Bio Factsheet

Number 7

Comparing Transport in Mammals and Plants

Multi-cellular organisms need to provide every cell with oxygen, water and nutrients and to do this they need a transport system because diffusion would be too slow.

The development of a transport system is therefore closely connected to an organism's surface area:volume ratio. Organisms which have a very large surface area:volume ratio e.g. protozoans, can rely upon diffusion, but as an organism gets larger, its surface area to volume ratio decreases and this makes a specialised transport system essential. Transport can be analysed under four headings:

1. The Structure of the Transport System

Transport in both plants and mammals is by a system of specialised tubes. The smallest of these tubes - capillaries - may have a lumen of 5-8μm whilst veins may have lumens of 3cms diameter. In mammals this forms a circulatory system of arteries, capillaries and veins. In flowering plants, transport is not circulatory and occurs in microscopic xylem and phloem. Both transport systems use water as the basis for transport since it is a good solvent, has a high specific heat capacity, is not too viscous and is unreactive (inert).

Both animals and plants have more than one type of tissue which is specialised to make transport an efficient process. The vessels and tracheids in xylem are made up of dead, lignified cells. Phloem tubes are living, as are all the mammalian transport cells and tissues.

2. What substances are Transported?

In mammals, blood forms the liquid medium of transport. Blood consists of 55% plasma and 45% cells and cell fragments. Plasma consists of water, proteins e.g. fibrinogen and inorganic ions, e.g. Na^+ and Ca^{2+}. Plasma has several functions:

a) maintains blood pressure;
b) transports the products of digestion - amino acids, sugars, fatty acids, minerals and vitamins to where they are needed;
c) transports waste products of metabolism (excretory products) away from the tissues. This includes carbon dioxide which is carried in the form of dissolved bicarbonate ions;
d) transports proteins important in blood-clotting, eg. fibrinogen;
e) transports hormones from endocrine organs to target organs;
f) transports inorganic ions which are essential for maintaining osmotic potential and for many physiological processes.

Red blood cells contain the pigment haemoglobin which carries oxygen used in aerobic respiration. White blood cells play a key role in attacking pathogens and platelets are involved in the clotting process.

The xylem of plants carries water and minerals such as nitrate ions. The phloem carries a solution of sucrose (produced in photosynthesis), amino acids, fatty acids, glycerol, minerals such as nitrate and phosphate and hormones such as gibberelins. Both systems thus exploit water's excellent properties as a solvent to carry essential metabolites and hormones from one part of the organism to another. Mammals however use their blood to transport oxygen and carbon dioxide, whereas plants do not use their xylem and phloem solutions to do this - an interconnecting series of air spaces are used instead. Both transport systems provide the organisms with support but by far the most important contributor in this respect are the dead, lignified cells of the xylem tissues. Finally, mammals use blood in defence (platelets, white cells etc.) whereas plants rely on a very different mechanism based upon compartmentalisation of tissues which has little to do with the transport mechanisms.

3. The Transport Mechanism

Mammals have a closed circulatory system i.e. blood circulates constantly from a pump through a series of tubes and back to the pump. Unless a blood vessel is cut open or ruptures, the cells never come into contact with blood. Instead, they are bathed by a fluid (tissue fluid) which leaks out of the thinnest walled blood vessels known as capillaries. The blood returns to the pump (the heart) via veins. Much of the blood flow in veins is against the force of gravity and one way in which this is overcome is by the contraction of skeletal muscles around the veins. Backflow is prevented by valves. The tissue fluid eventually re-enters the blood via capillaries or via the lymph system.

In plants, the situation is quite different. Water enters the xylem by the root hairs and moves up through the plant via vessels to the leaves where water molecules diffuse out in a process known as transpiration. The loss of water from plant surfaces maintains a diffusion gradient across the leaf to the xylem vessels in the leaves. In turn, the loss of water from the vessels maintains the movement of the water column in the xylem. Movement of liquids in the xylem is therefore unidirectional - in this case upwards - but in the phloem, substances may move up or down. Sucrose, produced by chloroplasts in leaves may be transported to any actively growing region (meristem) and this may be above or below the site of production. Useful substances such as sucrose pass from the phloem into other tissues via the cellulose cell walls and water and minerals may pass from xylem vessels and tracheids into the tissues via pits in the lignified walls.

Mammalian circulation is energy intensive. ATP is required for the maintenance of the heart-beat, the contraction of the arterial walls and for the contraction of the skeletal muscle around veins - this helps to push the blood back to the heart. Active transport also occurs in the phloem. The ATP which is required for active transport is provided by the mitochondria in companion cells adjacent to sieve tube elements. ATP is also required for the generation of root pressure in the xylem, but apart from this, movement of water and minerals in the xylem - the transpiration stream - is a passive process, i.e. it does not require ATP.

4. Control of Transport

In mammals, the rate of flow of blood into particular vessels can be controlled by mechanisms of vasodilation and constriction. Blood pressure can also be controlled homeostatically. Similarly, the rate of movement of sugars in the phloem can be increased or decreased according to metabolic needs. However, the rate of transpiration can only be controlled through control of stomatal opening and closure and this is heavily influenced by environmental conditions such as light intensity, temperature and water availability. The rate of movement of solutions in the xylem and phloem is much slower than the rate of flow of blood in the mammalian circulation and this is a reflection of the greater metabolic needs of mobile, endothermic organisms.

Transport in mammals and plants compared

Mammals	Plants
Specialised tubes - arteries, veins and capillaries	Specialised but much smaller diameter tubes - xylem vessels and tracheids and phloem sieve tubes
Tubes form a closed circulation system	Tubes do not form a circulatory system but system is closed
All parts of transport network are composed of living cells	Not all parts of the transport system are composed of living cells
Glucose, amino acids, fatty acids, glycerol, vitamins, minerals and hormones are transported from gut to wherever they are needed eg. active cells in blood	Sucrose, amino acids, fatty acids, glycerol, vitamins and hormones are transported from site of production or absorption to wherever they are needed eg. root and shoot apices or storage areas in the phloem. The xylem transport water and minerals
Concentration of metabolites in blood controlled homeostatically	No homeostatic control of metabolite concentration
Blood carries dissolved oxygen towards - and carbon dioxide away from- respiring tissues	Respiratory gases not carried by transport system
Blood has important role in clotting and destruction of pathogens which enter body	Solutions in xylem and phloem have no such roles
Much ATP energy required for operation of transport pump (heart) and for contraction of arteries and skeletal muscles and veins. Backflow in veins prevented by valves	No pump. ATP energy required only for translocation of substances in phloem sieve tube elements and for generation of root pressure. Most of the transpiration stream is a passive process - does not require energy
The circulatory system is controlled by the heart which is itself under the control of the autonomic nervous system	No central control in plants. Flow rate in xylem and phloem are independent
Rate of blood flow can be controlled eg. by vasoconstriction	Rate of flow in xylem is dependent upon external environmental conditions, through effect on stomata
Rate of flow of entire system quite rapid - reflects huge ATP demand for mobile homeotherms	Rate of flow slower - immobile, no temperature control therefore ATP demand is much lower

Practice Questions

1. Give three reasons for water's suitability as the basis of transport systems.
(3 marks)

2. Outline one similaritiy and one difference between the substances transported in plants and animals.
(2 marks)

3. State three processes in mammalian circulation that require ATP.
(3 marks)

4. Carefully read the following account of control of transpiration and then fill in the blanks:

The rate of transpiration can be controlled through opening and closure of .... This is influenced by environmental conditions such as .... and .... (2 marks)

5. Account for the difference in flow rates in the transport systems of mammals and plants.
(4 marks)

Answers

Semicolons indicate marking points.

1. good solvent;
high specific heat capacity;
low viscosity;
unreactive/inert; *(any 3)*

2. Similarity:
Both include metabolites/hormones between parts of organism;
Difference:
Mammals transport oxygen/carbon dioxide, plants do not;
Mammals use blood in defence; plants do not;

3. maintenance of heartbeat;
contraction of arterial walls;
contraction of skeletal muscle around veins;

4. stomata; light intensity/temperature/ water availability;

5. flow rate fast in mammals; because mobility/temp control creates high ATP demand;
flow rate slower in plants; ATP demand lower since immobile/no temperature control;

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