21.1 Structure of Blood

Composition of Mammalian Blood

Whole Blood

Plasma (55% by volume) cells (45% by volume)

10% dissolved substances 90% water

including proteins, mineral salts, eg.
dissolved substances, eg.
metabolic wastes, eg.
hormones, eg.
gases, eg.

A: __________ B: __________ C: __________
(5 million/mm³) (7000/mm³) (250000/mm³)

Composition of the plasma

<table>
<thead>
<tr>
<th>Substance</th>
<th>Function in the body</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Plasma proteins, eg. fibrinogen, antibodies</td>
<td></td>
</tr>
<tr>
<td>(2) Lipids</td>
<td></td>
</tr>
<tr>
<td>(3) Glucose</td>
<td></td>
</tr>
<tr>
<td>(4) Amino acids</td>
<td></td>
</tr>
<tr>
<td>(5) Hormones</td>
<td></td>
</tr>
<tr>
<td>(6) Mineral salts</td>
<td></td>
</tr>
<tr>
<td>(7) Urea</td>
<td></td>
</tr>
<tr>
<td>(8) Carbon dioxide</td>
<td></td>
</tr>
</tbody>
</table>

21.1 Functions of Blood

A. Transport

1. **Oxygen** - by RBCs in the form of ________________
2. **Carbon dioxide** - by plasma in the form of ________________
3. **Food** - carries absorbed food substances such as ________________ from the small intestine to various parts of the body
4. **Urea** - produced in the ________________, dissolves in plasma, is carried to the ________________ and excreted in the ________________
5. **Hormones** - secreted by endocrine glands into blood for transport
6. **Antibodies** - carried by blood for body defence
7. **Heat** - produced during ________________ in muscles and liver and transported to other parts of the body

B. Defence against infection

1. Phagocytes ________________
2. Lymphocyte ________________
3. Blood clot ________________

C. Regulation of body temperature
20.1.1 Respiratory Pigments

Most vertebrates and many invertebrates have evolved a group of coloured proteins (respiratory pigments) capable of loosely combining with oxygen, in order to increase the oxygen-carrying capacity of blood. These pigments with large relative molecular mass are found in the plasma while those of smaller relative molecular mass occur within cells to prevent them being lost by ultrafiltration in the kidneys.

**DISTRIBUTION OF RESPIRATORY PIGMENTS**

<table>
<thead>
<tr>
<th>PIGMENT</th>
<th>COLOUR</th>
<th>Metallic ion</th>
<th>R.M.M.</th>
<th>SITE</th>
<th>OCCURS IN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorocruorin</td>
<td>green</td>
<td>iron</td>
<td>3,000,000</td>
<td>plasma</td>
<td>sandworm</td>
</tr>
<tr>
<td>Haemoerythrin</td>
<td>red</td>
<td>iron</td>
<td>66,000-120,000</td>
<td>cells</td>
<td>earthworm</td>
</tr>
<tr>
<td>Haemocyanin</td>
<td>blue</td>
<td>copper</td>
<td>4,000,000 - 7,000,000</td>
<td>plasma</td>
<td>molluscs crustaceans</td>
</tr>
<tr>
<td>Haemoglobin</td>
<td>red</td>
<td>iron</td>
<td>16,000 - 3,000,000</td>
<td>plasma</td>
<td>earthworm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>cells</td>
<td>vertebrates</td>
</tr>
</tbody>
</table>

- **Property of respiratory pigments:**
  - They can combine readily with oxygen where its concentration is high, e.g. at the ____________, and to release it as readily where its concentration is low, i.e. in the ____________

**Haemoglobin:**
- Best known & most efficient respiratory pigment in most animals
- An Fe porphyrin compound (**haemo** group) and a protein (**globin**),
  - Globin group varies in different species but the haem group is always the same
- Each human haemoglobin has 4 haem groups and can carry 4 O₂

20.1.2 Transport of Oxygen

**Oxygen Dissociation Curve (Fig. 21.3)**
- When haemoglobin is exposed to a gradual increase in O₂ tension it absorbs O₂ rapidly at first, but more slowly as the tension continues to rise, e.g.
  - % saturation at 10 O₂ tension/kPa =
  - % saturation at 5 O₂ tension/Kpa =
  - % of O₂ released =
Oxygen dissociation curves for the haemoglobin of three mammals (Fig. 21.4):

**Llama** - animal living at high altitude:
Mouse - a small animal with a large surface area to volume ratio:
Human - has properties between these two mammals

Oxygen dissociation curve for adult human haemoglobin

Oxygen dissociation curves for the haemoglobin of three mammals

**Oxygen dissociation curves for the haemoglobin of 3 animal groups (Fig. 21.5):**

Arenicolus annulatus - Lives in muddy wallowed burrows where the O₂ tension is very low. If it is to obtain oxygen at all its haemoglobin must have a very high affinity for it.

Pigeon (bird) - As flight demands much energy, birds have high metabolic rates. To supply O₂ to the tissues rapidly their haemoglobin must increase affinity for it. With an oxygen tension of 21 kPa the air cell saturates the haemoglobin with O₂ despite its lowered affinity for it.

Low carbon dioxide tension (2 kPa)
Medium carbon dioxide tension (5 kPa)
High carbon dioxide tension (8 kPa)

Oxygen dissociation curves for the haemoglobin of three animals from different groups

Oxygen dissociation curve of human haemoglobin, illustrating the Bohr effect
General properties of the oxygen dissociation curves:

1. The release of oxygen from haemoglobin is speeded up by the presence of ________________ or **Bohreffect:** _________________.

   , i.e. the oxygen dissociation curve shifts to the _________________.

Comparison of the oxygen dissociation curves of adult & foetal haemoglobin

Comparison of the oxygen dissociation curves of human haemoglobin and myoglobin

*carboxyhaemoglobin:

*asphyxia:

**Air Breathing animals living under water**

i) Frogs have vascular permeable skin for oxygen diffusion in water

ii) Insects store air in their tracheal systems

iii) Water beetle stores air beneath its wing covers in addition to their tracheae

iv) Mammals like seals, whales & dolphins:

1. A larger total volume of blood
2. Increased concentration of red blood cells
3. Greater haemoglobin concentration
4. Reduced sensitivity to blood pH
5. Muscles rich in myoglobin
6. Reduction in cardiac output
7. Restriction of blood supply to vital organs
8. Tolerance of high lactate levels
9. Reduced metabolic rate during a dive
10. Larger tidal volume
11. Lungs may be almost entirely collapsed
12. Cartilaginous rings extend further into lungs
13. Expulsion of air during the dive
14. Closure of nostrils
Human diving problems:
1. pressurized oxygen & nitrogen - toxic & narcotic respectively
2. painful symptoms ('bends') when divers surface rapidly
Solutions: decompression, oxygen-helium mixture for breathing with heated diving suits & helium speech unscramblers

**Living At High Altitude**
Amount of oxygen at high altitude is the same as at sea level, but reduced atmospheric pressure with more difficulty for haemoglobin to load with oxygen.

**Acclimatization** (adaptations for high altitude living):
1. Adjustment of blood pH to avoid hyperventilation
2. Increased oxygen uptake
3. Improved transport of oxygen to the tissues by
   a) increased red blood cell concentration
   b) increased haemoglobin concentration
4. Changes in haemoglobin affinity for oxygen
5. Increased myoglobin levels in muscles

**20.2.3 Transport of Carbon Dioxide**
1. In aqueous solution
2. In combination with haemoglobin as carbamino-haemoglobin:
   
   3. In the form of hydrogen carbonate, catalyzed by carbonic anhydrase in the RBC:

**Transport of Other Materials**
The blood transport a wide variety of other materials, e.g. glucose, urea, etc.
The blood also distributes hormones and heat around the body, transports many important proteins, e.g. fibrinogen, antitoxins & antibodies, etc.

**21.2.4 Clotting of Blood**

**anticoagulants:**
oxalic acid which precipitates out Ca\(^{2+}\) as calcium oxalate; heparin which inhibits the conversion of prothrombin to thrombin
20.2.5 Defence Against Infections - Phagocytosis

Phagocytes are attracted to chemicals produced naturally by bacteria. The recognition is aided by the presence of opsonins - plasma proteins which attach themselves to the surface of bacteria. Specific proteins on the surface of phagocytes can bind these chemo-attractants. This causes the phagocytes to move towards the bacteria, possibly along a concentration gradient.

Inflammation: caused by phagocytosis at the site of infection, with hot & swollen area containing many dead bacteria & phagocytes forming a pus.

Inflammation results when histamine is released as a result of injury or infection: dilation of blood capillaries with plasma & antibodies leaking into the tissues; neutrophils also pass through capillary walls (diapedesis) macrophages: phagocytes concentrating in lymph nodes & liver, as part of the reticulo-endothelial system

21.3 The Immune Response

Immunity is ____________________________

It involves the recognition of __________________ and the production of _______________ (chemicals) which help to destroy it.

Two types of lymphocytes which produce antibodies: ____________________________

21.3.1 Self and Non-self Antigens

Effective defence of the body against infection lies in the ability of the lymphocyte to recognize its own cells and chemicals (self) and to distinguish these from cells and chemicals which are foreign to it (non-self).

Lymphocytes have receptors on their surfaces to fit exactly into one small part of every cell. Stem cells in the bone marrow of the embryo divide and give out a variety of lymphocytes: those with receptors fit cells must be the ones that recognize their own cells. They either die or are suppressed ensuring that the body's own cells will not be attached. The body has thus become self-tolerant. The remaining lymphocytes have receptors which fit chemical shapes of non-self material. Any material with one of these shapes to which lymphocyte receptors adhere is called an antigen.

Immune Responses

Primary immune response occurs when a lymphocyte has become attached to its complementary antigen it multiplies rapidly by mitosis to give a clone of identical lymphocytes. Some of these lymphocytes are memory cells which survive for years. Further infections by the same pathogen cause these memory cells to divide immediately to give the secondary immune response. Each time a pathogen enters the body more and more memory cells are built up, making future infection even less likely - acquired (or adaptive) immunity.
**B-lymphocytes and Humoral Immunity**

Lymphocytes that originate and mature in the _______ are called B-lymphocytes. Most micro-organisms possess more than one antigen then many lymphocytes are activated to produce clones in a process known as **polyclonal activation**. Plasma cells → antibodies

Antibodies are large **protein molecules** which comprise **four polypeptide chains** - 2 heavy chains and 2 light chains in a Y-shape with **two binding sites**. Antibodies are not restricted to the blood; they occur throughout the body. They may act as the first line of defence when they are poured out onto the mucus surfaces of the respiratory tract and alimentary canal, or present in tears.

There are a number of different antibodies each performing a different function:

1. ___________ - joining two pathogens together in clumps, thus making them more vulnerable to be attacked by other antibodies/lymphocytes
2. ___________ - they bind soluble antigens into precipitates
3. ___________ - bind to toxic molecules and neutralize their effects
4. ___________ - they bind to pathogens and act as binding sites for complementary system which breaks down pathogens

**T-lymphocytes and Cell-mediated Immunity**

Phagocytes that originated from the bone marrow but mature in the **thymus gland** are called T-lymphocytes. There are several cell types:

1. ___________ - They produce chemicals (opsonins) which attach to foreign materials and activate other lymphocytes to engulf harmful material. They also activate B-lymphocytes to divide into plasma cells and assist T-killer cells to destroy pathogens.
2. ___________ - They kill body cells which are invaded by viruses. They force cylindrical proteins through cell membrane and cause the cell to burst, sacrificing the host (body) cells and the viruses.
3. ___________ - They suppress the activities of the lymphocytes when an infection has been eliminated.

**21.3.2 Monoclonal Antibodies and their applications**

Polyclonal antibodies are produced when a foreign material enters the body and induces a clone of different B-lymphocytes. These clones produce a range of antibodies. **Hybridoma cells** are cancer B-lymphocytes which can divide indefinitely, thus producing antibodies of one type only - **monoclonal antibodies**.

**Applications**:

1. To separate a single chemical (antigen) from a complex mixture
2. In Immunoassays, e.g. presence of a pathogen in a blood sample
3. In Enzyme Linked Immunosorbant Assay, e.g. detect drugs in athletes' urine, pregnancy testing kits, AIDS test
4. "Magic Bullets" which link anti-cancer drugs and monoclonal antibodies to their target cancer cells
5. ADEPT (Antibody Direct Enzyme Prodrug Therapy) which allows high dose of the cytotoxic drug to be injected into the patient with very little harm
21.3.3 Types of Immunity & Immunization

Two basic types of immunity:

1. **Passive immunity** - antibodies passed into an individual from outside
   - natural: antibodies from mother to foetus through placenta & milk OR
   - artificial: injection of antibodies into an individual disease treatment (tetanus)

2. **Active immunity** - an organism makes its own antibodies
   - natural: response of body after a disease; could be permanent, e.g. measles
   - artificial or vaccination using:
     1. living attenuated microorganisms
     2. dead microorganisms
     3. toxoids
     4. extracted antigens
     5. artificial antigens

21.3.4 Acquired Immune Deficiency Syndrome (AIDS)

AIDS is caused by the Human Immunodeficiency Virus (HIV) which infects T-helper lymphocytes which help B-lymphocytes (which produce antibodies) & other T-lymphocytes (which kill cells infected by viruses) to carry out their functions.

21.3.5 Blood Groups

<table>
<thead>
<tr>
<th>Blood group</th>
<th>Antigen on RBCs</th>
<th>Antibodies in plasma</th>
<th>Can donate blood to</th>
<th>Can receive blood from</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>anti-B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>anti-A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AB</td>
<td>A &amp; B</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>None</td>
<td>anti-A &amp; anti-b</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Group O is the most numerous in Hong Kong.

In emergencies an injured person may die due to excessive bleeding. However, his life can be saved by giving him a __________________________. But mixing the wrong types of blood can be fatal because the RBCs clump together to form clots which block blood capillaries.

- **Antigens**: foreign materials (proteins) on the surface of RBCs
- **Antibodies**: proteins present in plasma
- **Universal recipients**: __________  Universal donors: __________

**Tissue Compatibility & Rejection**

In the absence of perfect cross-matching, the recipient treats the donated organ as foreign material and initiates an immune response which leads to rejection.

Solutions:
1. Grafted tissue, e.g. skin
2. Matching compatible tissues from close relatives
3. Use of immunosuppressant drugs
21.3.6 Chemotherapy & Immunity

Chemotherapy is to use ____________________________
examples: sulphonamides, antibiotics.

21.4 The Circulatory System

Every cell of an organism needs a continual supply of ________, ________ and other useful materials in order to carry out its metabolic activities, and a way of removing the metabolic wastes which are formed within the cell.

Small organism such as Amoeba has a _____________________________. They can absorb oxygen and remove carbon dioxide by ________. In larger animals, the surface area to volume ratio decreases

Demand (volume) > Supply (surface area), therefore a transport system is needed.

In man and many large animals the ________ system is the main transport system of the body.

Open blood system:
- in nematodes & arthropods
- blood is not confined in vessels, but also to haemocoel
- very low pressure with little control over its distribution

Closed blood system:
- for larger animals for more rapid transport and greater control of distribution and activity

Single circulation in fish  Vs  Double circulation in man

21.4.1 Blood Vessels

<table>
<thead>
<tr>
<th>Artery</th>
<th>Vein</th>
<th>Capillary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Thick muscular wall</td>
<td>Thin muscular wall</td>
<td></td>
</tr>
<tr>
<td>2 Much elastic tissue</td>
<td>Little elastic tissue</td>
<td></td>
</tr>
<tr>
<td>3 Small lumen</td>
<td>Large lumen</td>
<td></td>
</tr>
<tr>
<td>4 Can constrict</td>
<td>Cannot constrict</td>
<td></td>
</tr>
<tr>
<td>5 Not permeable</td>
<td>Not permeable</td>
<td></td>
</tr>
<tr>
<td>6. Valves in aorta &amp; pulmonary artery only</td>
<td>Valves throughout all veins</td>
<td></td>
</tr>
<tr>
<td>7 Transports blood from heart</td>
<td>Transports blood to heart</td>
<td></td>
</tr>
<tr>
<td>8 Oxygenated blood except pulmonary artery</td>
<td>Deoxygenated blood except in pulmonary vein</td>
<td></td>
</tr>
<tr>
<td>9 Blood under high pressure</td>
<td>Low pressure</td>
<td></td>
</tr>
<tr>
<td>10 Blood moves in pulses</td>
<td>No pulses</td>
<td></td>
</tr>
<tr>
<td>11 Blood flows rapidly</td>
<td>Slowly</td>
<td></td>
</tr>
</tbody>
</table>
21.4.2 Mammalian Circulatory System
The flow of blood is maintained in 3 ways:

1. 
2. 
3. 

General plan of the mammalian circulatory system

21.5 Heart Structure & Action
21.5.1 Structure of the Mammalian Heart
- Pericardium: membrane of the heart
- Cardiac muscles works (contracts) for 24 hours without rest
- __________ provides nutrients & oxygen to cardiac muscles
- __________ carry away wastes and carbon dioxide from heart muscles
- __________ divides the heart into right and left halves
- The heart is divided into 4 chambers: __________

Auricles
- Left & right auricles receive blood from veins and drain blood into the ventricles; have thinner walls than ventricles
- Right auricle receives ___________________________ blood from venae cavae (superior & inferior)
- Left auricle receives ___________________________ blood from pulmonary veins
21.5.2 Control of Heart Beat (Cardiac Cycle)

All vertebrates are **myogenic**, i.e. __________

**neurogenic** means __________

**Sino-atrial node (SA node)**
- Located in wall of R A near the vena cava
- *pace-maker* which determines __________

Wave of contraction from SA node → both atria → atrio-ventricular (AV) node
   → Purkinje fibres (bundle of His) → apex of ventricles
   → contraction from ventricular apex upwards
Cardiac Cycle
Systole - heart contraction
Diastole - heart relaxation

21.5.3 Factors Modifying Heart Beat
Cardiac output:
Volume of blood pumped at heart beat \( \times \) no. of beats/unit time
- controlled by medulla oblongata by 2 centres:
  - cardio-acceleratory centre (sympathetic) and
  - cardio-inhibitory centre (parasympathetic)

During heavy exercise:
\[ \text{CO}_2 \uparrow \rightarrow \text{pH} \downarrow \rightarrow \text{chemoreceptor in carotid artery} \rightarrow \text{cardio-acceleratory centre} \rightarrow \text{heart beat} \uparrow \]
until \( \text{CO}_2 \downarrow \rightarrow \text{cardio-inhibitory centre} \rightarrow \text{heart beat} \downarrow \)
also:
stretch receptors in aorta, carotid artery stimulated
\[ \rightarrow \text{cardio-inhibitory centre} \rightarrow \text{heart beat} \downarrow \]
stretch receptors in vena cava stimulated
\[ \rightarrow \text{cardio-acceleratory centre} \rightarrow \text{heart beat} \uparrow \]

21.5.4 Maintenance & Control of Blood Pressure

vasoconstriction: blood vessels narrowed \( \rightarrow \) blood pressure \( \uparrow \)
vasodilation: blood vessels dilated \( \rightarrow \) blood pressure \( \downarrow \)
Both controlled by vaso-motor centre in medulla oblongata \( \rightarrow \) arterioles in body

baroreceptors: pressure receptors in carotid artery detect blood pressure changes
and relay impulses to the vaso-motor centre

examples:

- blood pressure \( \downarrow \rightarrow \) baroreceptors \( \rightarrow \) vaso-motor centre \( \rightarrow \) sympathetic nerve
  \[ \rightarrow \text{arterioles} \rightarrow \text{vasoconstriction} \rightarrow \text{bp} \uparrow \]
- blood pressure \( \downarrow \rightarrow \) baroreceptors \( \rightarrow \) vaso-motor centre
  \[ \rightarrow \text{parasympathetic nerve} \rightarrow \text{arterioles} \rightarrow \text{vasodilation} \rightarrow \text{bp} \uparrow \]

Factors causing blood pressure increases:
1. \( \text{CO}_2 \)
2. Hormones, e.g. adrenaline

21.5.5 Heart Disease - coronary heart disease
1. Coronary thrombosis
2. Atherosclerosis
3. Spasm
21.6 Lymphatic System

21.6.1 Tissue fluid and its formation

- composition same as blood but without RBCs, platelets & proteins
  because they are too large to leak out of the capillaries
- forms a link between blood and cells, providing a medium
  for ___________ of materials between blood & cells

Lymph

some tissue fluid returns to capillaries by osmosis while
some (about 10%) goes into lymph capillaries;
this fluid is now called lymph

Path:
Blood ——> lymph capillaries
      ——> lymph vessels
      ——> lymph ducts
      ——> Blood
- Lymph re-enters blood

Lymph nodes

- filter lymph passing through;
  with numerous WBCs to kill bacteria
  or neutralize toxins for bodily defence
- during infection these nodes frequently swell
- major sites of lymphocytes production

Movement of lymph through the lymphatic system:
1. Hydrostatic pressure
2. Muscle contraction
3. Inspiratory movement
4. Valves to ensure one-way
   traffic towards the heart