Arteries

ı all vertebrates, including humans, arteries are the blood essels that carry blood away from the heart to the capillaries ithin the tissues. The large arteries that leave the heart divide nto medium-sized (distributing) arteries. Within the tissues and rgans, these distribution arteries branch to form very small essels called **arterioles**, which deliver blood to capillaries. rterioles lack the thick layers of arteries and consist only of an endothelial layer wrapped by a few smooth muscle fibers at intervals along their length. Resistance to blood flow is altered by contraction (**vasoconstriction**) or relaxation (**vasodilation**) of the blood vessel walls, especially in the arterioles. Vasoconstriction increases resistance and leads to an increase in blood pressure whereas vasodilation has the opposite effect. This mechanism is important in regulating the blood flow into tissues.

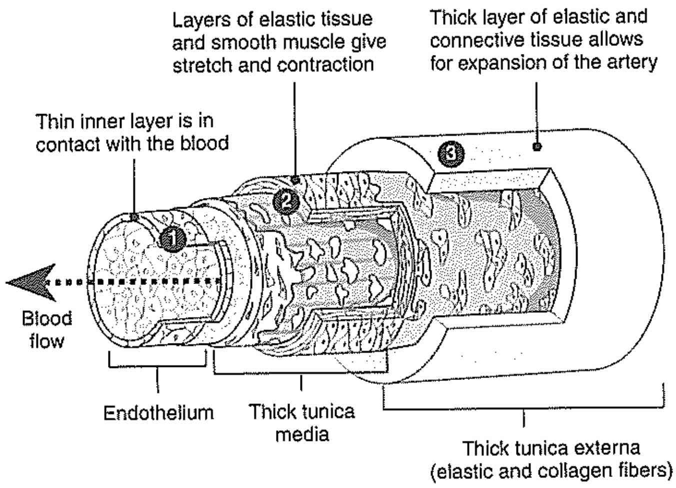
Arteries

Arteries have an elastic, stretchy structure that gives them the ability to withstand the high pressure of blood being pumped from the heart. At the same time, they help to maintain pressure by having some contractile ability themselves (a feature of the central muscle layer). Arteries nearer the heart have more elastic tissue, giving greater resistance to the higher blood pressures of the blood leaving the left ventricle. Arteries further from the heart have more muscle to help them maintain blood pressure. Between heartbeats, the arteries undergo elastic recoil and contract. This tends to smooth out the flow of blood through the vessel.

Arteries comprise three main regions (right):

1. A thin inner layer of epithelial cells called the **endothelium** lines the artery.
2. A central layer (the **tunica media**) of elastic tissue and smooth muscle that can stretch and contract.
3. An outer connective tissue layer (the **tunica externa**) has a lot of elastic tissue.

Artery Structure



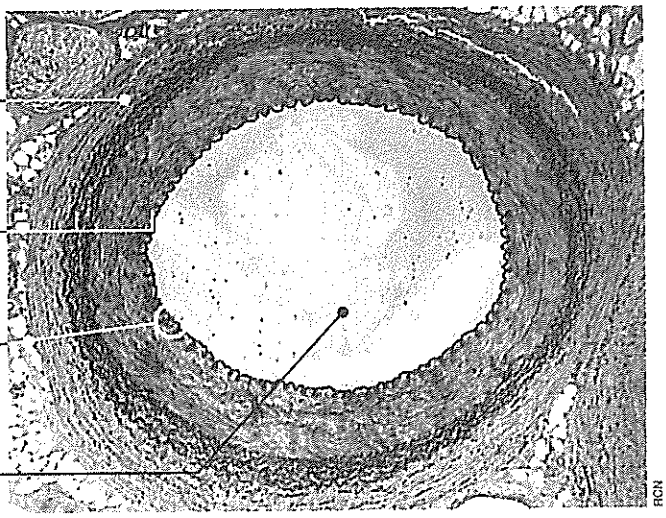
Cross section through a large artery

(a)

(b)

(c)

(d)



1. Using the diagram to help you, label the photograph of the cross section through an artery (above).
2. (a) Explain why the walls of arteries need to be thick with a lot of elastic tissue: __________

   (b) Explain why arterioles lack this elastic tissue layer: __________
3. Explain the purpose of the smooth muscle in the artery walls: __________
4. (a) Describe the effect of vasodilation on the diameter of an arteriole: __________

   (b) Describe the effect of vasodilation on blood pressure: __________

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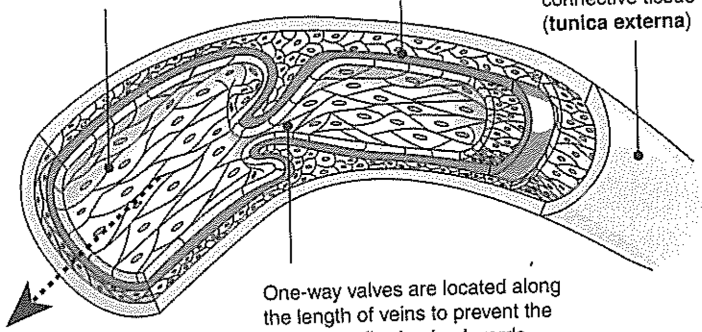
Veins

Veins are the blood vessels that return blood to the heart from the tissues. The smallest veins (**venules**) return blood from the capillary beds to the larger veins. Veins and their branches contain about 59% of the blood in the body. The structural differences between veins and arteries are mainly associated with differences in the relative thickness of the vessel layers and the diameter of the lumen. These, in turn, are related to the vessel's functional role.

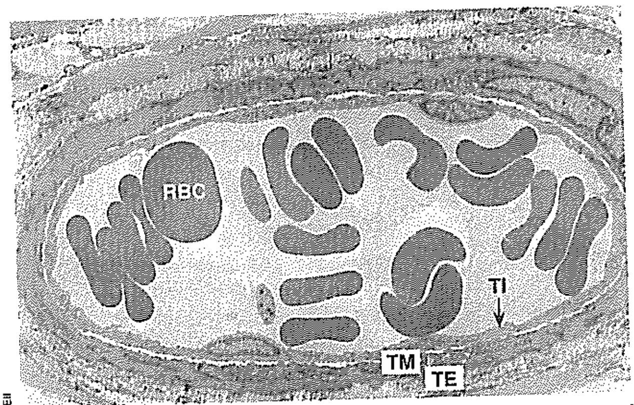
Veins

When several capillaries unite, they form small veins called **venules.** The venules collect the blood from capillaries and drain it into **veins.** Veins are made up of essentially the same three layers as arteries but they have less elastic and muscle tissue and a larger **lumen.** The venules closest to the capillaries consist of an **endothelium** and a tunica externa of connective tissue. As the venules approach the veins, they also contain the tunica media characteristic of veins (right). Although veins are less elastic than arteries, they can still expand enough to adapt to changes in the pressure and volume of the blood passing through them. Blood flowing in the veins has lost a lot of pressure because it has passed through the narrow capillary vessels. The low pressure in veins means that many veins, especially those in the limbs, need to have valves to prevent backflow of the blood as it returns to the heart.

Vein Structure



If a vein is cut, as is shown in this severe finger wound, the blood oozes out slowly in an even flow, and usually clots quickly as it leaves. In contrast, arterial blood spurts rapidly and requires pressure to staunch the flow.



Above: TEM of a vein showing red blood cells (RBC) in the lumen, and the tunica intima (TI), tunica media (TM), and tunica externa (TE).

1. Contrast the structure of veins and arteries for each of the following properties:

   (a) Thickness of muscle and elastic tissue: ______

   (b) Size of the lumen (inside of the vessel): ______

2. With respect to their functional roles, give a reason for the difference you have described above: ______

3. Explain the role of the valves in assisting the veins to return blood back to the heart: ______

4. Blood oozes from a venous wound, rather than spurting as it does from an arterial wound. Account for this difference: ______

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Related activities: Arteries, Capillaries and Tissue Fluid

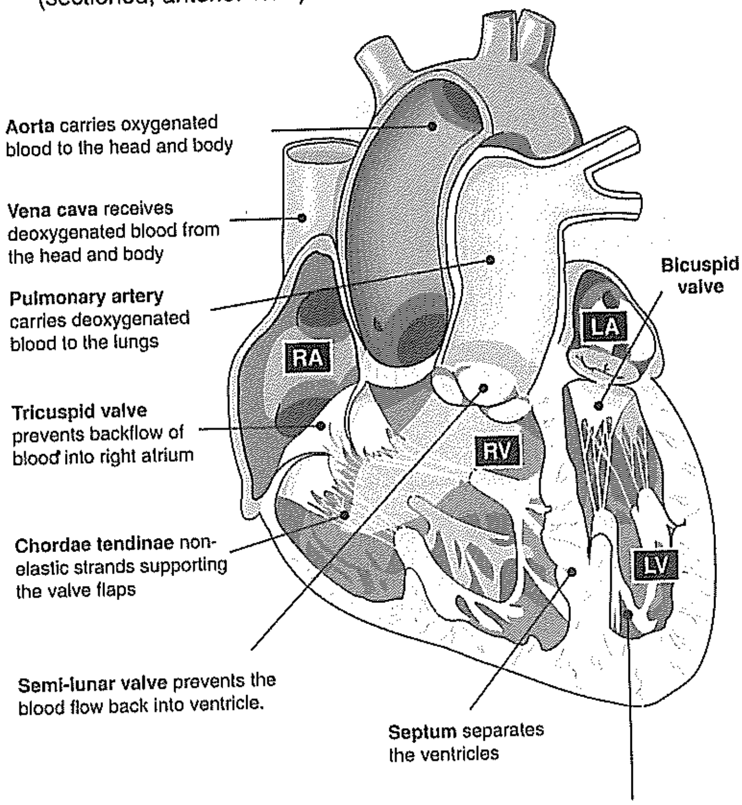
The Human Heart

he heart is at the center of the human cardiovascular system. is a hollow, muscular organ, weighing on average 342 grams. ach day it beats over 100 000 times to pump 3780 litres of blood ırough 100 000 kilometers of blood vessels. It comprises a ystem of four muscular chambers (two **atria** and two **ventricles**) ıat alternately fill and empty of blood, acting as a double pump.

The left side pumps blood to the body tissues and the right side pumps blood to the lungs. The heart lies between the lungs, to the left of the body's midline, and it is surrounded by a double layered **pericardium** of tough fibrous connective tissue. The pericardium prevents over-distension of the heart and anchors the heart within the **mediastinum**.

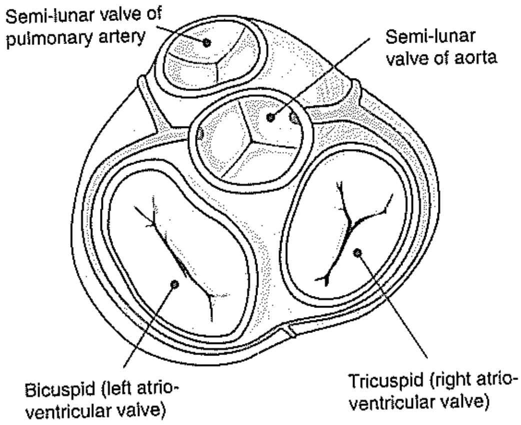
Human Heart Structure

(sectioned, anterior view)

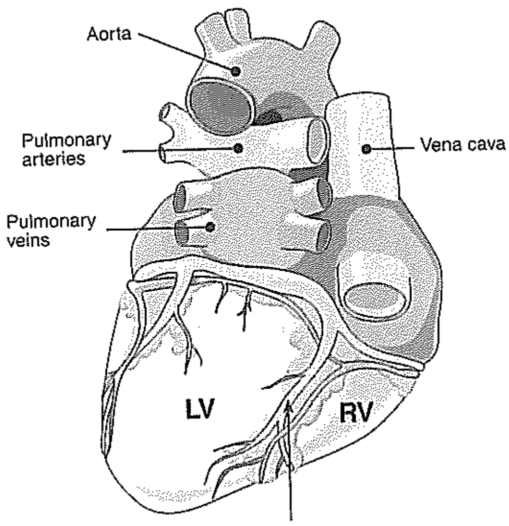


The heart is not a symmetrical organ. Although the quantity of blood pumped by each side is the same, the walls of the left ventricle are thicker and more muscular than those of the right ventricle. The difference affects the shape of the ventricular cavities, so the right ventricle is twisted over the left.

Top view of a heart in section, showing valves



Posterior view of heart

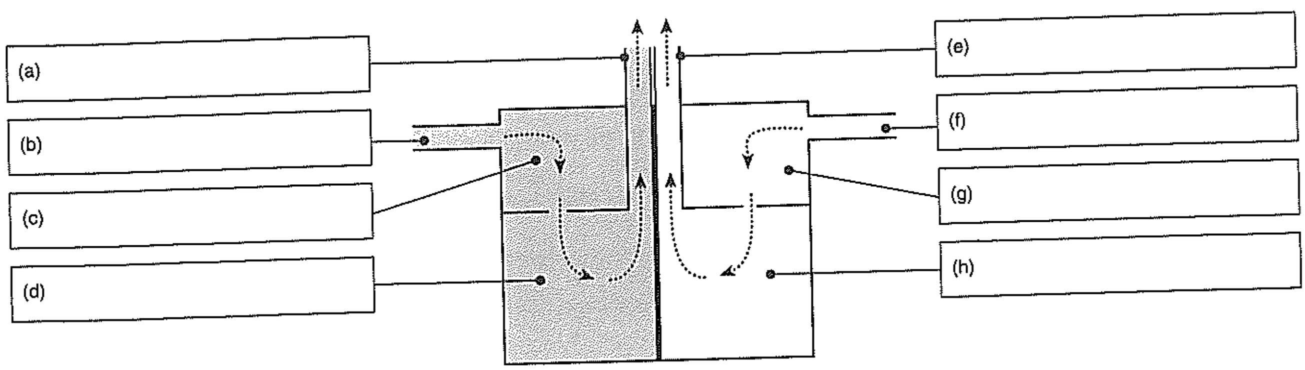


Coronary arteries: The high oxygen demands of the heart muscle are met by a dense capillary network. Coronary arteries arise from the aorta and spread over the surface of the heart supplying the cardiac muscle with oxygenated blood. Deoxygenated blood is collected by cardiac veins and returned to the right atrium via a large coronary sinus.

Key to abbreviations

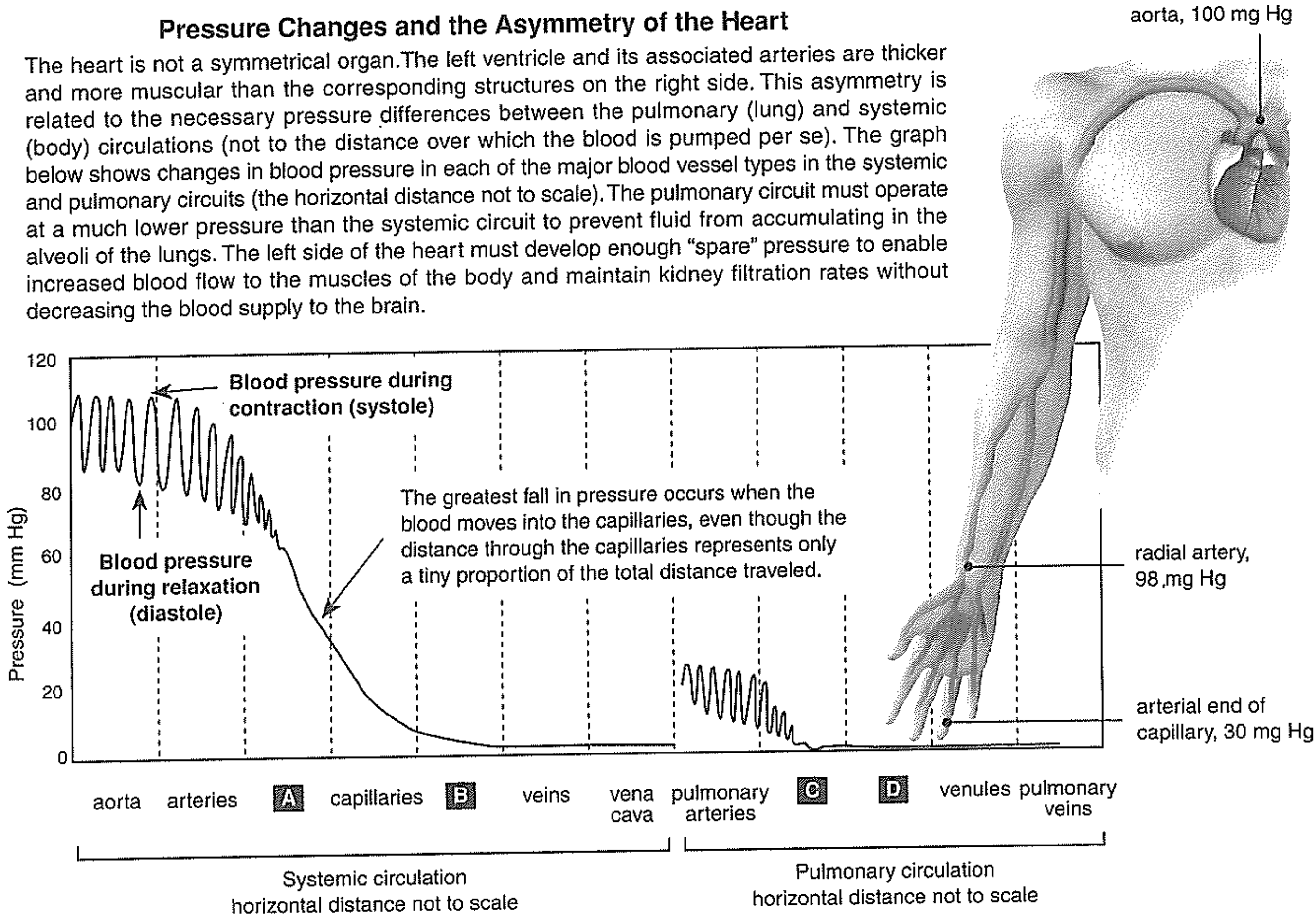
- **RA** Right atrium; receives deoxygenated blood via anterior and posterior vena cavae
- **RV** Right ventricle; pumps deoxygenated blood to the lungs via the pulmonary artery
- **LA** Left atrium; receives blood returning to the heart from the lungs via the pulmonary veins
- **LV** Left ventricle; pumps oxygenated blood to the head and body via the aorta

1. In the schematic diagram of the heart, below, label the four chambers and the main vessels entering and leaving them. The arrows indicate the direction of blood flow. Use large coloured circles to mark the position of each of the four valves.



Pressure Changes and the Asymmetry of the Heart

The heart is not a symmetrical organ. The left ventricle and its associated arteries are thicker and more muscular than the corresponding structures on the right side. This asymmetry is related to the necessary pressure differences between the pulmonary (lung) and systemic (body) circulations (not to the distance over which the blood is pumped per se). The graph below shows changes in blood pressure in each of the major blood vessel types in the systemic and pulmonary circuits (the horizontal distance not to scale). The pulmonary circuit must operate at a much lower pressure than the systemic circuit to prevent fluid from accumulating in the alveoli of the lungs. The left side of the heart must develop enough "spare" pressure to enable increased blood flow to the muscles of the body and maintain kidney filtration rates without decreasing the blood supply to the brain.



2. Explain the purpose of the valves in the heart: ____________________

3. The heart is full of blood. Suggest two reasons why, despite this, it needs its own blood supply:

   (a) ____________________

   (b) ____________________

4. Predict the effect on the heart if blood flow through a coronary artery is restricted or blocked: ____________________

5. Identify the vessels corresponding to the letters **A-D** on the graph above:

   A: __________ B: __________ C: __________ D: __________

6. (a) Explain why the pulmonary circuit must operate at a lower pressure than the systemic system: ____________________

   (b) Relate this to differences in the thickness of the wall of the left and right ventricles of the heart: ____________________

7. Explain what you are recording when you take a pulse: ____________________

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Control of Heart Activity

Vhen removed from the body, cardiac muscle continues to beat. 'his indicates that the origin of the heartbeat is **myogenic**; the ontractions arise as an intrinsic property of the cardiac muscle tself. The heartbeat is regulated by a special conduction system onsisting of the pacemaker (**sinoatrial node**) and specialized onduction fibers called **Purkinje fibers**. The pacemaker sets a basic rhythm for the heart, but this rate is influenced by the cardiovascular control center in the medulla in response to sensory information from pressure receptors in the walls of the heart and blood vessels, and by higher brain functions. Changing the rate and force of heart contraction is the main mechanism for controlling cardiac output in order to meet changing demands.

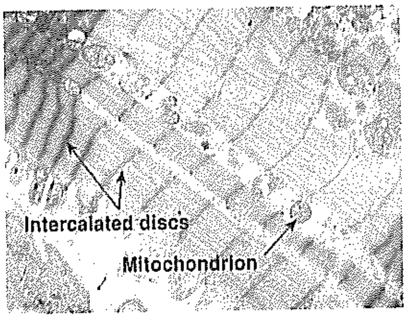
Generation of the Heartbeat

The basic rhythmic heartbeat is **myogenic**. The nodal cells (SAN and atrioventricular node) spontaneously generate rhythmic action potentials without neural stimulation. The normal resting rate of self-excitation of the SAN is about 50 beats per minute.

The amount of blood ejected from the left ventricle per minute is called the **cardiac output**. It is determined by the **stroke volume** (the volume of blood ejected with each contraction) and the **heart rate** (number of heart beats per minute).

Cardiac output
= stroke volume x heart rate

Cardiac muscle responds to stretching by contracting more strongly. The greater the blood volume entering the ventricle, the greater the force of contraction. This relationship is known as **Starling's Law**.

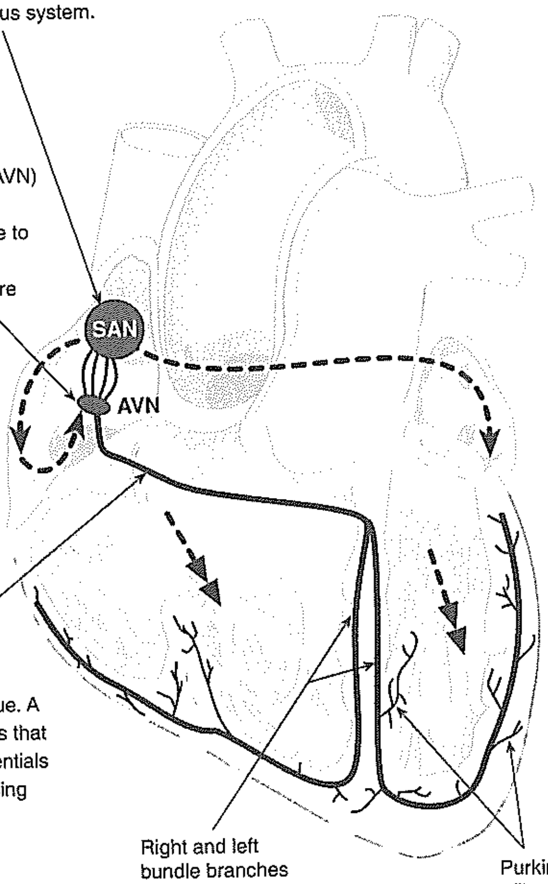


TEM of cardiac muscle showing branched fibers (muscle cells). Each fiber has one or two nuclei and many large mitochondria. **Intercalated discs** are specialized regions between neighboring cells that support synchronized contraction of the muscle. They contain **gap junctions**, specialized electrical synapses that allow very rapid spread of nerve impulses through the heart muscle.

Sinoatrial node (SAN) is also called the **pacemaker**. It is a mass of specialized muscle cells near the opening of the superior vena cava. The pacemaker initiates the cardiac cycle, spontaneously generating action potentials that cause the atria to contract. The SAN sets the basic pace of the heart rate, although this rate is influenced by hormones and impulses from the autonomic nervous system.

Key
Spread of impulses across atria
Spread of impulses to ventricles

Atrioventricular node (AVN) at the base of the atrium briefly delays the impulse to allow time for the atrial contraction to finish before the ventricles contract.



Bundle of His (atrioventricular bundle) containing Purkinje tissue. A tract of conducting fibers that distribute the action potentials over the ventricles causing ventricular contraction.

Right and left bundle branches

Purkinje fibers

1. Identify the role of each of the following in heart activity:
   (a) The sinoatrial node: ______
   (b) The atrioventricular node: ______
   (c) The bundle of His: ______
2. Explain the significance of the delay in impulse conduction at the AVN: ______
3. (a) Calculate the **cardiac output** when stroke volume is 70 cm^3 and the heart rate is 70 beats per minute:
   ______
   (b) Trained endurance athletes have a very high cardiac output. Suggest how this is achieved: ______

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Related activities: Review of the Human Heart, Exercise and Blood Flow

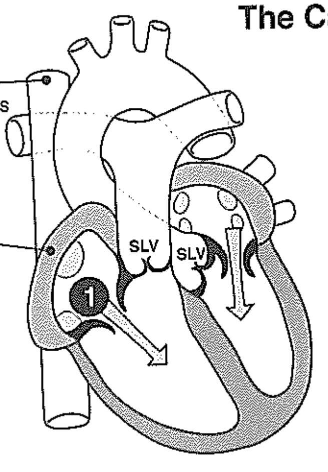
The Cardiac Cycle

ıe heart pumps with alternate contractions (**systole**) and ılaxations (**diastole**). The **cardiac cycle** refers to the sequence ⁱ events of a heartbeat and involves three main stages: atrial ⁄stole, ventricular systole, and complete cardiac diastole. Pressure ıanges within the heart's chambers generated by the cycle of ɔntraction and relaxation are responsible for blood movement and ause the heart valves to open and close, preventing the backflow f blood. The noise of the blood when the valves open and close produces the heartbeat sound (**lubb-dupp**). The heart beat occurs in response to electrical impulses, which can be recorded as a trace, called an **electrocardiogram** or **ECG**. The ECG pattern is the result of the different impulses produced at each phase of the cardiac cycle, and each part is identified with a letter code. An ECG provides a useful method of monitoring changes in heart rate and activity and detection of heart disorders. The electrical trace is accompanied by volume and pressure changes (below).

The Cardiac Cycle

he **pulse** results from the ıythmic expansion of the arteries s the blood spurts from the left entricle. Pulse rate therefore orresponds to heart rate.

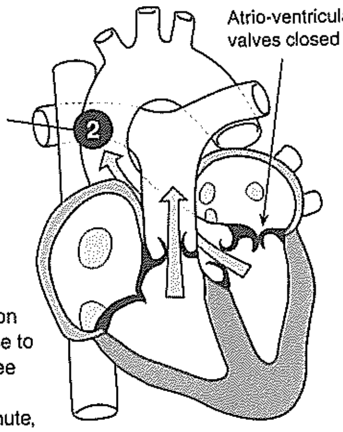
ɩtage 1: Atrial systole and entricular filling The ventricles elax and blood flows into them rom the atria. Note that 70% of he blood from the atria flows ɪassively into the ventricles. It is luring the last third of ventricular illing that the atria contract.



Heart during ventricular filling

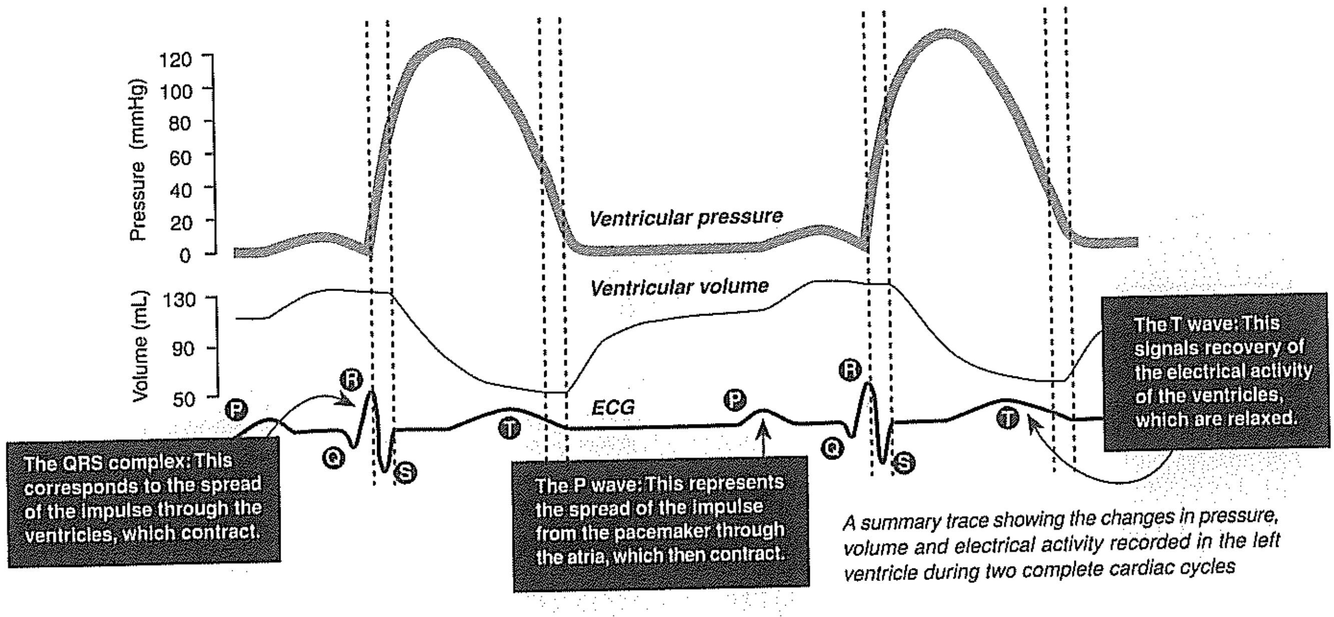
Stage 2: Ventricular systole The atria relax, the ventricles contract, and blood is pumped from the ventricles into the aorta and the pulmonary artery. The start of ventricular contraction coincides with the first heart sound.

Stage 3: (not shown) There is a short period of atrial and ventricular relaxation (diastole). Semilunar valves (**SLV**) close to prevent backflow into the ventricles (see diagram, left). The cycle begins again. For a heart beating at 75 beats per minute, one cardiac cycle lasts about 0.8 seconds.



Heart during ventricular contraction

Cardiac Cycle Events in the Left Ventricle



A summary trace showing the changes in pressure, volume and electrical activity recorded in the left ventricle during two complete cardiac cycles

1. Identify each of the following phases of an ECG by its international code:

   (a) Excitation of the ventricles and ventricular systole: ______________________

   (b) Electrical recovery of the ventricles and ventricular diastole: ______________________

   (c) Excitation of the atria and atrial systole: ______________________

2. Suggest the physiological reason for the period of electrical recovery experienced each cycle (the T wave):

   ____

3. Using the letters indicated, mark the points on the trace above corresponding to each of the following:

   (a) E: Ejection of blood from the ventricle

   (b) AVC: Closing of the atrioventricular valve

   (c) FV: Filling of the ventricle

   (d) AVO: Opening of the atrioventricular valve

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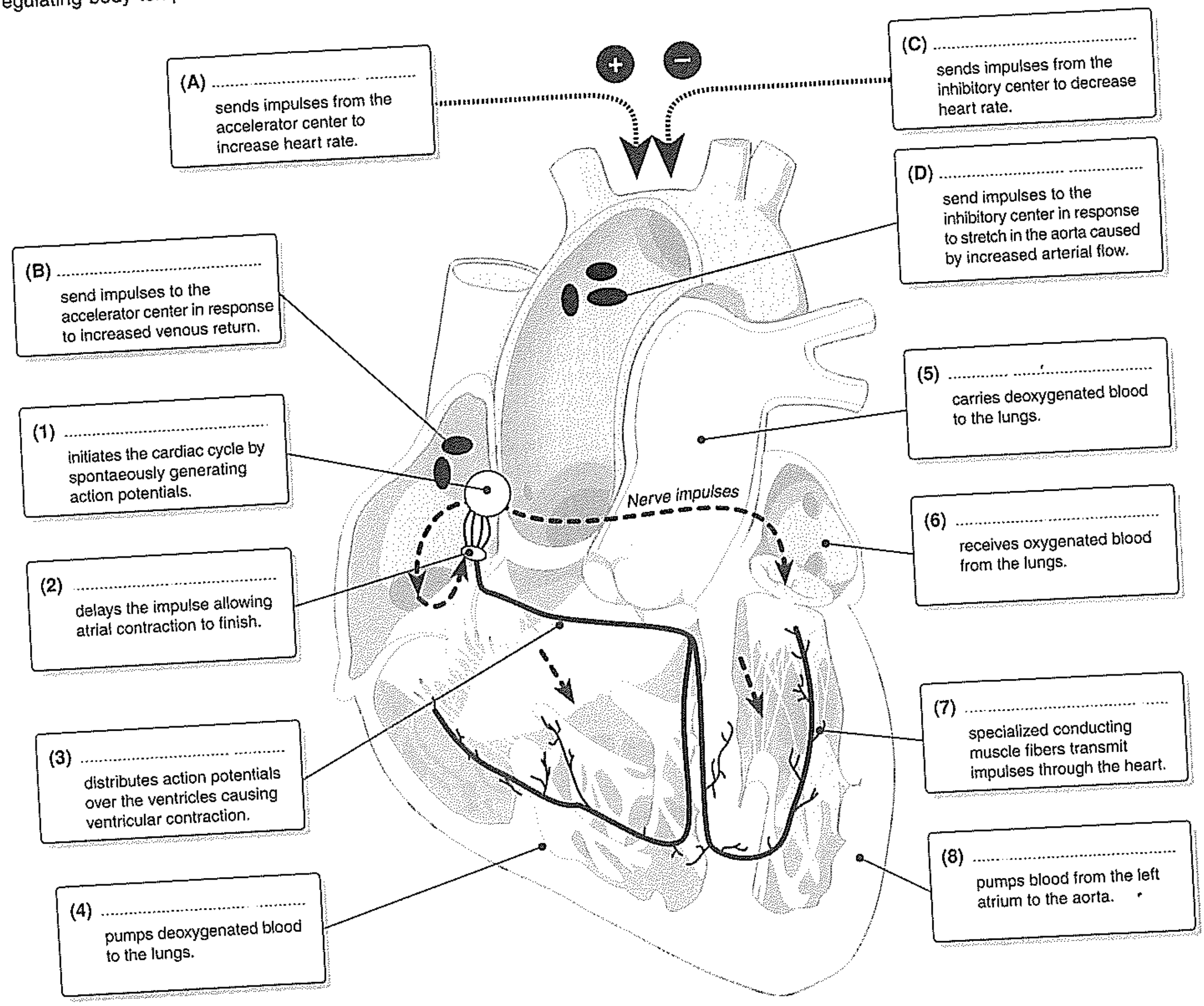
Related activities: The Human Heart
Web links: Electrocardiogram, Cardiac Cycle Animation

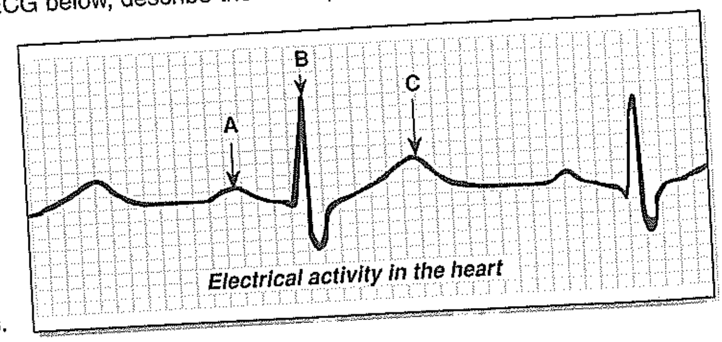
Review of the Human Heart

A circulatory system is required to transport materials because diffusion is too inefficient and slow to supply all the cells of the body adequately. The circulatory system in humans transports nutrients, respiratory gases, wastes, and hormones, aids in regulating body temperature and maintaining fluid balance, and has a role in internal defence. The circulatory system comprises a network of vessels, a circulatory fluid (blood), and a heart. This activity summarizes key features of the structure and function of the human heart. The necessary information can be found in earlier activities in this topic.



1. On the diagram above, label the identified components of heart structure and intrinsic control (**1-8**), and the components involved in extrinsic control of heart rate (**A-D**).

2. An **ECG** is the result of different impulses produced at each phase of the **cardiac cycle** (the sequence of events in a heartbeat). For each electrical event indicated in the ECG below, describe the corresponding event in the cardiac cycle:



A ....
The spread of the impulse from the pacemaker (sinoatrial node) through the atria.

B ....
The spread of the impulse through the ventricles.

C ....
Recovery of the electrical activity of the ventricles.

3. Describe one treatment that may be indicated when heart rhythm is erratic or too slow: ______________________

____

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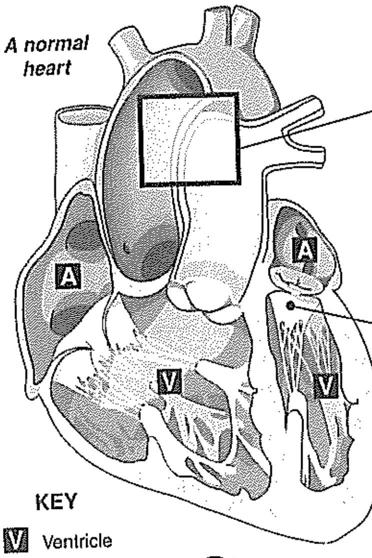
Cardiovascular Disease

ırdiovascular disease (CVD) is a term describing all diseases ⁄olving the heart and blood vessels. It includes coronary ıart disease (CHD), atherosclerosis, hypertension (high blood essure), peripheral vascular disease, stroke, and congenital ıart disorders. CVD is responsible for 20% of all deaths ›rldwide and is the principal cause of deaths in developed ıuntries. In westernized countries, deaths due to CVD have been declining since the 1970s due to better prevention and treatment. Despite this, CVD is still one of the leading causes of mortality,. The continued prevalence of CVD is of considerable public health concern, particularly as many of the **risk factors** involved, such as cigarette smoking, obesity, and high blood cholesterol, are controllable. Uncontrollable risk factors include advancing age, gender, and heredity.

Cardiovascular Diseases

therosclerosis: Atherosclerosis is a sease of the arteries caused by **heroma** (fatty deposits) on the inner alls of the arteries. An atheroma is ade up of cells (mostly macrophages) · cell debris, with associated fatty ɔids, cholesterol, calcium, and varying nounts of fibrous connective tissue. ɪe lining of the arteries degenerates ɹe to the accumulation of fat and aques. Atheroma weakens the arterial alls and eventually restricts blood flow ɪrough the arteries, increasing the risk **f aneurysm** and **thrombosis** (blood ot formation). Complications arising as result of atherosclerosis include **ıfarction**, stroke, and gangrene.

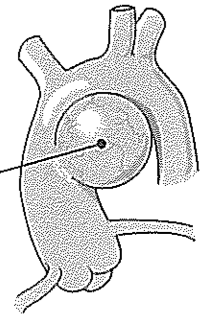
A normal heart



KEY

V Ventricle

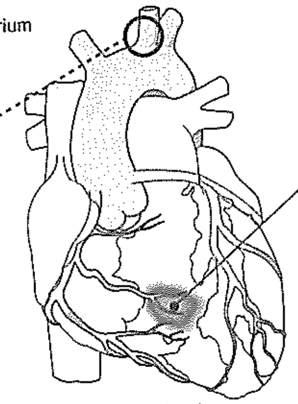
A Atrium



Aortic aneurysm: Ballooning of the wall of the aorta. Atheroma increases the risk of aneurysm in arteries because it weakens the artery wall. Aneurysms usually result from generalized heart disease and high blood pressure.

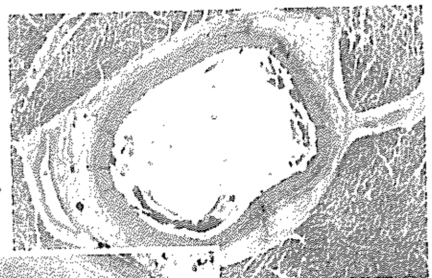
Valve defects: Unusual heart sounds (murmurs) can result when a valve (often the mitral valve) does not close properly, allowing blood to bubble back into the atria. Valve defects may be congenital (present at birth) but they can also occur as a result of rheumatic fever.

Atherosclerotic plaque in the carotid artery. Plaque material can detach from the artery wall and enters the circulation, increasing the risk of thrombosis.



Restricted supply of blood to heart muscle resulting in myocardial infarction

Myocardial infarction (*heart attack*): Occurs when an area of the heart is deprived of blood supply resulting in tissue damage or death. It is the major cause of death in developed countries. Symptoms of infarction include a sudden onset of chest pain, breathlessness, nausea, and cold clammy skin. Damage to the heart may be so severe that it leads to heart failure and even death (myocardial infarction is fatal within 20 days in 40 to 50% of all cases).



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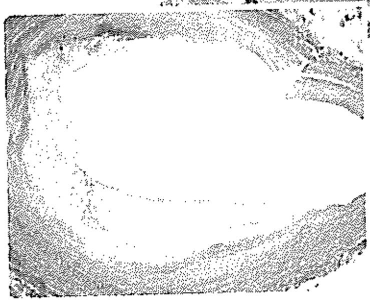

Normal unobstructed coronary artery above, and a coronary artery (left) with moderately severe atheroma. Note the formation of the plaque on the inside surface of the artery. Plaques obstruct blood flow through the artery.

Cholesterol and Risk of CVD

Cholesterol is a sterol lipid found in all animal tissues as part of cellular membranes. It is transported within complex spherical particles called **lipoproteins**. One form of cholesterol-transporting molecule is called **high density lipoprotein** or **HDL**. HDL helps remove cholesterol from the bloodstream by transporting it to the liver. Another form of lipoprotein, called **LDL (low density lipoprotein)** deposits cholesterol onto the walls of blood vessels to form **plaques**.

Abnormally high concentrations of LDL and lower concentrations of functional HDL are strongly associated with CVD because these promote development of atheroma in arteries. This disease process leads to a myocardial infarction. It is the **LDL:HDL ratio**, rather than total cholesterol *per se*, that best indicates the risk of cardiovascular disease, and the risk profile is different for men and women (tables right). The LDL:HDL ratio is mostly genetically determined but can be changed by body build, diet, and exercise regime.

Ratio of LDL to HDL

Risk	Men	Women
Very low (half average)	1.0	1.5
Average risk	3.6	3.2
Moderate risk (2X average risk)	6.3	5.0
High (3X average risk)	8.0	6.1

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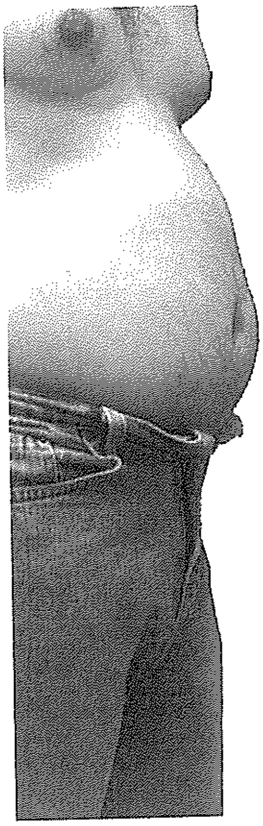
Related activities: Correcting Heart Problems, Organ Transplants, Smoking and the Lungs **Web links:** LifeBeat Online

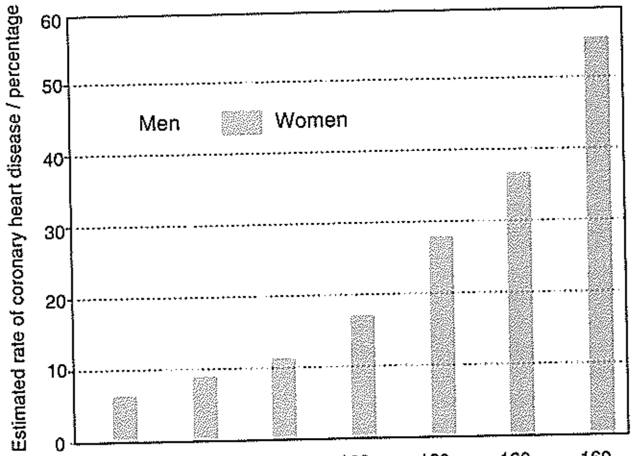


Cardiovascular Disease: Who is at Risk?

Controllable risk factors for cardiovascular disease

- High blood pressure
- Cigarette smoking
- High blood cholesterol
- High LDL:HDL ratio
- Obesity
- Type 2 diabetes mellitus
- High achiever personality
- Environmental stress
- Sedentary lifestyle

Estimated coronary heart disease rate according to various combinations of risk factors over 10 years
(source: International Diabetes Foundation, 2001)



Systolic blood pressure / mm Hg	120	160	160	160	160	160	160
Cholesterol / mg dL^{-1}	220	220	259	259	259	259	259
HDL cholesterol / mg dL^{-1}	50	50	50	35	35	35	35
Diabetes	–	–	–	–	+	+	+
Cigarette smoking	–	–	–	–	–	+	+
Enlargement of left ventricle	–	–	–	–	–	–	+

Risk factors

1. Explain how atherosclerosis leads to death of heart tissue and a heart attack (infarct):

2. Explain the link between atheroma and the risk of:

(a) Aneurysm:

(b) Thrombosis and stroke:

3. (a) Distinguish between controllable and uncontrollable risk factors in the development of CVD:

(b) Suggest why some of the controllable risk factors often occur together:

(c) Evaluate the evidence supporting the observation that patients with several risk factors are at higher risk of CVD:

4. (a) Explain the link between high LDL:HDL ratio and the risk of cardiovascular disease:

(b) Explain why this ratio is more important to medical practitioners than total blood cholesterol *per se*:

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