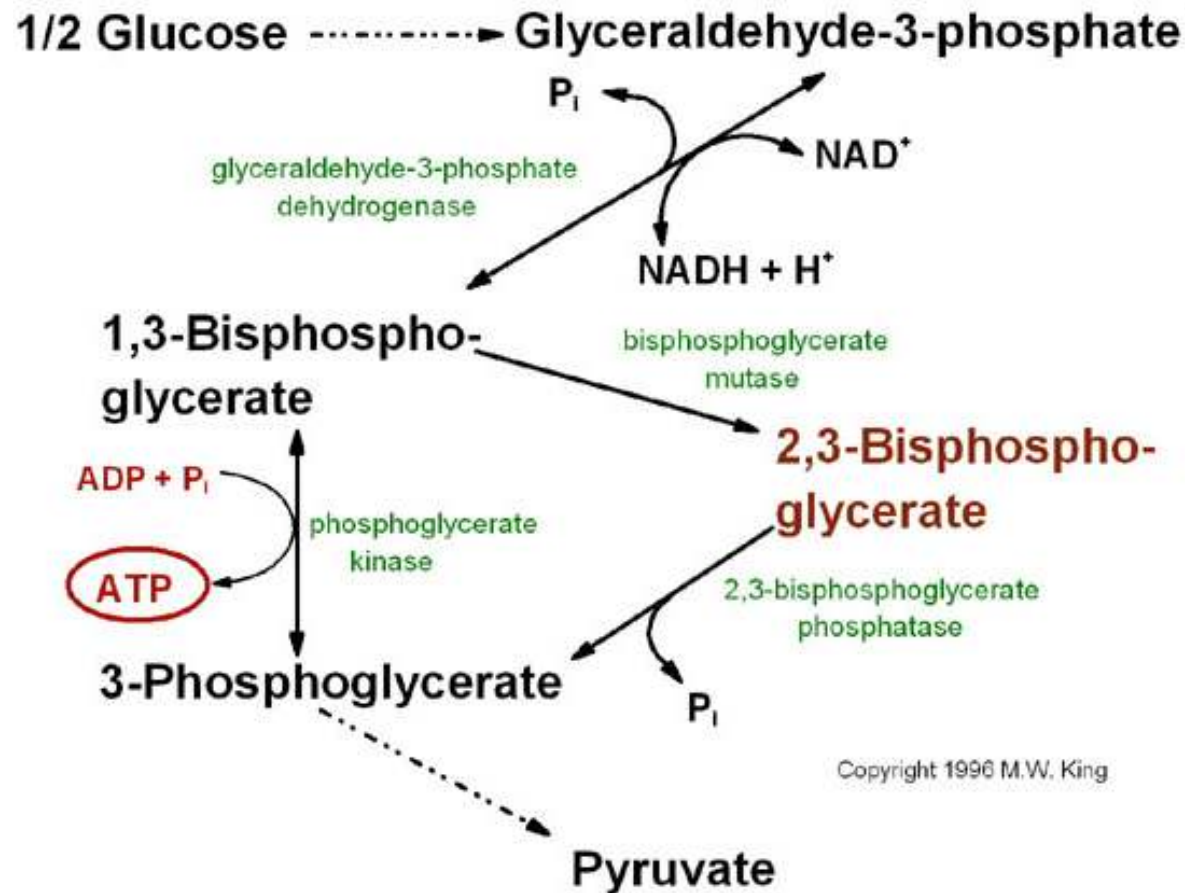


Diagram to explain the terminology applied to oxygen dissociation curves of oxygen-carrying pigments. Loading tension is the tension at which 95% of the pigment is saturated with oxygen; unloading tension is the tension at which 50% of the pigment is saturated with oxygen.

Effect of Carbon dioxide concentration

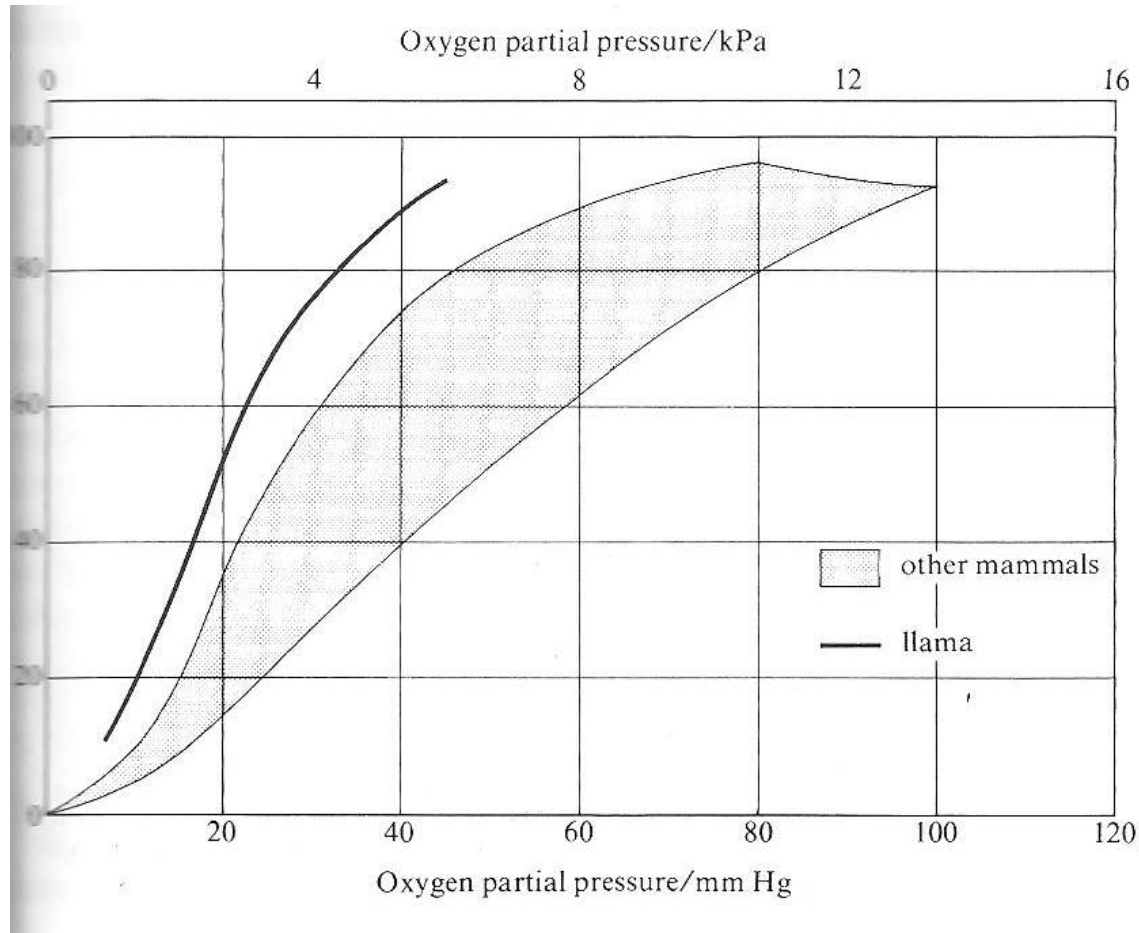


Role of 2,3-bisphosphoglycerate (2,3-BPG)



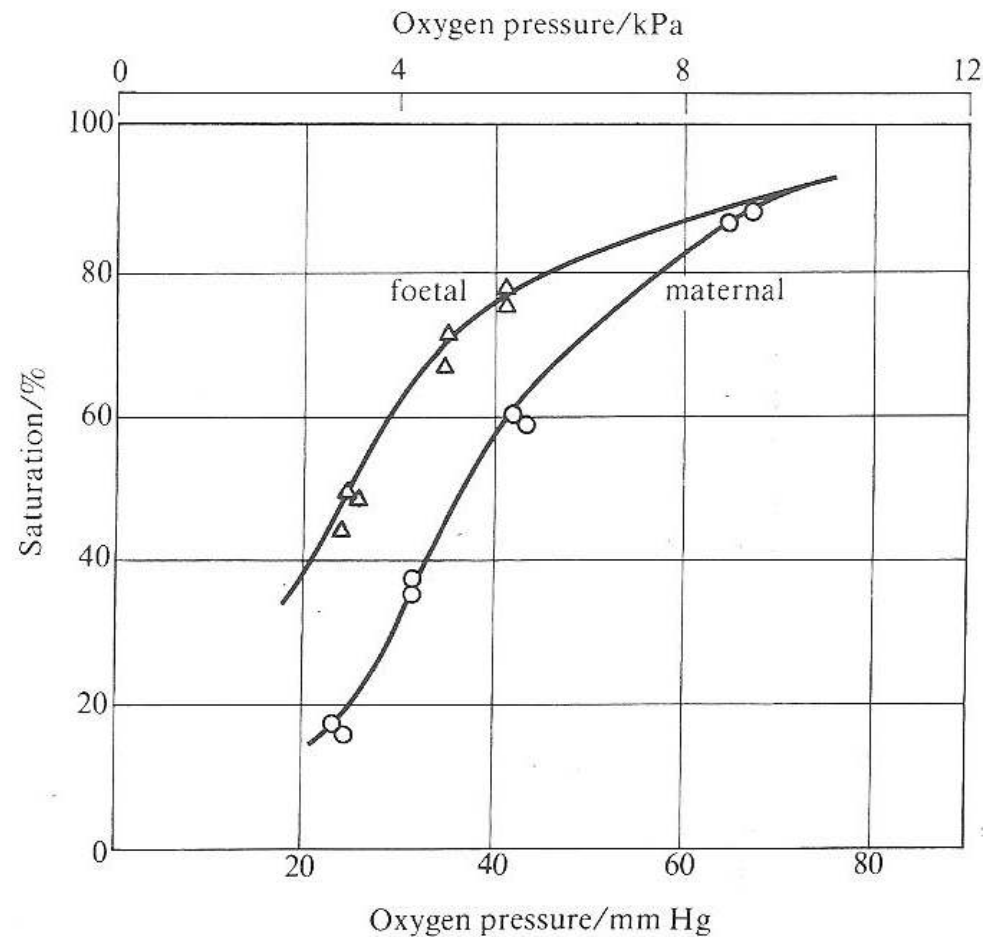
The compound 2,3-bisphosphoglycerate (2,3-BPG), derived from the glycolytic intermediate 1,3-bisphosphoglycerate, is a potent allosteric effector decreasing the oxygen binding properties of haemoglobin.

Dissociation curve for llamas



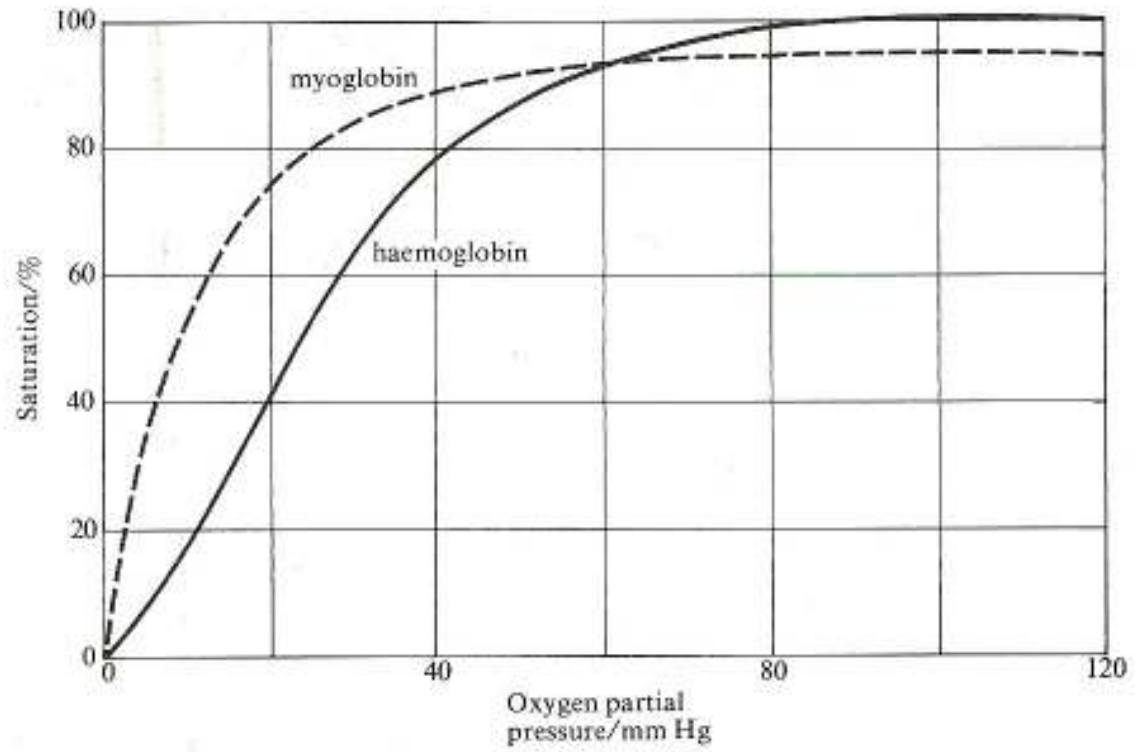
The llama lives at high altitude with a dissociation curve to the left of other mammals. How come?

Fetal haemoglobin

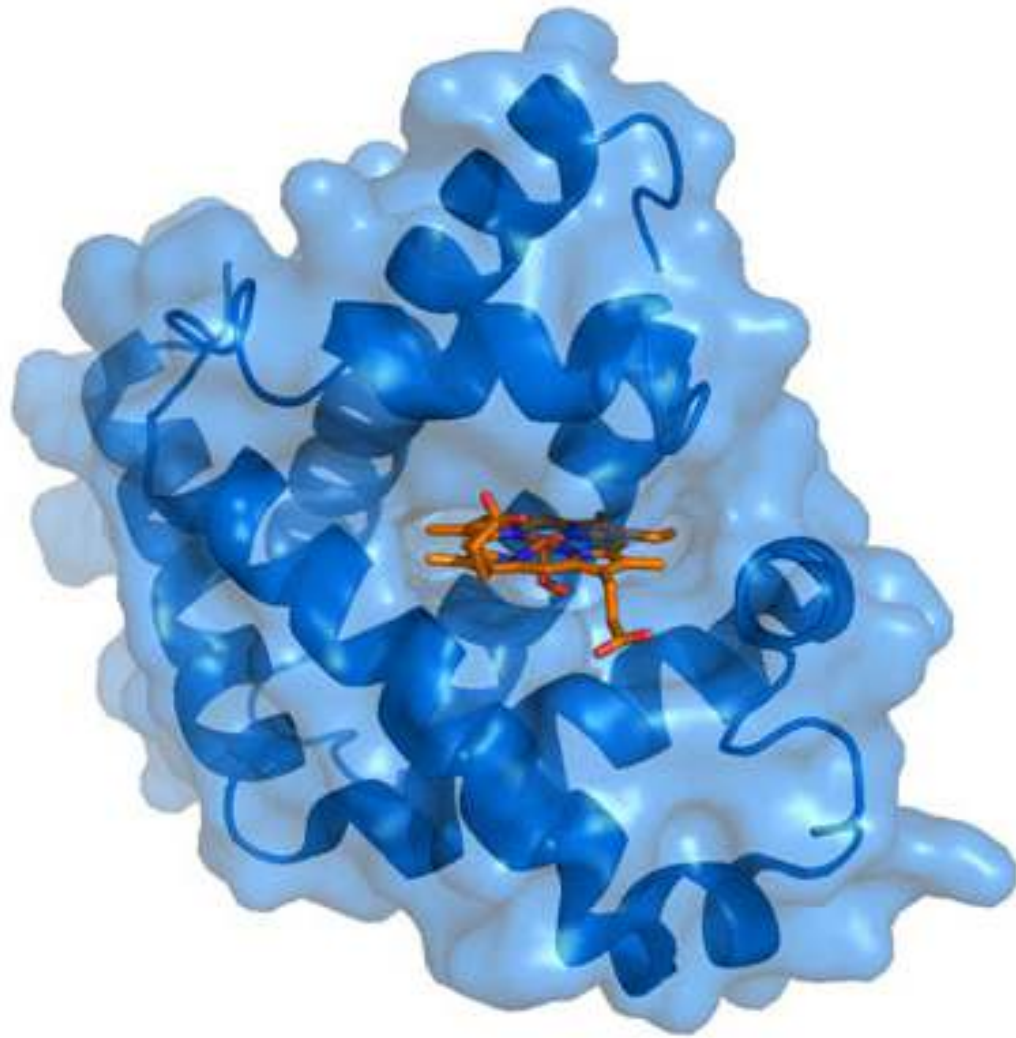


HbF (the fetal form of haemoglobin) binds 2,3-BPG much less well than HbA (the adult form of haemoglobin) with the result that HbF in fetuses of pregnant women binds oxygen with greater affinity than the mothers HbA, thus giving the fetus preferential access to oxygen carried by the mothers circulatory system.

Myoglobin



Myoglobin

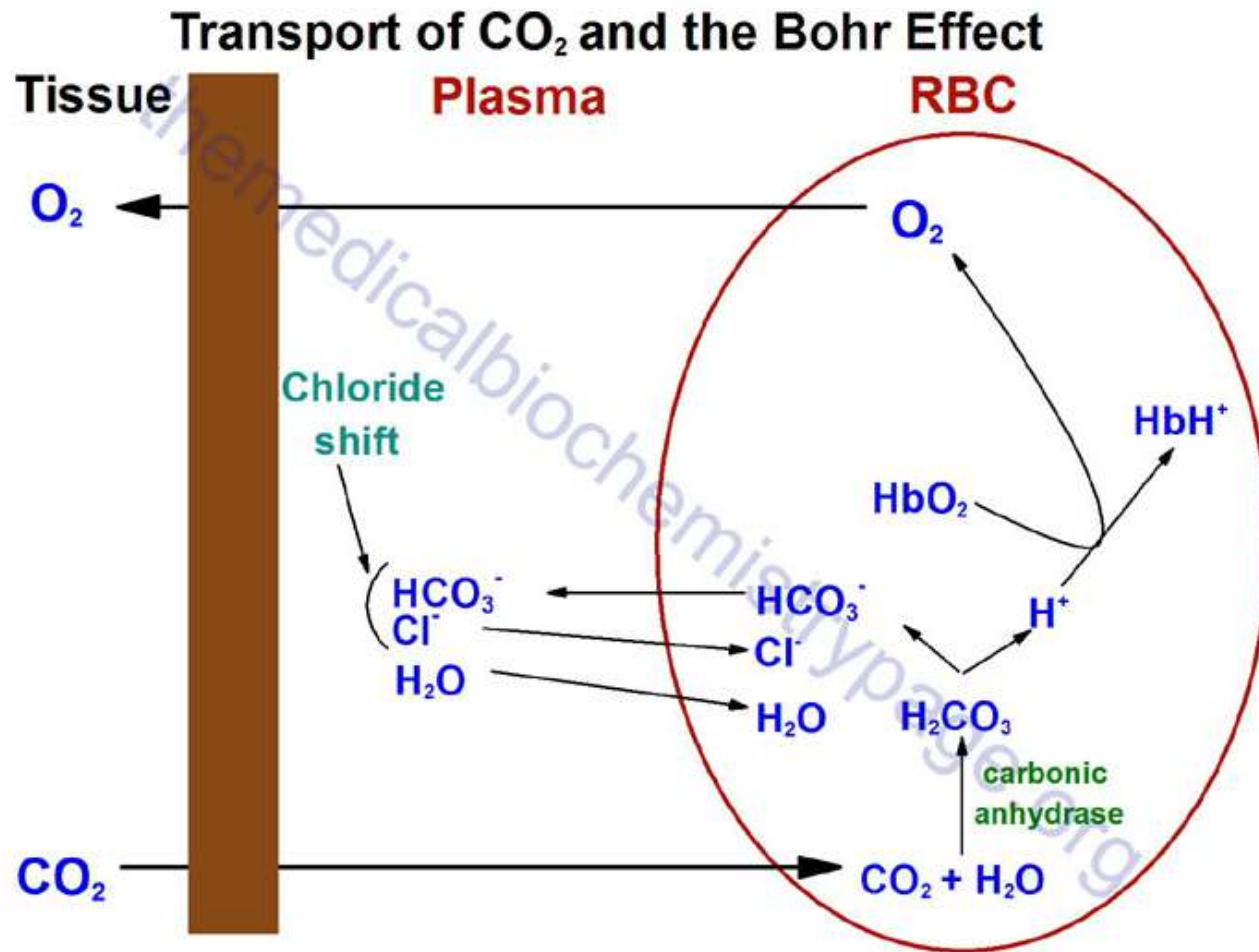


Myoglobin

Myoglobin like haemoglobin is a haemproteins whose physiological importance is principally related to their ability to bind molecular oxygen. Myoglobin is found mainly in muscle tissue where it serves as an intracellular storage site for oxygen. During periods of oxygen deprivation oxymyoglobin releases its bound oxygen which is then used for metabolic purposes. Its secondary structure is unusual in that it contains a very high proportion (75%) of α -helical secondary structure.

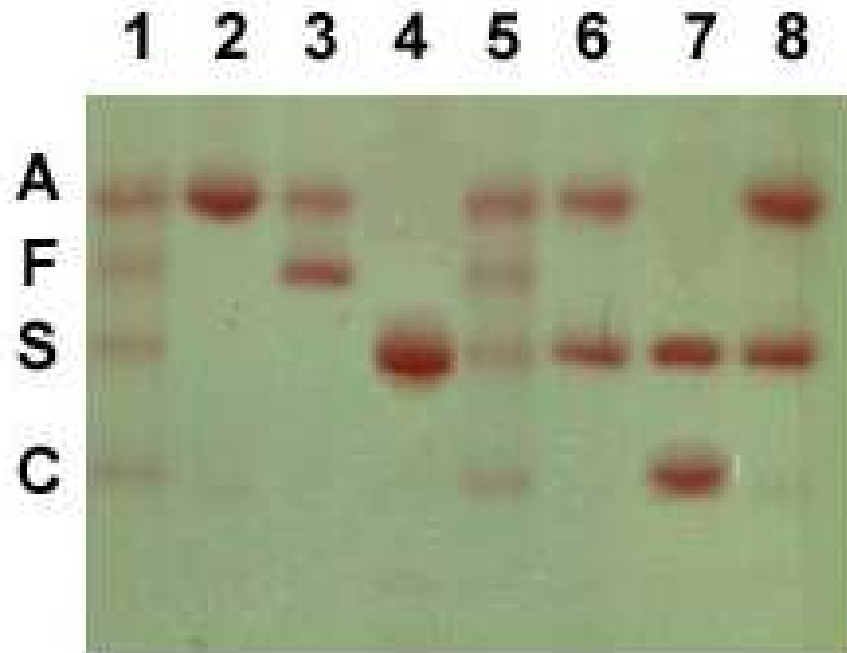
Carbon monoxide also binds to haem iron atoms in a manner similar to that of oxygen, but the binding of carbon monoxide to haem is much stronger than that of oxygen. The preferential binding of carbon monoxide to haem iron is largely responsible for the asphyxiation that results from carbon monoxide poisoning.

Transport of Carbon dioxide



Carbon dioxide is carried attached to haemoglobin - Carbamino compound – but most is carried in solution as hydrogen carbonate.

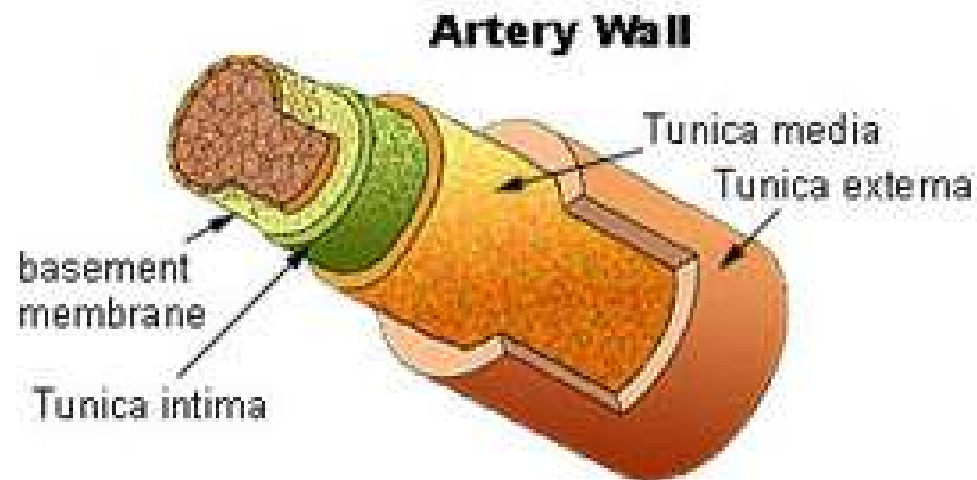
Sickle cell disease



Pattern of hemoglobin electrophoresis from several different individuals. Lanes 1 and 5 are hemoglobin standards. Lane 2 is a normal adult. Lane 3 is a normal neonate. Lane 4 is a homozygous HbS individual. Lanes 6 and 8 are heterozygous sickle individuals. Lane 7 is a SC disease individual.

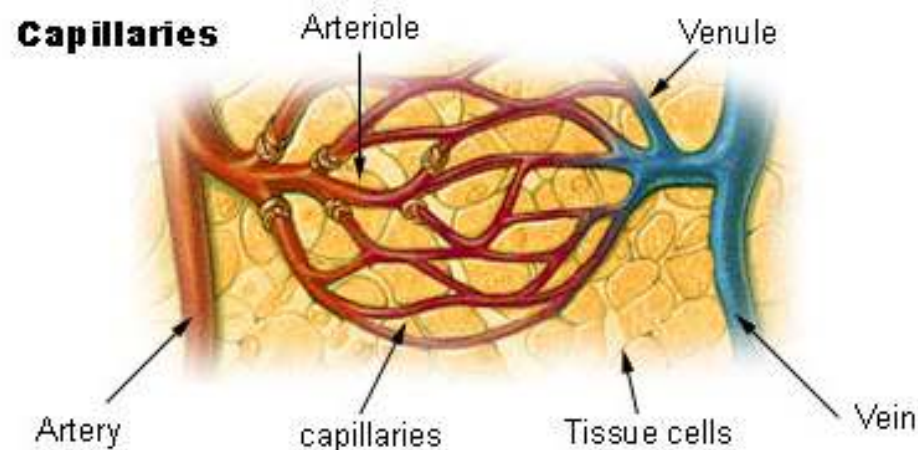
Arteries

The wall of an artery consists of three layers. The innermost layer, the tunica interna, is simple squamous epithelium surrounded by a connective tissue basement membrane with elastic fibres. The middle layer, the tunica media, is primarily smooth muscle and is usually the thickest layer. It not only provides support for the vessel but also changes vessel diameter to regulate blood flow and blood pressure. The outermost layer, which attaches the vessel to the surrounding tissue, is the tunica externa. This layer is connective tissue with varying amounts of elastic and collagenous fibers. The connective tissue in this layer is quite dense where it is adjacent to the tunic media, but it changes to loose connective tissue near the periphery of the vessel.



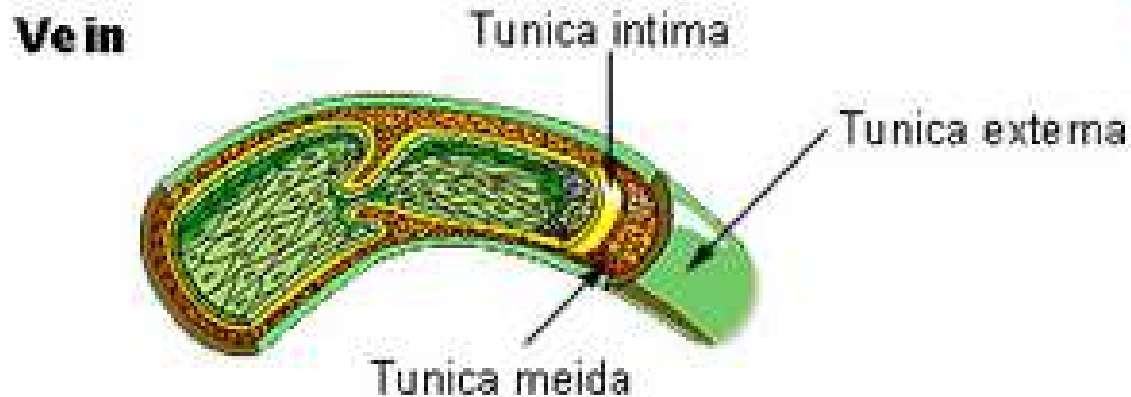
Capillaries

Capillaries, the smallest and most numerous of the blood vessels, form the connection between the vessels that carry blood away from the heart (arteries) and the vessels that return blood to the heart (veins). The primary function of capillaries is the exchange of materials between the blood and tissue cells. Capillary distribution varies with the metabolic activity of body tissues. Tissues such as skeletal muscle, liver, and kidney have extensive capillary networks because they are metabolically active and require an abundant supply of oxygen and nutrients. Other tissues, such as connective tissue, have a less abundant supply of capillaries. The epidermis of the skin and the lens and cornea of the eye completely lack a capillary network. About 5 percent of the total blood volume is in the systemic capillaries at any given time. Another 10 percent is in the lungs. Smooth muscle cells in the arterioles where they branch to form capillaries regulate blood flow from the arterioles into the capillaries.



Veins

Veins carry blood toward the heart. The walls of veins have the same three layers as the arteries. Although all the layers are present, there is less smooth muscle and connective tissue. This makes the walls of veins thinner than those of arteries, which is related to the fact that blood in the veins has less pressure than in the arteries. Because the walls of the veins are thinner and less rigid than arteries, veins can hold more blood. Almost 70 percent of the total blood volume is in the veins at any given time. Medium and large veins have venous valves, similar to the semilunar valves associated with the heart, that help keep the blood flowing toward the heart. Venous valves are especially important in the arms and legs, where they prevent the backflow of blood in response to the pull of gravity.



Lymph and tissue fluid

Veins carry blood toward the heart. The walls of veins have the same three layers as the arteries. Although all the layers are present, there is less smooth muscle and connective tissue. This makes the walls of veins thinner than those of arteries, which is related to the fact that blood in the veins has less pressure than in the arteries. Because the walls of the veins are thinner and less rigid than arteries, veins can hold more blood. Almost 70 percent of the total blood volume is in the veins at any given time. Medium and large veins have venous valves, similar to the semilunar valves associated with the heart, that help keep the blood flowing toward the heart. Venous valves are especially important in the arms and legs, where they prevent the backflow of blood in response to the pull of gravity.

