OCR (A) Biology A-level

Topic 5.1: Communication and homeostasis

Notes

Communication is essential for the survival of organism as all living organisms must be able to **detect and respond to changes** in their **internal and external environments**. In multicellular organisms, the change necessary for survival is triggered by **nervous and endocrine systems.**

Cell signalling involves the communication between cells, in the form of **electrical signals** which are carried by neurones or with the help of hormones**. Neuronal cell signalling** is faster and short term whereas chemical is slower and long term.

Cell signalling in the form of **endocrine signalling** can be used for long distance signalling, where the signalling molecule is carried by the **circulatory system**. Other examples of signalling include paracrine signalling which occurs between cells which are in close proximity to each other and occurs directly or with the help of extracellular fluid. **Autocrine signalling** is a form of signalling where the cell releases signals to stimulate its own receptors thus triggering a response within itself.

Homeostasis

Homeostasis serves to ensure that **a constant internal environment** consisting of factors such as **temperature, water potential, pH and blood glucose level** is maintained, **despite changes in the external environment** of the organism.

This is achieved with the help of **negative feedback which counteracts any change in internal conditions**. This means that all changes are **reversed to restore the optimum conditions**. In order for the negative feedback pathway to work, the following elements need to be present:

- **sensory receptors** such as temperature receptors **to detect changes in internal conditions**,
- **effectors such as muscles and glands which can provide a response.**
- **I**n a case where a change is detected, the **receptors** pass the message either via the **nervous or hormonal system** to the **effectors** such as liver or muscles which bring about a response to restore the optimum conditions.

Another example of a control pathway is **positive feedback** which doesn't occur as often as negative and has an opposing effect in that it increases the original change in the conditions. An example of positive feedback is **dilation of the cervix during childbirth.**

Thermoregulation

An **ectotherm** is an organism which regulates its body temperature with the help of external source. Ectotherms are **unable to increase their respiration rate to increase the internal production of heat therefore they cannot rely on internal energy sources**. Therefore, they control their body temperature by **exchanging heat with their surroundings**, for instance by exposing their body to sun, orientating it to either minimise or maximise sun exposure, hiding away from sun or increasing breathing for heat loss via evaporation of water.

Endotherms are able to maintain a **constant body temperature**, independent of the external temperature. They contain **thermoreceptors which monitor core body temperature changes** and communicate them to the **hypothalamus which in turn coordinates**

appropriate responses to restore the optimum temperature through either physiological or behavioural responses. Actions taken by endotherms to control body temperature through heat gain or heat loss include:

- **Shivering** – contractions of **skeletal muscles** stimulated by nerve impulses sent out by the hypothalamus, lead to increase in temperature as heat is released
- **Sweat glands** – sweat production to **decrease body temperature via evaporation**
- Hairs on skin – lie flat to minimise insulation and increase heat loss, raised to **provide insulation** and reduce heat loss
- **Arterioles** – **dilate** to increase heat loss as blood flows closer to skin, **constrict** to reduce blood flow and therefore minimise heat loss

Excretion as Homeostatic Control

During metabolism, **waste products** are produced, that is products not required by cells such as carbon dioxide or nitrogen containing ammonia. As the majority of waste products are toxic, the removal of metabolic waste known as **excretion** is of high importance.

Liver

The **liver** plays an important role in excretion – it breaks down harmful substances as well as **toxic waste**. It converts the substances into less harmful forms, ready to be disposed of via excretion.

The liver is composed of **liver lobules** which are cylinders made of **hepatocytes** arranged in rows, connected at the centre. Each lobule is connected to the **hepatic vein**, that is the vein which takes deoxygenated blood away from the liver, through the **central vein**. Each lobule is also connected to the hepatic artery responsible for supplying the liver with oxygenated blood. Apart from this, the lobule is connected to the **hepatic portal vein** which contains the products of digestion, as well as the **bile duct** which is involved in transport of bile, a fat emulsifier, to the **gall bladder** to be stored. **Sinusoids**, a type of capillary connect the central vein to the hepatic artery and portal vein. The hepatocytes break down the toxic substances which then re-enter the blood which runs to the central vein, and eventually reaches the hepatic vein. Sinusoids are specially adapted for their role – they contain **Kupffer cells** which are involved in the break down of old red blood cells as well as removal of bacteria.

The liver is also involved in the breakdown of **excess of amino acids** coming from the digestion of protein. The reason why the excess amino acids need to be excreted is because nitrogenous substances are **damaging to the body** therefore if they are not used up, they must be excreted.

The first step of amino acid excretion is the **deamination,** that is the removal of the amino group from excess amino acids, leading to formation **of ammonia and organic acids**. In the next step, respiration of the acids occurs to produce ATP or alternatively, the acids are

converted to carbohydrates and stored as glycogen. Ammonia is converted to **urea** by the addition of carbon dioxide in the **ornithine cycle**. All of this occurs in the **hepatocytes**. Finally, the urea is released from liver into the blood and subsequently filtered out by the kidneys to produce **urine**.

Apart from this, the liver is involved in the **detoxification** process, that is the removal of harmful substances such as drugs and alcohol. For instance, the liver breaks alcohol down into **ethanal** which is further broken down into **acetic acid.**

Kidneys

The main role of the kidneys is **excretion of waste products**, such as urea in the form of urine.

Summary of kidney function:

- Blood enters the kidney through the **renal artery** and subsequently passes through the **capillaries in the cortex** of the kidneys.
- The waste products are **filtered out of the blood** as it passes through the capillaries and into the **long tubules called nephrons** which surround the capillaries in a process known as **ultrafiltration**.
- **Selective reabsorption** is the name of a process where useful substances such as **amino acids, glucose, vitamins** are reabsorbed back through the tubules in the medulla.
- The substances to be excreted pass along the **tubules and ureter** and finally reach the bladder where they're disposed of as urine.
- The filtered blood then passes out of the kidneys through the **renal vein**.

Ultrafiltration

Blood arrives at the **Glomerulus** through the **afferent arteriole**. The Glomerulus is a capillary bed found within the **Bowman's Capsule** of the Nephron. Blood leaves the glomerulus through the **efferent arteriole**. The afferent arteriole has a wider lumen than the efferent arteriole allowing hydrostatic pressure to build in the gomerulus.

Water containing molecules of less than 69,000 Mr is able to leave the capillary and enter the Bowman's capsule having passed through a number of barriers. The fluid passes through the holes in capillary **endothelium**, the **basement membrane** (made of collagen) and then through the **epithelium** of the Bowman's capsule itself. The fluid is now called filtrate.

Molecules that can pass through these barriers are water, glucose, amino acids, urea, ions and hormones. **Red blood cells and plasma proteins can't pass into the nephron due to their large size.**

Selective Reabsorption

Many of the molecules lost into the nephron are needed by the body so **selective reabsorption** happens in the **proximal convoluted tubule (PCT)**.
100% of **glucose and amino acids** are reabsorbed in this part of the nephron. A large proportion of water and salts are also reabsorbed here.
The cells lining the PCT are adapted for this function by having **microvilli** (large surface area) and **many mitochondria** (to provide the ATP for active transport)

Glucose and amino acids are reabsorbed by active transport by **co-transporter** proteins (Na^+ needs to be reabsorbed at the same time)

Loop of Henle

The main function of the Loop of Henle is to **produce a low water potential in the medulla of the kidney**. It does this by acting as a **countercurrent multiplier** to produce concentration gradients.
The **descending limb** is permeable to water and so as filtrate flows down this part of the loop its water potential decreases. The filtrate's water potential is at its lowest at the bottom of the loop. The **ascending limb** is impermeable to water but allows the movement of Na^+ and Cl^- out of the filtrate so the water potential of the filtrate rises again.

This process allows the kidney to produce **urine that is more concentrated than the blood**.

Control of water potential of the blood

In the case of **dehydration**, where the water potential of blood is too low, more water is **reabsorbed into the blood by osmosis from the loop of Henle, the distal convoluted tubule and collecting duct** thus leading to production of more concentrated urine and vice versa in the case of water content of blood being too high. **It is an example of negative feedback.**
Hormones play an important role in controlling the reabsorption of water.

Osmoreceptors in the **hypothalamus** control the water potential of the blood. In the case where the osmoreceptors detect the occurrence of low water potential of the blood, the hypothalamus sends nerve impulses **to posterior pituitary gland** to release **antidiuretic hormone (ADH)** into the blood which makes walls of **DCT and collecting duct** more permeable to water therefore increasing the reabsorption of water from the tubules into the blood. This results in a lower volume of more **concentrated urine** being produced to ensure that less water is lost from the body. The opposite occurs in the case where the body is well hydrated.

ADH works by binding to **receptors** in the plasma membrane of collecting duct cells. This activates enzymes in the cell to produce more **cAMP** (secondary messenger) which in turn causes **vesicles** in the collecting duct cell to **fuse** with the plasma membrane in contact with the filtrate. The membranes of the vesicles have **aquaporins** (water channel proteins) so

when these are inserted into the plasma membrane it makes the cells more permeable to water.

Kidney failure

Kidney failure can be triggered by various **kidney infections** which cause **inflammation**. The resulting damage causes the kidneys to perform processes such as **filtration and reabsorption** less efficiently. High blood pressure can also cause damage to the kidney by damaging the **capillaries of glomeruli** thus meaning that larger molecules can find their way into urine.

The consequences of kidney failure include the **build-up of toxic waste** products such as urea which causes symptoms such as vomiting. In cases where excess water cannot be removed from the blood by the kidneys, **fluid accumulation** occurs which leads to swelling. Apart from this, kidney failure can **disrupt the balance of ions**, resulting in making the bones **more brittle** or causing water to be retained.

If not treated, kidney failure may cause death.

Kidney failure can be treated with a **renal dialysis** which filters the blood with the help of a machine containing **dialysis fluid** which serves as a means of removing the waste products as well as excess water and ions. Dialysis is only a temporary solution while the patient awaits a transplant. Dialysis needs to be performed several times a week and causes the patient to feel unwell between sessions as the toxic waste builds up.
There are 2 types of dialysis:

- **Haemodialysis** – removes blood from the body and pumps it through a machine where the blood is run in **countercurrent** flow alongside dialysis fluid. These fluids are separated by an **artificial membrane** so must rely on diffusion gradients for molecules to move from one fluid to the other. A blood thinning agent must be added to avoid the blood clotting outside of the body.
- **Peritoneal** dialysis – dialysis fluid is put into the body cavity so that exchange can happen across the **body's own peritoneal membrane**. The fluid must be drained and replaced.

Kidney transplant is required to replace the damaged kidney and to reverse kidney failure symptoms, it is believed to be the better solution as it is a long term solution. Sometimes patients need to wait a long time for a **suitable donor** which needs to be of the **same blood type and tissue type** to minimise the risk of rejection. However, **immunosuppressants** still need to be taken by the patient to prevent rejection. In most cases a donor is a family member due to the degree of similarity, this is possible as only one kidney is required for survival.

Medical diagnosis

Urine samples can be used in diagnostic tests such as **pregnancy testing** with the use of **monoclonal antibodies** which test for the presence of **human chorionic gonadotropin** which is found in the urine of pregnant women.

Urine samples can also be used to test for the presence of **anabolic steroids**. Anabolic steroids are used to **build muscle mass** which are banned due to their **dangerous side effects**

as well as to ensure that the **competition between athletes is fair**. The presence of steroids is detected via **gas chromatography** by measuring the time taken for the urine sample to pass the column compared to the time taken for a steroid to pass through.

Neuronal communication

The nerve cells called **neurones** play an **important role in coordinating communication** within the nervous system.

The **structure of all neurones is similar**, as they all have **a cell body containing the nucleus** as well as **organelles such as mitochondria within the cytoplasm**. Neurones also haveextensions called **dendrites** involved in conducting impulses towards the cell body, as well as **axons** which conduct them away from the cell body.

There are three types of neurones, **sensory, motor and relay** with different functions which differ by the position of the cell body within the neurone.

Motor neurones are involved in transmitting electrical impulses from the central nervous system to muscles and glands in the body.

Sensory neurones transmit impulses from receptors to the central nervous system whereas the **relay neurons,** which are located within the central nervous system, are involved in transmitting the electrical impulses from sensory neurones to motor neurones.

The structure of neurones, that is the length of axons as well as the **polarised** nature of the neurone membrane in the resting state where the **outside of the membrane is positively charged** and the **inside is negatively charged** enables the neurones to carry electrical impulses called **action potentials**.

The speed at which the electrical potential is carried can be increased with the help of **myelin sheath** which serves as an insulator of axons and dendrons produced by **Schwann cells**. The mechanism by which the speed is increased is known as **saltatory conduction** where the action potential jumps between gaps in the myelin sheath called **nodes of Ranvier.**

Nerve impulse conduction

As previously mentioned, nerve cells are **polarised in their resting state**. This occurs as a result of **imbalance between sodium ions and potassium ions**, thus giving the inside of the nerve cell a negative charge in comparison to the external environment. As a result of the polarisation, there is a difference in the voltage across the neurone membrane, with a value of -70mV known as the **resting potential**.

This resting potential is generated, as well as maintained, with the help of **sodium-potassium pump** which **moves sodium ions out of the neurone** thus creating an electrochemical gradient as the **concentration of sodium ions is higher outside the cell** because the **membrane is not permeable to sodium ions**. The sodium-potassium pump is also involved in **transporting the potassium ions into the neurone**. However, the **potassium ions diffuse**

back out due to the presence of potassium ion channels. As a result of that, the **outside of the cell is positively charged** due to the imbalance of positively charged ions.

Upon stimulation, the neurone cell membrane becomes **depolarised**. This occurs as following:

- firstly, the excitation of neurone cell triggered by stimulus **causes the sodium ion channels to open**, as a result **making it more permeable to sodium ions** which subsequently **diffuse into the neurone** down the electrochemical gradient, as a result **making the inside less negative**.
- Upon reaching the threshold of **-55mV**, even **more sodium channels open** eventually giving a potential difference of **+30mV** which is the end of the depolarisation and start of **repolarisation**.
- Repolarisation is achieved as a result of **sodium ion channels closing and potassium ion channels opening**. The **potassium ions diffuse out of the neurone** down the concentration gradient and eventually **restore the resting potential**.
- However, as the **closing of potassium ion channels is slightly delayed**, this leads to **hyperpolarisation** i.e. when the potential difference becomes greater than the resting potential. The resting potential is then reestablished with the help of the sodium-potassium pump which returns the potential difference to the value of -70mV.

The action potential travels along the neurone as a **wave of depolarisation** where the **sodium ions move through the cytoplasm to the adjacent resting region** where they **trigger a change in potential difference**, thus **stimulating another action potential**.

Afterwards, there is a short period during which the neurone membrane cannot be excited as the sodium channels enter a recovery stage. This period is known as the **refractory period** and serves an important role in ensuring that the **action potentials can only pass in one direction as discrete impulses**.

Synapses

Synapses are junctions between two neurones. Upon the arrival of an action potential, the **presynaptic membrane** depolarises therefore **causing the calcium ion channels to open** which subsequently **allow calcium ions to enter the neurone**. The presence of calcium ions in the neurone causes **the fusion of synaptic vesicles** filled with a particular neurotransmitter such as **acetylcholine** to **fuse with the presynaptic membrane** thus causing the release of neurotransmitter into the **synaptic cleft** (the gap between the two neurons). The neurotransmitters diffuses across the synaptic cleft where they **bind to the receptors** located on the postsynaptic membrane therefore **stimulating the opening of cation channels** which enable sodium ions to enter the neurone. As a result of that, the post-synaptic membrane depolarises therefore **triggering another action potential**. This process only occurs if the neurotransmitter originates from an **excitatory neurone**. In the case of **inhibitory neurones**, chloride ion channels open, thus causing hyperpolarisation of the post synaptic membrane therefore triggering a new action potential becomes more difficult.

This sequence of events is controlled with the help of digestive enzymes in the synaptic cleft which serve to break down the neurotransmitter to prevent overstimulation of the post-synaptic membrane. Following the breakdown of the neurotransmitter, it is **taken up by the pre-synaptic membrane and reused**. Apart from this, the **presence of receptors on one**

side of the synapse only, that is the post-synaptic side serves to ensure that the **action potential can only travel in one direction only.**

Detection of stimuli

Cells specialised for detection of stimuli are known as **receptors**. Sense organs such as the ear, eye and skin are composed of groups of receptors. Receptors are described as **transducers** as they are able to **convert one form of energy into another form**.

Pacinian corpuscles are pressure receptors found in the skin. They convert **mechanical** energy into **electrical** energy. When a Pacinian corpuscle is squashed the plasma membrane is **deformed** and this makes it **more permeable to sodium ions** which starts **depolarization** in the sensory neurone.

All action potentials have the same magnitude (change in polarisation) therefore this can't be used by the brain to interpret the **strength of stimulus**. Instead it is the **frequency of action potentials** that conveys this information. **The stronger the stimuli the more frequent the action potentials.**

Hormonal communication

Hormones are signalling molecules secreted by ductless **endocrine glands**, such as adrenal glands which secrete them directly into the blood. Hormones only affect target cells which contain complementary receptors on their plasma membrane, thus **making them very specific**.

An **exocrine gland** is a gland that secretes substances into a duct which then carries the molecules to a particular target in the body.

Adrenal glands

Adrenal glands are located above the kidneys and are composed of an outer **adrenal cortex** surrounding the inner **adrenal medulla**. The **medulla secretes adrenaline** in response to danger, stress or excitement which is involved in the fight or flight response. The adrenal cortex produces **mineralocorticoids** such as aldosterone which targets the kidney and gut to control the **concentration of sodium and potassium ions in the blood**. It also secretes **glucocorticoids** such as cortisol and corticosterone which stimulate an **increase in blood glucose concentration**.

Pancreas

The pancreas functions in both an endocrine and exocrine way. The **Islets of Langerhans have an endocrine function** which **involves secreting insulin from beta cells** and **glucagon from alpha cells** directly into the blood. The **exocrine function of the pancreas involves secreting digestive enzymes** such as amylase, trypsin and lipase to the duodenum via the pancreatic tract.

The **alpha and beta cells** mentioned above **contain many ribosomes and RER** to efficiently manufacture protein hormones.They also **contain a large number of Golgi** involved in packaging the hormones into vesicles, the hormones are then secreted via exocytosis from secretory vesicles. As the cells are very active, they contain a large number of mitochondria for ATP production.

Blood glucose regulation

The concentration of glucose in blood varies depending on food intake and energy requirements. It is **important to keep the blood glucose concentration in the correct range** of about 90mg per 100cm3 of blood to **ensure that all the essential processes such as respiration of brain cells is maintained**. However, if the concentration of blood glucose is too high, it is **excreted in urine** thus meaning it is of **no use to the body** as it cannot be stored in the form of either glycogen or fat.

In a case where the blood glucose concentration is too high, for instance after a meal high in carbohydrates, the following actions take place:

- The rise in glucose concentration is detected by the **beta cells**
- Insulin is secreted by beta cells, thus inhibiting the action of **alpha cells**
- Insulin travels to target cells in the liver (**hepatocytes)**, fat and muscle cells
- Binding of insulin to the receptors on the plasma membrane of these cells causes **vesicles containing glucose transport proteins** to fuse with the cell membrane.
- This **increases the permeability of the cells** to glucose, increasing the rate of glucose uptake into the cell. The glucose are then **converted to glycogen or fats** (stored in the muscle) and subsequently used for respiration

In a case where the blood glucose concentration is too low:

- **Alpha cells** detect change and secrete **glucagon**
- Glucagon secretion inhibits **beta cell** action
- Glucagon stimulates **hepatocytes** to convert **glycogen** into glucose (**glycogenolysis**)
- **Glucose** diffuses out of hepatocytes into the blood
- Cells use fatty acids and amino acids for respiration instead

Control of insulin secretion

Beta cells contain potassium and calcium ion channels. As potassium ions diffuse out of the cell, the inside of the cell becomes more negative than the outside, thus giving rise to a potential difference of **-70mV**. As glucose concentration increases, glucose diffuses into the beta cells through specific channel proteins down a concentration gradient. ATP is produced from respiration of glucose, which causes the ATP-gated potassium ion channels to close. As a result of that, potassium ions no longer diffuse out of the cell, thus making the potential inside the cell more positive, **causing depolarisation to take place**. This change in potential difference opens the calcium ion channels, allowing Ca^{2+} to enter the cell thus **causing the vesicles containing insulin to fuse with the plasma membrane** via **exocytosis**.

Diabetes

Diabetes mellitus is a disease where the body cannot control the blood glucose levels. There are two types of the disease, **Type I** is an autoimmune disease where the **beta cells are destroyed by the body**, thus meaning that the body does produce sufficient amounts of insulin. The condition can be managed by monitoring the blood glucose concentration and regular injections of insulin. **Type II diabetes** is a result of **cells becoming less responsive to insulin** as the affected person becomes older. It can be treated by insulin supplements, diet and careful monitoring. Risk factors of type II diabetes include obesity, diet high in sugar as well as ethnicity and sedentary lifestyle. Symptoms of diabetes include tiredness, thirst and ketoacidosis.

People suffering from diabetes can be **treated by insulin produced by genetically engineered bacteria**. The **use of genetically engineered organisms is very advantageous** in this case as it means it's possible to synthesise human insulin, instead of treating the patients with animal derived versions. Therefore, this means that there is a **lower change of rejection and infection**. Also, since bacteria are easy to grow, this means that manufacturing it that way is cheaper than extracting it from other animals.

Other treatment options include the use of **stem cells**. **Precursor pancreatic cells** have been found in the pancreas of mice, meaning that if a human equivalent of those cells is found, it could be used to treat type I diabetes via the synthesis of new beta cells.

Plant and animal responses

- **Tropisms** are directional growth responses of plants
- **Phototropism** is the growth response to light, shoots exhibit **positive phototropism** as they grow towards light whereas roots exhibit **negative phototropism** and grow away from light

- **Geotropism** is a growth response to gravity, roots grow with gravity thus they exhibit **positive geotropism** whereas shoots exhibit **negative geotropism** and oppose the force of gravity

- **Chemotropism** is a growth response to chemicals

Plant growth responses can also be triggered by **plant growth regulators**. Examples include **auxins** which promote cell elongation, **gibberellins** which promote seed germination and stem growth, **abscisic acid** which inhibits seeds germination and causes closing of stomata and **ethene** which is a gas that promotes ripening of fruit.

Auxins

Auxins cause cell elongation via the transport of hydrogen ions into the cell walls, which as a result lowers the pH of the walls, which is required for **expansins**. Expansins are a special type of enzyme **involved in loosening the cellulose**, this makes **cell walls stretch to accommodate more water**- thus enabling the expansion and growth of cells.

When the shoot is illuminated from all sides, the auxins are distributed evenly and move down the shoot tip thus causing elongation of cells across the zone of elongation. Whereas **if the shoot is only illuminated from one side**, the auxins **move towards the shaded part** of the shoot thus causing **elongation of the shaded side** only which results in bending of the shoot towards the light.

Leaf abscission

The dropping of leaves known as **leaf abscission** is controlled by auxin, ethene and cytokinins. **Cytokinins** are produced by young leaves to make it a suitable sink for transport in the **phloem**. **Auxin** is produced to prevent the leaves from aging. As the leaf ages, the levels of both cytokinin and auxin decrease, thus increasing the levels of ethene. As a result of that, **cellulose enzymes** are produced, which are involved in the **breakdown of cells walls** in the **abscission layer,** thus causing the **weakening of leaves**. Eventually, the leaves break from the branch. Below the abscission layer, a layer of **suberin** forms for protective purposes to prevent pathogens from entering.

Apical dominance

Apical dominance is the phenomenon where during the growth of the shoot, the growth of side shoots does not take place. In a case where the apex is removed, the growth of side shoots begins. This phenomenon is **controlled by auxin, abscisic acid and cytokinins**.

The auxin production in the apex maintains high levels of **abscisic acid**, thus **inhibiting the growth of side shoots**. When the apex is removed, the auxin levels drop thus causing the abscisic acid levels to drop as a result, therefore **allowing the growth of side shoots**. The **bud growth is promoted by cytokinins**, which is concentrated near the auxin reserve in the bud, therefore when the bud is removed, the cytokinins spread out more evenly thus **allowing the growth of lateral buds**.

Commercial uses of plant hormones

- **Auxins** – used in rooting powder, for growth of seedless fruit, in herbicides, to prevent leaf and fruit growth in small concentrations and in high concentrations to promote fruit drop
- **Gibberellins-** used to delay senescence in citrus fruits, elongation of apples in combination with cytokinins, for elongation of grape stalks, in brewing of beer for production of malt, to increase yield of sugar cane, to speed up seed formation in young conifer trees, to prevent lodging
- **Cytokinins** – to prevent yellowing of lettuce leaves, to promote shoot growth
- **Ethene** – speeds up ripening, to promote lateral growth, to promote fruit drop

Organisation of mammalian nervous system

The mammalian nervous system consists of the

- **central nervous system** (brain and spinal cord) which is made up of grey and white matter,
- **peripheral nervous system** made up of sensory and motor neurones which carry nerve impulses towards and away from the central nervous system
- **autonomic nervous system made up of sympathetic and parasympathetic neurones** which operate without conscious thought
- **somatic nervous system** which is involved in voluntary control of skeletal muscles.

The autonomic nervous system controls **homeostatic mechanisms** as well as response to stress. It consists of **sympathetic and parasympathetic systems**, which are **antagonistic systems with opposing effects**. If the equilibrium between the two systems is disturbed, a response is generated by the effector. The **parasympathetic system** is involved in processes such as decreasing the heart rate and constriction of pupils whereas the **sympathetic system** is involved in processes such as increasing the heart rate and dilation of pupils.

Human brain

- **Cerebrum** is the largest part of the brain composed of two halves known as the **cerebral hemispheres**. The two hemispheres are connected by a band called the **corpus callosum**. The cerebrum is involved in controlling vision, thinking, learning as well as emotions as well as voluntary control of the body– collectively referred to as advanced mental activity. Different parts of the cerebrum have different functions, for instance the **parietal lobe** controls orientation, movement, some types of recognition and memory whereas **the occipital lobe** located at the back of the cerebrum is known as the visual cortex. Auditory information is processed by the **temporal lobe**.

- **The cerebellum** is located underneath the cerebrum and plays an important role in coordinating muscle movements as well as balance

- **Hypothalamus**, found just beneath the middle part of the brain is involved in thermoregulation as well as production of hormones involved in control of the pituitary gland.

- **Medulla oblongata**, located at the base of the brain controls many vital body processes such as breathing, heart rate and blood pressure.

Nervous and endocrine systems in coordination

If the brain perceives a threat, it stimulates the stress responses involving **adrenaline**- this **triggers a number of physiological changes** that prepare the body to tackle the threat. The main physiological changes include pupil dilation, inhibition of the digestive system, increased heart rate and stroke volume, increased blood flow to brain for mental awareness, increased metabolic rate.

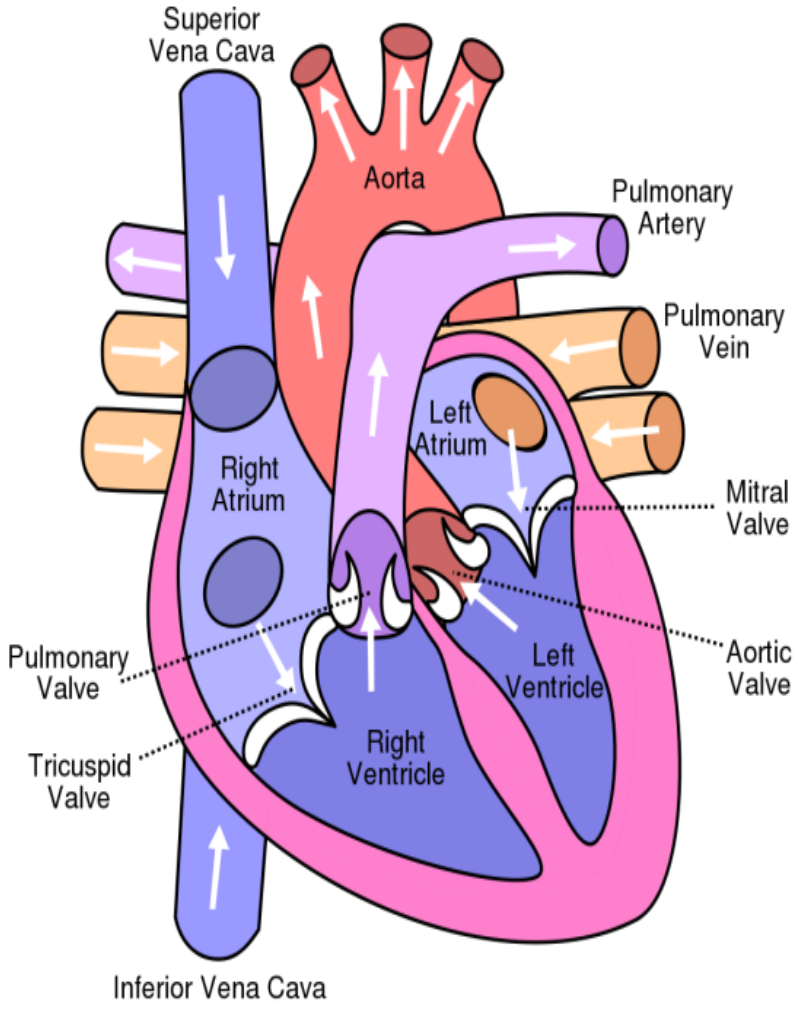


Figure 1 Wikipedia

As **adrenaline cannot cross the plasma membrane**, it must **interact with the cell via the receptors on its surface**. The receptors that adrenaline interacts with are known as **adrenergic receptors**. In response to binding of adrenaline to the adrenergic receptor, a specific series of events is triggered. The binding activates a membrane associated enzyme called **adenyl cyclase** which converts ATP to cyclic AMP which in turn interacts with a kinase enzyme. **The kinase enzyme activates enzymes** required to achieve a particular response. It is said that **adrenaline is the first messenger** whereas **cyclic AMP is the secondary messenger**.

Heart rate

Due to the heart's ability to initiate its own contraction, it is referred to as **myogenic**. In the wall of the right atrium there is a region of specialised fibres called the **sinoatrial node** which is the pacemaker of the heart, as it **initiates a wave of electrical stimulation** which **causes the atria to contract** at roughly the same time. **The ventricles do not start contracting until the atria have finished** due to the presence of tissue at the base of the atria which is **unable to conduct the wave of excitation**. The electrical wave eventually reaches the **atrioventricular node** located between the two atria which passes on the excitation to ventricles, down the **bundle of His** to the apex of the heart. The bundle of His branches into **Purkyne fibres** which carry the wave upwards. This **causes the ventricles to contract, thus emptying them.**

The sinoatrial node is connected to two nerves from the **medulla oblongata in the brain**. The **accelerator nerve**, which is a part of the **sympathetic** nervous system, deliver a higher frequency of impulses to the SAN to **increase the heart rate**, whereas the **vagus nerve does** the exact opposite – it is a part of the **parasympathetic** nervous system, and delivers **a slower frequency of impulses** to slow down the heart rate.

Factors which increase the heart rate include:

- **Low pH** caused by high carbon dioxide concentration, detected by chemoreceptors located in carotid arteries, aorta and the brain. The receptors send impulses to the medulla oblongata where the cardiovascular centre is located
- **Stretch receptors** respond to muscle movement, for instance during exercise
- **Decrease** in blood pressure, monitored by baroreceptors in the sinus
- **Adrenaline** is a hormone released to stimulate the fight or flight response

Heart rate is decreased when the opposite of the above occur, that is – when the pH increases as a result of decrease in carbon dioxide concentration and increase in blood pressure.

Mammalian muscle and contraction

Key words:

- **Tendons –** non-elastic tissue which connects muscles to bones
- **Ligaments –** elastic tissue that joins bones together and determines the amount of movement possible at a joint
- **Joints –** the area where two bones are attached for the purpose of permitting body parts to move, they're made of fibrous connective tissue and cartilage

- **Skeletal muscles-** muscles attached to bones, they are arranged in antagonistic pairs

- **Antagonistic muscle pairs-** pairs of muscles which pull in opposite directions – as one muscle contracts, the other relaxes. **Flexors and extensors** are an antagonistic muscle pair such as triceps and biceps. When the triceps relaxes, the biceps contracts to lift the arm

Muscles

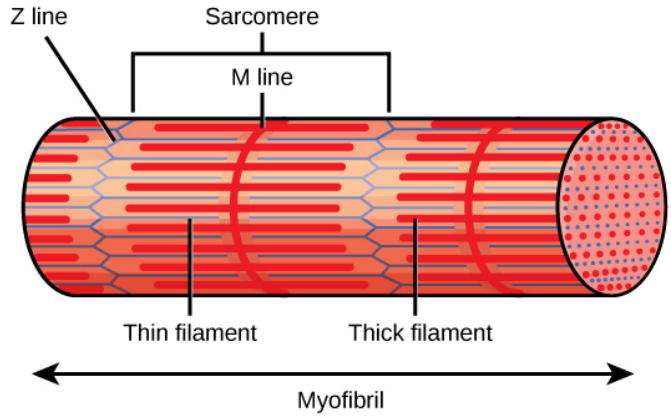


Figure 2 Boundless - Skeletal Muscle Fibers

- Skeletal muscle is made up of muscle fibres enclosed within a plasma membrane (the **Sarcolemma**).
- Parts of the sarcolemma fold inwards (**T-tubules**) to allow the electrical impulses to travel throughout the **sarcoplasm**.
- The sarcoplasm contains the **sarcoplasmic reticulum** which contains Ca^{2+} needed for contraction to occur.
- Each muscle fibre contains many myofibrils which are made of 2 proteins (**Myosin – the thick filament** and **Actin – the thin filament**)
- Myofibrils are organised into regular units called sarcomeres
- Sarcomeres shorten when muscles contract as the actin myofilament is pulled over the Myosin filament.
- Skeletal muscle is described as **striated** due to the striped appearance of the sarcomeres. (Dark bands = A bands, Light bands = I bands)
- When an action potential arrives at the sarcolemma sodium ion channels open and so depolarization occurs. This causes Ca^{2+} to be released from the sarcoplasmic reticulum. The Ca^{2+} bind to **troponin** which causes **tropomyosin** to move away from the myosin binding sites on the actin molecules. Myosin-actin cross bridges can now form so when myosin heads change their angle they pull the actin molecules towards the centre of the sarcomere. ATP is needed to break the cross bridges and hydrolysis of this ATP provides myosin with the energy needed to return to its original conformation. This myosin head can now bind to a binding site further along the actin and the cycle is repeated.

Muscle contraction occurs as following:

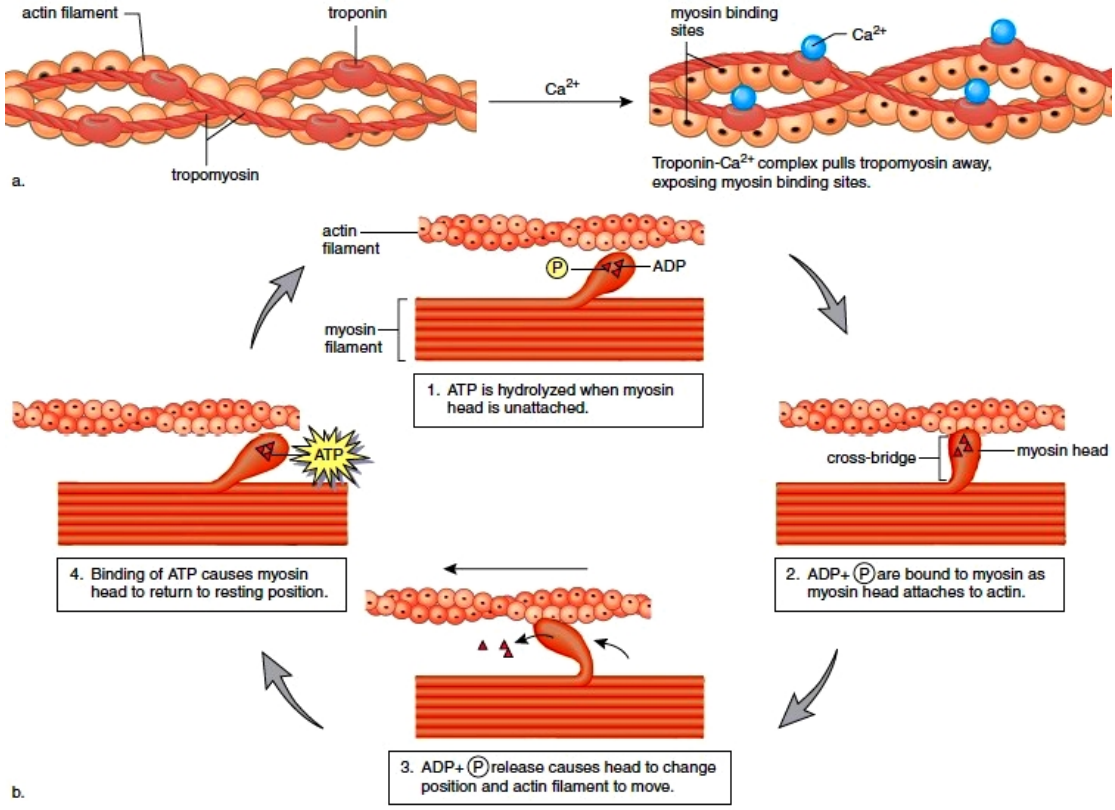
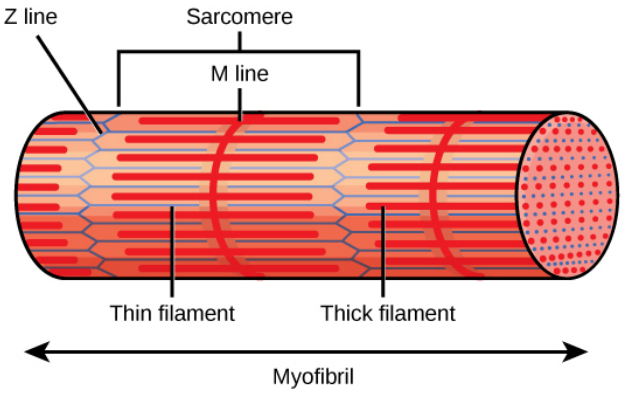


Figure 3 encyclopedia.lubopitko-bg.com

Sources of ATP

- Most ATP needed by skeletal muscle is provided by oxidative phosphorylation (aerobic respiration)
- Anaerobic respiration can also provide ATP used for short periods of high intensity activity
- Creatine Phosphate is a molecule that can be used to generate ATP by acting as a reserve supply of phosphate.



- **Slow twitch fibres** are specialised for **slow contractions** and are adapted to **long periods of exercise** such as marathon running therefore they **do not fatigue quickly** whereas **fast twitch fibres** are adapted for **rapid release of energy** during intense exercise such as sprinting – **the contractions are intense and in short bursts**

- Slow twitch fibres contain many **mitochondria**, a lot of **myoglobin** which results in slow twitch fibres being dark in colour – fast twitch fibres have very few mitochondria and not a lot of mitochondria thus they are lighter in colour