Chapter 15: Body Fluids and Circulation

Exercises — Exercises

Q1 Name the components of the formed elements in the blood and mention one major function of each of them.

SOLUTION

The formed elements constitute about 45% of blood and include three types of cells:

1. Erythrocytes (Red Blood Cells, RBCs): Biconcave, anucleate cells containing haemoglobin. Major function: transport of respiratory gases (O_2 and CO_2) between lungs and body tissues.

2. Leucocytes (White Blood Cells, WBCs): Nucleated, colourless cells. There are two categories:
- Granulocytes (neutrophils, eosinophils, basophils): Neutrophils and monocytes are phagocytic and destroy foreign organisms; basophils secrete histamine and heparin involved in inflammatory reactions; eosinophils resist infections and are associated with allergic reactions.
- Agranulocytes (lymphocytes, monocytes): B and T lymphocytes are responsible for immune responses of the body.

Overall major function: defense against pathogens and immune response.

3. Platelets (Thrombocytes): Cell fragments produced from megakaryocytes in bone marrow. Major function: release substances involved in coagulation (clotting) of blood, thereby preventing excessive blood loss.

Answer: Formed elements: (1) Erythrocytes — transport of O_2 and CO_2 via haemoglobin; (2) Leucocytes — defense and immune response; (3) Platelets — blood coagulation.

Q2 What is the importance of plasma proteins?

SOLUTION

Plasma contains three major groups of proteins, each with a distinct physiological role:

1. Fibrinogen: Essential for clotting (coagulation) of blood. It is an inactive precursor that is converted to fibrin threads by the enzyme thrombin during the

clotting cascade, forming the clot at the site of injury.

2. Globulins: Primarily involved in the defense mechanisms of the body. They include immunoglobulins (antibodies) that neutralise antigens and pathogens, contributing to humoral immunity.

3. Albumins: Help in maintaining osmotic balance (oncotic pressure) of blood. They prevent excessive loss of water from blood into the interstitial spaces, thus maintaining blood volume and pressure.

In addition, plasma also contains clotting factors (in inactive form) that are essential for the coagulation cascade. Plasma without clotting factors is called serum.

Answer: Fibrinogen aids blood clotting; globulins provide immune defense (antibodies); albumins maintain osmotic balance of blood.

Q3 Match Column I with Column II:

Column I	Column II
(a) Eosinophils	(i) Coagulation
(b) RBC	(ii) Universal Recipient
(c) AB Group	(iii) Resist Infections
(d) Platelets	(iv) Contraction of Heart
(e) Systole	(v) Gas transport

SOLUTION

(a) Eosinophils — (iii) Resist Infections: Eosinophils resist infections and are also associated with allergic reactions.

(b) RBC — (v) Gas transport: Red blood cells contain haemoglobin, which transports O_2 from the lungs to tissues and aids in CO_2 transport back to the lungs.

(c) AB Group — (ii) Universal Recipient: Individuals with AB blood group have no antibodies in their plasma against A or B antigens, so they can receive blood from AB, A, B, or O donors — making them universal recipients.

(d) Platelets — (i) Coagulation: Platelets (thrombocytes) release substances involved in the coagulation (clotting) of blood at the site of injury.

(e) Systole — (iv) Contraction of Heart: Systole refers to the contraction phase of the heart (atrial systole or ventricular systole), during which blood is pumped out.

Answer: (a)-(iii), (b)-(v), (c)-(ii), (d)-(i), (e)-(iv)

Q4 Why do we consider blood as a connective tissue?

SOLUTION

Blood is classified as a connective tissue because it shares the fundamental features that define connective tissues:

1. Mesodermal origin: Like all connective tissues, blood develops from mesoderm during embryonic development.

2. Fluid matrix (extracellular matrix): Blood consists of a fluid matrix called plasma (about 55% of blood volume), which corresponds to the extracellular matrix characteristic of connective tissues. The cells (formed elements) are suspended in this matrix.

3. Specialised cells in a matrix: Blood contains formed elements — erythrocytes, leucocytes, and platelets — suspended in plasma, analogous to cells embedded in the matrix of other connective tissues.

4. Connects and integrates body parts: Blood connects different organs and systems of the body by transporting nutrients, gases, hormones, and waste products between them.

Thus, blood fulfils all criteria of a connective tissue — mesoderm-derived, cells dispersed in an abundant extracellular matrix — and is classified as a special or fluid connective tissue.

Answer: Blood is a connective tissue because it is mesodermal in origin, has cells (formed elements) dispersed in a fluid extracellular matrix (plasma), and connects/integrates all body systems.

Q5 What is the difference between lymph and blood?

SOLUTION

Key differences between lymph and blood:

1. Colour: Blood is red due to haemoglobin in RBCs. Lymph is colourless (pale yellow).

2. Formed elements: Blood contains all formed elements — RBCs, WBCs, and platelets. Lymph lacks RBCs and platelets; it mainly contains lymphocytes (a type

of WBC). Hence lymph has far fewer cells.

3. Protein content: Blood plasma has higher protein content (6-8%), including fibrinogen, globulins, and albumins. Lymph has a much lower protein content as larger proteins cannot pass through capillary walls.

4. Composition: Blood plasma and lymph have a similar mineral distribution (Na+, K+, Ca++, etc.), but lymph is essentially a filtrate of blood plasma that has leaked out of capillaries into interstitial spaces.

5. Flow direction: Blood circulates in a closed system of blood vessels (arteries, veins, capillaries) driven by the heart. Lymph flows in one direction only — from tissues to the subclavian vein — through the lymphatic system.

6. Fat absorption: Lymph (especially in lacteals of intestinal villi) is an important carrier of dietary fats absorbed from the gut. Blood does not absorb fats directly in this way.

7. Function: Blood transports respiratory gases, nutrients, hormones, and waste products. Lymph primarily returns interstitial fluid back to blood, carries immune cells, and transports fats from the gut.

Answer: Lymph is colourless, lacks RBCs and platelets, has lower protein content, flows one-way through lymphatic vessels, and is a filtrate of blood plasma. Blood is red, contains all formed elements, higher protein content, and circulates through a closed vascular system driven by the heart.

Q6 What is meant by double circulation? What is its significance?

SOLUTION

Double Circulation: In birds and mammals (including humans), the heart is four-chambered and blood passes through the heart TWICE in each complete circuit of the body. There are two separate circulatory pathways:

1. Pulmonary circulation: The right ventricle pumps deoxygenated blood into the pulmonary artery, which carries it to the lungs. In the lungs, CO_2 is released and O_2 is picked up. The oxygenated blood returns to the left atrium via pulmonary veins.

2. Systemic circulation: The left ventricle pumps oxygenated blood into the aorta, which distributes it to all body organs and tissues. After delivering O_2 and nutrients and collecting CO_2 and waste, the deoxygenated blood is returned to

the right atrium via the vena cava.

Significance of double circulation:
- Complete separation: Oxygenated and deoxygenated blood never mix, ensuring tissues always receive fully oxygenated blood.
- Efficient oxygen delivery: Since the systemic circulation carries only oxygenated blood at high pressure, oxygen delivery to tissues is highly efficient.
- Supports high metabolic rate: Birds and mammals are warm-blooded (endothermic) with high energy demands; double circulation sustains this by ensuring a constant, high-pressure, oxygen-rich blood supply.
- Contrast with single/incomplete circulation: Fishes have single circulation (blood passes through heart once); amphibians and reptiles have incomplete double circulation (mixing of blood in ventricle). Double circulation eliminates mixing entirely.

Answer: Double circulation means blood passes through the heart twice per circuit — once through pulmonary circulation (heart to lungs and back) and once through systemic circulation (heart to body and back). Its significance is complete separation of oxygenated and deoxygenated blood, ensuring efficient O2 delivery and supporting high metabolic rates in birds and mammals.

Q7 Write the differences between:
(a) Blood and Lymph
(b) Open and Closed system of circulation
(c) Systole and Diastole
(d) P-wave and T-wave

SOLUTION

(a) Blood vs Lymph:
- Colour: Blood is red (haemoglobin); lymph is colourless.
- Formed elements: Blood has RBCs, WBCs, and platelets; lymph has mainly lymphocytes (no RBCs, no platelets).
- Protein content: Blood plasma has high protein (6-8%); lymph has low protein content.
- Flow: Blood circulates in a closed loop via heart and blood vessels; lymph flows one-way from tissues to veins through lymphatic vessels.
- Origin: Blood is pumped by the heart; lymph is formed from interstitial fluid that has filtered out of blood capillaries.

- Fat transport: Lymph in lacteals absorbs dietary fats from intestine; blood does not.

(b) Open vs Closed Circulatory System:
- Open system (e.g., arthropods, molluscs): Blood pumped by the heart passes into open body cavities called sinuses (haemocoel); blood is not always enclosed in vessels and directly bathes the organs.
- Closed system (e.g., annelids, chordates): Blood is always enclosed in a closed network of blood vessels (arteries, veins, capillaries); it never directly contacts body cells.
- Regulation: Flow can be more precisely regulated in a closed system; open system has lower pressure and less regulated flow.

(c) Systole vs Diastole:
- Systole: The contraction phase of the heart chambers. During atrial systole, atria contract and push blood into ventricles; during ventricular systole, ventricles contract and pump blood into the aorta and pulmonary artery.
- Diastole: The relaxation phase of the heart chambers. During diastole, chambers relax, pressure falls, and blood flows in from veins/pulmonary vessels to refill the chambers.
- Blood pressure reference: Systolic pressure (120 mm Hg normal) and diastolic pressure (80 mm Hg normal) correspond to these two phases.

(d) P-wave vs T-wave in ECG:
- P-wave: Represents electrical excitation (depolarisation) of the atria, leading to contraction (systole) of both atria. It is the first wave in a normal ECG cycle.
- T-wave: Represents the return of the ventricles from the excited state back to the resting state (repolarisation). It marks the end of ventricular systole.
- In short: P-wave = atrial depolarisation (atria contract); T-wave = ventricular repolarisation (ventricles relax).

Answer: (a) Blood: red, all formed elements, high protein, closed circulation; Lymph: colourless, mainly lymphocytes, low protein, one-way flow. (b) Open: blood in sinuses, no vessels around organs; Closed: blood always in vessels, precise regulation. (c) Systole = contraction; Diastole = relaxation. (d) P-wave = atrial depolarisation; T-wave = ventricular repolarisation.

Q8 Describe the evolutionary change in the pattern of heart among the vertebrates.

SOLUTION

The vertebrate heart shows a progressive evolutionary increase in complexity, from a simple 2-chambered heart in fishes to a 4-chambered heart in birds and mammals:

1. Fishes (2-chambered heart — 1 atrium + 1 ventricle):
- Heart pumps only deoxygenated blood.
- Blood goes from heart → gills (oxygenation) → body tissues → back to heart.
- This is single circulation — blood passes through the heart only once per complete circuit.
- No separation of oxygenated and deoxygenated blood within the heart.

2. Amphibians and most Reptiles (3-chambered heart — 2 atria + 1 ventricle):
- Left atrium receives oxygenated blood from lungs/gills/skin; right atrium receives deoxygenated blood from body.
- Both atria open into a single, common ventricle.
- The single ventricle leads to mixing of oxygenated and deoxygenated blood.
- This is incomplete double circulation — some separation of circuits but blood still mixes in the ventricle.

3. Crocodiles, Birds, and Mammals (4-chambered heart — 2 atria + 2 ventricles):
- Right atrium receives deoxygenated blood; right ventricle pumps it to lungs (pulmonary circulation).
- Left atrium receives oxygenated blood from lungs; left ventricle pumps it to the body (systemic circulation).
- Complete separation of oxygenated and deoxygenated blood — no mixing.
- This is complete double circulation, the most efficient pattern.
- Supports endothermy (warm-bloodedness) in birds and mammals by ensuring a constant, high-pressure supply of fully oxygenated blood to all tissues.

Summary of evolutionary trend: 2-chambered (single circulation) → 3-chambered (incomplete double circulation) → 4-chambered (complete double circulation). This reflects increasing metabolic demands and thermoregulatory needs across vertebrate evolution.

Answer: Fishes: 2-chambered (1 atrium + 1 ventricle), single circulation; Amphibians/most reptiles: 3-chambered (2 atria + 1 ventricle), incomplete double circulation with blood mixing; Crocodiles/birds/mammals: 4-chambered (2 atria + 2 ventricles), complete double circulation with full separation of oxygenated and deoxygenated blood.

Q9 Why do we call our heart myogenic?

SOLUTION

The human heart is called myogenic because the impulse for its contraction originates from the cardiac muscle (myo = muscle; genic = arising from) itself, not from any external nerve stimulus.

This is made possible by a specialised cardiac musculature called nodal tissue distributed in the heart:
- The sino-atrial node (SAN), located in the right upper corner of the right atrium, is the primary pacemaker. It is capable of generating action potentials spontaneously and rhythmically (70-75 per minute) without any external stimulation.
- The nodal musculature is autoexcitable — it can generate action potentials on its own.

Contrast with neurogenic hearts: In some lower invertebrates (e.g., crustaceans), the heart requires a nerve impulse to initiate each contraction — these are called neurogenic hearts. In such hearts, cutting the nerve supply stops the heart.

In contrast, if the nerves to the human heart are cut, the heart continues to beat because the SAN continues to generate its own action potentials. The autonomic nervous system (sympathetic and parasympathetic) can only modulate the rate and strength of cardiac contractions — it cannot start or stop the heart beat entirely.

Therefore, the human heart is myogenic — cardiac contraction is initiated intrinsically by the muscle cells of the nodal tissue.

Answer: The human heart is myogenic because the impulse for contraction originates from within the cardiac muscle itself — specifically the sino-atrial node (SAN), which is autoexcitable and generates rhythmic action potentials without requiring external nerve stimulation.

Q10 Sino-atrial node is called the pacemaker of our heart. Why?

SOLUTION

The sino-atrial node (SAN) is called the pacemaker of the heart for the following reasons:

1. Location: The SAN is a patch of specialised nodal tissue located in the right upper corner of the right atrium.

2. Autoexcitability: The nodal musculature (including the SAN) has the unique property of being autoexcitable — it can generate action potentials spontaneously, without any external neural stimulus.

3. Highest frequency of impulse generation: Among all parts of the nodal system (SAN, AVN, AV bundle, Purkinje fibres), the SAN generates the maximum number of action potentials — 70 to 75 per minute. This is higher than any other nodal tissue, so the SAN sets the rhythmic pace for the entire heart.

4. Initiates each cardiac cycle: Each action potential generated by the SAN spreads across both atria, causing atrial systole. It then passes to the AVN, AV bundle (Bundle of His), and Purkinje fibres, triggering ventricular systole in the correct sequence.

5. Sets heart rate: By generating action potentials at ~70-75 per minute, the SAN determines the heart rate (normal resting heart rate = 72 beats per minute). If the SAN is damaged, other nodal tissues can take over but at a slower rate.

Thus, the SAN acts as a biological pacemaker — it initiates, maintains, and sets the rhythm and rate of the heart beat, which is why it is called the pacemaker of the heart.

Answer: The SAN is called the pacemaker because it generates the highest frequency of action potentials (70-75/min) among all nodal tissues, initiating each cardiac cycle spontaneously and setting the rhythmic rate of the heartbeat for the entire heart.

Q11 What is the significance of atrio-ventricular node and atrio-ventricular bundle in the functioning of heart?

SOLUTION

The atrio-ventricular node (AVN) and atrio-ventricular bundle (AV bundle / Bundle of His) are essential components of the cardiac conduction system that ensure proper, coordinated heart function:

Atrio-Ventricular Node (AVN):
- Location: Lower left corner of the right atrium, close to the atrio-ventricular septum.
- Function: The AVN receives the action potential from the SAN after it has spread through the atria. It acts as the only electrical gateway between the atria and ventricles.
- Delay function: The AVN introduces a brief delay before transmitting the impulse to the ventricles. This delay is critical — it allows the atria to complete their contraction and empty blood into the ventricles BEFORE the ventricles begin to contract. Without this delay, atria and ventricles would contract simultaneously, reducing cardiac efficiency.

Atrio-Ventricular Bundle (AV Bundle / Bundle of His):
- Location: Continues from the AVN, passes through the atrio-ventricular septum, emerges on top of the inter-ventricular septum, then divides into right and left bundle branches.
- Purkinje fibres: The bundle branches give rise to fine Purkinje fibres that spread throughout the entire ventricular musculature of both sides.
- Function: The AV bundle and Purkinje fibres rapidly conduct the action potential from the AVN to ALL ventricular muscle cells simultaneously. This ensures that the entire ventricular wall contracts as a coordinated unit — from the apex upward — producing an effective, forceful ejection of blood into the aorta and pulmonary artery.

In summary: AVN delays the impulse (for sequential atrial then ventricular contraction); AV bundle + Purkinje fibres rapidly distribute the impulse across both ventricles for simultaneous, coordinated ventricular contraction.

Answer: The AVN delays the action potential, allowing atria to complete contraction before ventricular contraction begins. The AV bundle and Purkinje fibres rapidly distribute the impulse throughout ventricular walls, ensuring coordinated ventricular contraction and efficient blood ejection.

Q12 Define a cardiac cycle and the cardiac output.

SOLUTION

Cardiac Cycle:

The cardiac cycle is the sequence of events that constitutes one complete heartbeat — including the contraction (systole) and relaxation (diastole) of both the atria and ventricles in a coordinated manner.

Sequence of events in one cardiac cycle:

1. Joint diastole: All four chambers are relaxed; blood flows from pulmonary veins and vena cava into left and right ventricles respectively through the open AV valves.
2. Atrial systole: SAN generates an action potential; both atria contract simultaneously, increasing blood flow into ventricles by about 30%.
3. Ventricular systole: Action potential conducted via AVN → AV bundle → Purkinje fibres; ventricles contract, pressure rises, AV (bicuspid and tricuspid) valves close, semilunar valves open, blood is pumped into aorta and pulmonary artery.
4. Ventricular diastole: Ventricles relax, pressure falls, semilunar valves close to prevent backflow; AV valves open again as atrial pressure exceeds ventricular pressure.
5. Joint diastole again: Cycle repeats.

Duration: Since the heart beats 72 times per minute, the duration of one cardiac cycle = 60/72 = 0.8 seconds.

Cardiac Output:

Cardiac output is defined as the volume of blood pumped out by EACH ventricle per minute.

Cardiac Output = Stroke Volume x Heart Rate

= 70 mL x 72 beats/min = approximately 5000 mL (5 litres) per minute in a healthy adult at rest.

Stroke volume is the volume of blood pumped out by each ventricle in one contraction (~70 mL). Cardiac output can be increased by increasing either heart

rate or stroke volume (e.g., during exercise or in athletes).

Answer: Cardiac cycle: the complete sequence of contraction (systole) and relaxation (diastole) of all four heart chambers in one heartbeat (duration ~0.8 s at 72 beats/min). Cardiac output: volume of blood pumped by each ventricle per minute = Stroke Volume (70 mL) x Heart Rate (72/min) = ~5 litres/min.

Q13 Explain heart sounds.

SOLUTION

During each cardiac cycle, two prominent sounds are produced that can be heard through a stethoscope. These are the two heart sounds:

First Heart Sound — 'lub':
- Timing: Occurs at the beginning of ventricular systole.
- Cause: Produced by the sudden closure of the two atrio-ventricular (AV) valves — the tricuspid valve (between right atrium and right ventricle) and the bicuspid/mitral valve (between left atrium and left ventricle).
- These valves snap shut when ventricular pressure rises above atrial pressure at the start of ventricular contraction, preventing backflow of blood into the atria.
- The 'lub' sound is low-pitched, dull, and relatively prolonged.

Second Heart Sound — 'dub':
- Timing: Occurs at the end of ventricular systole / beginning of ventricular diastole.
- Cause: Produced by the sudden closure of the two semilunar valves — the pulmonary semilunar valve (at the opening of the pulmonary artery) and the aortic semilunar valve (at the opening of the aorta).
- These valves close when ventricular pressure falls below the pressure in the aorta/pulmonary artery at the end of ventricular contraction, preventing backflow of blood into the ventricles.
- The 'dub' sound is sharp and shorter in duration than 'lub'.

Clinical Significance:
- Heart sounds are of great diagnostic importance. Abnormal heart sounds (heart murmurs) — such as whooshing or swishing sounds — indicate defective valves (e.g., stenosis or regurgitation), septal defects, or other cardiac abnormalities.
- The sequence 'lub-dub' heard in each cycle corresponds to systole and diastole, allowing assessment of heart rate and rhythm.

Answer: First heart sound ('lub'): caused by closure of tricuspid and bicuspid (AV) valves at the start of ventricular systole. Second heart sound ('dub'): caused by closure of semilunar valves (aortic and pulmonary) at the end of ventricular systole. Both sounds have clinical diagnostic significance.

Q14 Draw a standard ECG and explain the different segments in it.

SOLUTION

A standard ECG (Electrocardiogram) is a graphical recording of the electrical activity of the heart during one cardiac cycle. It is obtained by an electro-cardiograph with three electrical leads (one to each wrist and one to the left ankle). The ECG has a characteristic wave pattern with peaks labeled P, Q, R, S, and T.

Description of a standard ECG trace (draw a baseline with the following waves in order):
- A small rounded upward wave P
- A small downward deflection Q
- A tall sharp upward peak R (the highest point)
- A small downward deflection S
- A broad rounded upward wave T
- A flat baseline (isoelectric line) between T and the next P wave

Labelled parts and their significance:

P-wave:
- Represents the electrical excitation (depolarisation) of the atria.
- This depolarisation spreads from the SAN across both atria.
- It leads to contraction (systole) of both the atria, pushing blood into the ventricles.
- P-wave is a small, rounded, upward (positive) deflection.

QRS Complex:
- Represents the depolarisation of the ventricles, which initiates ventricular contraction.
- Q: small downward deflection (initial septal depolarisation).
- R: tall upward peak (main ventricular depolarisation spreading through ventricular walls).
- S: small downward deflection (terminal ventricular depolarisation).

- Ventricular contraction (ventricular systole) starts shortly after the Q wave; the QRS complex marks the beginning of systole.
- The QRS complex is the most prominent feature of the ECG.

T-wave:
- Represents the return of the ventricles from the excited state back to the resting state (repolarisation of the ventricles).
- It is a broad, rounded, upward wave appearing after the QRS complex.
- The end of the T-wave marks the end of ventricular systole (beginning of ventricular diastole).

Clinical significance:
- By counting QRS complexes per unit time, heart rate can be determined.
- ECGs from different individuals with a given lead configuration have roughly the same shape; any deviation indicates a possible abnormality or disease (e.g., arrhythmia, myocardial infarction, bundle branch block).
- The atrial repolarisation wave is not visible in a standard ECG because it is masked by the QRS complex.

Note: For the diagram, draw a horizontal baseline, then sketch (left to right): small rounded upward P-wave; then QRS complex (small dip Q, tall spike R, small dip S); then broad rounded upward T-wave; then flat isoelectric line back to baseline before the next P-wave. Label each wave clearly.

Answer: Standard ECG has three segments: P-wave (atrial depolarisation, atria contract); QRS complex (ventricular depolarisation, ventricles contract — systole begins); T-wave (ventricular repolarisation, systole ends). Each QRS complex represents one heartbeat; deviations from normal shape indicate cardiac abnormalities.