MDCAT Biology Unit 11: Circulation, study guide with practice MCQs

What MDCAT asks

Unit 11 covers the heart and its beat, blood vessels and blood, tissue fluid and lymph, and the disorders of the circulation: atherosclerosis, hypertension and heart attack. Its three subtopics carry equal weight, together about 4% of the Biology paper, so expect roughly 3 to 4 of the 81 Biology questions, most of them one fact or one step of reasoning.

B11.1 The heart

B11.1.1 Structure of the human heart and the path of blood through it

The heart lies between the lungs inside the **pericardium**; its wall is **myocardium**, cardiac muscle that never tires. The two thin-walled **atria** receive blood; the two thick-walled **ventricles** pump it. The left ventricle has the thickest wall because it pushes blood round the whole body, while the right ventricle pushes it only to the lungs. A muscular **septum** keeps the two sides apart, so oxygenated and deoxygenated blood never mix.

Four valves keep the flow one way; they have no muscle, pressure differences open and shut them.

- **Tricuspid valve**: right atrium to right ventricle; **bicuspid (mitral) valve**: left atrium to left ventricle. Their flaps are held by **chordae tendineae** so they cannot turn inside out.
- **Pulmonary and aortic semilunar valves**: at the start of the pulmonary artery and the aorta.

Path of blood: venae cavae → right atrium → tricuspid valve → right ventricle → pulmonary artery → lungs → pulmonary veins → left atrium → bicuspid valve → left ventricle → aorta → body. Blood passes through the heart twice in one round of the body: a **double circulation** (pulmonary circuit to the lungs, systemic circuit to the body). The heart muscle itself is fed by the **coronary arteries** from the base of the aorta.

B11.1.2 The cardiac cycle, heart sounds and the origin and control of the heartbeat

One heartbeat is a **cardiac cycle**: contraction is **systole**, relaxation **diastole**. At 75 beats per minute a cycle lasts 60 ÷ 75 = 0.8 s, in three phases.

1. **Atrial systole (0.1 s)**: the atria push the last of their blood through the open AV valves.
2. **Ventricular systole (0.3 s)**: ventricular pressure rises above atrial pressure, so the AV valves shut (first sound); once it exceeds arterial pressure the semilunar valves open and blood is ejected.
3. **Joint diastole (0.4 s)**: all chambers relax. Ventricular pressure falls below arterial pressure, so blood falls back and shuts the semilunar valves (second sound); venous blood fills the atria, the AV valves open and the ventricles fill.

Heart sounds are made by valves closing, never opening. **'Lubb'**, long and low, is the AV valves closing at the start of ventricular systole; **'dupp'**, short and sharp, is the semilunar valves closing at the

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start of ventricular diastole. The volume one ventricle pumps per beat is the **stroke volume** (about 70 cm^3); stroke volume × heart rate = **cardiac output**, about 5 dm^3 per minute at rest.

Origin of the beat: the heartbeat is **myogenic**, starting in the muscle itself, at the **sinoatrial (SA) node** in the wall of the right atrium: the **pacemaker**.

- The impulse spreads across both atria, which contract together.
- Non-conducting tissue blocks it except at the **atrioventricular (AV) node** at the base of the right atrium, which delays it about 0.1 s so the atria finish emptying first.
- It then runs down the **bundle of His** in the septum and through **Purkinje fibres** to the apex, so the ventricles contract from the bottom upwards.

Control of the rate: the cardiac centre in the **medulla oblongata** adjusts the SA node. **Sympathetic** nerves speed and strengthen the beat, as in exercise or fear; the **vagus** nerve (parasympathetic) slows it at rest. The hormone **adrenaline** acts like the sympathetic nerves.

Phase (75 beats per minute)	Time	AV valves	Semilunar valves	Sound
Atrial systole	0.1 s	Open	Closed	None
Ventricular systole	0.3 s	Closed	Closed, then open	'Lubb' at the start
Joint diastole	0.4 s	Closed, then open	Closed	'Dupp' at the start

MDCAT trap: an artery is not defined by the blood it carries. An artery carries blood *away from* the heart, a vein *towards* it. The pulmonary artery leaves the right ventricle, so it is an artery, yet it carries deoxygenated blood to the lungs; the pulmonary veins enter the left atrium with the most oxygenated blood in the body. 'The pulmonary artery carries oxygenated blood' is always a distractor.

Worked example. At rest a student's heart rate is 60 beats per minute and stroke volume 70 cm^3; running, 150 beats per minute and 100 cm^3. Find the cycle length in each case and the factor by which cardiac output rises.

Step 1: cycle at rest = 60 ÷ 60 = 1.0 s; running, 60 ÷ 150 = 0.4 s.

Step 2: cardiac output at rest = 70 × 60 = 4 200 cm^3 per minute; running = 100 × 150 = 15 000 cm^3 per minute, a factor of 15 000 ÷ 4 200 ≈ 3.6.

Answer: the cycle shortens from 1.0 s to 0.4 s and cardiac output rises about 3.6 times (sympathetic nerves and adrenaline).

B11.2 Blood and blood vessels

B11.2.1 Arteries, veins and capillaries compared, and blood pressure

Blood leaves the heart in **arteries**, which branch into **arterioles** and then **capillaries**; these join into **venules** and **veins** that return blood to the heart. Both arteries and veins have an inner endothelium, a **tunica media** of smooth muscle and elastic fibres (thick in arteries, thin in veins) and an outer collagen

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layer.

Arteries receive blood in spurts at high pressure. Their thick elastic walls stretch with each spurt and recoil between beats, smoothing the flow; the stretch felt over a bone is the **pulse**.

Capillaries are about 8 µm wide, so red cells pass one at a time, with a wall one endothelial cell thick: the only site of exchange with the tissues.

Veins carry blood at low pressure, so their walls are thin and the lumen wide; **valves** stop backflow. Blood is pushed back to the heart by skeletal muscles squeezing the veins and by breathing movements.

Pressure and speed round the circuit: pressure is highest in the aorta and falls steadily to almost zero in the venae cavae. Speed is fastest in the aorta, slowest in the capillaries, faster again in the veins, because millions of capillaries together have a far larger total cross-sectional area than the aorta, so blood moves slowly through them, giving time for exchange.

Blood pressure, measured with a **sphygmomanometer**, is written as **systolic** (ventricles contracting) over **diastolic** (ventricles relaxed): about **120/80 mm Hg** at rest.

Feature	Artery	Vein	Capillary
Direction	Away from the heart	Towards the heart	Arteriole to venule
Wall	Thick, muscular, elastic	Thin, little muscle	One cell thick
Lumen	Narrow for its wall	Wide	About 8 µm
Valves	None (except at the heart)	Present	None
Pressure	High, pulsing	Low, steady	Falling, no pulse
Speed	Fastest	Moderate	Slowest

B11.2.2 The components of blood and their functions

An adult has about 5 dm^3 of blood, roughly 8% of body mass: about **55% plasma** and **45% cells**.

Plasma is about 90% water carrying proteins (7 to 8%), salts, glucose, amino acids, urea, hormones and dissolved gases. The plasma proteins come from the liver: **albumin** (holds water in the blood by osmosis), **globulins** (include the antibodies) and **fibrinogen** (clotting).

Red blood cells (erythrocytes) number about 5 million per mm^3: biconcave discs 7 to 8 µm across with **no nucleus and no mitochondria**, packed with **haemoglobin**, the iron-containing protein that binds oxygen as oxyhaemoglobin. They are made in red bone marrow, live about **120 days** and are broken down in the spleen and liver. Too little haemoglobin is **anaemia**.

White blood cells (leucocytes), about 7 000 to 8 000 per mm^3, are larger, nucleated, and can leave the capillaries.

- Granulocytes: **neutrophils** (60 to 70%, lobed nucleus, main phagocytes), **eosinophils** (parasitic worms, allergy), **basophils** (rarest; release heparin and histamine).
- Agranulocytes: **lymphocytes** (20 to 30%, large round nucleus; B cells make antibodies, T cells kill infected cells), **monocytes** (largest; become macrophages).

Platelets (thrombocytes), about 250 000 per mm^3, are fragments of marrow cells (megakaryocytes).

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At a wound they form a plug and start clotting:

1. Damaged tissue and platelets release **thromboplastin**.
2. Thromboplastin, with **calcium ions**, converts inactive **prothrombin** (made in the liver, needing **vitamin K**) into the enzyme **thrombin**.
3. Thrombin converts soluble **fibrinogen** into insoluble **fibrin** threads, which trap cells to form the clot.

MDCAT trap: lowest pressure is not the same as slowest flow. Pressure falls steadily from the aorta to the venae cavae and never rises again. Speed is highest in the aorta, lowest in the capillaries, and then *increases* again in the veins, where pressure is lowest. Speed depends on total cross-sectional area, not pressure: the same volume per second shared among millions of capillaries moves slowly in each, and the veins, with a smaller total cross-section, speed it up again.

Worked example. A man has 5 dm^3 of blood with 5 million red cells per mm^3. How many red cells does he have, and how many must his marrow make each second?

Step 1: 1 $dm^3 = 10^6$ mm^3, so 5 $dm^3 = 5 \times 10^6$ mm^3; total red cells = $5 \times 10^6 \times 5 \times 10^6 = 2.5 \times 10^{13}$.

Step 2: 120 days = $120 \times 24 \times 3\,600 \approx 1.04 \times 10^7$ s, so cells made per second $\approx 2.5 \times 10^{13} \div 1.04 \times 10^7 \approx 2.4 \times 10^6$.

Answer: about 2.5×10^{13} red cells, over two million replaced each second.

B11.3 Lymphatic system and disorders

B11.3.1 The lymphatic system and the formation of tissue fluid

Cells are bathed by **tissue fluid**, made from blood at the capillaries by two opposing forces.

- **Hydrostatic (blood) pressure** pushes fluid out: about 35 mm Hg at the arterial end, falling to about 15 mm Hg at the venous end.
- **Osmotic pressure** of the plasma proteins pulls fluid in: proteins are too large to cross the wall, so they stay in the plasma, and the pull is about 25 mm Hg along the whole capillary.

Net filtration pressure = hydrostatic pressure – osmotic pressure. At the arterial end it is +10 mm Hg (35 – 25), so water and small solutes are filtered out as tissue fluid; at the venous end it is –10 mm Hg (15 – 25), so most of the fluid is drawn back. Tissue fluid is plasma without the large proteins and red cells.

About a tenth of the fluid does not return. It drains, with any escaped protein, into blind-ended **lymph capillaries** and is then called **lymph**. Lymphatic vessels resemble veins: thin walls, valves, flow driven by skeletal muscles and breathing. All lymph returns to the blood through the **thoracic duct** and right lymphatic duct, which open into the subclavian veins.

Lymph nodes hold lymphocytes and macrophages; they filter the lymph and swell during infection. In each intestinal villus a lymph capillary, the **lacteal**, absorbs fats, giving gut lymph a milky look (chyle).

The lymphatic system therefore returns tissue fluid and protein to the blood, carries absorbed fat and

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defends the body. Fluid collecting in the tissues is **oedema**: from low plasma protein (kwashiorkor, liver disease), raised venous pressure (heart failure) or blocked lymph vessels (elephantiasis, caused by a parasitic worm).

Feature	Blood	Tissue fluid	Lymph
Red blood cells	Present (suspended)	None	None
White blood cells	Present	Some phagocytes	Mainly lymphocytes
Large plasma proteins	High	Very low	Low
Moved by	Heart	Pressure differences	Muscles, breathing, valves

B11.3.2 Cardiovascular disorders: atherosclerosis, hypertension and heart attack

Atherosclerosis is the build-up of fatty material in an artery wall. Cholesterol (carried as LDL) is deposited under a damaged endothelium as a plaque, an **atheroma**, which narrows the lumen and makes the wall rough and stiff; hardening with calcium deposits is **arteriosclerosis**. Risk factors: saturated fat, smoking, obesity, inactivity, diabetes, hypertension and age.

A narrowed artery leads to:

- **Thrombosis**: the rough plaque cracks and triggers clotting; a clot fixed where it formed is a **thrombus**.
- **Embolism**: a fragment that breaks off and travels is an **embolus**; it lodges in a narrow vessel, in the brain causing a stroke.

Hypertension is resting blood pressure that stays at about 140/90 mm Hg or above (normal is about 120/80 mm Hg). Usually no single cause is found; salt, obesity, alcohol and stress contribute. It gives no symptoms (the silent killer), yet it speeds atherosclerosis, overworks the left ventricle and raises the risk of stroke, heart attack and kidney failure.

Coronary heart disease is atherosclerosis of the coronary arteries. When a narrowed artery cannot supply enough oxygen during exertion the muscle hurts: a crushing chest pain, **angina pectoris**. The pain stops with rest and no muscle dies. When a coronary artery is blocked completely, usually by a thrombus on a plaque, the muscle beyond the block dies: a **heart attack** or **myocardial infarction**. The pain persists, and a large infarct can stop the heart (ventricular fibrillation). Treatment: clot-dissolving drugs, angioplasty (balloon and stent) or bypass surgery; prevention is the risk-factor list in reverse.

Condition	What it is	Does muscle die?	Key feature
Atherosclerosis	Cholesterol plaque (atheroma) in the artery wall	No, by itself	Narrow, rough, stiff artery
Hypertension	Resting pressure about 140/90 mm Hg or higher	No, by itself	No symptoms; damages vessels, kidneys, brain, heart
Angina	Heart muscle short of oxygen during effort	No	Chest pain that stops with rest

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Heart attack (myocardial infarction)	Coronary artery blocked, usually by a thrombus	Yes	Pain that persists; may cause fibrillation

MDCAT trap: angina is not a small heart attack. Both come from coronary atherosclerosis and both give chest pain. In angina the artery is narrowed, not blocked: enough blood passes at rest, too little during exertion, so the muscle aches but recovers when demand drops, and no muscle dies. In a myocardial infarction the artery is blocked, usually by a thrombus on a cracked plaque, so the muscle beyond dies; the damage is permanent and the pain does not ease with rest. 'Infarction' means death of tissue from loss of blood supply.

Worked example. Capillary hydrostatic pressure is 35 mm Hg at the arterial end and 15 mm Hg at the venous end; plasma osmotic pressure is 25 mm Hg. A patient with liver disease makes too little albumin, so his plasma osmotic pressure is only 15 mm Hg. Find the net pressure at each end for both people and explain the patient's swollen ankles.

Step 1, healthy: arterial end 35 – 25 = +10 mm Hg outward; venous end 15 – 25 = –10 mm Hg inward, so fluid returns.

Step 2, patient: arterial end 35 – 15 = +20 mm Hg outward, twice normal; venous end 15 – 15 = 0 mm Hg, nothing is drawn back.

Answer: tissue fluid forms faster than the lymph can drain it and collects where venous pressure is highest, the ankles.

Practice MCQs

1. Which valve lies between the left atrium and the left ventricle?
   A. Tricuspid valve
   B. Pulmonary semilunar valve
   C. Aortic semilunar valve
   D. Bicuspid (mitral) valve
2. The second heart sound, 'dupp', is produced by:
   A. closure of the AV valves as the ventricles begin to contract
   B. opening of the semilunar valves during ventricular systole
   C. closure of the semilunar valves as the ventricles begin to relax
   D. contraction of the atria
3. At 75 beats per minute atrial systole lasts 0.1 s, ventricular systole 0.3 s and joint diastole 0.4 s. If the rate rises to 100 beats per minute and the systole times stay the same, how long is joint diastole?
   A. 0.2 s
   B. 0.3 s
   C. 0.4 s
   D. 0.6 s
4. In which vessels does blood flow most slowly?
   A. Aorta
   B. Capillaries

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C. Venae cavae
D. Arterioles

5. Which feature is found in veins but not in arteries?
   A. A thick tunica media of smooth muscle
   B. An endothelial lining
   C. Elastic fibres in the wall
   D. Valves along the length of the vessel
6. What is the direct role of thrombin in blood clotting?
   A. It converts soluble fibrinogen into insoluble fibrin
   B. It converts prothrombin into its active form
   C. It releases thromboplastin from damaged platelets
   D. It binds calcium ions so that they cannot act
7. A person has 4 dm^3 of blood with a red cell count of 5 million per mm^3. Approximately how many red cells are in circulation?
   A. 2×10^{10}
   B. 2×10^{13}
   C. 2×10^{9}
   D. 2×10^{16}
8. A child with severe protein deficiency develops a swollen abdomen and ankles because:
   A. plasma osmotic pressure has fallen, so less tissue fluid returns to the capillaries
   B. blood pressure has risen and widened the arteries
   C. the lymph nodes are infected and swollen
   D. the capillary walls have become less permeable
9. A clot that breaks away, travels in the blood and lodges in a small artery of the brain is called:
   A. a thrombus
   B. an atheroma
   C. an embolus
   D. a plaque
10. A man feels a crushing chest pain whenever he climbs stairs; it goes after a few minutes of rest and tests show no damage to the heart muscle. His condition is most likely:
    A. myocardial infarction
    B. stroke
    C. hypertension
    D. angina pectoris

1. D. The bicuspid (mitral) valve is the left AV valve; the tricuspid is on the right and the semilunar valves guard the arteries.

2. C. 'Dupp' is the semilunar valves shutting at the start of ventricular diastole. Option A is the first sound; opening valves are silent.

3. A. One cycle now lasts 60 ÷ 100 = 0.6 s; minus the unchanged 0.4 s of systole leaves 0.2 s.

4. B. Capillaries have the greatest total cross-sectional area, so flow is slowest there; the venae cavae have the lowest pressure, not the slowest flow.

5. D. Both vessels have an endothelium, a tunica media and elastic fibres; only veins have valves

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along their length.

6. A. Thrombin turns fibrinogen into fibrin; option B describes how thrombin is formed, not what it does.

7. B. 4 dm^3 = 4 × 10^6 mm^3; × 5 × 10^6 per mm^3 = 2 × 10^{13}.

8. A. Little albumin means low plasma osmotic pressure, so fluid is not drawn back at the venous end and oedema follows.

9. C. An embolus travels; a thrombus stays where it formed; an atheroma is the plaque in the wall.

10. D. Pain on exertion that goes with rest, with no dead muscle, is angina: the artery is narrowed, not blocked, as it is in a myocardial infarction.

Before the test: 12 facts to recite

1. Path: venae cavae → right atrium → tricuspid → right ventricle → pulmonary artery → lungs → pulmonary veins → left atrium → bicuspid → left ventricle → aorta.
2. Arteries carry blood away from the heart, veins towards it: the pulmonary artery carries deoxygenated blood, the pulmonary veins oxygenated.
3. Cardiac cycle at 75 beats per minute = 0.8 s: atrial systole 0.1 s, ventricular systole 0.3 s, joint diastole 0.4 s.
4. 'Lubb' = AV valves close at the start of ventricular systole; 'dupp' = semilunar valves close at the start of ventricular diastole.
5. Myogenic beat: SA node (pacemaker) → AV node (delay) → bundle of His → Purkinje fibres; ventricles contract from the apex.
6. Sympathetic nerves and adrenaline speed the heart; the vagus (parasympathetic) nerve slows it; control centre in the medulla.
7. Arteries: thick elastic wall, high pulsing pressure, no valves. Veins: thin wall, wide lumen, valves. Capillaries: one cell thick, site of all exchange.
8. Pressure: highest in the aorta, lowest in the venae cavae; flow slowest in the capillaries (greatest total cross-sectional area); normal blood pressure about 120/80 mm Hg.
9. Blood = 55% plasma, 45% cells; per mm^3 about 5 million red cells (no nucleus, 120 days), 7 000 to 8 000 white cells, 250 000 platelets.
10. Clotting: thromboplastin + Ca^{2+} turn prothrombin → thrombin; thrombin turns fibrinogen → fibrin; prothrombin needs vitamin K.
11. Tissue fluid leaves at the arterial end (hydrostatic 35 against osmotic 25 mm Hg) and returns at the venous end (15 against 25); the rest drains as lymph into the subclavian veins; lacteals absorb fat.
12. Atheroma narrows arteries; thrombus = fixed clot, embolus = travelling clot; hypertension = about 140/90 mm Hg or above; angina = pain, no muscle death; heart attack = blocked coronary artery, muscle dies.

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