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Cells: cellular compartment, transport system, fluid movements

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Test your knowledge

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- List some of the structures of the human cell.
- What is a cytosol?
- What is the difference between active and passive transport?
- Where is most of the fluid volume found, in the intracellular or extracellular compartments?
- Define the function of body fluids and electrolytes.
- Define the terms endocytosis and exocytosis.

Learning outcomes

On completion of this section the reader will be able to:

- Outline the structure and function of the plasma membrane
- Describe the functions of the organelles
- Explain the cellular transport system
- Identify the fluid compartments of the body
- List the major electrolytes of the extracellular and intracellular compartments of the body
- Define the terms osmosis and diffusion

Introduction

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Cells are the structural and functional units of all living organisms. Some organisms, such as bacteria, are unicellular, consisting of a single cell. Others, such as humans, are multicellular, indicating that humans are made up of many cells (see Figure 2.1). Cells are the smallest independent units of life with different parts (see Figure 2.2) that perform their own function (see Table 2.1) and to survive some fundamental chemical activities must occur within the cell. These activities include cellular growth, metabolism and reproduction. Each cell is an amazing unit of life; it can take in nutrients, convert these nutrients into energy, carry out specialised functions and reproduce as necessary. Most amazingly, each cell stores its own set of instructions for carrying out each of these activities.

Substances such as water, electrolytes and nutrients move in and out of a cell utilising the transport system. The cell membrane is not impermeable, it is semi-permeable to water and solutes. It regulates the movement of water, nutrients and waste products into and out of the cell. The cell consists of four basic parts:

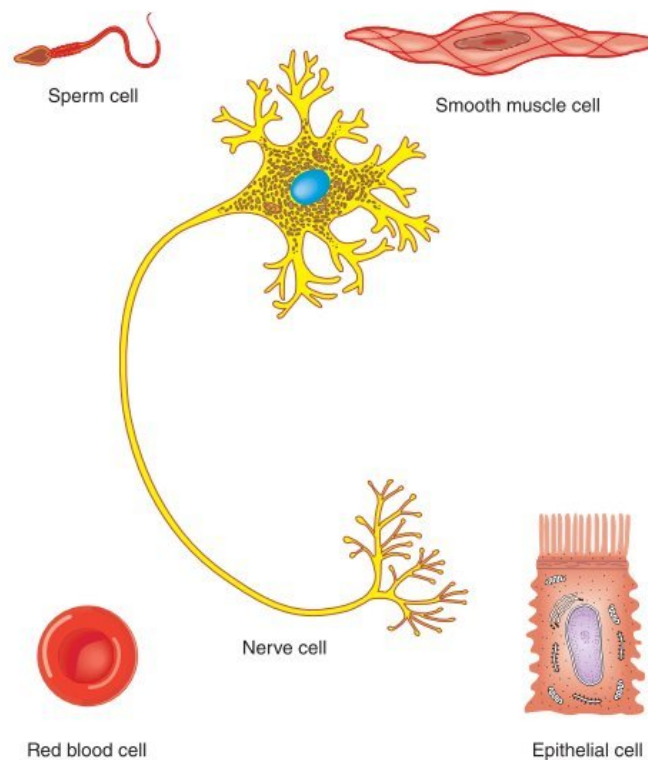


Figure 2.1 Examples of some cells of the human body (Tortora and Derrickson 2009)

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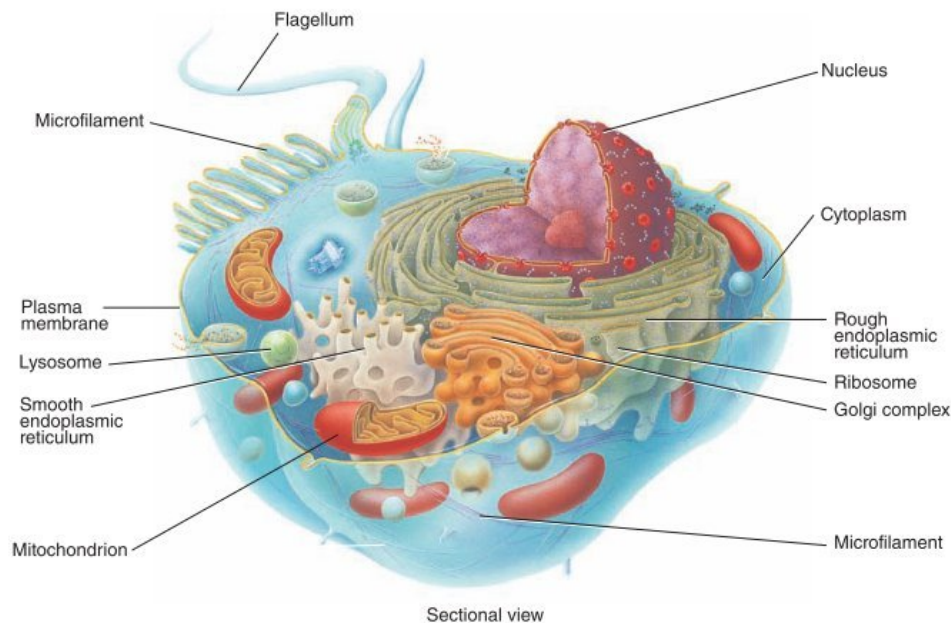


Figure 2.2 Structure of a cell (Nair and Peate 2009)

- The cell membrane
- Cytoplasm
- The nucleus
- Nucleoplasm.

Cell membrane

The cell membrane is thin and forms the outermost layer of a cell; it is also called the plasma membrane. This membrane ensures that the boundary and integrity of the cell and its contents are separate from the surrounding environment. The cell membrane contains a variety of biological molecules, mainly proteins and lipids which are involved in many cellular functions such as cellular communication and cellular transport. The cell membrane is made up of a double layer (bilayer) of phospholipid (fatty) molecules with protein molecules interspersed between them (see Figure 2.3). The cell membrane can vary from 7.5 nanometres (nm) to 10 nm in thickness (Vickers 2009).

The phospholipid bilayer consists of a polar 'head' end which is hydrophilic (water-loving) and fatty acid 'tails' which are hydrophobic (water-hating). The hydrophilic heads are situated on the outer and inner surface of the cell while the hydrophobic areas point into the cell membrane (see Figure 2.3). The phospholipid molecules are arranged as a bilayer with the heads facing outwards. This means that the bilayer is self-sealing. It is the central part of the plasma membrane, consisting of hydrophobic 'tails', that makes the cell membrane impermeable to water-soluble molecules,

Table 2.1 Cellular compartments and their functions

Components	Functions
Centrioles	Cellular reproduction
Chromatin	Contains genetic information
Cilia (pleural)	Moves fluid or particles over the surface of the cell
Cytoplasm	Fluid portion which supports organelles
Cytoskeleton	Provides support and site for specific enzymes
Endoplasmic reticulum (rough and smooth)	Many functions, including site for protein transportation, modification of drugs and synthesis of lipids and steroids
Glycogen granules	Stores for glycogen
Golgi complex	Packages proteins for secretion
Intermediate filament	Helps to determine the shape of the cell
Lysosomes	Break down and digest harmful substances. In normal cells, some of the synthesised proteins may be faulty – lysosomes are responsible for their removal
Microfilaments	Provide structural support and cell movement
Microtubules	Provide conducting channels through which various substances can move through the cytoplasm. Provide shape and support for cells
Microvilli	Increase cell surface; site for secretion, absorption and cellular adhesion
Mitochondria	Energy-producing site of the cell. Mitochondria are self-replicating
Nucleolus	Site for the formation of ribosomes
Nucleus	Contains genetic information
Peroxisomes	Carry out metabolic reactions. Site for the destruction of hydrogen peroxide. Protects the cell from harmful substances such as alcohol and formaldehyde
Plasma membrane	Regulates substances in and out of a cell
Ribosomes	Sites for protein synthesis
Secretory vesicles	Secretes hormone, neurotransmitters

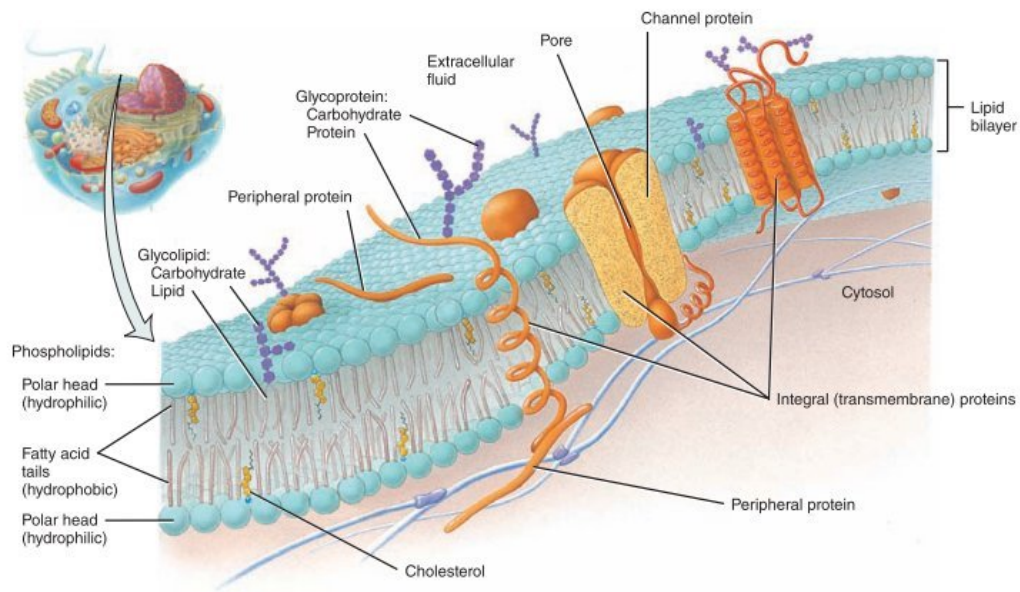


Figure 2.3 Cell membrane (Tortora and Derrickson 2009)

and so prevents the passage of these molecules into and out of the cell (Marieb and Hoehn 2007). However, for the cells to survive and function, substances need to enter and leave the cells and this is provided by special proteins, such as integral and peripheral membrane proteins (see Figure 2.3).

The integral transmembrane proteins are attached to the cell membrane and they can form channels which allow for the transportation of materials into and out of the cell. Examples of integral transmembrane proteins include voltage-gated ion channels, such as those which transport potassium ions in and out of cells, certain types of T-cell receptors, the insulin receptor and many other receptors and neurotransmitters. On the other hand, peripheral membrane proteins adhere temporarily to the cell membrane with which they are associated. Peripheral membrane proteins may interact with other proteins or directly with the lipid bilayer.

Functions of the cell membrane

Cell membranes serve several important functions. They:

- Anchor the cytoskeleton (a cellular 'skeleton' made of protein and contained in the cytoplasm) and gives shape to the cell
- Attach the cell to the extracellular matrix (non-living material that is found outside the cells), so that the cells group together to form tissues

- Transport materials needed for the functioning of the cell organelles. The cell membrane is semi-permeable and controls the in and out movements of substances. Such movement of substances may be either at the expense of cellular energy or passive, without using cellular energy
- The protein molecules in the cell membrane receive signals from other cells or the outside environment and convert the signals to messages, which are passed to the organelles inside the cell
- In some cells, the protein molecules in the cell membrane group together to form enzymes, which carry out metabolic reactions near the inner surface of the cell membrane
- The proteins in the cell membrane also help very small molecules to be transported through the cell membrane, provided the molecules are travelling from a region with lots of molecules to a region with less number of molecules.

Some of the proteins embedded in a cell membrane provide structural support to the cell, while others are enzymes where chemical reactions occur. Some membrane proteins regulate water-soluble substances through pores in the cell membrane; others are receptors where hormones and other substances such as neurotransmitters act. Other important cell membrane proteins are glycoproteins and they play an important role in cell cell recognition. One example are mucins, which are secreted in the mucus of the digestive and respiratory tracts.

Transport systems

Cells utilise two processes to move substance in and out of the cell: the passive and active transport systems. When molecules pass in and out of a cell membrane without the use of cellular energy, it is called passive transport system. This includes:

- Simple diffusion
- Facilitated diffusion
- Osmosis
- Filtration.

On the other hand, the active transport system requires energy to move substances in and out of a cell. The active transport systems include:

- Active transport with the utilisation of adenosine triphosphate (ATP)
- Endocytosis
- Exocytosis.

Simple diffusion

The term simple diffusion refers to a process whereby a substance passes through a membrane without the aid of an intermediary such as an integral membrane protein (see Figure 2.4). Water, oxygen, carbon dioxide, ethanol and urea are examples of molecules that readily cross cell membranes by simple diffusion. They pass either directly through the lipid bilayer or through pores created by certain integral membrane proteins (see Figure 2.3). Small, nonpolar substances can diffuse directly through the plasma membrane. One example of simple diffusion is the exchange of respiratory gases between the cells of the alveolar sac and the blood in the lungs. The rate of diffusion depends on several factors:

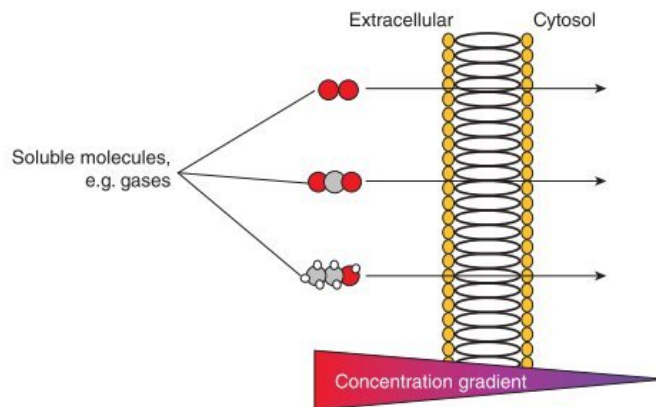


Figure 2.4 Simple diffusion (Nair and Peate 2009)

- Gases diffuse rapidly and liquids diffuse more slowly
- In high temperature the rate of diffusion is much faster
- Smaller molecules such as glycerol diffuse much faster than larger molecules like fatty acids
- The surface area of the cell membrane over which the molecule can work
- The solubility of the molecule
- The concentration gradient.

Facilitated diffusion

Facilitated diffusion (facilitated transport) is a process of passive transport (diffusion) via which molecules diffuse across cell membranes, with the help of transport proteins. Small, uncharged molecules can easily diffuse across cell membranes. However, due to the hydrophobic nature of the lipids that make up cell membranes, water-soluble molecules and ions cannot do so; instead, they are helped by transport proteins. Larger molecules, such as amino acids, cannot pass the cell membrane and therefore they use a process called facilitated diffusion (see Figure 2.5). No direct cellular energy is used in this process. Glucose, sodium and chloride ions are just a few examples of molecules and ions that must efficiently get across the plasma membrane. Their transport must therefore be 'facilitated' by proteins that span the cell membrane and provide a passageway for these substances. Like simple diffusion, facilitated diffusion transports substances from an area of high concentration to an area of low concentration.

Osmosis

Osmosis is a process whereby water moves from an area of high volume to an area of low volume through a selective permeable membrane. A selective permeable membrane is one that allows the unrestricted passage of water, but not solute molecules or ions. The relative concentrations of water are determined by the amount of solutes dissolved in the water. For example, a higher

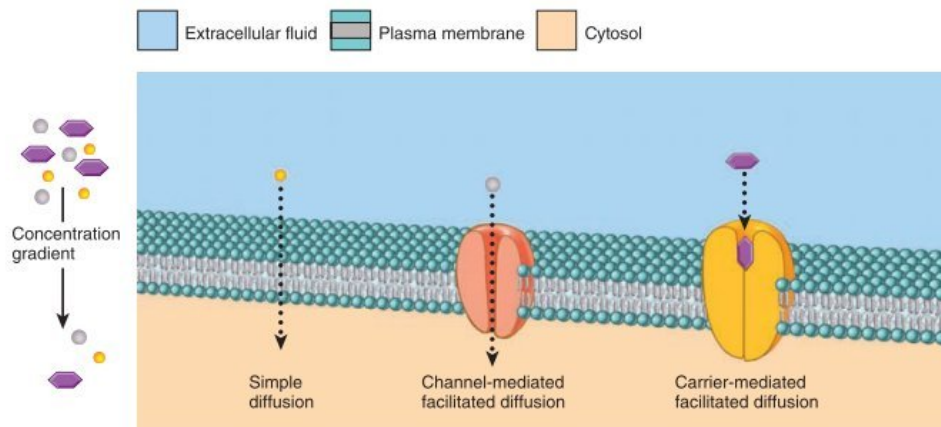


Figure 2.5 Facilitated diffusion (Tortora and Derrickson 2009)

concentration of salt on one side of the cell membrane means that there is less space for water molecules. Water then will move from the side where there is a greater number of water molecules through the cell membrane to the other side of the cell where there are fewer water molecules. This is known as osmotic pressure. The higher the concentration of the solute on one side of the membrane, the higher the osmotic pressure available for the movement of the water (Colbert *et al.* 2007).

The osmotic pressure can be sufficient to damage the cell membrane and therefore it is important for the cell to have a relatively constant pressure between the internal and external environment. If the osmotic pressure on one side of the cell is greater than that on the other side, changes to the cell could take place, resulting in cell damage. A red blood cell placed in a solution with less concentration of solute will undergo haemolysis and if placed in a fluid with high concentration of solutes the red blood cell will crenate (see Figure 2.6). On the other hand, if the red blood cell is placed in a solution with a relatively constant osmotic pressure between the internal and external environment, the red blood cell does not undergo any changes. The net movement of water in and out of the cell is minimal.

Filtration

Filtration is a process where small substances are forced through a selective permeable membrane by means of hydrostatic pressure. An example of filtration within the human body is at the capillary end of the blood vessels. With the aid of blood pressure, fluid and solutes are forced out of the single layered cells of the capillaries into the interstitial fluid space. Large molecules such as proteins and red blood cells remain in the capillaries. Another example of filtration that occurs in the human body takes place in the kidneys. Blood pressure forces water and dissolved wastes products such as urea and uric acid into the kidney tubules during the formation of urine (see Chapter 14, The renal system).

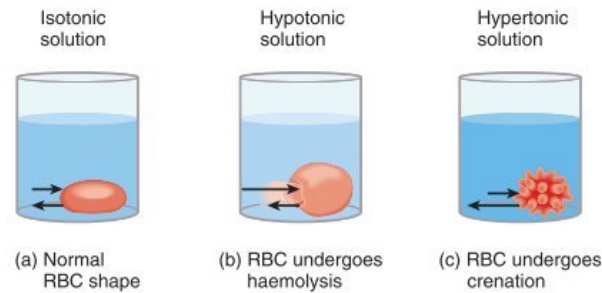


Figure 2.6 Effect of solute concentration on a red blood cell (Tortora and Derrickson 2009)

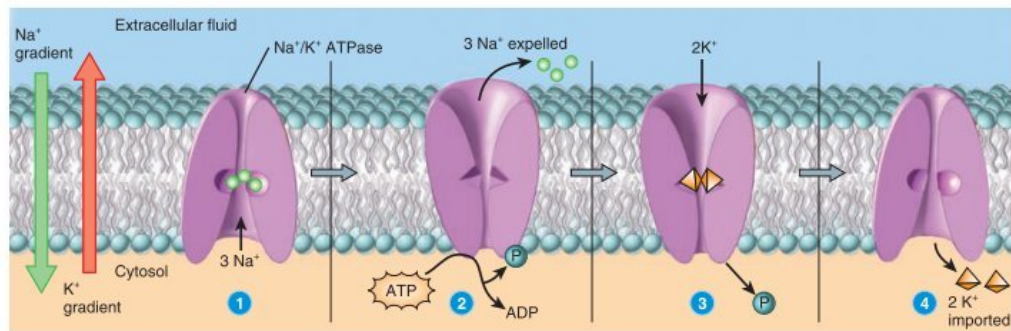


Figure 2.7 Active transport system (Tortora and Derrickson 2009)

Active transport system

The main difference between the active and passive transport systems is that the active transport system utilises cellular energy to move substances through a semipermeable membrane. The energy is obtained by splitting ATP into adenosine diphosphate (ADP) and phosphate (see Figure 2.7). Examples of active transport processes are active transport, endocytosis and exocytosis.

Active transport

An active process is one in which substances move against a concentration gradient from an area of lower to higher concentration. The cell must expend energy which is released by splitting ATP into ADP and phosphate. ATP is a compound made up of a base, a sugar and three phosphate groups (triphosphate). These phosphate groups are held together by high-energy bonds, which when broken release a high level of energy. Once one of these phosphate bonds has been broken and a phosphate group has been released, that compound now has only two phosphate groups (diphosphate) leaving a spare phosphate group, which in turn will join up with another adenosine diphosphate group, so forming another molecule of ATP (with energy stored in the phosphate bonds), and the whole process continues (Vickers 2009).

In the human body, the four main active transport systems considered when discussing cellular energy are:

- The sodium-potassium pump: sodium and potassium concentration gradients are generated to produce electrical energy
- The calcium pump: calcium ions essential for muscle contraction are transported into muscle cells
- The sodium-linked cotransporter: glucose and amino acids are actively transported into the cells and at the same time sodium moves passively via the cotransporter
- The hydrogen-linked cotransporter: glucose is actively transported into the cell and at the same time hydrogen ions move into the cell via the cotransporter.

Endocytosis

Endocytosis is the process by which cells take in molecules such as proteins from outside the cell by engulfing them with their cell membrane. It is used by all cells of the body because most substances important to them are polar and consist of big molecules, and thus cannot pass through the hydrophobic plasma membrane. During endocytosis only a small section of the cell membrane plays a part to form a fold and a new intracellular pod is formed containing the substance. There are three types endocytosis:

- Pinocytosis ('cell drinking'). In pinocytosis the molecule engulfed is relatively small (see Figure 2.8)
 - occurs in almost all cells
 - occurs continuously
- Phagocytosis ('cell eating') (see Figure 2.8)
 - results in the ingestion of particulate matter (e.g. bacteria) from the ECF
 - the endosome is so large that it is called a phagosome or vacuole
 - phagocytosis occurs only in certain specialised cells (e.g. neutrophils, macrophages)
 - occurs sporadically

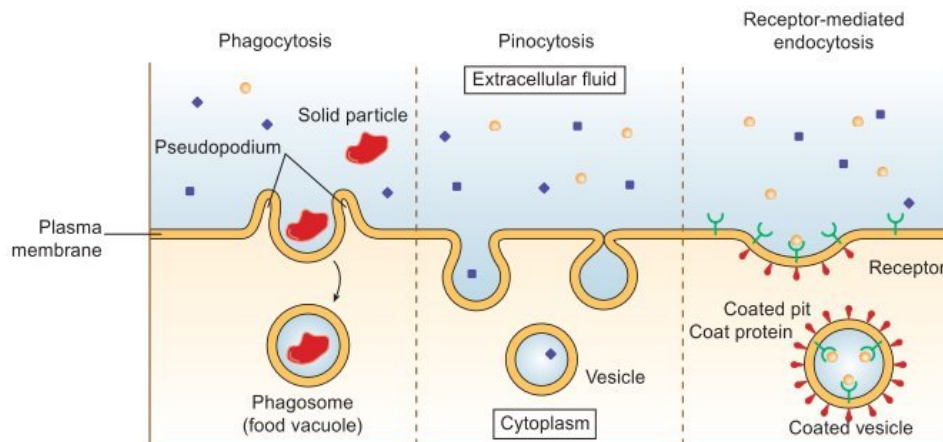


Figure 2.8 Pinocytosis, phagocytosis and receptor-mediated endocytosis

- Receptor-mediated endocytosis (see Figure 2.8)
 - involves specific receptors that bind to large molecules in the extracellular fluid
 - the substance bound to the receptor is called a ligand.

Exocytosis

Exocytosis is a process for moving items from the cytoplasm of the cell to the outside. The intracellular vesicle with its ingested substances fuses with the cell membrane to get rid of the unwanted substance from the cell (see Figure 2.9). This process is also utilised by nerve cells to release chemical messengers into the synapse of a neurone. Gland cells release proteins by exocytosis.

Many cells in the body use exocytosis to release enzymes or other proteins that act in other areas of the body, or to release molecules that help cells communicate with one another. For instance, clusters of α - and β -cells in the islets of Langerhans in the pancreas secrete the hormones glucagon and insulin, respectively. These enzymes regulate glucose levels throughout the body. As the level of glucose rises in the blood, the β -cells are stimulated to produce and secrete more insulin by exocytosis. When insulin binds to liver or muscle, it stimulates uptake of glucose by those cells. Exocytosis from other cells in the pancreas also releases digestive enzymes into the gut.

Cells also communicate with each other, through exocytosis, more directly through the products that they secrete. For instance, a neurone cell relays an electrical pulse through the use of neurotransmitters. The neurotransmitters are stored in vesicles and lie next to the cytoplasmic face of the plasma membrane. When the appropriate signal is given, the vesicles holding the neurotransmitters must make contact with the plasma membrane and secrete their contents into the synaptic junction, the space between two neurones, for the other neurone to receive those neurotransmitters.

Fluid compartments

The two principal body fluid compartments are intracellular and extracellular. The intracellular compartment is the space inside a cell and the fluid inside the cell is called intracellular fluid (ICF). The extracellular compartment is found outside the cell and the fluid outside the cell is called

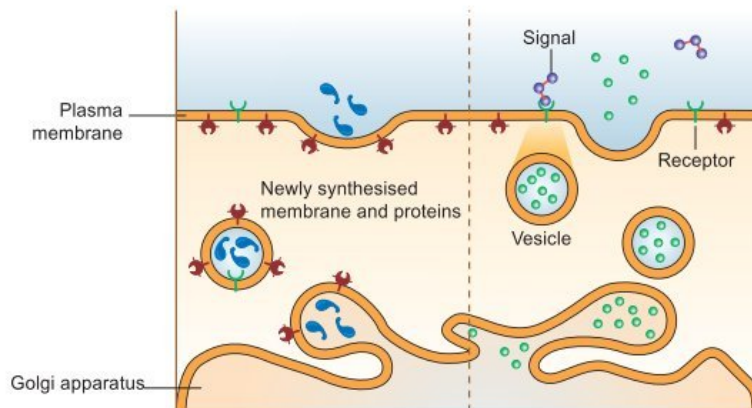


Figure 2.9 Exocytosis

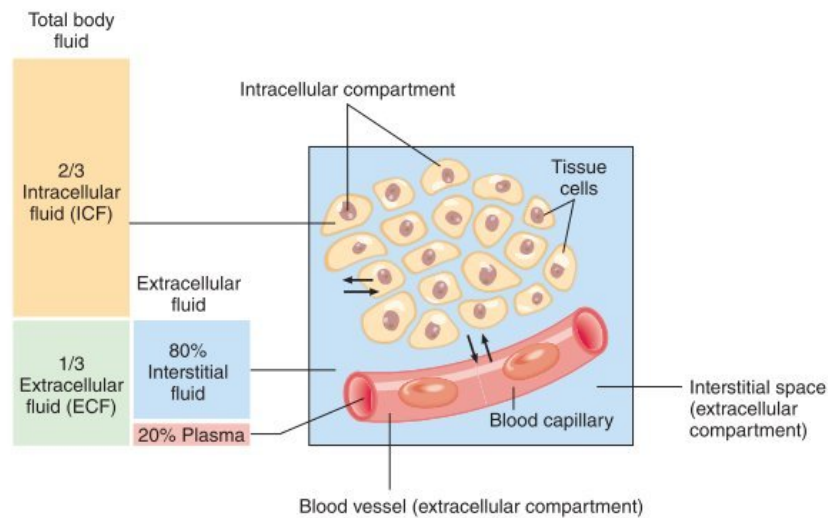


Figure 2.10 Fluid compartments and distribution (Nair and Peate 2009)

extracellular fluid (ECF). However, the extracellular compartment is further divided into the interstitial and the intravascular compartments. Two thirds of body fluid is found inside the cell and one third outside the cell. Eighty per cent of the ECF is found in the interstitial compartment and 20% in the intravascular compartment as plasma (see Figure 2.10).

Intracellular fluid (ICF)

- The ICF is primarily a solution of potassium and organic anions, proteins, etc.
- The cell membranes and cellular metabolism control the constituents of this ICF
- ICF is not consistent in the body; it represents a collection of fluids from all the different cells.

Extracellular fluid (ECF)

- The ECF primarily consists of NaCl and NaHCO_3 solution.
- The ECF is further subdivided into three compartments:
 - Interstitial fluid (ISF) surrounds the cells, but does not circulate. It comprises about three quarters of the ECF
 - Plasma circulates as the extracellular component of blood. It makes up about one quarter of the ECF
 - Transcellular fluid is a set of fluids that are outside of the normal compartments. These 1–2 litres of fluid make up the CSF, digestive juices, mucus, etc.

Movement of body fluid between compartments

The movement of fluid between the intracellular and the extracellular compartments is primarily controlled by two forces:

- Hydrostatic pressure: pressure exerted by the fluid
- Osmotic pressure: the pressure that must be exerted on a solution to prevent the passage of water into it across a semipermeable membrane.

Furthermore, the movement of fluid is dependent on solutes dissolved within the fluid; changes in the concentration of solutes will affect fluid movement between compartments. Similarly, changes in fluid volume will also affect the fluid movement between compartments. An example of fluid and solute movement that occurs in the body is when blood pressure (hydrostatic pressure) forces fluid and solutes from the arterial end of the capillaries into the interstitial fluid space (see Figure 2.11). Fluid and solutes return to the capillaries at the venous end as a result of the osmotic pressure. Fluid also enters the lymphatic capillaries from the interstitial space as a result of the osmotic pressure in the lymphatic vessels.

The movement of fluid between the intracellular and extracellular compartments is the result of hydrostatic and osmotic pressures. In a normal state of health, the hydrostatic pressure in the intracellular compartment and the interstitial space is in balance and therefore the fluid movement is minimal. However, changes in the osmotic pressure, either in the intracellular or extracellular compartments, can affect fluid movement. As the capillary barrier is readily permeable to ions, the osmotic pressure within the capillary is principally determined by plasma proteins that are relatively impermeable. Therefore, instead of speaking of 'osmotic' pressure, this pressure is referred to as the 'oncotic' pressure or 'colloid osmotic' pressure because it is generated by colloids. Albumin generates about 70% of oncotic pressure. This pressure is typically 25–30 mmHg. Oncotic pressure increases along the length of the capillary, particularly in capillaries having high net filtration (e.g. in renal glomerular capillaries), because the filtering fluid leaves behind proteins, leading to an increase in protein concentration.

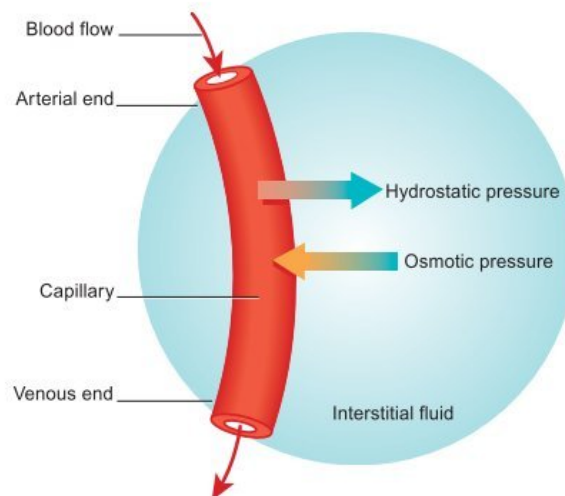


Figure 2.11 Capillary hydrostatic and osmotic pressures

Clinical considerations

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Intravenous infusion

Nurses are responsible for administering prescribed intravenous (IV) fluid. For a patient who is dehydrated, IV infusion is commenced for rehydration purposes. The fluid is instilled into the vascular space (extracellular compartment). Safe administration of intravenous fluid requires the nurse to understand the role of electrolytes and water in the body, the mechanism for movements between different body compartments and how fluid balance is maintained. Patients on intravenous infusion may not be able to take oral fluid as a result of their illness. The type of fluid to be administered depends on the patient's condition. Regardless of the type of intravenous fluid, nurses need to be aware that when patients are on fluid therapy, they need careful monitoring to ensure that the fluid is administered without complications, such as fluid overload.

Intravenous fluid can either be colloid or crystalloid. Colloid solutions in practice include albumin and gelfusin, and are also effective for volume replacement in major haemorrhage. Crystalloid solutions for intravascular volume replenishment are typically isotonic (e.g. 0.9% normal saline). Water freely travels outside the vasculature, so as little as 10% of isotonic fluid remains in the intravascular space. With hypotonic fluid (e.g. 0.45% normal saline), even less remains in the vasculature and thus is not ideal as fluid replacement.

Composition of body fluid

Body fluid is composed of water and dissolved substances such as electrolytes (sodium, potassium and chloride), gases (oxygen and carbon dioxide), nutrients, enzymes and hormones. Total body water constitutes 60% of total body weight and water plays an important part in cellular function (LeMone and Burke 2008). Water is essential for the body as it:

- Acts as a lubricant and so makes swallowing easy.
- Is the major component of the body's transport systems. The blood transports nutrients, oxygen, glucose and fats to various tissues and cells. Also, the waste products of cellular metabolism, such as lactic acid and carbon dioxide, are removed. Via urine, a number of waste products are transported out of the body, for example, urea, phosphates, sulphites, minerals, ketones from fat metabolism and nitrogenous waste from protein breakdown.
- Is needed for regulation of body temperature at 37°C. When body temperature starts to rise, blood vessels near the surface of the skin dilate to release some of the heat; the reverse happens when body temperature starts to drop. Also, when body temperature rises, sweat glands secrete sweat, which is 99% water. As the sweat evaporates, heat is removed from the body.
- Provides an optimum medium for the cells to function.
- There are chemical reactions in the body which require water. A synthesis reaction involves the joining of two molecules by the removal of a water molecule and a hydrolysis reaction involves a molecule being split into two smaller molecules with the addition of water.

- Breaks down food particles in the digestive system.
- Provides lubrication for the joints as it is a component of synovial fluid. It is also a component of tears which lubricate the eyes and of saliva to provide lubrication to food which aids chewing, swallowing and digestion. It also has a protective function, washing away particles that get into the eyes, providing cushioning against shock to the eyes and the spinal cord. It is also a component of amniotic fluid, which provides protection for the foetus during pregnancy.

Effects of water deficiency

Deficiency of water in the body can affect various functions and in severe conditions may lead to death. Some of the problems associated with water deficiency include:

- Low blood pressure
- Problem with clotting of blood
- Kidney dysfunction leading to renal failure
- Severe constipation
- Multisystem failure
- Proneness to infection
- Electrolyte imbalance.

Electrolytes

Chemically, electrolytes are substances that become ions in solution and acquire the capacity to conduct electricity. Electrolytes are present in the human body, and the balance of the electrolytes in our bodies is essential for normal function of our cells and our organs.

Fluid balance is linked to electrolyte balance. Electrolytes are chemical compounds that dissociate in water to form charged particles called ions (Lemone and Burke 2008). They include potassium (K), sodium (Na), chloride (Cl), magnesium (Mg) and phosphate (HPO_4). Electrolytes are either positively or negatively charged. Positively charged ions are called cations (for example, Na^+ and K^+) and negatively charged ions are called anions (for example, Cl^- and HCO_3^-). Remember that an anion and a cation will combine to form a compound, for example, potassium (K^+) and chloride (Cl^-) combine to form potassium chloride (KCl). The composition of electrolytes differs between the intracellular and the extracellular compartments (see Figure 2.12).

Functions of electrolytes

Electrolytes are compounds that dissociate into ions when placed in liquid, thus enabling the liquid to conduct an electric current. The positive ions are called cations and the negative ions are called anions. An electrolyte is a compound that does not form ions in solution. Electrolytes have numerous functions in the body. They:

- Regulate fluid movement between compartment
- Regulate hydrogen-ion concentration for normal cellular function

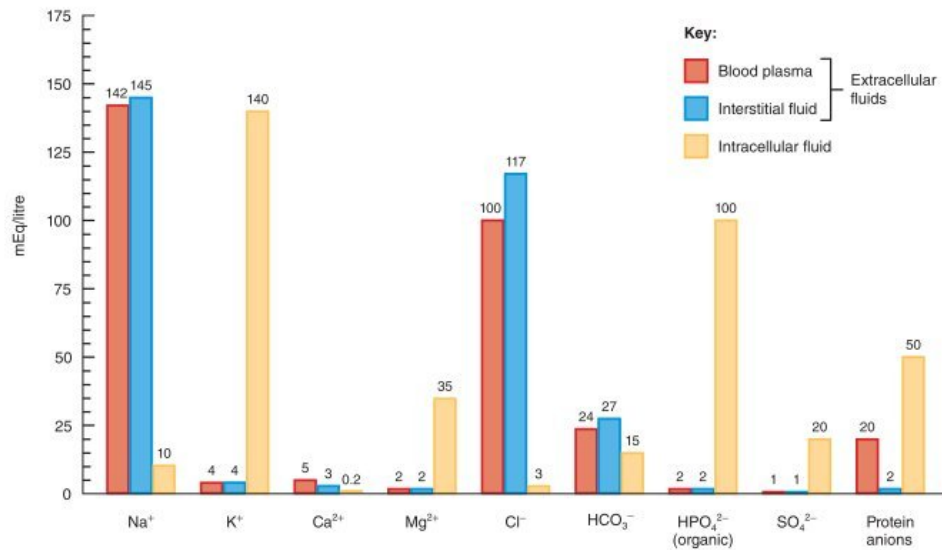


Figure 2.12 Electrolytes of intracellular and extracellular compartments (Nair and Peate 2009)

- Play a vital role in membrane potentials and action potentials
- Are essential for neuronal function.

To function normally, the body must be able to maintain the levels of electrolytes within very narrow limits. These limits are controlled by hormones. The body maintains the levels of electrolytes in each compartment (cells, tissues, organs) by moving electrolytes into, or out of, cells based upon the signals provided by the hormones. If the balance of electrolytes is disturbed, disorders can develop. An imbalance of electrolytes can occur if a person:

- Uses certain drugs, especially long-term use of laxatives and/or diuretics
- Becomes dehydrated as a result of profuse sweating, vomiting, chronic diarrhoea, very poor nutrition, etc.
- Has certain heart, liver or kidney disorders
- Is given intravenous fluids in inappropriate amounts.

Loss of electrolytes can have serious consequences for the body. In severe dehydration, the loss of electrolytes can result in circulatory problems, such as tachycardia (rapid heartbeat), and problems with the nervous system, such as loss of consciousness or shock. See Table 2.2 for a summary of electrolytes and their functions.

Table 2.2 Principal electrolytes and their functions

Electrolytes	Normal values in extracellular fluid	Function	Main distribution
Sodium (Na^+)	135–145 mmol/L	Important cation in generation of action potentials. Plays an important role in fluid and electrolyte balance. Increases plasma membrane permeability. Helps promote skeletal muscle function. Stimulates conduction of nerve impulses. Maintains blood volume	Main cation of the extracellular fluid
Potassium (K^+)	3.5–5 mmol/L	Important cation in establishing resting membrane potential. Regulates acid-base balance. Maintains intracellular fluid volume. Helps promote skeletal muscle function. Helps promote the transmission of nerve impulses	Main cation of the intracellular fluid
Calcium (Ca^{2+})	2.1–2.6 mmol/L	Important clotting factor. Plays a part in neurotransmitter release in neurones. Maintains muscle tone and excitability of nervous and muscle tissue. Promotes transmission of nerve impulses. Assists in the absorption of vitamin B_{12}	Mainly found in the extracellular fluid
Magnesium (Mg^{2+})	0.5–1.0 mmol/L	Helps to maintain normal nerve and muscle function; maintains regular heart rate, regulates blood glucose and blood pressure. Essential for protein synthesis	Mainly distributed in the intracellular fluid
Chloride (Cl^-)	98–117 mmol/L	Maintains a balance of anions in different fluid compartments. Combines with hydrogen in gastric mucosal glands to form hydrochloric acid. Helps to maintain fluid balance by regulating osmotic pressure	Main anion of the extracellular fluid
Hydro carbons (HCO_3^-)	24–31 mmol/L	Main buffer of hydrogen ions in plasma. Maintains a balance between cations and anions of intracellular and extracellular fluids	Mainly distributed in the extracellular fluid
Phosphate – organic (HCO_4^-)	0.8–1.1 mmol/L	Essential for the digestion of proteins, carbohydrates and fats and absorption of calcium. Essential for bone formation	Mainly found in the intracellular fluid
Sulphate (SO_4^{2-})	0.5 mmol/L	Involved in detoxification of phenols, alcohols and amines	Mainly found in the intracellular fluid

Hormones that regulate fluid and electrolytes

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The three principal hormones that regulate fluid and electrolyte balance are antidiuretic hormone (ADH), aldosterone and atrial natriuretic peptide (Thibodeau and Patton 2007).

Antidiuretic hormone

Antidiuretic hormone (ADH) is a peptide and its main role is to regulate fluid balance in the body. This hormone is produced in the hypothalamus by neurones called osmoreceptors and it is stored in the posterior pituitary gland. Osmoreceptors are sensitive to plasma osmolality and a decrease in blood volume. The target organs for ADH are the kidneys. ADH acts on the distal convoluted tubule and the collecting ducts which make the tubules more permeable to water, thus increasing reabsorption of water. This occurs through insertion of additional water channels (Aquaporin-2s) into the apical membrane of the tubules and collecting duct epithelial cells. The aquaporins allow water to pass out of the nephron (at the distal convoluted tubules and the collecting tubules) and into the cells, increasing the amount of water reabsorbed from the filtrate. Therefore, when a person is lacking fluid, as in dehydration, more ADH is released, thus increasing water reabsorption resulting in less fluid loss. The secretion of ADH is decreased by a drop in plasma osmotic pressure, increased extracellular fluid volume and increased alcohol intake. ADH is also known as vasopressin because it causes constriction of arterioles, thus raising blood pressure.

Aldosterone

Aldosterone is a steroid hormone produced by the adrenal glands which are situated on top of each kidney. The adrenal gland is divided into the cortex and medulla. The cortex produces aldosterone. Aldosterone regulates electrolyte and fluid balance by increasing the reabsorption of sodium and water and the release of potassium in the kidneys. This increases blood volume and therefore increases blood pressure. Aldosterone stimulates H^+ secretion by intercalated cells in the collecting duct, regulating plasma bicarbonate (HCO_3^-) levels thus maintaining the acid base and electrolyte balance. The main target areas for aldosterone are the kidney tubules and the collecting duct epithelial cells.

Atrial natriuretic peptide

Atrial natriuretic peptide (ANP), atrial natriuretic factor (ANF), atrial natriuretic hormone (ANH), or atriopeptin, is a powerful vasodilator and a polypeptide hormone secreted by heart muscle cells (myocytes). The myocytes produce, store and release ANP in response to atrial stretch. It is involved in the homeostatic control of body water, sodium, potassium and fat (adipose tissue). It is released by muscle cells in the upper chambers (atria) of the heart (atrial myocytes), in response to high blood pressure. ANP acts to reduce the water, sodium and adipose loads on the circulatory system, thereby reducing blood pressure. ANP stimulates vasodilation, increased glomerular filtration and salt and water excretion, and blocks the release and/or actions of several hormones, including angiotensin II, aldosterone and vasopressin. ANP levels are commonly elevated in situations of excessive fluid volume or hypertension, and the hormone plays an important role in regulating fluid/electrolyte balance.

Clinical considerations

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Hyponatraemia

Hyponatraemia is the commonest electrolyte imbalance encountered in clinical practice. In healthy individuals, the normal range for serum sodium is 135–147 mmol/l. In hyponatraemic patients, serum sodium levels fall below 135 mmol/l. Hyponatraemia can be fatal; in less severe cases it can significantly impede the patient's recovery. Common symptoms include weakness, agitation, confusion, nausea and vomiting. Hyponatraemia may occur when there is an excessive consumption of water, which dilutes electrolytes in the body, and/or excessive sweating or electrolyte loss as a result of vomiting and/or diarrhoea.

Causes of hyponatraemia include:

- Burns
- Congestive heart failure
- Diarrhoea
- Use of medications called diuretics, which increase urine output
- Kidney diseases
- Liver cirrhosis
- Syndrome of inappropriate antidiuretic hormone secretion (SIADH)
- Sweating
- Vomiting.

Mild chronic hyponatraemia may not require treatment other than adjustments in diet, lifestyle or medications. For severe or acute hyponatraemia, treatment typically involves the intravenous administration of fluids and electrolytes. In this case medications are often needed to treat the underlying cause of the hyponatraemia as well as medications to manage the symptoms.

Conclusion

Cells are the basic living structures of the body and they contain special proteins that perform specific functions to maintain homeostasis within the cell. All cells have four basic parts: cytoplasm, plasma membrane, nucleus and nucleolus. Although the cell membrane is in a constant state of flux, it allows substances in and out of the cell. The nucleus is the place where genetic information is stored. Cells utilise various transport systems to move nutrients, oxygen, electrolytes, water and hormones into the cell and waste products of cellular metabolism, such as carbon dioxide, urea and uric acid, out of the cell. Electrolytes and hormones play a vital role in maintaining homeostasis. Many hormones, such as antidiuretic hormone, aldosterone and atrial natriuretic hormone, help to regulate fluid balance and maintain homeostasis.

Body fluids consist of water and substances dissolved in it. Water is the main component of the human body and, in any individual, the body water content stays remarkably constant from day to day. There is constant movement of fluid between compartments. There are two main body fluid compartments: inside and outside the cells (intracellular and extracellular).

The extracellular compartment is divisible into (a) the plasma, which is extracellular fluid within the blood vessels; (b) the interstitial fluid, which is extracellular fluid outside the blood vessels and separated from plasma by the walls of the capillaries; and (c) transcellular fluids, which are fluids with specialised functions. They include synovial fluid (which lubricates joints), cerebrospinal fluid (which cushions and nurtures the brain) and the aqueous and vitreous humours of the eyes (which maintain the shape of the eyeball and the integrity of structures within it). The transcellular fluids are separated from the plasma by a cellular membrane, which takes part in their formation, in addition to the capillary wall.

Glossary

Active transport:	The process in which substances move against a concentration gradient by utilising cellular energy.
Adenosine diphosphate:	ADP is the end-product that results when ATP loses one of its phosphate groups located at the end of the molecule.
Adenosine triphosphate:	Compound that is necessary for cellular energy.
Chemical reactions:	Reactions that involve molecules, in which they are formed, changed, or broken down.
Compartments:	Spaces.
Cytoplasm:	Fluid found inside the cell.
Diffusion:	The most common form of passive transport of materials, it is the ability of gases, liquids and solutes to disperse randomly and to occupy any space available, so that there is an equal distribution.
Electrolytes:	Substances that dissociate in water to form ions.
Endocytosis:	Processes by which cells ingest foodstuffs and infectious micro-organisms.
Extracellular:	Space found outside the cell.
Exocytosis:	The system of transporting material out of cells.
Facilitated diffusion:	Diffusion with the aid of a transport protein.
Hydrophilic:	Water-loving.
Hydrophobic:	Water-hating.
Hypertonic:	Solution that has large amount of solutes dissolved in it.
Hypotonic:	Solution that has low concentration of solutes.

Interstitial:	Space between cells.
Intracellular:	Space inside the cell.
Organelles:	Structural and functional parts of a cell.
Osmosis:	Movement of water through a selectively permeable membrane so that concentrations of substances in water are the same on either side of the membrane.
Osmotic pressure:	The pressure that must be exerted on a solution.
Passive transport:	The process by which substances move on their own down a concentration gradient without utilising cellular energy.
Plasma membrane:	Outer layer of the cell.
Transport protein:	Small molecules that help in the movement of ions across a cell membrane.

References

- Colbert, B.J., Ankney, J. and Lee, K.T. (2007) *Anatomy and Physiology for Health Professionals: An Interactive Journey*. Upper Saddle River, NJ: Pearson Prentice Hall.
- LeMone, P. and Burke, K. (2008) *Medical-Surgical Nursing: Critical Thinking in Client Care*, 4th edn. Upper Saddle River, NJ: Pearson Education.
- Marieb, E.N. and Hoehn, K. (2007) *Human Anatomy and Physiology*, 7th edn. San Francisco: Pearson Benjamin Cummings.
- Nair, M. and Peate, I. (2009) *Fundamentals of Applied Pathophysiology: An Essential Guide for Nursing Students*. Oxford: Wiley-Blackwell.
- Thibodeau, G.A. and Patton, K.T. (2007) *Anatomy and Physiology*, 6th edn. St Louis, MO: Elsevier Mosby.
- Tortora, G.J. and Derrickson, B.H. (2009) *Principles of Anatomy and Physiology*, 12th edn. Hoboken, NJ: John Wiley & Sons.
- Vickers, P.S. (2009) Cell and body tissue physiology. In: Nair, M. and Peate, I. (eds) *Fundamentals of Pathophysiology*. Chichester: John Wiley & Sons.

Activities

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Multiple choice questions

1. Which of the following is not made of microtubules?
 - (a) centrioles
 - (b) microvilli
 - (c) cilia
 - (d) cytoskeleton

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