

## The Circulatory System

The circulatory system consists of the heart and the vascular system:

- Arteries, arterioles, capillaries
- Capillaries
- Venules, veins
- Lymphatics
- Blood
- Lymph

Figure 1 - Structure of Arteries and Veins

### Arteries

These are tubes that have a strong muscular wall. They have three layers:

- **Tunica interna** (endothelial layer)
- **Tunica media** (muscle layer)
- **Tunica externa**, or **adventitia** (fibrous connective tissue)

### Arterioles

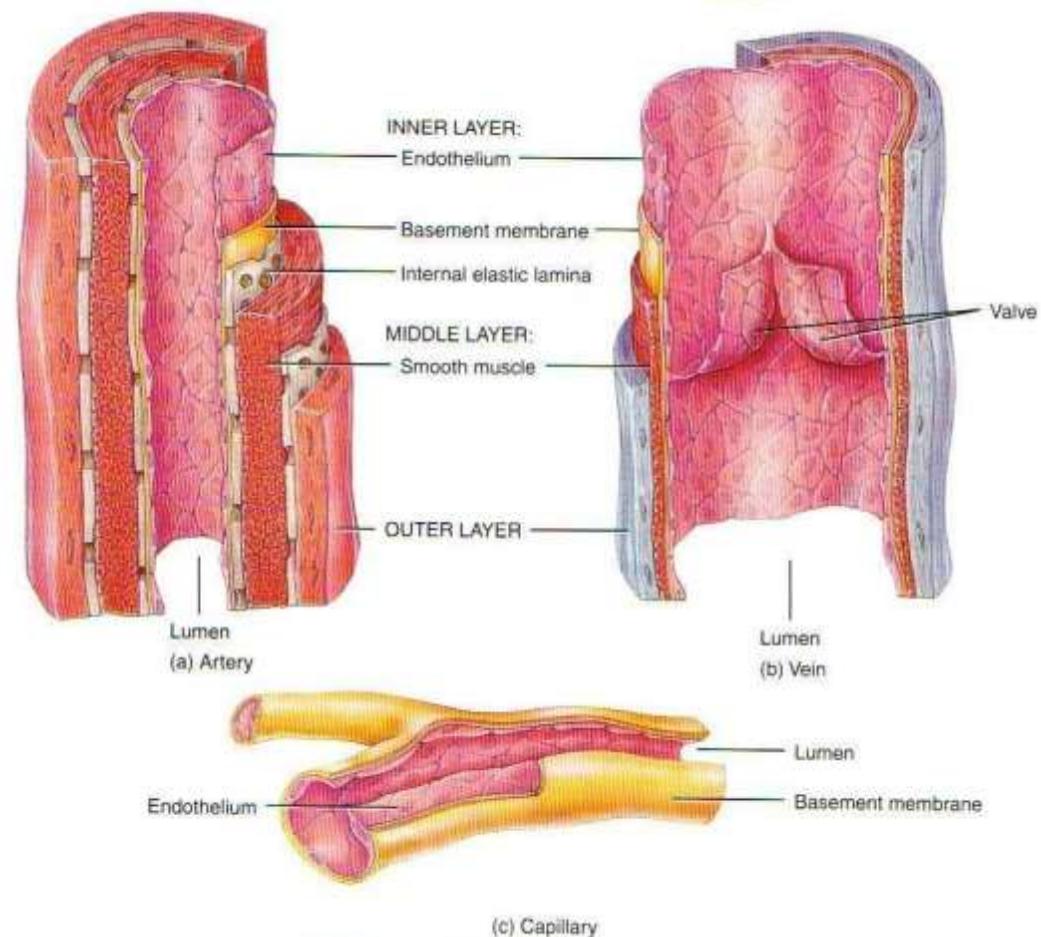
These are very small arteries that delivery blood to the capillaries. The main difference between these and arteries is that the flow in arterioles is non-pulsatile

### Capillaries

These are microscopic blood vessels whose walls are only one cell thick. It is here where the exchange of gases and other materials between the blood and tissues takes place.

### Venules and veins

Venules are small vessels that continue on from the capillaries and merge to form veins. Their structure is similar to an artery, but the tunica interna and media are thinner; the lumen of a vein is also larger than a comparable artery. Veins also have valves to prevent backflow of blood.



## Lymphatics

These vessels are similar to veins in structure, but with thinner walls and more valves. They begin as blind ended tubes with pressure sensitive valves, only allowing fluid in.

## The Heart

The heart is a roughly cone shaped, hollow muscular organ. It is about 10cms long and is the size of the owner's fist. The heart is located in the thoracic cavity between the lungs (mediastinum). It lies obliquely and a little more to the left than the right.

## Structure of the Heart

The heart is formed of three layers.

- Endocardium is the epithelial layer that lines the cavities of the heart and is continuous with the lining of the blood vessels.
- Myocardium is a strong layer of cardiac muscle making up the bulk of the heart. It is supplied with blood by the coronary arteries and is drained by the coronary veins and coronary sinuses.
- Pericardium is an outer covering of connective tissue and serous epithelium. It forms a double layered sac enclosing the heart.

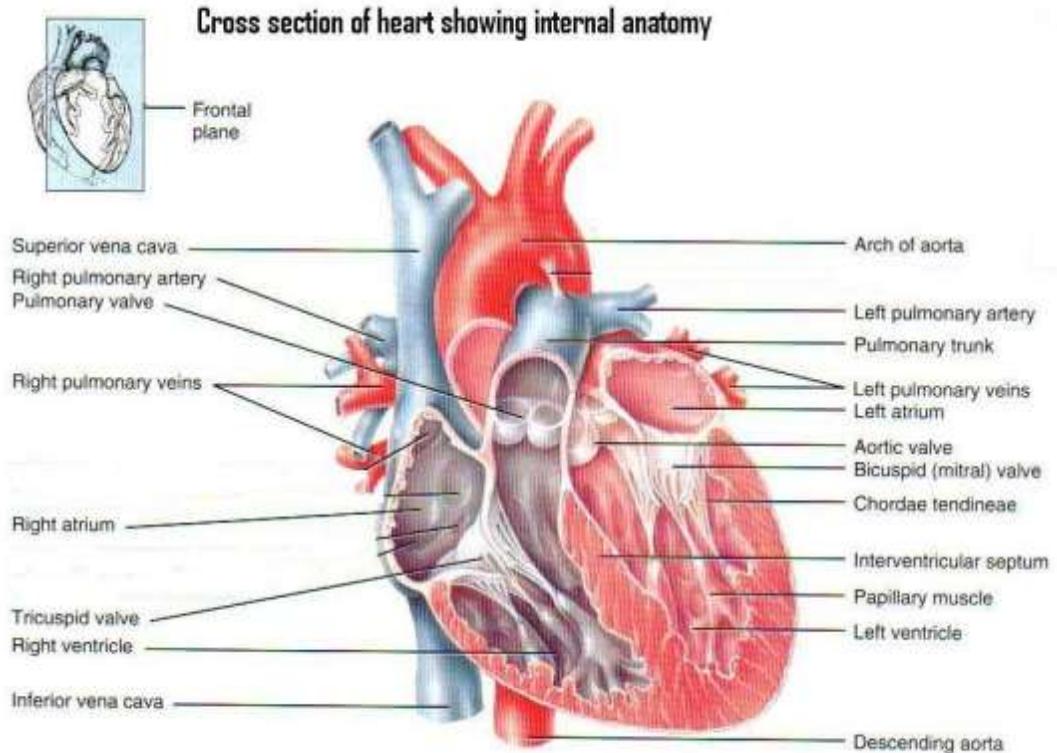
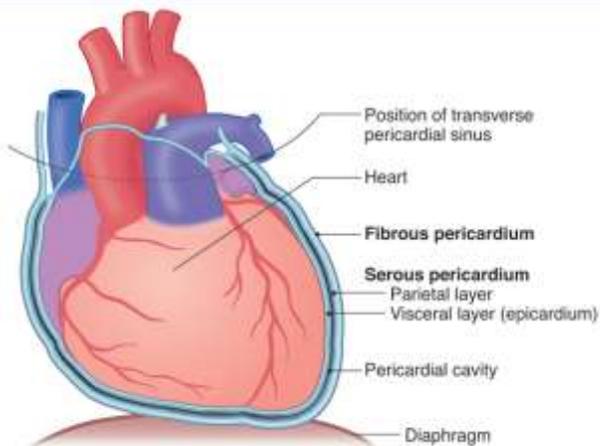


Figure 2 - Cross Section Through Heart

## Internal structure of the Heart

The cavity of the heart is divided into four chambers. A vertical partition called the septum divides the heart in two. Each side is further divided into a thin walled atrium above and a thick walled ventricle below. The valve separating the right atrium from the right ventricle is called the tricuspid valve (3 flaps). The valve separating the left atrium from the left ventricle is called the bicuspid valve or the mitral valve (2 flaps). The valves prevent regurgitation of blood from the ventricles into the atria. Attached to these valves are fine tendinous cords (chordae tendinae) which insert on the free border of each flap and originate in small pillar of muscle projecting from the ventricular wall (papillary muscles).

## The Flow of Blood through the Heart

See the heart as a continual flow mechanism, with a pump in it. The two largest veins in the body, the superior and inferior venae cavae, empty their contents into the right atrium. This deoxygenated blood flows through the tricuspid valve into the right ventricle.

The atrium contracts and pushes more blood into the right ventricle. Essentially, they are both filling up with blood, and the atrial contraction pushes that bit more blood into the ventricle, stretching the muscular wall a bit to facilitate a more powerful contraction there.

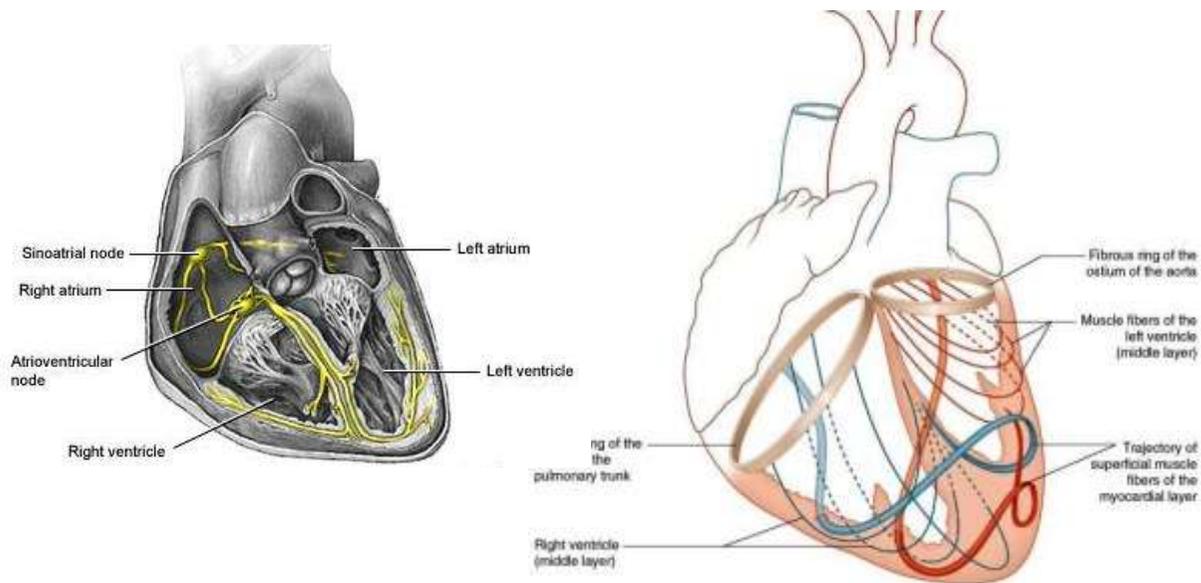
When the right ventricle contracts the blood is pumped into the pulmonary artery (the only artery in the body to carry deoxygenated blood). The pulmonary valve (tricuspid valve) guards the opening of the pulmonary artery, to prevent any backflow into the heart. After leaving the heart, the pulmonary artery divides into the right and left pulmonary arteries; these then carry the blood to each lung where an exchange of gases take place.

The now oxygenated blood is carried from the lungs in two pulmonary veins that empty their contents into the left atrium. The same flow and contraction situation occurs here, the atrium pushing it through the bicuspid valve into the left ventricle. From here it is pumped into the aorta, which is guarded by the aortic valve.

It is important to see that the heart works as a unit, with both atria contracting at the same time, and similarly both ventricles contracting both at the same time.

## Conduction system in the heart

Cardiac muscle, and its rhythm, is unique in that it has its own inherent rhythm without an internal nerve supply. It receives a nerve supply from the ANS, which can affect its rate, but remember cardiac muscle is inherently myogenic and has its own rhythm anyway. In fact the atria and ventricle have different rates of contraction, but the overall rhythm is controlled by the **sino-atrial (SA) node** at the top of the right atrium. It is specialized muscle tissue which depolarizes faster than all the others, hence defines the rhythm. It is from the SA node that the impulse flows over the surface of the atria and down special conduction pathways to the apex of the heart. Likewise these pathways are not nerves but specialized muscle fibres (Purkinje fibres). This ensures that the atria contract from the top down and the ventricles contract from the bottom up.



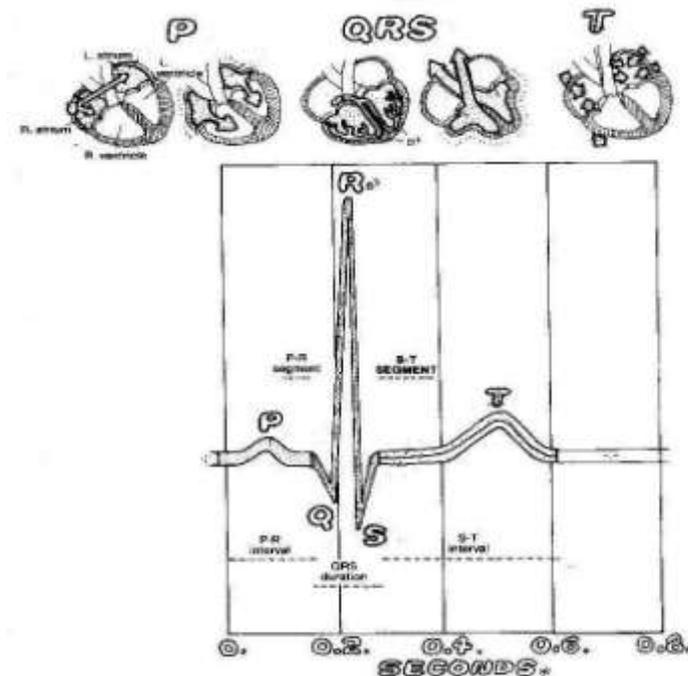
**Figure 3 - Schematics of Conduction Pathways in the Heart**

This design of conduction pathway matches the direction of contraction of the cardiac muscle. The end result of all this is that blood is 'wrung' out of the heart and not just squeezed.

### Heart Sounds

Two sounds are produced in quick succession in each cardiac cycle. These are followed by a brief pause before being repeated in the next cycle. Through the stethoscope the heart sounds are heard as a lubb-dupp, and are produced by closure of the heart valves. The first heart sound is produced by the closing of both atrioventricular valves just before ventricular systole (contraction). The second heart sound is produced by the closing of the aortic and pulmonary valves just before ventricular diastole (relaxation). Another way of 'seeing' this is by the electrocardiogram (ECG), which is 'looking' at the heart, via an electronic telescope.

- The P wave is the wave flowing over the top of atria, contracting them from the top down
- The QRS complex is the impulse passing down the Purkinje complex to the apex of the heart, causing them to contract from the apex up towards the pulmonary artery and aorta
- The T wave is the period of rest (diastole) when the muscle repolarises itself, ready for the next contraction (systole).

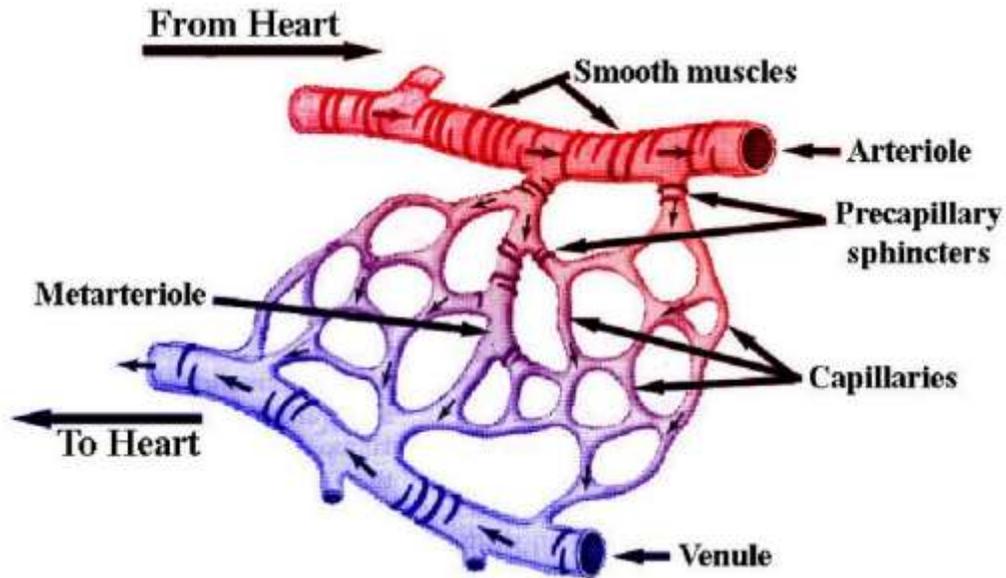


**Figure 4 - ECG With Stages of Cardiac Cycle**

## Arteries & Veins

Arteries are thick walled vessel to withstand the pressure inside . They divide in smaller arteries and then, finally, into arterioles; the smallest vessels of all are capillaries. The walls of capillaries are only one cell thick; this allows gases to pass across them.

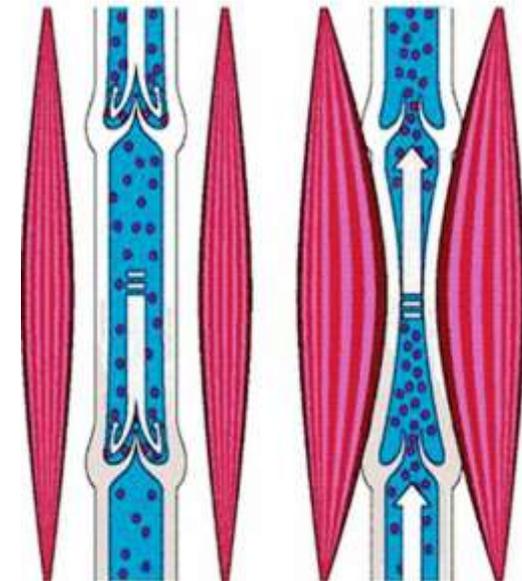
Figure 5 - Schematic Showing Continuance of Arteries - Capillaries - Veins



The capillaries come together to form small vessels called venules, which link together to form veins and finally arrive back to the superior & inferior vena cava and drain into the right atrium. Veins have thinner walls than arteries and can only tolerate low pressures.

This point presents a problem in getting blood to flow against gravity up from the legs. The solution is that veins have valves in them to stop backflow and to break up the head of pressure; in addition to this, they are wrapped up between the muscles the contraction of which squeezes the veins, acting as a secondary pump.

Figure 6 - Calf Pump schematic



## Blood Pressure

It has already been said that arteries and veins are essentially different in structure. Arteries have thick muscular walls to withstand the pressure, but as one quality of muscles they are elastic and allow for expansion. This allows for a continuous, pulsatile flow, in the arteries, ending in a non-pulsatile flow of blood through to the capillaries.

$$F \propto r^4$$

This formula represents the flow of a gas or fluid along a tube at a continuous rate. The rate of flow along a tube is proportional to the 4th power of the radius of the tube. Basically this shows that a very small change in the radius results in a very big change in the rate of flow.

In normal circumstances, when the heart contracts it pushes a fixed volume of blood into a tube. It is the muscular elasticity of the wall that allows it to expand to accommodate this volume of blood. The healthy tonus of the wall then gently contracts to push the blood on (almost as a secondary pump); this can be felt as the 'pulse'. If, however, there is an excess tension in the arterial wall, it will act to reduce the rate of flow and increase the pressure therein (hypertension-high blood pressure) and the heart will have to work harder to push the blood through the arteries. This occurs especially in hardening of the arteries (arteriosclerosis). Here there is little or no elasticity of the larger vessels and so no accommodation in them. So imagine the work the heart has to do to expel all the blood (and how it feels about it?).

Blood pressure may be defined as the force, or the pressure, which blood exerts on the walls of the blood vessels. There are two pressures measured:

- **Systolic blood pressure**—this is when the left ventricle contracts and pushes blood in to the aorta; i.e. it is the maximum pressure experienced by the arteries. In adults it is about 120mmHg.
- **Diastolic blood pressure**—this is when the heart is resting, following the ejection.

The same principle of flow applies to veins. Veins have a much thinner wall, with much of blood. It is sometime arbitrarily called the minimum, but it is really the resting the pressure in the artery. In an adult this is about 80mmHg. These figures vary according to the time of the day, state of mind, fitness, health less muscle but more fibrous tissue. As there is no pump, per se, there is no pulsatile motion of the blood, only continuous flow. However, the same mathematics regarding flow applies. Hence if the fibrous tissue stretches due to excess pressure, or if there is valve failure, the radius of the vein increases and the flow decreases. If the flow gets too slow then the blood can coagulate and form a clot (thrombus). This can eventually occlude a vein. The function of the valves is to prevent backflow, but they

are also there to break up the head of pressure; blood has to get from the leg back up to the heart again, without an in-built pump. Hence the body puts in valves to break up the head of pressure, so no part of the vein will need to experience any significant pressure. The body tries to help this, by creating a calf pump

Figure 7 - Calf Pump Muscle Action



## Composition of Blood

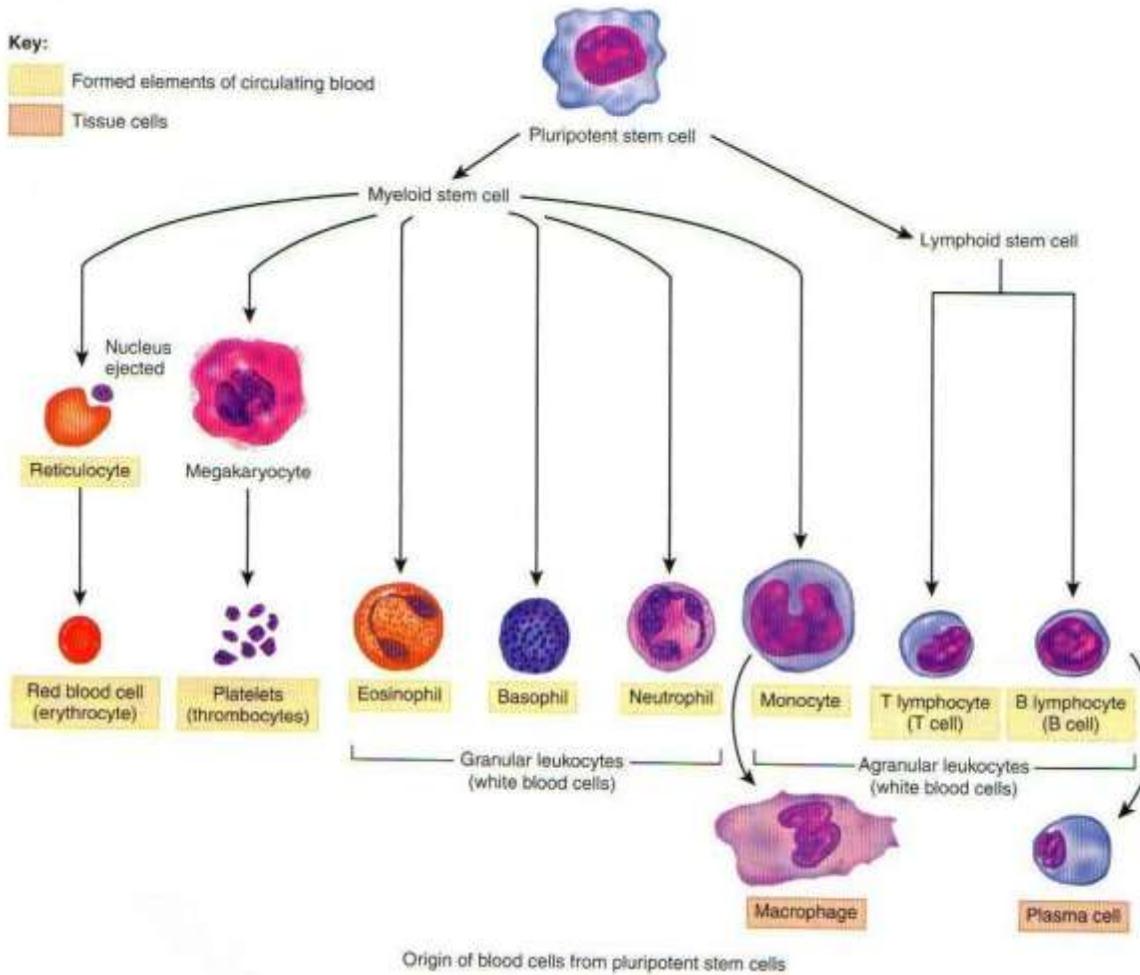


Figure 8 - Blood Cells and Their Origin in the Bone Marrow

Blood has the function of delivering oxygen, nutrients, hormones and enzymes to all parts of the body; and of removing carbon dioxide and waste products from them. It also regulates pH, body temperature, prevents haemorrhage and combats disease.

Blood contains different cells, which have different functions (for more details, see The Immune System)

- **Erythrocytes** (red cells) - carry O<sub>2</sub> and CO<sub>2</sub> via haemoglobin.
- **Leukocytes** (white cells) – concerned with defence against foreign matter.
- **Platelets** – concerned with coagulation (clotting) of blood.

## The Lymphatic System

The lymphatic system consists of thin walled vessels starting as blind-ended capillaries. Like veins it has valves to ensure unidirectional flow. Generally, it has two functions:

- Drains excess fluid from the interstitial space (in the tissues) and returns it to the cardiovascular system
- It is involved in the production and maturation of lymphocytes, therefore has an important role in the workings of the immune system

There is a close relationship between the lymphatic system and blood, which is reflected in their similar function and fluid movement.

## Lymph

Lymph is a transparent, colourless or slightly yellow liquid that is formed in the tissues. It is a fluid that normally occurs in the interstitial (extravascular, intercellular) space. Blood in the capillaries loses fluid into the tissue spaces around them. This exudate forms the lymph. It has two main functions:

- It provides nutrients to the cells, and
- Removes waste products

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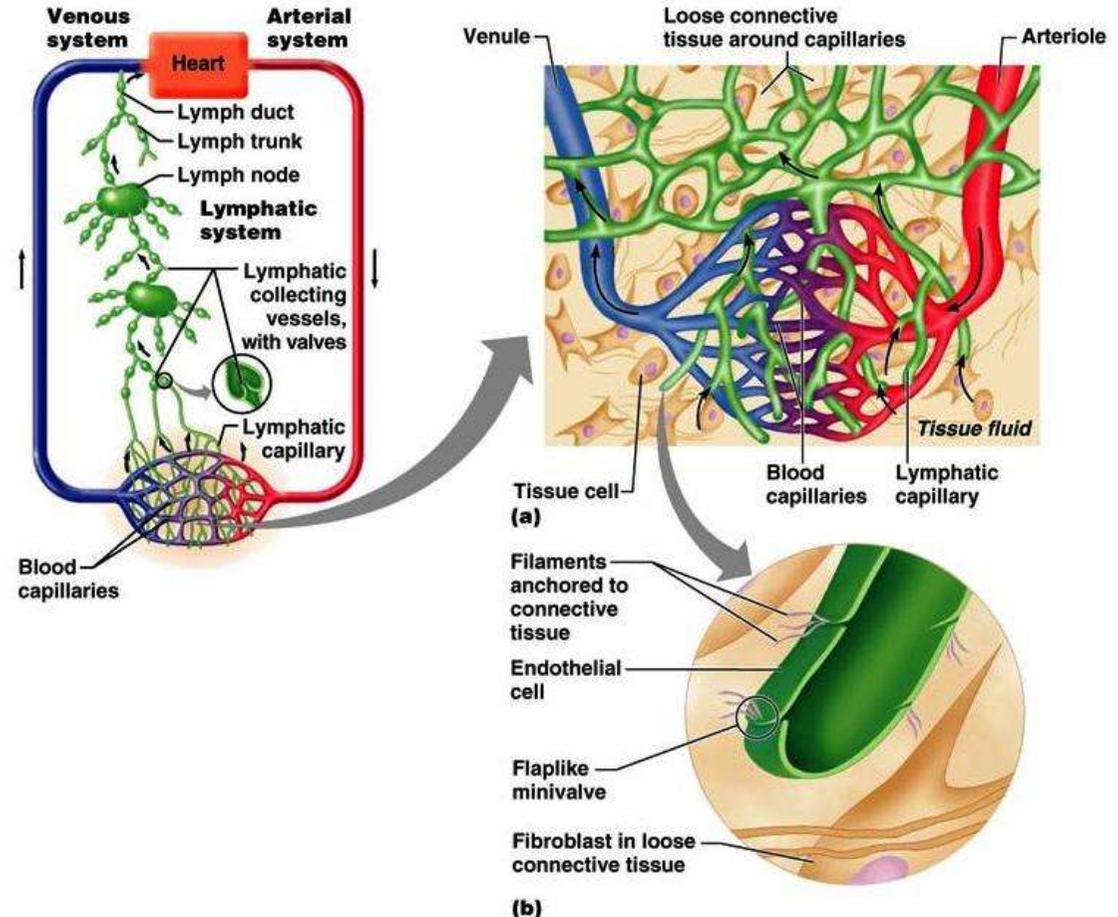
**Figure 9 - Schematic of Vascular System showing continuance of Arteriolar Vessels to Capillaries to Venules, With Any Loss of Fluid from these Returning to the Systemic Circulation via the Lymphatic System**

There are various factors that allow fluid to escape out to the interstitial space:

- Arterial pressure; here greater than osmotic pressure (with the osmotic pressure pulling the water back in again)
- Capillary permeability
- Balance of extracellular sodium and intracellular potassium
- Volume of water in the body

There are various factors affecting fluid draining away from the interstitial space:

- Osmotic pressure greater than venous pressure
- Capillary permeability
- Patency of veins and lymphatics



Lymph passes into the **lymphatics**. These start as lymph capillaries, then accumulate and drain into the **lymph nodes**.

These nodes are

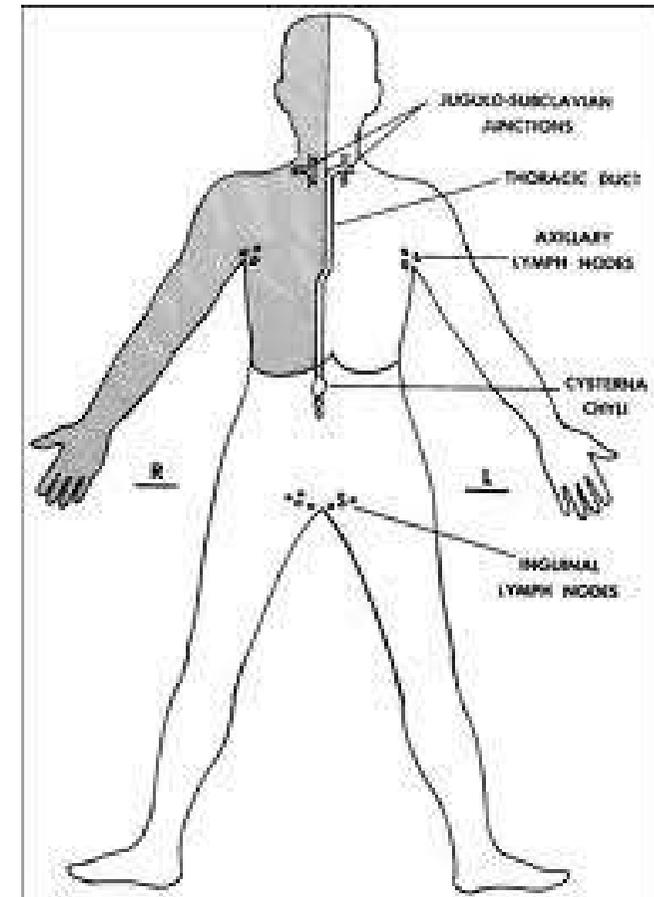
- Important sites of **immune response**
- Contain **lymphocytes**. These recognize any foreign bodies and respond to it as necessary.

If there was an infection, e.g. in a limb; the infection would drain into the lymphatic system and thence to the regional lymph nodes. Here the lymphocytes would recognize the foreign material and institute an appropriate **immune reaction**. It would also cause a generalized systemic reaction, sending immune cells to the site of infection. Hence there is a local reaction at the site of infection, a reaction at the local draining lymph nodes to **prevent infection** passing into circulation, and a generalized systemic 'alarm' of some immune cells to check if any did get past the local defences.

Lymphatics have valves, like veins, to prevent backflow; they all converge into two main channels:

- **Thoracic duct**: from the head, neck, chest, left arm and all the body below the ribs.
- **Right thoracic duct**: upper right side of the body

Figure 10 - Schematic Showing Areas of Body draining into Right and Left Subclavian Veins



## Disorders of the Circulatory System

**Anaemia** - The term anaemia implies a reduction in the oxygen carrying capacity of the blood. It may be primary, but frequently is secondary to some other disorder, like a dietary deficiency. Signs and symptoms include general fatigue, shortness of breath, anorexia, pallor, headache, faintness, and palpitation.

Figure 11 - Symptoms of Anaemia

It can be caused by:

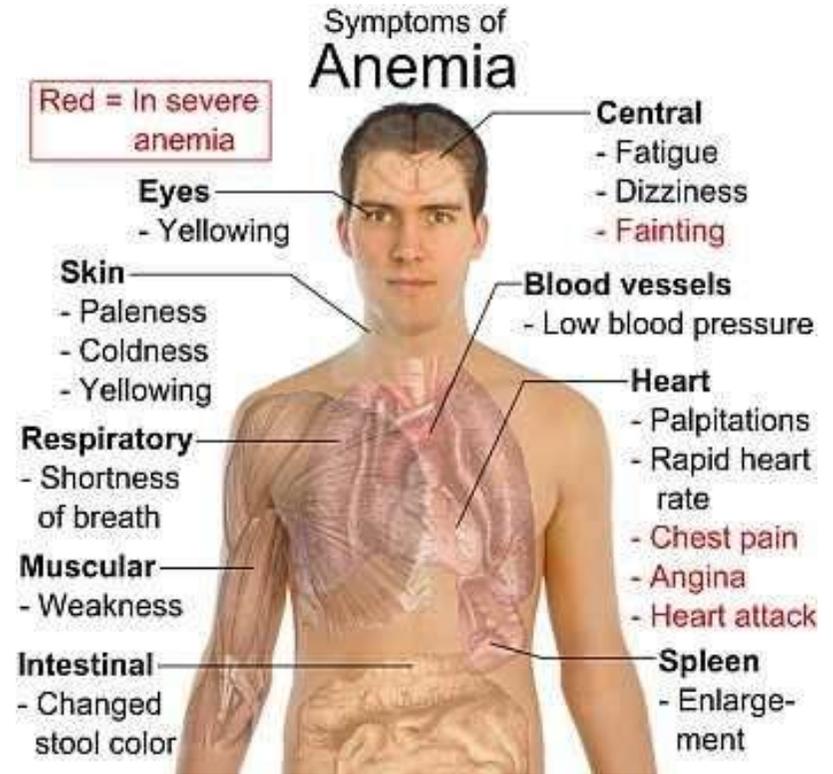
- Iron deficiency
- B12 or B9 deficiency (pernicious anaemia)
- Genetic disorder (sickle cell anaemia, thalassaemia)
- Blood loss (haemorrhagic) possibly from bleeding from the gut
- Abnormal blood breakdown (haemolytic)

**Iron deficiency anaemia** can be caused by:

- An insufficient dietary intake
- Chronic or acute blood loss
- Impaired intestinal absorption
- An increased requirement

**Pernicious anaemia** (Vitamin B12 deficiency/Addisonian Anaemia) which is treated with intramuscular injections of B12, Due to:

- Non-absorption of vitamin B12
  - From the body not producing intrinsic factor from the parietal cell in the stomach, hence the complexes do not form and so B12 is not absorbed.
  - Irritable bowel disease or syndrome, affecting that part of the small intestine where B12 is absorbed
- Rarely, inadequate dietary intake.
- Inadequate vitamin B9 (folate): B12 and B9 activate each other in the body



## Sickle Cell Anaemia

This is caused by a genetic defect and results in polymerisation of the haemoglobin, causing the red blood cells to turn into a rigid sickle shape. This can cause the cells to jam and block small capillaries; causing the sufferer great pain.

Figure 12 - Sickle Cell Anaemia



## Leukaemia

This is a disease in which there is excessive uncontrolled production of leukocytes in an immature (blast) form. They continue to proliferate and remain immature and are unable to perform their normal functions. The disease is classified according to which type of leukocyte is involved and whether it is acute or chronic. Acute leukaemia is seen most frequently in children and young adults.

## Acute Cardiac Failure

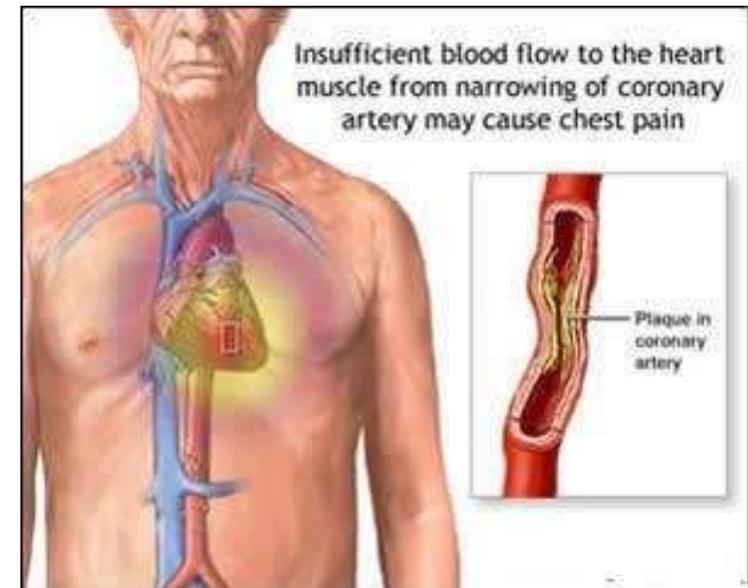
A sudden reduction in the output of blood from both ventricles causes acute reduction in the oxygen supply to all the tissues. Common causes are

1. Severe damage to an area of cardiac muscle
2. Pulmonary embolism.
3. Severe cardiac arrhythmia.
4. Severe malignant hypertension.

## Ischaemic Heart Disease

A narrowing or obstruction in the coronary arteries reduces the blood supply to the myocardium. This results in a deficiency in oxygen and nutrients to the muscle. Acute myocardial infarction is the most serious and acute form of ischaemic heart disease. A coronary artery becomes blocked and the myocardial area, which it supplies, suffers oxygen deficiency and necrosis. The occlusion may be preceded by angina or it may occur suddenly without any warning.

Figure 13 - Ischaemic Heart Disease

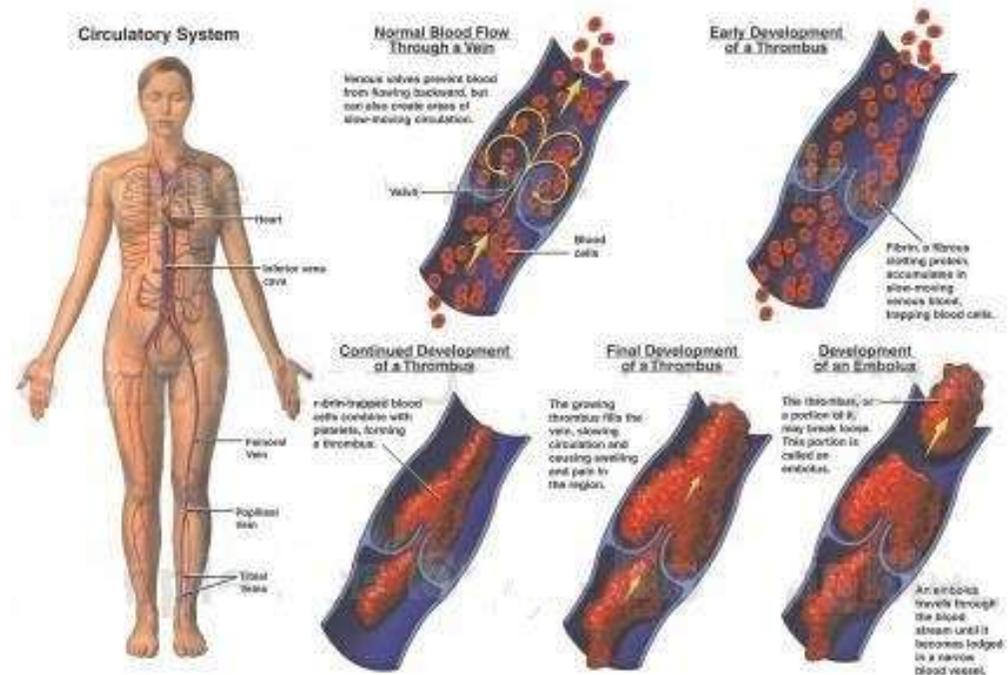


## Deep Venous Thrombosis (DVT)

A thrombus (static blood clot) usually occurs in the deep veins of the lower limbs. It can occur if there is inadequate blood flow through the veins. Here the slow blood flow causes stasis and blood clotting. It can have serious complications:

- **Pulmonary Embolism** - an embolism is a mobile blood clot, and can occur if a piece dislodges, or breaks of a larger clot; form here it will pass up the veins (their diameter getting larger) and then enter the pulmonary arteries (now getting smaller) where it can jam and block
- **Post-phlebitic syndrome** - phlebitis is an inflammation of an artery and consists of oedema, pain and skin changes due to destruction of venous valves.

Figure 14 - DVT - Deep Venous Thrombosis



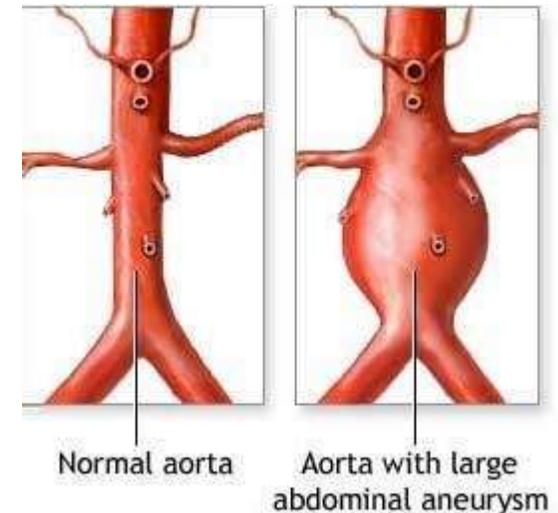
### Phlebitis

Inflammation of veins; causing pain and heat usually below the knees

### Aneurysm

This is a weakened section of an artery or vein that causes it to bulge. If this ruptures it can cause sudden death.

Figure 15 - Aortic Aneurysm



### AIDS (Acquired immunodeficiency syndrome)

A condition thought to result from infection from the Human Immunodeficiency Virus (HIV), which is carried in bodily fluids and can be transmitted by blood semen and cervical fluids.

### Haemochromatosis

A condition where there is **too much iron** in the body. It results in iron being deposited in the tissues, especially the liver and pancreas; it results in a bronze colouration of the skin.

## Haemophilia

A genetic disease is sex linked and carried by both sexes but only symptomatic in men; the man lacks a clotting factor in his blood and thus his blood cannot clot.

## Septicaemia

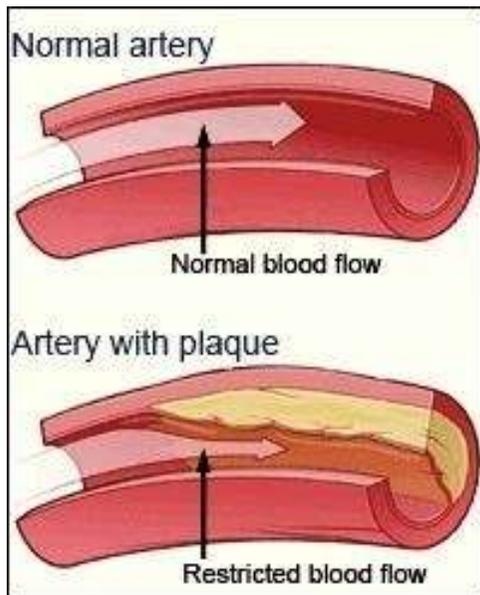
Blood poisoning from infection

## Haemorrhoids

Dilatation of the veins around the rectum and anus; can be caused by liver disease or by constipation (straining).



Figure 16 - External Haemorrhoids



## Arteriosclerosis

Hardening of the arterial blood vessel wall; this reduces its compliance.

## Atherosclerosis

A build up of fat (cholesterol and triglycerides) on the inner surface of the arteries; it can upset laminar flow and predispose to clot formation. It can even lead to necrosis and death of the tissue it supplies; this is especially significant if it occurs in the coronary blood vessels of the heart

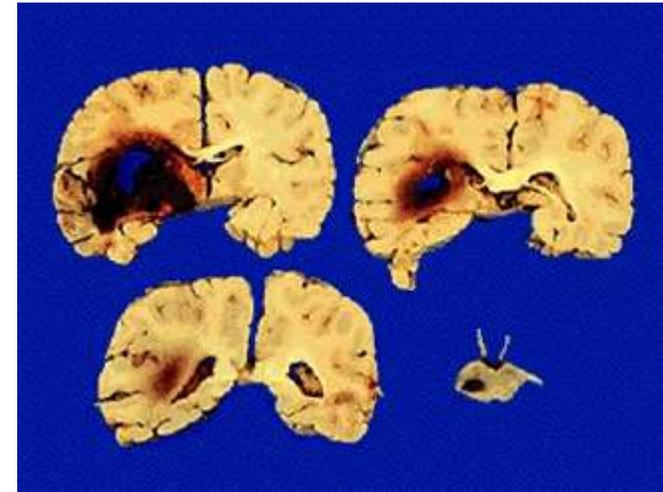
These two terms are frequently interchangeable.

Figure 17 - Arteriosclerosis

## Cardiovascular Accident (CVA)

Also known as a stroke, it is a bleed from a blood vessels or a blood clot in an artery causing part of the brain to be deprived of oxygen; this causes that part of the brain to die.

Figure 18 - Section of Brain Showing CVA - Stroke



## Hypotension

Low blood pressure. This can be significant just in terms of getting up, resulting in dizziness or fainting. If it occurs in the heart, the myocardium can die; the blood can only supply the myocardium during diastole (in between beats when the heart muscle is at rest) but if the pressure is insufficient a myocardial infarction can occur.

## Hypertension

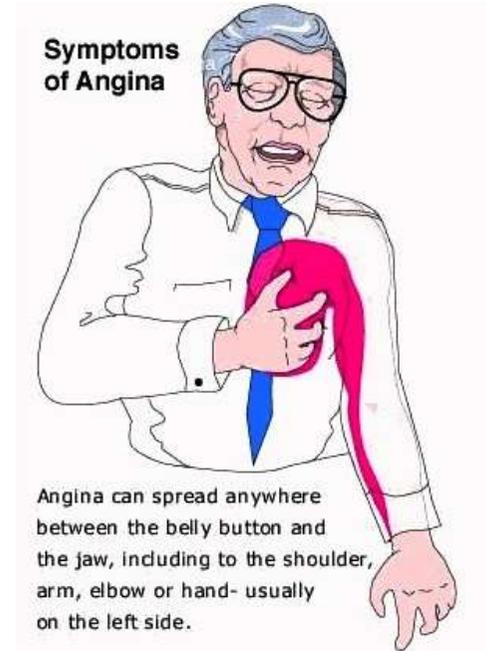
This is high blood pressure. There are two types:

- Primary (no known reason)
- Secondary (from a secondary identifiable cause, e.g. renal insufficiency, pheochromocytosis (an adrenal tumour secreting too much adrenaline))

## Angina pectoris

Acute pain in the chest from reduced blood flow to the cardiac muscle; it may or may not be associated with coronary heart disease.

Figure 19 - Angina Symptoms



## Arrhythmias

Irregular heart beat. It can be from an irregular sinus rhythm or a blockage affecting the conduction pathways in the heart

### **Infective endocarditis**

This is an inflammation of the membranes lining the inside of the heart

### **Varicose Veins**

These are areas of dilatation along a vein. They can be caused by valve failure, pathology elsewhere (e.g. haemorrhoids and oesophageal varices from hepatic congestion), or can run in families. They appear as 'lumpy, blue' areas.

**Figure 20 - Varicose Veins**

