Cardiovascular system

Components

The circulatory system consists of the heart, blood vessels (arteries, arterioles, veins, venules, capillaries, lymph capillaries and lymph vessels) and blood (red and white blood cells, plasma).

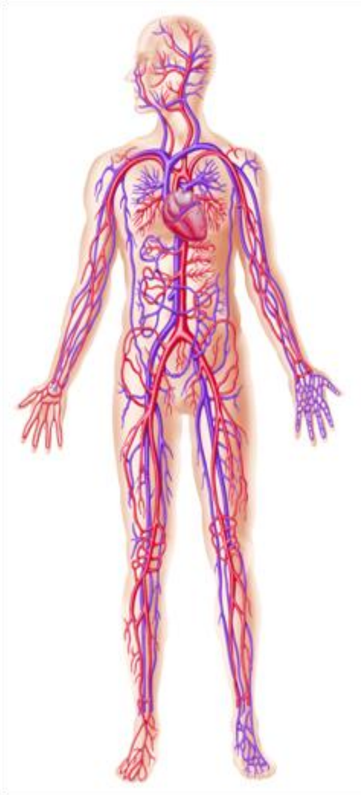

Figure 1 The circulatory system.

Functions

- Exchanges materials and heat vital to the functioning of all other systems.
- Transports oxygen, carbon dioxide, inorganic ions (electrolytes), hormones and wastes throughout the body.
- Blood clotting helps to maintain barriers to invaders and prevents fluid loss.
- White blood cells use phagocytosis and antibodies to defend the body against invaders.[1]

Key mechanisms

Blood circulation

The heart circulates blood around the body through all systems *via* a network of arteries, capillaries and veins, assisted by lymph vessels and capillaries.

- Arterial circulation is maintained by the heart.

  The heart is mainly cardiac muscle which contracts and relaxes continuously to pump blood to the body. One-way flow of blood is maintained by valves. It flows from the right side of the heart to the lungs (pulmonary circulation) and is pumped from the left side of the heart to all other parts of the body (systemic circulation). Blood under low pressure from veins is pumped from atria into ventricles, filling and expanding them. It is put under high pressure when ventricles contract and force it through arteries and arterioles (small arteries) into organs.

- Capillary circulation is maintained by osmosis.

  Blood enters the capillaries under high hydrostatic pressure generated by the contraction of heart muscle. Plasma is filtered through the thin walls of the capillary endothelium (single cell thick) to bathe cells in tissue fluid. Dissolved molecules (including oxygen), ions, hormones and nutrients such as glucose are carried to cells. Proteins are retained lowering the osmotic potential of the plasma. As blood flows through capillaries fluid is lost so that the hydrostatic pressure falls. Water is reabsorbed back into capillaries when the osmotic pressure exceeds the hydrostatic pressure, maintaining blood flow through the capillaries and into venules (small veins).

- Venous and lymph circulation are maintained by skeletal muscle and valves.

  Blood flows into venules from capillaries and thence into veins. Excess tissue fluid that does not re-enter capillaries drains into lymph capillaries and then into lymph vessels at very low pressure. Lymph contains no red blood cells and very little protein. Veins and lymph vessels are organised to pass through muscles. When muscles contract they compress veins and lymph vessels. They contain valves to prevent backflow, so that blood and lymph are pumped

[1] See *Defences: the immune system.*

away from the tissues. Lymph is passed back into the blood. Blood in veins is pumped to the venae cavae which connect to the right atrium of the heart.

Action of cardiac muscle

Cardiac muscle generates electrical impulses that stimulate the heart's contractions. It has thick and thin filaments arranged in a regular banding pattern, with connecting side bridges that allow waves of electrical pulses to spread through the heart wall. Smooth contraction of the atria is followed by smooth contraction of the ventricles.

A pacemaker, controlled by an autonomic nerve and by hormones such as adrenaline, regulates the rate and strength of contraction to meet the body's demands for blood flow.

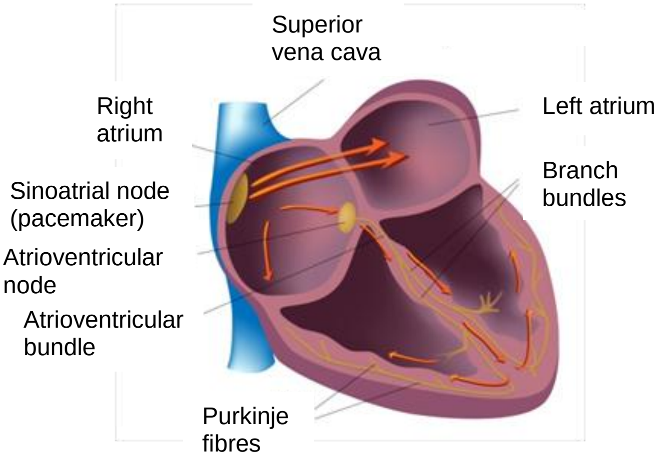

Figure 2 The heart's conduction system.

The pacemaker and associated cells

The sinoatrial node (SAN), a small region in the right atrial wall near the superior vena cava, acts as a pacemaker. Cardiac muscle contractions are coordinated. Both sides of the heart contract in unison, first the atria then the ventricles.

Non-contractile cardiac cells can initiate and generate action potentials that stimulate contraction of the cardiac muscle cells. Action potentials generated by the SAN spread through the atria causing them to contract.

When action potentials reach the atrioventricular node (AVN) at the base of the right atrium, this sends action potentials through the bundle of His into Purkinje fibres which direct them to the base of the ventricles and then upwards throughout the walls of the ventricles. The atria contract, fill and expand the ventricles. As they relax the ventricles contract from the base upwards to pump blood into the arteries.

Role in homeostasis

Homeostasis is the maintenance of conditions inside the body at reasonably constant levels. Blood plays a vital role by:

- supplying essential materials to cells, e.g. glucose absorbed by the gut and oxygen absorbed by the lungs for respiration;
- removing waste materials from cells, e.g. carbon dioxide from the lungs;
- keeping the temperature steady by transferring energy around the body (capillaries carry homeostatically regulated blood within 0.1 mm of every cell in the body);
- distributing hormones, secreted from the endocrine glands, to their target organs.

Blood flow is regulated to meet these demands through the control of heart rate and stroke volume under the influence of the autonomic nervous system and the hormone adrenaline.

Examples of what can go wrong

Atherosclerosis

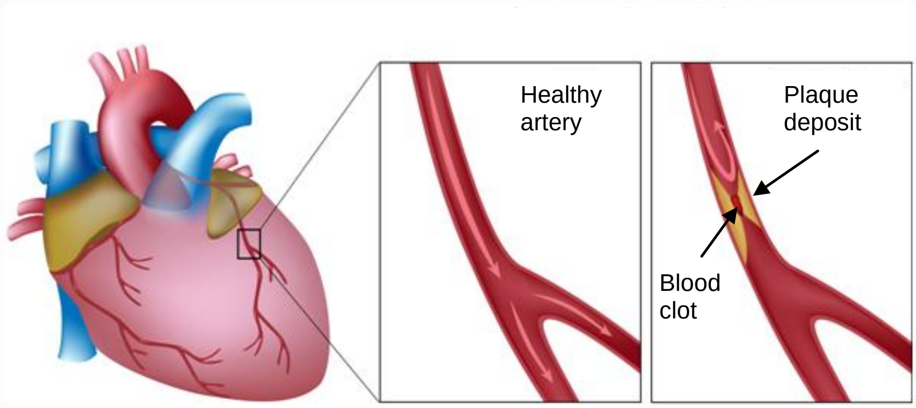

Figure 3 In a heart attack, blockage of a cardiac artery cuts off the oxygen supply and causes death of heart muscle.

Atherosclerosis is a degenerative disease of arteries that causes gradual blockage, reducing the blood flow through them. Plaques with lipid containing cores appear as bulges in artery walls.

This may cause serious harm in the brain and heart. Narrowing of cardiac arteries can reduce the oxygen supply to heart muscle, leading to angina (pain in the chest). Plaques may rupture exposing collagen and stimulating blood clotting to block arteries.[2] Clots, called a thrombus, may detach (forming a free embolus) and flow into a narrower vessel to block it (thromboembolism).

'Good' and 'bad' cholesterol

Risk of atherosclerotic heart disease is associated with the amount of cholesterol bound to protein carriers. Cholesterol is a lipid and not very soluble in plasma, so it is carried attached to protein carriers as lipoprotein complexes:

- Low density lipoproteins (LDLs) – less protein, more cholesterol – ''bad' cholesterol taken to cells, aiding deposition in atherosclerosis.
- High density lipoproteins (HDLs) – most protein, least cholesterol – 'good' cholesterol taken from cells to the liver where it may be eliminated from the body.

Smoking lowers HDL and regular exercise raises HDL, therefore increasing the risk and lowering the risk of heart attack respectively.

Aspirin and heart attacks

Low-dose aspirin is used to help prevent the formation of plaque and blood clots that can cause a heart attack or stroke. The British pharmacologist John Vane won the Nobel Prize for Medicine for discovering that aspirin suppressed the production of prostaglandins. Aspirin inactivates the cyclooxygenase enzyme used in prostaglandins and thromboxane synthesis.2

Finding out

Cardiac output is the volume of blood pumped by each ventricle per minute. The average resting heart rate is about 70 beats per minute. The average resting stroke volume (volume of blood pumped per beat per ventricle) is about 70 cm^3. The total blood volume of the body is about 5 dm^3. During exercise cardiac output can increase to 20-25 dm^3 per minute. In elite athletes this may be up to 40 dm^3 per minute.

1. Calculate resting cardiac output.
2. At rest, what proportion of the blood in the body is pumped by the heart per minute?
3. How long does it take to pump the entire volume of blood in the body to the lungs during exercise?

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[2] See *Defences: the integumentary system.*