

**The Circulatory System**

**The Lymphatic System**

**The Immune System**

## The Circulatory System

The *circulatory system*, by carrying blood, provides the other systems of the body with energy and nutrients, and transports waste products towards excretion.

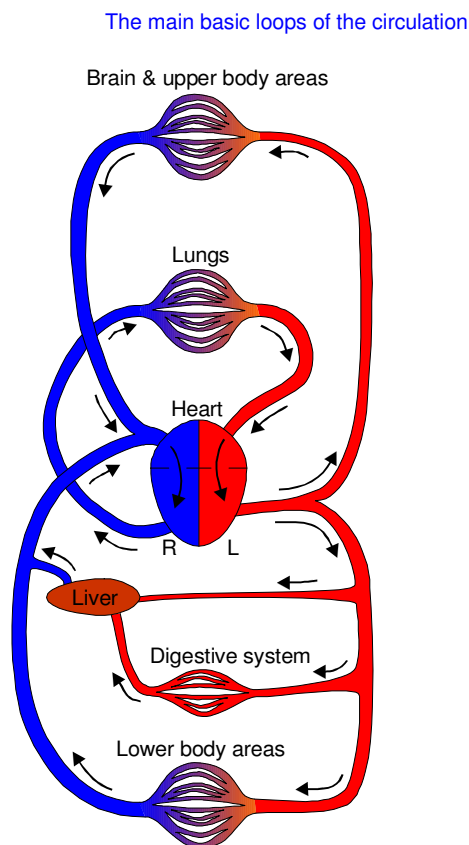
The system also provides defence against infection, and the mechanism of healing.

The circulatory system comprises the heart and blood vessels, together with blood itself. Also included is the lymphatic system.

### Circulation Loops

The *circulation* is a closed system, organised as a series of complex loops of blood vessels, with the heart as a central pump. [Figure 5 - 1]

**Figure 5 - 1** circulation loops



Blood from the body enters the right side of the heart.

The blood is pumped to the lungs, where it gives off Carbon Dioxide, and takes on Oxygen.

The Oxygenated blood then returns to the left side of the heart.

From the left side of the heart, the blood is pumped to the body - the brain, muscles, digestive system, and other organs.

In the body, the blood gives off Oxygen, and takes on Carbon Dioxide, and then returns once more to the right side of the heart.

A secondary loop passes blood from the digestive system via the liver, where glucose and amino acids may be extracted for storage, before passing it back to the heart.

The loop through the lungs is known as the *pulmonary circulation*.

The loop through the remainder of the body is known as the *systemic circulation*.

The loop from the digestive system via the liver is known as the *portal circulation*.

### Blood

*Blood* is a mixture of fluid and solids. The main constituent is a fluid called *plasma*, in which a variety of types of cells are suspended. Blood composition is approximately 45% solid (cells) and 55% fluid (plasma).

#### Plasma

*Plasma* is a clear, straw coloured liquid, made up mainly of water, but with dissolved salts, proteins, gases, and nutrients derived from food in the digestive system.

#### Serum

*Serum* is plasma from which the clotting factors, particularly fibrinogen, have been removed. It is a clear fluid.

#### Blood Cells - Red

*Red blood cells (erythrocytes)* are generated in bone marrow.

They are cells without nuclei, approximately 7µm in diameter, numbering approximately 5 million per mm<sup>3</sup> of blood, and contain the pigment, haemoglobin.

*Haemoglobin* combines loosely with Oxygen in the lungs, becoming bright red in colour. It is then able to pass this Oxygen into the tissues, at which point it becomes purple in colour.

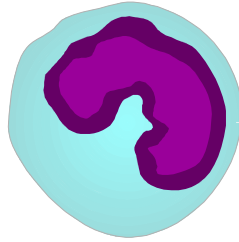
Red blood cells survive in the body for about 120 days, after which time they are destroyed through phagocytosis, mainly in the liver and spleen.



## Blood Cells - White

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*White blood cells (leukocytes)* have nuclei and are larger than red cells. They number approximately 4000 to 10000 per mm<sup>3</sup> of blood. There are three main varieties of white blood cells:



**Granulocytes.** (Polymorphs) These are approximately 10µm in diameter, and are generated in the bone marrow.

The most common granulocyte is the neutrophil (forming around 50% - 70% of total leukocytes). *Neutrophils* are phagocytes and are major contributors to the body's defence mechanisms.

**Lymphocytes.** These are approximately 10µm in diameter, and are generated in lymph nodes, the thymus gland, the spleen, and the bone marrow. Their main functions are the production of antibodies which promote the phagocytosis of foreign material and infections, and the production of toxins which attack foreign material.

**Monocytes.** These are approximately 20µm in diameter, and are generated in bone marrow. Their main functions are to act as phagocytes, and to produce a substance called *interleukin 1*, the agent which causes a rise in body temperature in response to an infection.

## Blood Cells - Platelets

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*Platelets (thrombocytes)* are not true cells, but are minuscule fragments of bone marrow cells, approximately 2 - 4µm in diameter.



They have the basic form of an asterisk, with radiating extensions, and number approximately 150000 - 350000 per mm<sup>3</sup> of blood.

The sole purpose of platelets is to assist in the process of clotting.

Platelets survive in the body for eight to eleven days, after which time they are destroyed - mainly in the spleen.

## Clotting

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Blood coagulates and *clots* whenever it comes into contact with air, or with a damaged blood vessel.

Initially, platelets clump together at the site of the damage, becoming sticky. They stimulate vasoconstriction, and initiate the action of clotting.

The process of clotting is complex, requiring many different biochemical reactions.

In basic terms, when blood comes into contact with air, or a discontinuous blood vessel wall, the enzyme *thrombin* is produced from the inactive agent *prothrombin*. The thrombin acts on the protein *fibrinogen* to produce *fibrin*, which then forms a meshwork and traps blood cells. The clot then shrinks, squeezing out serum, and dries out to form a solid 'plug'.

## Blood Groups

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Red cells and plasma contain antigens. These antigens differ from person to person; the presence or absence of particular antigens determines a person's *blood group*.

The antigens are named 'A' and 'B', giving rise to four blood groups:

**A**, having only A antigen.

**B**, having only B antigen.

**O**, having neither antigen.

**AB**, having both A and B antigens.

It is important that a person's blood group is known in advance of them either donating or receiving a blood transfusion, in order to prevent rejection of the donated blood.

### *Rhesus factor*

In approximately 80% of people, an additional chemical factor, known as *rhesus factor*, is present in the red cells. These people are known as rhesus positive. Those without the factor are known as rhesus negative.

## Blood Vessels

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Blood flows around the body in a complex system of tubes known as *blood vessels*. [Figure 5 - 2]

Blood vessels are classified into five types: arteries, arterioles, veins, venules, and capillaries.

*Arteries* carry blood away from the heart, and divide into *arterioles*. The arterioles themselves divide, and sub-divide, eventually becoming *capillaries*.

Capillaries are the most numerous blood vessels in the body, their total length extending to approximately 100,000km. Capillary walls are only around 0.2µm thick, so that gases, nutrients, and waste cells may pass through them, between the blood and the surrounding tissues.

The capillaries combine, eventually forming *venules*.

The venules combine into *veins*, and carry the blood back to the heart.

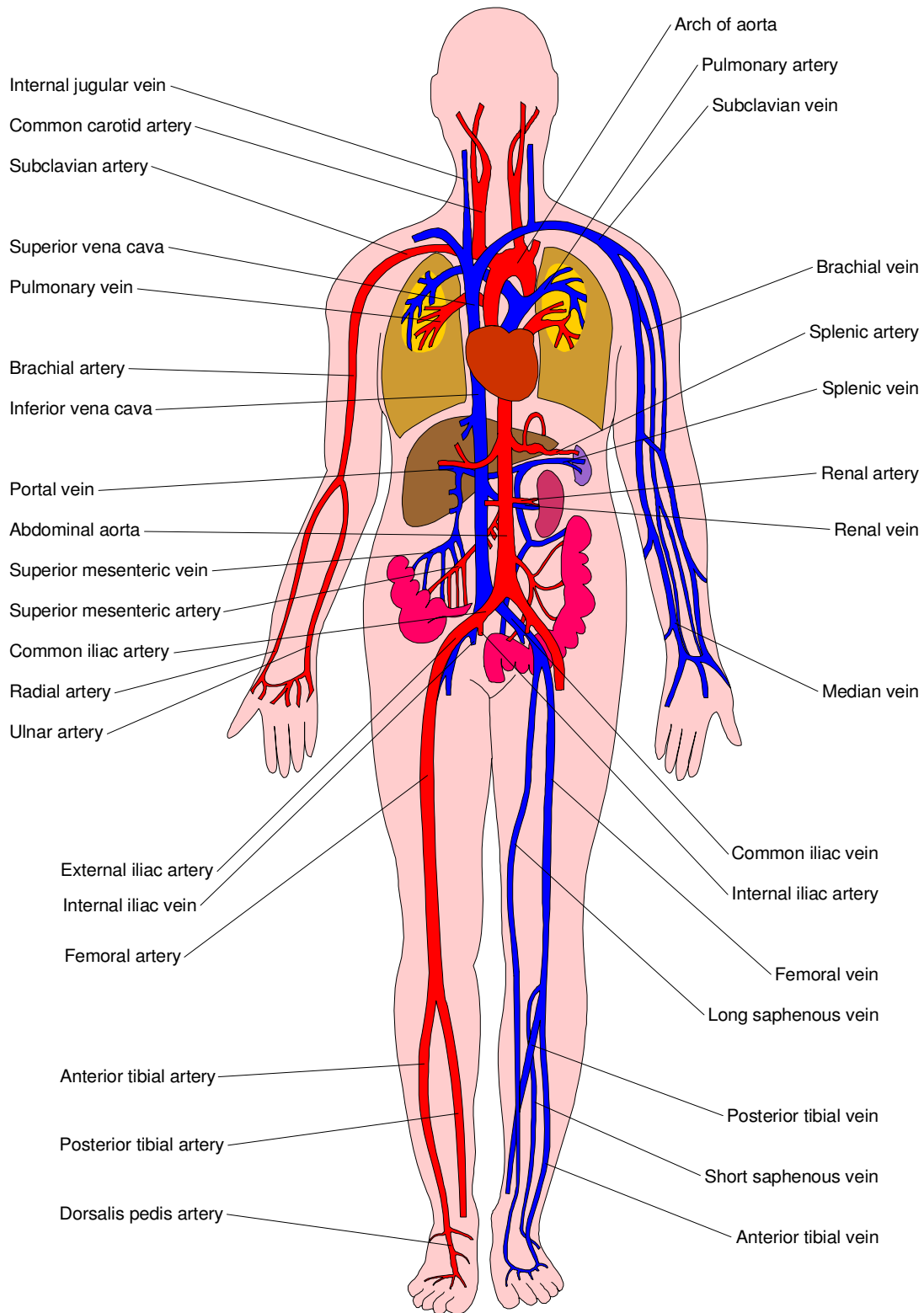
*Sinusoids* are large capillaries, but with very thin walls. They are found in bone marrow, the liver, the spleen, and in glands.

The arteries supplying a part of the body form a cross-connected network with secondary arterioles, termed *anastomoses*.

An artery distal to the final anastomoses on the route to a specific area is known as an *end artery*.

**Figure 5 - 2** principal arteries and veins

The main blood vessels in the circulatory system



## Construction of Blood Vessels

Blood vessels, [Figure 5 - 3] with the exception of capillaries, are made up from three layers of tissue:

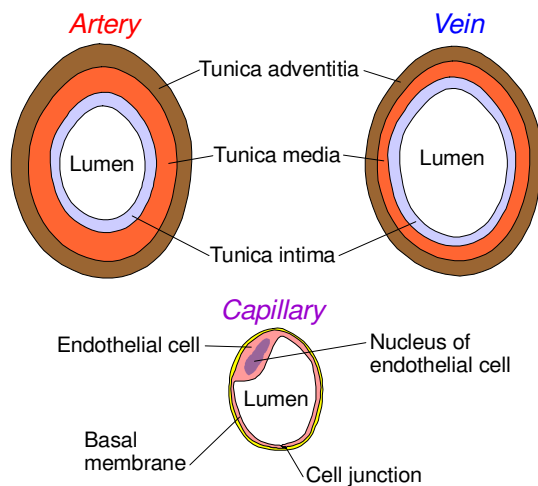
**Tunica adventitia.** (outer layer) This is formed from fibrous tissue, providing strength and preventing over dilation of the vessel.

**Tunica media.** (middle layer) This is formed from smooth muscle and elastic tissue, providing the ability for the blood vessel to constrict and dilate. The thicker tunica media in arteries gives the nervous system greater control over arterial flow than venous flow.

**Tunica intima.** (inner layer) This is formed from squamous epithelium, providing a very smooth surface to reduce friction against blood flow.

Capillaries are composed of a single layer of squamous epithelial cells, forming a semi-permeable membrane.

**Figure 5 - 3** construction of blood vessels



### Valves

Some veins, particularly those situated in the limbs, have *valves* to ensure that the direction of blood flow is always towards the heart.

These valves are made up from folds of tunica intima, together with connective tissue.



## Control of Blood Vessels

Blood vessels, with the exception of capillaries, are able to dilate and constrict, because of the presence of smooth muscle in the tunica media. This smooth muscle is controlled via the autonomic nervous system, from the vaso-motor centre in the medulla oblongata.

Blood vessels are also controlled by a variety of secretions. For example, adrenaline (from the adrenal glands) constricts blood vessels; histamine (released by cells in response to antibodies) dilates blood vessels.

The tunica media of medium and small arteries has a greater proportion of muscle than that of large arteries. The medium and small arteries are thus more able to dilate and contract in response to nervous stimulation. This allows selective control over the blood supply to individual areas of the body.

## Heart

The *heart* is situated in the *mediastinum*, the space behind the sternum, and between the lungs.

It is a muscular organ which acts as a dual pump. Its function is to pump blood around the circulatory system. [Figure 5 - 4]

## Construction of the Heart

The heart contains four distinct chambers, which operate in pairs - left and right. The left and right sides of the heart are separated by the *interventricular septum*.

The two sides of the heart operate as synchronised pumps, each with an inflow chamber - the *atrium*, and an outflow chamber - the *ventricle*. Valves between the atria and ventricles, and at the exits of the ventricles, control the direction of blood flow as the heart pumps by contracting.

The heart is made up from three layers of tissue:

**Pericardium.** (outer layer) This is the sac of fibrous tissue which surrounds the heart, protecting it and preventing over distension. The inside of the pericardium is a fine layer of serous membrane; an inner serous membrane is closely attached to the myocardium. Serous fluid is secreted between these two layers, acting as a lubricant and allowing the heart to beat freely.

**Myocardium.** (middle layer) This is formed from cardiac muscle tissue. This layer varies in thickness, being thickest over the left ventricle. Myocardium is 'special' muscle tissue, having the property of generating waves of contraction without control from the nervous system, although this does not normally occur. It is controlled waves of contraction which form the beating action of the heart.

**Endocardium.** (inner layer) This is formed from very smooth epithelium, lining the cavities of the heart and is continuous with the tunica intima of the connecting blood vessels.

## Valves

In order to operate as a pump, the heart includes *valves* to control the flow of blood. These are situated at the entrances and exits of the ventricles.

The valves are made up from cup shaped cusps, formed out of endocardium and fibrous tissue.

The valves are named as follows:

**Tricuspid valve.** This is between the right atrium and the right ventricle. It has three cusps.

**Pulmonary valve.** This is at the exit from the heart to the pulmonary arteries. It has three cusps.

**Mitral valve or bicuspid valve.** This is between the left atrium and the left ventricle. It has two cusps.

**Aortic valve.** This is at the exit from the heart to the aorta. It has three cusps.

The tricuspid and mitral valves are prevented from inverted opening by fine tendons, *chordae tendineae*, attached to small extensions of the myocardium known as *papillary muscles*.

## Operation of the Heart

Blood reaches the heart from the systemic circulation via the inferior and superior venae cavae. The blood is not drawn into the heart, but flows partly under gravity, and by the action of certain muscles - particularly those in the legs.

The blood enters the heart at the right atrium. As this contracts (synchronous with the left atrium) the blood is forced into the right ventricle via the tricuspid valve.

As the right ventricle contracts (synchronous with the left ventricle) the blood is forced into the pulmonary arteries, via the pulmonary valve.

The blood then flows through the lungs, where gas exchange takes place.

Blood re-enters the heart at the left atrium. As this contracts the blood is forced into the left ventricle via the mitral valve.

As the left ventricle contracts, the blood is forced into the aorta, via the aortic valve.

From the aorta, the blood is distributed throughout the body via the systemic circulation system.

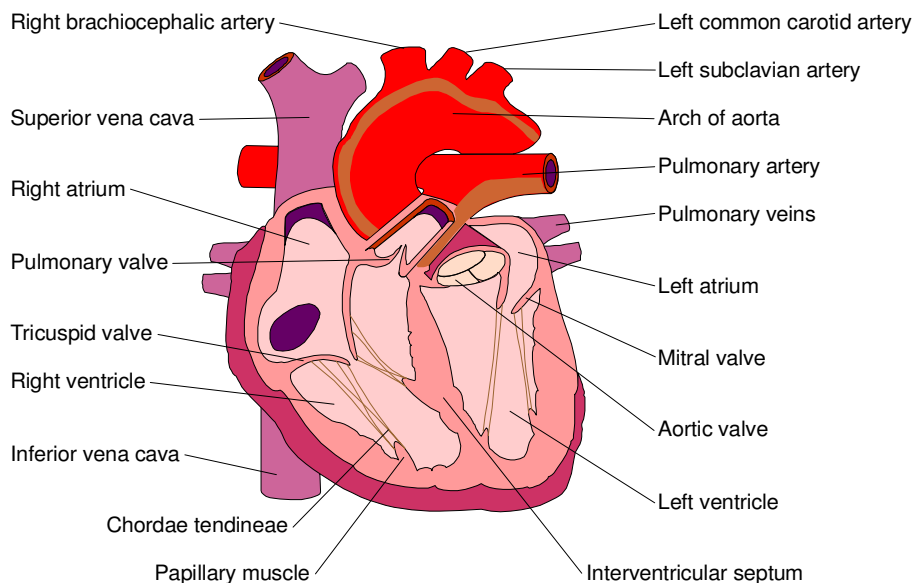
The timing of the heart operation is such that the ventricles contract almost immediately following the atria, giving a contraction phase, or *systole*.

This is followed by a relaxation stage, or *diastole*.

The left ventricle is the largest and strongest chamber in the heart, allowing it to deliver sufficient pressure to pump blood around the systemic circulation.

Figure 5 - 4 the heart

The main components of the heart



## Blood Supply to the Heart

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Being a powerful muscle, the heart requires a considerable supply of blood to provide the necessary energy.

The blood supply to the heart is carried in two arteries, the left and right *coronary arteries*, which branch from the aorta immediately distal to the aortic valve. These arteries run over the surface of the heart, dividing eventually into capillaries.

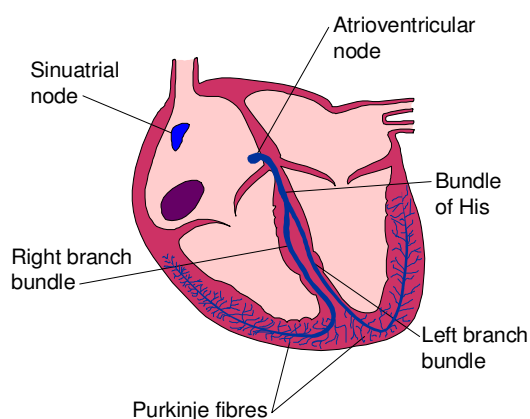
The venous return from the heart passes via the *coronary sinus* and flows directly into the right atrium.

## Electrical System of the Heart

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An electrical conducting system within the heart controls the heart's pumping action through a flow of electrical impulses. [Figure 5 - 5]

**Figure 5 - 5** the electrical conducting system of the heart



Each electrical impulse originates in the *sinuatrial node* or *sinoatrial node* (known also as the *pacemaker node*) at the opening into the right atrium.

The impulse then travels through the heart tissue to the *atrioventricular node* - at the border between the right atrium and right ventricle. As the impulse travels across the atria, it causes the atrial myocardium to contract.

The impulse travels on through the *bundle of His*, into the left and right *branch bundles*, and finally into the *Purkinje fibres* which envelop the ventricles.

As the impulse travels through the Purkinje fibres, it causes the ventricular myocardium to contract - from the lower end upwards - giving a powerful pumping action.

## Nervous Control of the Heart

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The *cardiac centre* in the medulla oblongata in the brain exerts control over the heart's beating action via the vagus nerve.

Parasympathetic stimulation of the sinuatrial and atrioventricular nodes, together with stimulation of the atrial myocardium, tends to slow down generation of electrical impulses and hence the heart rate.

Sympathetic nervous stimulation of the sinuatrial and atrioventricular nodes, together with stimulation of the ventricular myocardium, tends to speed up generation of electrical impulses, and hence increase the heart rate.

The stimulation of the myocardium respectively depresses or enhances the force of heart beats.

## Chemical Control of the Heart

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In times of stress, the adrenal glands are stimulated to secrete the hormones adrenaline and noradrenaline. Both these hormones increase the rate and strength of the heart beat. They also dilate the coronary blood vessels which allows the myocardium an increased blood supply.

## Blood Pressure

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In order for blood to flow, the heart must exert pressure. This manifests itself as what is known as *blood pressure*.

Blood pressure may be measured by use of a device called a *sphygmomanometer*, which operates by measuring the external pressure required to close off the flow in arteries. (usually in the arm).

Blood pressure is usually expressed in 'millimetres of Mercury', as two values, eg. 130/80. The first (and higher) number represents the *systolic* pressure - that which occurs during *systole* - and the second number represents the *diastolic* pressure - that which occurs during *diastole*.

Because the capillary network dissipates pressure, the pressure in arteries is higher than that in veins.

### Factors affecting blood pressure

A variety of mechanisms contribute towards keeping blood pressure within 'normal' limits:

**Cardiac output.** The rate and strength of the heart's beat vary the amount of blood pumped.

**Venous return.** The rate of blood returning to the heart affects the cardiac output, and in turn is dependent on posture, plus muscular and respiratory movement.

**Blood volume.** A significant loss of blood volume will directly reduce blood pressure.

**Arteriolar resistance.** The smooth muscle in the arterioles is controlled via the autonomic nervous system in response to stimulation of baroreceptor nerve endings in the aorta and carotid sinuses. *Baroreceptors* sense 'stretch' of blood vessels as a direct measure of blood pressure.

**Blood vessel elasticity.** Blood vessels stretch during systole to accommodate blood flow. During diastole, the elasticity contracts and pushes the blood onwards maintaining diastolic pressure.

## Pulse

The *pulse* is a wave of distension, which may be detected in an artery, caused when the left ventricle contracts and forces blood into the already full aorta, and on into the circulation.

A person's pulse rate will vary depending on several factors:

**Sex.** Males tend to have slower pulse rates than females.

**Age.** Adults tend to have slower pulse rates than children.

**Posture.** Lying down tends to decrease the pulse rate.

**Activity or emotion.** Any activity or heightened emotional state tends to increase the pulse rate.

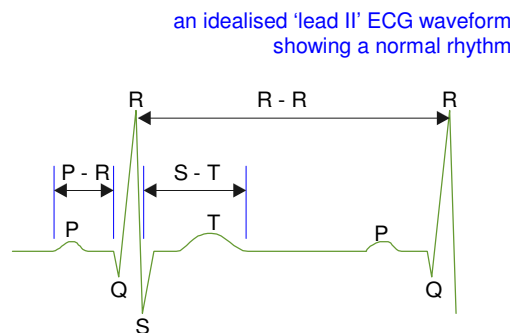
## Electro-Cardiogram

The travel of the electrical impulses through the heart may be detected by attaching electrodes, from a machine known as an *electro-cardiograph*, to the skin surface of the body. The resulting electrical waveform may be displayed or printed as an *electro-cardiogram*. (ECG)

Common positions for electrodes are over the right breast, and on the left side at the level of the lowest rib. The signal thus measured is known as a 'lead II' signal. [Figure 5 - 6]

For diagnostic purposes, electrodes are placed in twelve positions across the body, to give electrical 'views' across the heart from a variety of different directions.

**Figure 5 - 6** an ECG



The various parts of the ECG waveform are associated with the travel of electrical impulses through the heart:

**P wave.** This occurs as an electrical impulse at the sinuatrial node causes the atria to contract.

**P-R interval.** This is the time taken for the electrical impulse to travel from the sinuatrial node to the atrioventricular node, with the delay caused by a high resistance path.

**Q.** This is the point at which the impulse reaches the atrioventricular node.

**QRS complex.** This occurs as the impulse travels through the ventricular areas, causing them to contract, and allowing the atria to relax.

**S - T interval.** This is the time during which the ventricles relax and the atria begin to refill.

## Normal values

In an adult, normal values for the timings on an ECG are:

**R - R** 750 - 1000ms

**P wave** 80 - 100ms

**P - R interval** 120 - 200ms

**QRS complex** ~120ms

*Normal sinus rhythm* occurs when the ECG is similar to that shown above, with a rate of 60 - 100 beats per minute.

*Bradycardia* is defined as a heart rate of less than 60 beats per minute.

*Tachycardia* is defined as a heart rate of faster than 100 beats per minute.

## Heart Sounds

If a stethoscope is placed over the anterior wall of the chest, over the heart, a pattern of two main sounds will be heard, often referred to as 'lubb-dupp':

**Lubb.** This corresponds to ventricular contraction and the closure of the mitral and tricuspid valves.

**Dupp.** This corresponds to the closure of the aortic and pulmonary valves and the end of systole.

### Anaemia

*Anaemia* occurs when the level of haemoglobin in the blood is reduced. This, in turn, reduces the blood's ability to carry Oxygen, and leads to excessive fatigue, breathlessness - especially on exertion, and pallor. It also increases susceptibility to infection.

Causes of anaemia include heavy blood loss, a lack of dietary Iron, reduced production of erythrocytes, and excessive destruction of erythrocytes by poisons, parasites, or other disease.

### Aneurysm

An *aneurysm* is a pronounced and balloon-like dilation in the wall of a blood vessel. The larger blood vessels, including the aorta, are most commonly affected.

Muscle cells in the tunica media stretch and weaken. This may occur as a result of atherosclerosis, or may be caused by infection, or congenital defect.

Aneurysms are often asymptomatic until the later stages of their development, when the risk of rupture is heightened. A ruptured aneurysm in the aorta, or in a blood vessel in the brain, is likely to prove fatal.

### Arrhythmias

Damage or disturbances to the heart's electrical conducting system or to the myocardium may lead to abnormal heart beat rhythms.

#### *Asystole*

*Asystole* is a condition where there is no significant electrical or muscular activity within the heart.

The ECG shows an almost straight line, although occasional low amplitude P waves or other deflections may be observable.

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#### *Heart block*

*Heart block* occurs when there is a blockage in the conduction of impulses from the sinuatrial node. This may occur either through damage from heart disease, or may result from a congenital condition. The severity of heart block varies:

**First degree heart block.** Conduction to the ventricles is simply delayed following atrial contraction.

**Second degree heart block.** Not all impulses are conducted to the ventricles, leading to an irregular heart beat.

**Third degree heart block.** Conduction to the ventricles is completely blocked. The ventricles then contract at their own intrinsic rate of around 20 - 40 beats per minute.

#### *Pulseless electrical activity*

*Pulseless electrical activity (PEA)* - also known as *electro-mechanical disassociation (EMD)* - is a condition where the electrical system of the heart operates almost normally, but muscular activity is much reduced or has ceased. PEA is often caused by pressure on the myocardium from cardiac tamponade, or by the straightforward lack of blood in hypovolaemia.

The ECG appears to show a relatively normal rhythm, although this will deteriorate as the effects of the condition worsen.

#### *Sinus arrhythmia*

*Sinus arrhythmia* occurs naturally during the process of respiration - especially in young persons. It is characterised by variations in the rate of otherwise normal sinus rhythm. It occurs because of the variations in pressure applied to the heart during inhalation and exhalation.

Sinus arrhythmia may also follow a myocardial infarction.

#### *Sinus bradycardia*

*Sinus bradycardia* is characterised by an abnormally low heart rate but an otherwise normal ECG trace.

Sinus bradycardia is associated with the well trained athlete, fainting, and hypothermia, or it may follow a myocardial infarction.

#### *Sinus tachycardia*

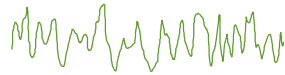
*Sinus tachycardia* is characterised by an abnormally high heart rate, but an otherwise normal ECG trace.

Sinus tachycardia is associated with exercise, stress, pain, and shock.

#### *Ventricular fibrillation*

*Ventricular fibrillation (VF)* occurs when spurious electrical impulses occur at random from more than one point in the ventricular myocardium. The myocardium twitches and quivers in a random manner and the heart is totally ineffective as a pump.

The ECG trace is totally random, showing no recognisable P waves, or QRS complexes.



Ventricular fibrillation is known as *coarse* or *fine*, depending on the amplitude of its ECG trace.

### **Ventricular tachycardia**

*Ventricular tachycardia (VT)* occurs when spurious electrical impulses originate from within the ventricular myocardium. These ectopic impulses occur at a fast and slightly irregular rate (probably in excess of 140 beats per minute)

The rapid beat does not allow the heart to fill and empty properly, reducing the effectiveness of the pumping action to almost zero.

P waves are not observable on the ECG, and the QRS complex is wide and bizarre.



### **Atherosclerosis**

Adhesion of *plaque* - composed of fats, fibrin, calcium, and cell debris - on the tunica intima leads to a reduction of arterial lumen, and *atherosclerosis*.

The causes of atherosclerosis are not fully known, but contributory factors include smoking, a high intake of animal fats in food, stress, diabetes, and straightforward ageing.

Atherosclerosis causes problems by narrowing arteries and impeding blood flow, which leads to elevated blood pressure and extra load on the heart. It also gives a rough surface inside blood vessels, which can encourage the growth of *thromboses* (blood clots) and subsequent blockages in the smaller vessels in the brain - causing a *stroke*, the heart - causing a *heart attack*, or the lungs - causing a *pulmonary embolism*.

### **Haemophilia**

*Haemophilia* is a hereditary genetic condition whereby a deficiency in blood clotting factors reduces the blood's ability to clot.

Two main types of haemophilia exist:

**Haemophilia A.** This is caused by a deficiency of clotting factor *VII*.

**Haemophilia B.** This is caused by a deficiency of clotting factor *IX*.

Haemophilia affects only males, although it is inherited via the female line.

Indications vary from case to case, usually appearing first during infancy.

Bleeding, may occur spontaneously, and whatever its cause, is difficult to control. There is a high vulnerability of the slightest knock causing internal bleeding, and a particular risk that even normal movement may provoke bleeding into the joints. This results in pain, oedema, and - in the long term - tissue damage. Chronic disability may result, and the fear of fatal haemorrhage is always present.

The similar and more prevalent condition known as *von Willebrand's disease* affects both sexes, but tends to be less severe.

### **Ischaemic Heart Disease**

*Ischaemic heart disease* occurs as the partial occlusion of the coronary arteries through atherosclerosis leads to a decreased blood supply to the myocardium.

Initially, this will not cause direct problems, but the extra work required of the heart during physical exertion may outstrip the available blood supply. This results in central chest pain known as *angina pectoris*.

### **Leukaemia**

*Leukaemia* is a malignant cancerous disease which leads to uncontrolled production of leukocytes.

Abnormal and immature leukocytes overwhelm normal blood cell production and increase the susceptibility to other disease and infection.

### **Malaria**

*Malaria* is an infection by plasmodium parasites. It is spread in blood by mosquitoes. The parasites are injected into the bloodstream in the mosquito's saliva as it 'bites'. The parasites then migrate to organs such as the liver and multiply, returning later into the bloodstream where they infect erythrocytes. Further rapid multiplication then causes an 'attack' - a period of fever, uncontrollable chills, a headache, other vague pains, vomiting, and a drenching sweat.

Once infected with malaria, a sufferer is at risk of indefinite recurrences and the condition may become chronic.

In extreme cases (the strain *malignant tertian malaria*), malaria can be incurable and fatal.

### **Myocardial Infarction**

If a blockage - caused by a thrombosis - occurs in a coronary artery, the section of the myocardium served by that artery will die. This death is known as a *myocardial infarction (MI)*. The occurrence of an MI is often referred to as a *heart attack*.

The severity of an MI depends on its extent, and location: an MI on the right side of heart has a potentially less severe outcome than an MI on the left side.

The effects on the heart's function also depend on the extent and location of the MI, varying from almost indiscernible symptoms, through disruption of the heart's pumping action, to ventricular fibrillation or even immediate cardiac arrest.

Other arrhythmias may also occur if the MI has interrupted the heart's electrical conducting system.

An MI usually - but not always - leads to severe pain in the central chest area, perhaps radiating into the neck and arms, together with signs and symptoms related to impeded circulation.

### **Pericarditis**

*Pericarditis* is an inflammation of the pericardium. It may be caused directly through infection, but often leads on from other conditions. In some cases pericarditis is idiopathic.

The condition leads to central chest pain, made worse when lying down, pain and difficulty in breathing, and maybe a dry cough.

In an extreme case, the inflammation leads to a fluid build-up in the pericardial sac. This causes the dangerous condition of *cardiac tamponade*, where myocardial movement is inhibited by the pressure of the fluid and the heart's pumping action is reduced.

### **Septicaemia**

An absorption of malevolent bacteria or their resultant toxins into the bloodstream results in *septicaemia*, and can cause tissue destruction throughout the body.

#### **Toxic shock syndrome**

*Toxic shock syndrome* is an acute and potentially life threatening condition resulting from septicaemia.

A common cause of toxic shock syndrome is a retained tampon or inter-uterine contraceptive device together with staphylococcal bacterial infection.

### **Shock**

*Shock* is a term applied to the condition where the effective circulating volume of blood is insufficient to carry adequate Oxygen and nutrients to body tissues.

This may result from direct blood loss, from other fluid losses such as severe diarrhoea or vomiting, or from serum lost into burned tissue.

Other causes of shock include loss of nervous control of the tunica media, leading to arterial dilation and 'pooling' of blood in lower areas of the body.

Particularly in *hypovolaemic shock* - that caused by blood loss - the body will attempt to compensate for the loss. Initially this will be by constricting medium sized blood vessels under autonomic nervous control.

**Table 5 - 1** development of shock

The likely effects of blood loss on an adult person

Blood lost	Likely effects
10%	Maybe a slight increase in pulse rate.
15%	Pale skin; pulse rate around 100 (Blood pressure is maintained by constriction of blood vessels).
15% - 30%	This is the limit of compensation. Pale, cold, clammy skin with slow capillary refill. Pulse rate above 100. Raised respiratory rate.
30% - 40%	Anxiety, restlessness, and agitation. Pulse rate above 120. Systolic blood pressure 100 or less.
over 40%	Extreme pallor and cyanosis. Very fast weak pulse. Systolic blood pressure 70 or less. Respiratory distress. Reduced level of consciousness.

As blood loss continues, the heartrate increases to compensate for the reduced volume.

Eventually, though, continuing blood loss will overwhelm possible compensation, and the basic processes of life will begin to falter.

### **Sickle Cell Anaemia**

*Sickle cell anaemia* (also known as *drepanocytosis*) is a hereditary genetic condition, sometimes attributed to an evolutionary reaction to malaria.

Erythrocytes take on an inflexible crescent shaped form (hence the term "sickle"). This leads to a reduction in their Oxygen carrying ability. It also leads to a risk that they cannot readily pass through small capillaries.

This risk may develop into 'crises' where the 'sickle' shaped cells block small blood vessels, causing severe pain, and potentially leading to tissue damage.

## Valvular Disease

*Valvular disease* affects the valves in the heart. It is usually the result of rheumatic fever, other infection, or a congenital problem. There are two main manifestations:

**Incompetence.** This occurs when a valve does not close fully and allows a back-flow of blood during diastole.

**Stenosis.** This occurs when a valve fails to open fully and restricts the forward flow of blood during systole.

Either case leads to circulatory deficiency and may eventually lead to heart failure.

Valvular problems may be heard as 'murmurs' in the heart sounds.

## Varicose Veins

*Varicose veins*, or *varices*, are veins which have become distended and engorged. The saphenous veins in the legs are most commonly affected. The condition may be inherited, but long term obstruction of the blood flow through pressure or poor posture may also cause the condition.

The tunica media becomes fibrous, with reduced elasticity, and at the same time, the non-return valves may cease to close fully, compounding the problem.

Varicose veins are frequently unsightly, and are vulnerable to damage and haemorrhage, or thromboses.

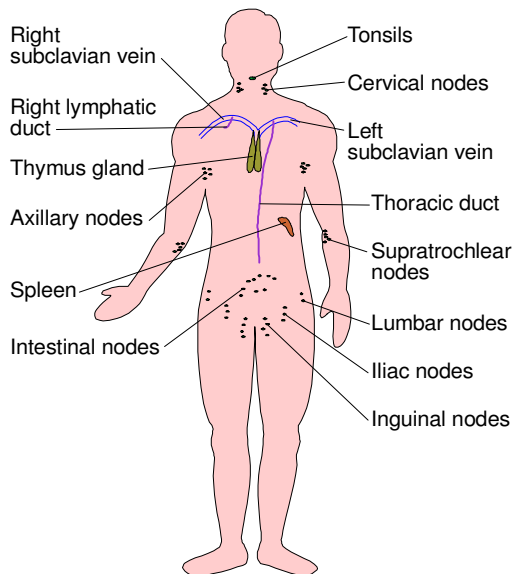
# The Lymphatic System

The *lymphatic system* is considered as part of the circulatory system as it returns fluid (*lymph*) from interstitial spaces into the veins. [Figure 5 - 7]

The lymphatic system is also involved in the absorption of fats from the digestive system into the body, and with the control of infection.

**Figure 5 - 7** the lymphatic system

The main organs of the lymphatic system



## Lymph

*Lymph* is a pale yellow fluid. It is of a similar nature to blood, but without erythrocytes or significant protein.

## Lymph Vessels

*Lymph vessels* are formed, and vary in size, in a similar manner to blood vessels, although there are no very large lymph vessels.

*Lymph capillaries* begin as closed end capillaries in the interstitial spaces. They are composed of the same endothelial tissue as blood capillaries, but are more permeable.

Lymph capillaries combine to produce vessels similar to small veins. Numerous valves in these vessels prevent a backward flow of lymph.

The movement of lymph is not pumped, but relies on rhythmic contraction of the lymph vessels together with movement from other muscles.

Lymph from the right thorax, the head, the neck, and the right arm drains into the *right lymphatic duct* and then into the right subclavian vein.

Lymph from the remainder of the body, including that from the digestive system, drains into the *thoracic duct*. This is a large lymph vessel passing from the area of the first lumbar vertebrae up to the left subclavian vein, into which it drains.

The start of the thoracic duct is a dilated portion of lymph vessel, known as the *cisterna chyli*.

Whilst food is being digested, the lymph in the thoracic duct has a milky appearance, because of the presence of digested fatty compounds.

## Lymph Nodes

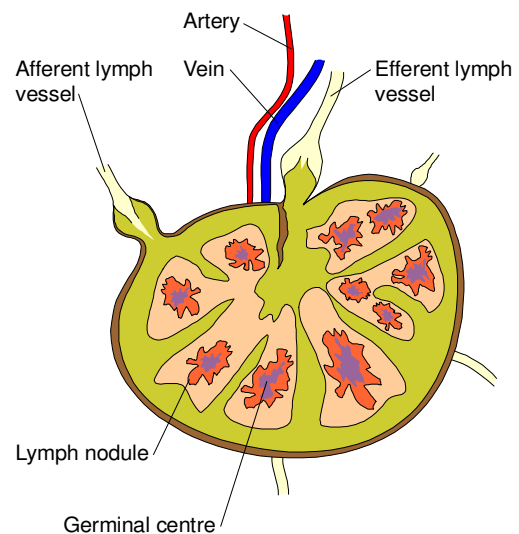
*Lymph nodes* occur where small and medium lymph vessels combine into larger vessels.

[Figure 5 - 8]

Each lymph node is also supplied with blood.

**Figure 5 - 8** a lymph node

The basic construction of a lymph node - simplified



Lymph nodes are situated throughout the body, with clusters at the joints of the limbs, by the main abdominal organs, and along the aorta and venae cavae.

The nodes provide filtration functions, removing cell debris for phagocytosis. They also produce new lymphocytes.

Lymph enters the node through four or five afferent lymph vessels, and leaves via just one efferent vessel.

Each node is covered by a capsule of fibrous tissue, which projects inwards to divide the interior into irregular segments.

The segments contain *lymph nodules*, which are composed of clusters of lymphocytes. Within each lymph nodule is a *germinal centre* in which lymphocytes are produced.

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## **Lymphatic Tissue**

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### **Macrophages**

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*Macrophages* are phagocytic cells which multiply in fixed positions throughout the body. They are found in the liver (where they are known as *Kupffer cells*), in the kidneys, the spleen, the thymus gland, and in bone marrow and lymph nodes.

Macrophages function together with monocytes and lymphocytes, destroying cell debris and foreign material. They multiply at the site of 'invading' material, in an attempt to seal the area, and prevent the spread of infection.

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### **Spleen**

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The *spleen* is located in the left hypochondriac region of the abdominal cavity. It may be considered as a large special lymph node. It is composed mainly of lymphatic material known as *splenic pulp*.

The spleen destroys old blood cells, other debris, and microbes, passing the resultant products to the liver via the splenic vein.

The spleen is a major centre for the production of lymphocytes.

It also provides storage for a small reserve of blood - around 200ml, for use at times when blood is lost from the circulation.

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## **Thymus Gland**

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The *thymus gland* is located behind the upper part of the sternum, anterior to the heart. It is at its largest in the young child, and shrinks in adulthood, becoming much smaller.

The thymus is formed as two lobes, enclosed in a fibrous capsule.

The thymus produces many lymphocytes, but not all enter the circulation - some remain to promote further lymphocyte development.

The main purpose of the thymus is during the foetal and infant stages when it controls the development of the lymph nodes. It is also involved in the development of the immune system, although this is not fully understood.

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## **Tonsils**

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The *tonsils* are formed from lymphatic tissue. They are placed at the entrances to the respiratory and digestive systems, which they protect from foreign substances by being able to release lymphocyte cells.

### Glandular Fever

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*Glandular fever (infectious mononucleosis)* is an infection by the Einstein-Barr virus, spread in the saliva. It is sometimes known as the *kissing disease* as the act of kissing is a potential method of spreading the infection.

Initially the viruses multiply in the epithelium of the pharynx. They then spread to lymphoid tissue across the body, invading lymphocytes and causing an intense immune response.

The condition gives rise to fever, a sore throat with yellow spots on tonsils and small red spots on the back of the throat. A fine red rash and jaundice may also develop.

The lymph nodes under the jaw and in the armpit and groin become inflamed and painful. The inflammation may spread to the liver and spleen, which then becomes vulnerable to permanent damage.

### Injury to the Spleen

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The spleen, because of its soft structure, is vulnerable to injury.

The high blood content of the spleen and its ready blood supply mean that rupture may lead to serious haemorrhage and a potentially dangerous situation.

The spleen may be surgically removed if badly damaged. Although this is a life-saving procedure, it will probably weaken the immune system.

A condition known as *post-splenectomy syndrome* may result, where there is increased platelet count, increasing the risk of thromboses, and an increased susceptibility to bacterial infections, particularly to streptococcal pneumonia.

### Lymphoma

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A *lymphoma* is a tumour in lymphoid tissue.

*Hodgkin's disease* is a malignant, but usually painless, enlargement of the lymph nodes throughout the body.

If the condition progresses, it damages the spleen, liver, and bone marrow. It reduces natural immunity to disease, and is eventually fatal.

*Non-Hodgkin's lymphoma* may occur as a malignant tumour in any lymphoid tissue, or in the bone marrow. The disease may be either in one isolated area, or may be widespread. Degrees of severity and resulting complications are wide ranging.

### Measles

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*Measles (morbilli)* is a debilitating viral infection. Children are more susceptible than adults.

The infection begins with 'cold' like symptoms and fatigue. Then body temperature rises sharply, with a harsh cough, running bloodshot eyes with photophobia and swollen eyelids. White spots appear on the inside of the cheeks, and finally a red facial rash spreads downwards all over the body.

Measles may also lead to ear infections, pneumonia, encephalitis, febrile convulsions, and potentially brain damage.

### Rubella

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*Rubella* is an illness caused by the rubella virus.

It tends to occur more in children and starts with 'cold' like symptoms. Then a slight rose coloured rash appears on the face, and spreads all over the body. Lymph nodes in the neck and behind the ears may swell.

Rubella is known as a risk to an unborn foetus if contracted during pregnancy.

### Scarlet Fever

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*Scarlet fever (scarlatina)* is a highly infectious disease caused by group A streptococcus bacteria.

The onset is rapid and leads to high fever with a flushed face, a white furred tongue which then turns bright red, and a rash of fine dense red spots spreading all over the body.

Potential complications include inflammation of the kidneys and ears.

### Tonsillitis

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Being positioned at the entrance to the respiratory and digestive systems, the tonsils are prone to infection from both viruses and bacteria. This may cause tonsillitis, an inflammation of the tonsils, with a sore throat, fever, and maybe difficulty in swallowing.

Untreated tonsillitis caused by streptococcal bacteria may lead on to rheumatic fever or kidney infection.

# The Immune System

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The *immune system* protects the body from infection and invasion by foreign substances.

The immune system operates in two main ways: non-specific defences and specific defences.

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## Non-specific Defences

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*Non-specific defences* operate equally against all foreign substances.

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### Physical Barriers

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**The skin.** The structure of the dermis and epidermis forms a barrier to many micro-organisms, and provides a hostile environment inhibiting their growth.

**Mucous membranes.** Mucous membranes at body openings secrete mucus which entraps many micro-organisms and prevents them gaining access to body tissues and internal structures.

**Sweat.** Sweat washes away micro-organisms from the pores and prevents their access via this route.

**Hairs.** Nasal hairs and cilia in the upper respiratory tract trap bacteria and other particulates, directing them into the digestive tract.

**Gastric acid.** Most micro-organisms entering the stomach are destroyed by gastric acid.

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### Inflammatory Response

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When tissue is damaged, either through infection or as a result of injury, it releases histamine.

Histamine causes vasodilation. The increased blood flow, together with any damaged blood vessels, allows more fluid into the interstitial spaces around the damaged tissue. This leads to oedema, redness, pain, and heat.

Fibrinogen clots then restrict the spread of infection into surrounding tissue by restricting surrounding blood vessels.

Leukocytes, especially neutrophils, enter the affected area. *Neutrophils* are excellent phagocytes and work on removing any infection and cell debris.

As the resultant waste passes into the lymphatic system, specific defences are triggered as appropriate.

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### Phagocytosis

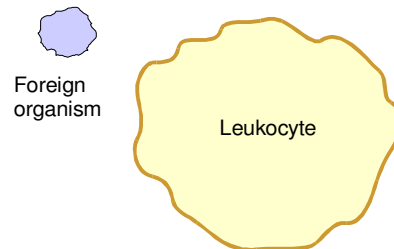
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*Phagocytosis* is the process by which leukocytes, macrophages, and other 'killer' cells ingest and destroy foreign matter or dead tissue.

The process takes place in five main stages, but usually completes in less than a second.

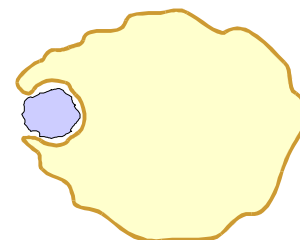
#### Stage 1

The leukocyte comes into the vicinity of a foreign substance, to which it then attaches.



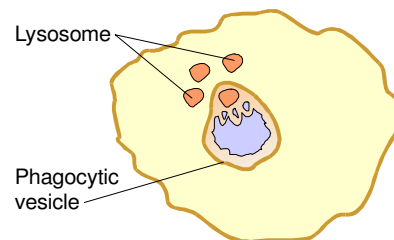
#### Stage 2

The leukocyte surrounds and engulfs the foreign substance.



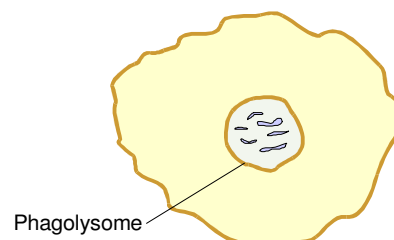
#### Stage 3

The engulfed foreign substance is contained in minute sac - a *phagocytic vesicle* - inside the leukocyte. *Lysosomes* (sub-cellular bodies) containing digestive enzyme approach and fuse with the phagocytic vesicle to form a *phagolysome*. Destructive digestion of the foreign substance begins.



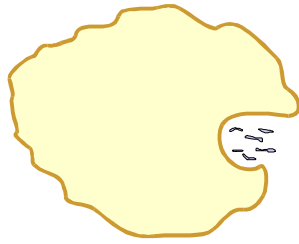
#### Stage 4

The foreign substance is destroyed by the digestive enzyme. Some of its tissue may be used as nutrient for the leukocyte.



### Stage 5

The phagolysome fuses with the leukocyte's cell wall and breaks open, emptying any remnants of the foreign substance back into the circulation.



Leukocytes cannot continue phagocytosis indefinitely; they eventually die.

A fight against a significant infection may lead to the generation of *pus*, which is a whitish fluid containing a mixture of dead leukocytes, plus dead and living micro-organisms.

### Anti-bacterials and Anti-virals

The body produces non-specific defending substances against attack by bacteria and viruses.

**Complement.** This is a group of proteins and factors present in blood plasma. Complement is activated when body cells are damaged and assists other mechanisms in combating foreign substances.

**Interferons.** These are protein molecules which form as a reaction to viral infection. They encourage cells to produce enzymes which block viral multiplication.

**Defensins.** These are natural antibiotic substances found inside neutrophils.

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### Specific Defences

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The *specific defences*, or the *immune response*, target specific substances, particularly proteins and polysaccharides, which are foreign to the body.

When a foreign substance enters the body, lymphocyte cells produce defensive proteins, known as *antibodies*, specific to the foreign substance - the *antigen*.

The body is capable of producing probably around 1 million different types of antibody, each targeted to a different antigen.

Antibodies are not present until needed. The first attack by an antigen causes a response which the immune system 'remembers'. Subsequent attacks by the same antigen trigger antibody production much more rapidly and effectively.

The function of antibodies is complex; it involves initiating the destruction of foreign substances by phagocyte cells and complement proteins.

Antibodies may also attach onto viruses or bacteria to inhibit them 'latching onto' their target cells within the body.

### AIDS

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*AIDS (Acquired Immune Deficiency Syndrome)* is the final stage of an infection by the human immunodeficiency virus.

This virus may be transmitted from person to person through blood interchange, sexual contact, or via breast milk. Its effects are to reduce the effectiveness of the immune system so that other, otherwise benign, infections lead to serious, and eventually fatal, disease.

Signs and symptoms tend to be vague and varied, and are often masked by the signs and symptoms of other infections, but may include:

Lethargy, weight loss, diarrhoea, enlargement of lymph nodes, pneumonia, and skin lesions.

### Allergies

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An *allergy* is a condition which leads to an exaggerated response by the immune system to a substance which is not generally harmful.

The underlying cause of allergies is not known, although environmental and inherited factors may contribute.

In a susceptible person, the first contact with the trigger substance or *allergen* does not generally lead to a detectable reaction. However, the immune system develops antibodies to the allergen.

Subsequent exposure to the allergen then causes an allergic reaction. This reaction will cause the release of histamine and other inflammatory substances.

Depending on the nature of the allergen, and its distribution through the body, the severity of the allergic reaction will vary:

An inhaled allergen, such as grass pollen or dust, is likely to cause annoying and sometimes distressing (but generally harmless) inflammation and irritation to the mucous membranes in the upper airway and eyes.

An allergen which enters the bloodstream, perhaps from the digestive system or by being injected, may cause much more widespread effects.

### Anaphylactic shock

*Anaphylactic shock* is an abnormal and intense reaction to an allergen to which the body is particularly sensitive.

This reaction includes an excessive release of histamine, which leads to a variety of problems, including skin rashes, itching, oedema, flushed skin, nausea, and vomiting.

Tissues within the airway may swell, causing difficulty in breathing, and eventually airway obstruction.

At the same time, the histamine causes dilation of blood vessels and a significant fall in blood pressure.

If not treated immediately, a severe anaphylactic shock attack can be fatal within a few minutes.

### Vaccination

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*Vaccination*, or *inoculation*, is a method of protecting the body against a specific disease.

A small amount of antigen, usually 'deactivated' or of reduced virulence, is introduced into the body. This antigen triggers an immune response and production of antibodies.

This then leads to a much greater response to a subsequent infection by the same (or closely related) virus or bacterium. In many cases, the resultant immunity is such as to prevent the disease taking hold.