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Structure & Function of Blood and Lymph

This Factsheet summarises
1. The structure and function of blood plasma, red blood cells and white blood cells.
2. The formation of lymph and tissue fluid from blood plasma.
3. The ABO and Rhesus blood group systems.

The components of blood
Blood is the main medium of transport within the body and consists of a liquid phase called plasma in which are floating cells and formed elements. (Fig 1).

Fig 1. The components of blood

Blood plasma
The composition of plasma e.g. its pH, salt concentration and osmotic pressure are precisely regulated by the kidney. This helps to provide an optimum environment for the cells which are bathed in tissue fluid, itself derived from blood. Plasma contains:

- Plasma proteins e.g. albumins, globulins and clotting factors, such as fibrinogen. Albumins and fibrinogen are made by the liver and secreted into the blood, while the gamma globulins are made by plasma cells (activated lymphocytes) already present in the blood and lymphatic system. The gamma globulins are antibodies which protect against disease organisms. Albumins are the most abundant of the plasma proteins and are responsible for much of the osmotic pressure of blood, therefore holding water in the blood, thus maintaining blood pressure and volume. Albumins and some globulins also act as carrier proteins for substances which are insoluble in plasma. For example, the hormone thyroxine is transported from the thyroid gland by attaching onto a specific globulin and cholesterol is carried on lipoproteins (protein plus lipid units). Absorbed digested food products such as glucose, excretory products such as urea, salts such as sodium chloride and many hormones are dissolved and carried in the plasma.

Erythrocytes
Erythrocytes (Fig 2) are little more than packets of the red coloured protein, haemoglobin, surrounded by a cell membrane. The nucleus is lost during differentiation in the red bone marrow so that a mature red cell is shaped like a biconcave disc. This disc shape gives it a large surface area in relation to volume, as required for efficient gas exchange. The shape can also be distorted to enable cells to squeeze through capillaries and sinusoids as narrow as 6 micrometres in diameter. Thus the passage of red cells is slowed up allowing more efficiency in gas exchange in the capillaries.

About 55% of the blood volume consists of a straw coloured liquid called plasma, the other 45% being made up of cells. The cells are either erythrocytes (red cells) or leucocytes (white cells). In addition there are also platelets (thrombocytes) present which are fragments of cytoplasm. (Table I).

Blood has several major functions:
1. Transport  
2. Defence  
3. Formation of lymph and tissue fluid  
4. Homeostasis

Table 1. Characteristics of different blood components

<table>
<thead>
<tr>
<th>Component</th>
<th>Diameter (micrometres)</th>
<th>Made in</th>
<th>Life span</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erythrocyte</td>
<td>7.1</td>
<td>Red bone marrow</td>
<td>120 days</td>
<td>Transport of respiratory gases</td>
</tr>
<tr>
<td>Leucocytes</td>
<td>7 - 19</td>
<td>Red bone marrow or lymphatic system (lymphocytes)</td>
<td>Few hours to few days</td>
<td>Various defence functions</td>
</tr>
<tr>
<td>(5 types)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Platelets</td>
<td>2 - 4</td>
<td>Red bone marrow</td>
<td>5 - 9 days</td>
<td>Clotting</td>
</tr>
</tbody>
</table>
The respiratory pigment, haemoglobin, allows the blood to carry enough oxygen to meet the body’s needs, buffers the blood pH to between 7.2 and 7.6, and carries some waste carbon dioxide. The red cells also contain the enzyme carbonic anhydrase, which is involved with blood carbon dioxide transport in the form of hydrogen carbonate ions.

In order to synthesise haemoglobin when red blood cells are made in the red bone marrow, there must be a supply of iron, vitamin B12 and folic acid. A lack of any of these results in some form of anaemia. Before birth, red cells are also formed in the fetal liver and in the placenta. As red cells age they become fragile and eventually rupture when squeezing through the narrow blood sinuosoids of the liver and spleen. Eventually, they are broken down in the liver.

**Leucocytes**

The structure of the five types of leucocyte is shown in Table 2. The granulocytes have granules in their cytoplasm and multilobed nuclei (i.e. they are polymorphonuclear), whereas the agranulocytes have no cytoplasmic granules and have either an oval or horseshoe shaped nucleus.

The granulocytes and monocytes can all move through the tissues by amoeboid action. Lymphocytes cannot, since they do not have enough cytoplasm to form pseudopodia. They move passively with blood and tissue fluid flow.

### Table 2. Structure and function of leucocytes

<table>
<thead>
<tr>
<th>Leucocyte Type</th>
<th>Produced in</th>
<th>Function</th>
<th>Appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agranulocytes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monocytes</td>
<td>red bone marrow</td>
<td>Strong phagocyte against bacteria and viruses which have been coated in antibodies. Promotes immune response by transferring some of the ingested bacteria or virus into the lymph nodes.</td>
<td>(largest white cell) Horseshoe shaped nucleus Phagocytosed bacteria</td>
</tr>
<tr>
<td>Lymphocytes</td>
<td>lymphatic tissue (spleen, lymph nodes, tonsils)</td>
<td>Produce antibodies which will neutralise specific bacterial or viral antigens.</td>
<td>Round, indented nucleus Small amount of cytoplasm.</td>
</tr>
<tr>
<td><strong>Granulocytes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutrophil</td>
<td>red bone marrow</td>
<td>Act as phagocytes - ingesting and breaking down the debris of antigen-antibody reactions. Attracted to inflamed tissue by chemotaxis. Contain lysosomes (packets of digestive enzymes) used for breaking down ingested bacteria.</td>
<td>Lobed nucleus (2 - 5 lobes) Phagocytosed bacteria Lysosomes</td>
</tr>
<tr>
<td>Eosinophil</td>
<td>red bone marrow</td>
<td>Produce antihistamines which combat the effects of allergens. Act as phagocytes.</td>
<td>Bilobed nucleus Large red staining granules</td>
</tr>
<tr>
<td>Basophil</td>
<td>red bone marrow</td>
<td>Release: 1. Antihistamines 2. Heparin - suppresses unnecessary blood clotting 3. Serotonin - makes capillary walls more ‘leaky’ during infection so that phagocytes can escape more easily</td>
<td>Lobed nucleus Large blue staining granules containing heparin, histamine and serotonin</td>
</tr>
</tbody>
</table>

*The formation and drainage of lymph*

This is illustrated in Fig 3.

**Fig 3. The formation and drainage of lymph**

<table>
<thead>
<tr>
<th><strong>BP</strong></th>
<th><strong>Op</strong></th>
<th><strong>Filtration of lymph from plasma</strong></th>
<th><strong>Exchange of nutrients and wastes between tissue fluid (lymph) and cells</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>4.8kPa</td>
<td>4.3kPa</td>
<td>0.5kPa (net filtration pressure)</td>
<td>Osmosis</td>
</tr>
<tr>
<td>3.9kPa</td>
<td>4.3kPa</td>
<td></td>
<td>Lymph</td>
</tr>
</tbody>
</table>

BP = blood pressure in kilopascals
OP = osmotic pressure of plasma proteins in kilopascals
Intercellular fluid or lymph is derived from blood plasma but contains virtually no protein, since the plasma proteins are too large to escape through the capillary walls. Thus they are retained within the blood where they exert an osmotic pressure. Lymph is formed at the arterial end of the capillary bed where it is forced out of the capillaries by a relatively high blood pressure of around 4.8 kilopascals. This carries glucose, salts, other nutrients, oxygen and hormones to the cells. The proteins, retained in the blood plasma, exert an osmotic pressure of around 4.3 kPa which tends to draw some of the water of the lymph back into the blood, thus concentrating the lymph. The effective filtration pressure forming lymph is thus 4.8 - 4.3 = 0.5 kPa.

The lymph then percolates around the cells exchanging oxygen and nutrients for waste products, such as carbon dioxide and urea. The lymph in this situation is known as tissue fluid. Much of the lymph returns to the blood plasma at the venous end of the capillary bed. Here the blood pressure has fallen to around 3.9 kPa, but the osmotic pressure of the plasma proteins remains around 4.3 kPa. Thus the net uptake pressure for drawing lymph back into the capillaries is 4.3 - 3.9 = 0.4 kPa. Since the formation pressure was 0.5 kPa, this means that some of the lymph formed cannot get back into the capillaries at the venous end. This surplus lymph is collected up into open ended vein like vessels called lymphatics. These eventually all join up and empty the lymph into the blood at the left subclavian vein.

The lymph vessels contain valves to prevent backflow of lymph which is moved along by the pressure of surrounding muscles and other organs. Along the lymph vessels, at intervals are small bodies called lymph nodes, through which the lymph drains. Here phagocytes can engulf any bacteria or other debris in the lymph. The lymph nodes also contain and produce lymphocytes, which can be released into the lymph.

**Exam Hint** - The two systems occurring on some Human Biology syllabuses are the ABO and Rhesus systems, although data questions have been set on other blood group systems, even in Biology syllabuses.

### Blood group systems

The ABO system concerns the presence or absence of two antigens (actually called agglutinogens since they can agglutinate or clump together the red cells). These agglutinogens are proteins A and B which are situated on the surface of the red blood cells.

#### Table 3. Presence of agglutinogen in each blood group

<table>
<thead>
<tr>
<th>Group</th>
<th>Agglutinogen A</th>
<th>Agglutinogen B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Group B</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>Group AB</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Group O</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

The presence or absence of agglutinogens is genetically controlled. Plasma contains specific antigens (called agglutinins) which are also determined genetically. Agglutinin A will cause the clumping together of red cells which contain agglutinogen A. Agglutinin B will clump together red cells which contain agglutinogen B. You do not possess agglutinins against your own red cells but your plasma does contain agglutinins to attack any foreign agglutinogens. Thus, Group A people possess agglutinin B in their plasma and Group B people possess agglutinin A. Thus in blood transfusions it is important to match the bloods correctly so that the recipient’s agglutinins (in their plasma) will not agglutinate the donor’s red cells. If this occurs the clumped red cells block small blood vessels, such as the glomeruli in the kidney, resulting in death. Table 4 summarises information about the ABO system.

#### Table 4. ABO blood group system

<table>
<thead>
<tr>
<th>Blood Group</th>
<th>Agglutinogen/ Antigen on red cells</th>
<th>Agglutinin/ Antibody in plasma</th>
<th>Can receive whole blood from</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>antibody B</td>
<td>Groups A and O</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>antibody B</td>
<td>Groups B and O</td>
</tr>
<tr>
<td>AB</td>
<td>A&amp;B</td>
<td>Neither</td>
<td>Groups A, B, AB &amp; O</td>
</tr>
<tr>
<td>O</td>
<td>Neither</td>
<td>Neither</td>
<td>Group O</td>
</tr>
</tbody>
</table>

Group AB people have no antibodies and so can, in theory, receive blood of all groups. Thus they are called ‘universal recipients’. Group O blood can, in theory, be given to all recipients, and thus Group O people are referred to as ‘universal donors’. In transfusion, the agglutinin in the donation is so diluted by entry into the whole blood volume of the recipient, that it does not cause any agglutination problems.

The rhesus system was first discovered in rhesus monkeys but also occurs in humans. People who are rhesus positive possess the rhesus agglutinogen on their red blood cells and make up about 85% of the UK population. 15% of the population have no agglutinogens and are called rhesus negative. Under normal circumstances the plasma does not contain anti rhesus agglutinins (anti D) which only develop if the immune response is invoked by the introduction of rhesus positive cells into a rhesus negative person. This could happen if a rhesus negative person receives a transfusion of rhesus positive blood in error. This is not serious on the first occasion, but if it occurs twice, because the first transfusion sensitised the immune system to the rhesus agglutinogen, a quick serious agglutination reaction occurs.

#### Blood clotting

Excess blood loss is prevented by haemostasis. Damaged blood vessels immediately constrict, decreasing blood flow and loss. Damage to the endothelium of the vessel exposes collagen fibres. Platelets that touch this collagen become large and sticky and rapidly form a plug to cover the exposed area. Clotting then occurs as follows:

1. Damaged tissue cells and platelets release the enzyme thromboplastin.
2. Thromboplastin converts the inactive plasma protein prothrombin into the enzyme thrombin. Ca$^{2+}$ ions are needed as a cofactor for this reaction.
3. Thrombin converts the soluble plasma protein fibrinogen into insoluble fibrin.
4. Fibrin plugs the damaged vessel.

In the hours and days after clotting the fibrin threads contract and cross bond to pull the walls of the damaged vessel closer together and to retract (shrink) the clot. More fibrin may be added as this ruptures more platelets, and so the clot thickens and hardens to become the scab. As the clot retracts, a yellowish fluid called serum is forced out of it. Serum is blood plasma minus the clotting factors. The scab acts as a scaffold on which the tissue can be repaired. Fibrinolysis is the dissolving of the clot once tissue repair is complete. Scabs on the body surface can fall off, but those deep in the body are broken down by enzymes called plasmins which are formed from plasma proteins known as plasminogens.
Practice questions
1. The diagram below represents some of the constituents of normal blood.

(a) Complete the table below giving a name for each of the constituents A, B, C and D, a place in the body where they are produced, and one function of each.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Name of Constituent</th>
<th>Site of Production</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(b) Describe the events which occur during the actual clotting of blood. (6 marks)

2. The tubes X and Y contain mammalian blood that has been treated with an anticoagulant and then centrifuged (X), and blood that has been allowed to clot and then centrifuged (Y).

(a) Identify the components A, B, C and D.

A .................
B .................
C .................
D ................. (4 marks)

(b) How does the composition of A differ from that of D? (1 mark)

(c) Certain types of white blood cell may increase in number during a bacterial infection. Suggest which cells they are and in each case give a reason for your answer. (6 marks)

3. Read through the following passage concerning haemolytic disease of the newborn child and then answer the following questions.

When a mother is rhesus negative and the father is rhesus positive there is a 50% chance that the baby will be rhesus positive. Towards the end of pregnancy some fetal red cells containing the rhesus agglutinogen may leak across the placenta into mother’s blood. This will stimulate her immune system to produce the agglutinin, anti-D, but the process is slow and the baby will be born before enough anti-D is produced to cause a problem. A second pregnancy with a rhesus positive baby, however, is more serious since the mother’s immune system will be sensitised to the rhesus positive cells. As soon as fetal cells leak across the placenta, the mother produces masses of anti-D which crosses the placenta back into the baby. These agglutinate the fetal red cells resulting in haemolytic anaemia or even death. If born alive the baby would require a complete change of blood by transfusion. The situation is easily avoided by giving mother an injection of anti-D immediately after the first baby is born. This prevents her becoming sensitised to rhesus positive cells.

(a) What is an agglutinogen? (2 marks)

(b) What is an agglutinin? (2 marks)

(c) What is agglutination and what might be its effects? (3 marks)

(d) Suggest how giving mother an injection of anti-D immediately after the baby has been born may avoid the problem with a second baby. (3 marks)

4. Read through the following passage and then fill in the spaces with the most appropriate word or words.

Blood consists of a straw coloured fluid called .............. in which are suspended several types of cells. The plasma contains various proteins, such as albumins, concerned with maintaining the .............. of blood, .............. which are antibodies and .............. which is involved in clotting. The red cells are concerned with the transport of .............. and ................ and contain haemoglobin and the enzyme ................ to enable this. Neutrophils and .............. are involved with phagocytosis, .............. produce heparin which is an .............. while.............. are concerned with producing antibodies.

(a) Distinguish tissue fluid from lymph (2 marks)

(b) Briefly describe the formation of lymph (3 marks)

(c) Describe how lymph is returned to the blood stream (4 marks)

(d) In patients with chronic kidney failure, plasma proteins are lost in the urine, and such patients suffer from oedema (too much fluid in the tissues). Suggest why this could happen (2 marks)
Answers
Semicolons indicate marking points

1. (a) A = lymphocyte;
   lymphnode/spleen/lymphatic tissue;
   antibody production

   B = erythrocyte;
   red bone marrow;
   transport of oxygen/carbon dioxide;

   C = neutrophil;
   red bone marrow;
   phagocytosis;

   D = platelets;
   red bone marrow;
   cloting;

(b) Thromboplastin;
   released from damaged platelets/platelet plug/damaged tissues;
   catalyses inactive prothrombin to active thrombin;
   thrombin changes to soluble fibrinogen to insoluble fibrin;
   fibrin meshes together with platelet plug and trapped cells to form
   the clot;
   comment on the need for calcium ions;

2. (a) A plasma;
   B white cells;
   C red cells;
   D serum;

(b) A contains clotting factors/fibrinogen/prothrombin, D does not;

(c) Neutrophils;
   active phagocytes;
   Monocytes;
   active phagocytes;
   Lymphocytes;
   produce antibodies;

3. (a) a chemical usually a protein;
   which will promote the immune response/cause antibody
   production;

(b) an antibody produced against a specific antigen/agglutinin;
   made of gamma globulin;

(c) The clumping together of cells;
   due to antigen/agglutinogen molecules on their surface reacting with
   specific antibody/agglutinin molecules;
   can impede circulation by agglutinated red cells blocking small
   blood vessels;
   particularly in glomeruli of kidney/coronary vessels of heart/cerebral
   vessels in brain;
   can cause death/paralysis;

(d) Anti-D immediately clumps any rhesus positive cells from baby
   in mother’s circulation;
   these rapidly phagocytosed/not enough to cause problems;
   thus mother does not become sensitised by overexposure to rhesus
   positive cells;

4. plasma;
   osmotic pressure/water content;
   gamma-globulins;
   fibrinogen/prothrombin;
   oxygen;
   carbon dioxide;
   carbonic anhydrase;
   monocytes/eosinophils;
   basophils;
   anticoagulant;
   lymphocytes;

5. (a) Lymph is blood plasma less plasma proteins formed from the
   arterial end of the capillary bed;
   tissue fluid is lymph where it actually bathes the cells and changes
   its composition by exchanging nutrients and wastes with the cells;

(b) High blood pressure at arterial end of capillary bed forces lymph
   out through capillary walls into tissues;
   Plasma proteins cannot escape from blood through differentially
   permeable capillary walls;
   These exert an osmotic pressure drawing water back from the
   lymph into the blood, thus concentrating the lymph;
   Blood pressure higher than osmotic pressure so more lymph flows
   out of capillary than water drawn back;

(c) At venous end of capillary bed, osmotic pressure of plasma proteins
   is greater than the blood pressure;
   since blood pressure is reduced when flowing through the
   capillaries;
   thus protein osmotic pressure draws lymph back into venous end
   of capillary;
   some lymph is drained back via lymphatic vessels/lymphatic
   system;

(d) If plasma proteins are lost in urine, then osmotic pressure of protein
   in the blood will be too low;
   Thus blood pressure causes too much lymph to form at arterial
   end/not counteracted adequately by osmotic pressure;
   Less lymph drawn back into venous end due to low osmotic
   pressure;
   (Thus lymph accumulates in tissues)