Animal Structure and Function

Embryology

Fertilization

- Contact: the sperm cell contacts the egg's jelly coat, triggering a series of reactions via binding of proteins to **ZP3 receptors** on the egg membrane
- **Acrosomal reaction**: enzymes stored in the acrosome are released, making a hole in the jelly coat surrounding the egg membrane
- Fusion: the head of the sperm fuses with the egg membrane
- Entry: entry of the sperm nucleus into the cytoplasm
- **Cortical reaction**: gamete fusion releases Ca2+ ions from the egg's cytosol, leading various granules to release their contents via exocytosis. This creates a swelled barrier between the other jelly coat and the cell membrane, acting to prevent polyspermy
- Nuclei fusion: the sperm and egg nuclei combine to form a new diploid cell called a zygote

Formation of the Blastula

- As the zygote undergoes cell division, it first forms a solid ball of cells called a morula
- At around the 32-cell stage, fluid enters the morula and re-arranges it into a hollow ball of cells called the blastocyst around a fluid-filled cavity
- A few days after entering the uterus, the blastua implants into the uterine wall

Formation of the Gastrula

- In gastrulation, one side of the blastula invaginates, forming what is called the gastrula
- This leads to the formation of the three germ-cell layers: the ectoderm (the 'far side' that the invagination points toward), the endoderm, the portion of the blastula that invaginated, and the mesoderm, in between the two

Organogenesis

- This stage follows gastrulation, and leads to the development of rudimentary organs
- The **notochord forms from the mesoderm**, while the neural tube forms from a folding of the ectoderm

Protostomes and Deuterostomes

- The hole formed by invagination during gastrulation is called the blastopore
- In protostomes, this indentation eventually forms the mouth, while in deuterostomes it eventually forms the anus
- Protostomes also divide by **spiral cleavage**, while deuterostomes divide by **radial cleavage**
- The Coelom forms by splitting in protostomes, but by outpocketing in deuterostomes

Tissues and Organs

Epithelial Tissue

- Sheets of closely packed cells that cover body surfaces and line internal organs
- Location: outer surface of Body, lines internal organs (e.g. digestive tract)

- Functions: protection (fluid loss, microbes), **absorption** (oxygen in lungs, nutrients in digestive tract), secretion (glands)
- Number of cell layers: simple epithelium (one layer), stratified epithelium (many layers above a basal membrane)
- Shape of cells: squamous (thin for gas exchange), cuboidal (secretion), columnar
- Stratified squamous epithelium is especially useful to line surfaces that are subject to regular abrasion, such as the oesophagus and the epidermis

Connective Tissue

- Tissue consisting of cells held in a nonliving matrix produced by the cells
- **Loose connective (areolar)**: most common, attaches epithelia to underlying tissues (e.g. skin to muscle), packs organs to hold them in place. Consists of collagen and elastic fibres, and various cells, embedded in semifluid ground substance
- Adipose: protects and insulates, stores energy. Consists of adipocytes closely packed together
- Blood: cells in a liquid matrix (here the matrix is not excreted by the other cells)
- **Fibrous connective**: matrix of densely packed bundles of collagen fibers; forms tendons and ligaments
- **Cartilage**: **chondrocytes** and **collagen and elastin fibres** embedded in a rubbery matrix, with does not contain blood vessels. Surrounds the ends of bones and forms vertebrae discs
- Bone: cells embedded in mineralised matrix

Muscular Tissue

- Skeletal muscle: attached to bones by tendons, appears striated
- Cardiac muscle: also striated, but with branched cells. Contractile tissue of the heart
- Smooth muscle: no striations; **spindle shaped cells**, lines the walls of arteries and the digestive tract to control involuntary muscle movements

Nervous System

Invertebrate Nervous Systems

- A **nerve net** is a diffuse mesh of nerve cells that takes part in simple reflex pathways; found in hydra and other radially symmetric organisms which lack brains
- Bilateral nervous system may have evolved from nerve nets
- Most bilateral animals have local nerve nets in some parts of the body

The Spinal Chord

- Expressway for signals between brain and peripheral nerves
- Sensory and motor neurons make direct reflex connections in the spinal cord
- Sympathetic nerves originate in the thoracic and lumbar regions of the spinal cord
- Parasympathetic nerves originate in the brain and the sacral region of the spinal cord

Divisions of Brain

- Hindbrain: includes medulla, pons, cerebellum; controls breathing, heart rate, blood pressure
- Midbrain: tectum; regulates temperature, sleep cycle, motor control
- Forebrain: cerebrum, thalamus, hypothalamus, limbic system
- Limbic system includes the amygdala, hypothalamus, hippocamus, olfactory bulb, thalamus,a nd cingulate gyrus

Digestive System

Types of Digestive Systems

- Intracellular digestion: occurs inside food vacuoles of simple animals like protozoa, keeping digestive enzymes separate from the cell cytoplasm
- Incomplete digestive system: a one-way, saclike cavity found in creatures like flatworms. Also called a gastrovascular cavity
- Complete digestive system: a tube running through the animal's body with an opening at each end
- Ruminant digestive tract: ruminants are mammals that are able to acquire nutrients from plant-based food by fermenting it in a specialized stomach, principally through bacterial actions. The process typically requires regurgitation of fermented ingesta (known as cud), and chewing it again. The process of rechewing the cud to further break down plant matter and stimulate digestion is called rumination

Mammalian Digestive System

- Includes the alimentary canal and accessory glands
- The **alimentary canal** is the connected sequence of digestive tubes running from the mouth to the anus
- Since the food moves in one direction, the tube can be organised into specialised regions that carry out digestion and absorption in a stepwise manner
- The digestive tract has a four layered wall: outer covering of connective tissue called the **serosa**, layer of smooth muscles called the **muscalaris**, another layer of connective tissue called the **submucosa**, and an internal epithelial tissue layer called the **mucosa**
- Sphincters are modifications of muscle layer into ringlike valves) that occur at some junctions between compartments and regulate passage of materials through the system
- The accessory organs are various glands that excrete enzymes necessary for digestive process. They include the salivary glands, the pancreas, the liver, and the gall bladder

Mouth

- Presence of food in oral cavity causes salivary glands to deliver saliva, which has antibacterial agents, lubricating agents, and a starch enzyme called **salivary amylase**
- The normal adult human number of teeth is 32, including the third molars

Oesophagus

- Pharynx serves as intersection for both digestive and respiratory systems. When we swallow, the epiglottis moves to block the entrance of the windpipe, directing food through the pharynx and into the esophagus
- The oesophagus is a muscular tube through which bolus of food moves by peristalsis -initial swallowing voluntary, peristalsis is involuntary contraction of smooth muscles

Stomach

- The stomach is a J-shaped organ that lies just below the diaphragm
- It connects with the esophagus via the esophageal sphincter, and with the small intestime by the phyloric sphincter
- A protective and structural outer layer of epithelium and connective tissue called the serosa covers a layer of smooth muscle called the muscularis

- Below that is the submucosa, a layer of vascularised connective tissue, which covers the innermost mucosa layer of simple columnar epithelial cells
- When empty, the mucosa of the stomach has many large macroscopic **folds called rugae**, which allows expansion to fit up to two liters
- The mucosa secretes gastric juice, which contains HCl and pepsin, an enzyme which severs peptide bonds
- HCL activates pepsinogen to pepsin by removing a short segment of amino acids which exposes pepsin's active site
- Mucus coating protects stomach lining from digestion; lining still constantly eroded and replaced roughly every 3 days
- Stomach contents are mixed by the churning action of smooth muscles around stomach, reducing it into a soupy liquid called chyme
- Little nutrient absorption occurs in the stomach, although water, some ions, and drugs like aspirin and alcohol are absorbed

The Duodenum

- The human small intestine is about 6 m in length site of most enzymatic hydrolysis of food and absorption of nutrients
- Most digestion occurs in first 25 cm of small intestine called the duodenum
- Here, acid chyme seeping in from the stomach is mixed with **digestive juices** from the pancreas, liver, gallbladder and gland cells of the intestinal wall
- Entry of acid chyme into the duodenum stimulates release of a hormone, **secretin**, from intestinal wall that signals pancreas to release bicarbonate to neutralise the acid
- Bile salts released by the gall bladder (and produced in the liver) emulsify fats, allowing the enzyme lipase to hydrolyse them into fatty acids
- Pancreatic amylase hydrolyses starch into maltose, which is hydrolysed by maltaseinto glucose. Other disaccharideases built into intestinal epithelium membranes split other disaccharides into monosaccharides
- Peptidases which hydrolyse proteins into amino acids are released by both the pancreas and the small intestine itself
- Nucleases hydrolyse DNA and RNA

The Jejunum and Ileum

- Remaining areas of small intestine, the jejunum and ileum, are **specialised for absorption** of nutrients
- They contain large folds covered with villa, which in turn have microscopic cytoplastic projections called microvilli, combining to greatly increase surface area
- Each villa has projections of the capillaries from the underlying submucosa inside it, so nutrients need only diffuse through the outermost layer of epithelial cells to reach the blood
- Capillaries that drain nutrients away from the villi converge into the hepatic portal vein, which **leads directly to the liver** where various organic molecules are used, stored, or converted to a different form
- Blood exiting the liver usually has a glucose concentration of 0.1%. Blood then travels to the heart and is then pumped to all parts of body

Absorption Mechanisms

- Nutrients are absorbed by **diffusion, passive transport, or active transport** across the mucusa into the blood vessels (capillaries) embedded in the submucosa
- Amino acids, sugars and lipoproteins (fat molecules bound to proteins) enter the capillaries
- Absorbed glycerol and fatty acids are recombined in epithelial cells to form fats. These pass into the lacteals (a lymphatic vessel), and are ultimately emptied into the bloodstream

Large Intestine

- This is divided into the cecum, the U-shaped colon, and the rectum
- Here, feces are concentrated and are moved along by peristalsis. Intestinal bacteria live on organic material in faeces and some produce Vitamin K which is absorbed by the host
- Feces concentration is accomplished by active pumping out of sodium ions; water follows
- Most mammalian herbivores have a relatively large cecum, hosting a large number of bacteria, which aid in the enzymatic breakdown of plant materials such as cellulose
- Faeces stored in the rectum and pass through two sphincters, one involuntary and one voluntary, to the anus

Locomotion and Muscles

Types of Skeletons

- The three functions of skeletons are: support the animal body, protect the animal body, assist movement of the animal body
- Hydrostatic skeleton: found in flatworms, nematodes, annelids, consists of fluid under pressure in a closed body compartment
- Hydrostatic skeletons support **peristaltic locomotion**, produced by rhythmic waves of muscle contractions passing from the head to the tail of many worms
- Exoskeletons: found in most molluscs and arthropods, hard coverings on the surface of the animal
- Muscles are attached to knobs and plates of the **cuticle** (non-living epidermal coat) that extend into the interior of the body, pulling on them and generating motion
- Endoskeletons: found in **sponges, echinoderms and chordates**, are hard supporting elements embedding within a soft animal body
- Sponges have hard spicules consisting of silicone and calcium carbonate, and echinoderms have plates of magnesium and calcium carbonate

The Mammalian Skeleton

- The mammalian skeleton is built from more than 200 bones, some fused together and others connected at joints by ligaments that allow freedom of movement
- The axial skeleton: the skull, vertebral column, and rib cage
- The appendicular skeleton: limb bones plus pectoral and pelvic girdles that anchor the appendages to the axial skeleton
- Types of bone: sesamoid, flat, long, irregular
- Animal movement is based on the contraction of muscles working against some type of skeleton. The action of muscles is always to contract; muscles can extend only passively

Bone Tissue Structure

- The basic unit of compact bone is an osteon, also known as a Haversian System. Each Haversian unit has a cylindrical structure that consists of four parts:
- A central tube called a Haversian Canal, which contains blood vessels and nerves
- The Haversian Canal is surrounded by alternate layers of lamellae, concentric rings of a strong matrix formed from mineral salts including calcium and phosphates and collagen fibres
- Lacunae are the small spaces between the lamellae in which contain the bone cells (osteocytes) are located
- The lacunae are linked together by minute channels called canaliculi. These provide routes by which nutrients can reach the osteocytes and waste products can leave them

Skeletal Muscle Structure

- A skeletal muscle consists of a bundle of long fibres running the length of the muscle
- Each fibre is a single cell with many nuclei, and contains many smaller myofibrils arranged longitudinally
- The myofibrils, in term, are comprised of a number of pairs of two kinds of myofilaments: thin myofilaments of actin and thick myofilaments of myosin
- Skeletal muscle is also called striated muscle because the regular arrangement of the myofilaments creates a repeating pattern of light and dark bands. Each repeating unit is called a sarcomere, the basic functional unit of the muscle

Sarcomeres

- The borders of the sarcomere, the Z lines, are lined up with adjacent myofibrils; the thin actin filaments are attached to the Z lines and project toward the centre of the sarcomere, while the thick myosin filaments are centred in the sarcomere
- At rest, the thick and thin filaments do not overlap completely and the area where there are only thin filaments is called the I band
- The A band corresponds to the length of the thick myosin filaments
- The thin actin filaments don't extend across the sarcomere, so the H zone is in the centre of the A band and contains only thick myosin filaments
- When a muscle contracts, the length of each sarcomere is reduced; i.e. the distance from one Z line to the next becomes shorter
- In a contracted muscle, the A bands do not change in length, but the I bands shorten and the H zone disappears

Sliding-Filament Mode

- Contraction begins when impulses from a motor neuron are transmitted to the muscle cell membrane through release of **acetylcholine** at the neuromuscular junction, through to the interior of the muscle cell via the T tubules in the sarcoplasmic reticulum
- When the fibre receives an action potential, the sarcoplasmic reticulum releases Ca2+ ions into the cytosol
- The calcium ions bind to the regulatory protein troponin, part of the troponin-tropomyosin complex on the thin actin myofilaments
- This calcium binding of **troponin** causes the long rodlike **tropomyosin** molecule to move and thus exposes the myosin binding sites on the actin filaments
- This allows the muscle to contract through the formation of **cross-bridges** between the myosin heads and the binding sites of the actin filaments

- The myosin heads tilt toward the M line, pulling the thin actin myofilaments toward the centre of the sarcomere
- The energy to move the myosin heads is provided by ATP, which is hydrolysed by the myosin thick myofilaments
- Muscle contraction stops when the sarcoplasmic reticulum pumps the calcium back out of the cytoplasm
- As the concentration of calcium falls, the tropomyosin-troponin complex again blocks the myosin binding sites on the thin actin myofilaments

Muscle Fatigue

- An inability to maintain muscle tension
- Occurs after a period of tetanic contraction

Graded Contractions

- A muscle twitch results from a single stimulus
- More rapidly delivered signals produce a graded contraction by summation
- Tetanus is a state of smooth and sustained contraction, obtained when motor neurons deliver a volley of action potentials
- The nervous system can also produce graded contractions of a whole muscle by taking advantage of the organisation of the muscle cells into motor units
- A motor unit consists of a branched motor neuron and the muscle fibres it innervates. When the unit fires, all of its fibres contract
- Multiple motor unit recruitment results in stronger muscle contractions

Fast and Slow Muscle Fibres

- We can identify fast and slow muscle fibres based on the duration of their twitches
- Fast muscle fibres are used for rapid, powerful contractions. Some, like flight muscles of birds, can sustain long periods of repeated contractions without fatiguing.
- Slow muscle fibres, which can sustain long contractions, are often found in muscles that maintain posture
- A **slow fibre has a smaller sarcoplasmic reticulum** and thus calcium remains in the cytoplasm longer. This causes a twitch in a slow fibre to last five times longer
- Slow fibres are also specialised to make use of a steady supply of energy; they have more mitochondria, a rich blood supply, and a brownish-red pigment, myoglobin, which binds oxygen more tightly than haemoglobin

Muscle Tension

- For a muscle to shorten, muscle tension must exceed the load that opposes it
- The load may be the weight of an object or gravity’s pull on the muscle
- Contraction without shortening of sarcomeres is called isometric contraction, compared with isotonic contraction when the muscle does not shorten

Cardiac Muscle

- Cardiac muscle, found only in the heart, consists of striated, branching cells that are electrically connected by intercalated discs, where **gap junctions** provide direct electrical coupling among cells
- Cardiac muscles can generate action potentials without neural input. The plasma membrane has pacemaker properties that cause rhythmic depolarisations

- These rhythmic depolarisations trigger action potentials and cause single cardiac muscles to 'beat' even when isolated from the heart and placed in cell culture
- Cardiac muscle cell action potentials also last twenty times longer than action potentials of skeletal muscle cells
- Unlike skeletal muscles where an action potential is only a trigger for contraction, in a cardiac muscle cell, the duration of the action potential plays an important role in controlling the duration of the contraction

Circulatory System

Types of Blood Circuits

- Fish: two-chambered heart with a single blood flow. Blood goes from the atrium to the ventricle, through the gill capillaries to collect oxygen, then through the systemic capillaries
- Amphibians: three-chambered heart with two circuits if blood flow, pulmocutaneous and systemic
- Mammals and birds: four-chambered heart that completely segregates the oxygen poor from oxygen rich blood

Main Blood Circuits

- The aorta is the artery that leads out of the left ventricle, bends through the aortic loop, and progressively branches off into all the other arteries
- Important among them are the **brachial arteries** (serving the arms), the **femoral arteries** (the legs) and the **carotid arteries** (for the brain)
- After delivering oxygenated blood to tissues via the capillaries, the blood returns to the heart via venules and veins
- The femoral veins from the legs, **jugular veins** from the head, and other veins from the arms, join to form the superior vena cava, which joins the right atrium of the heart
- Note: the vena cava above the heart is called the superior vena cava, below is the inferior vena cava. The aorta below the heart is called the thoracic aorta
- Blood is carried from the right ventricle through the pulmonary arteries to the heart, where it picks up oxygen and is taken back to the heart by the pulmonary veins

Heart Contraction

- Special autorhythmic cells in the **sinoatrial node** (**SA node**) of the right atrium continuously depolarise and repolarise spontenaously, emitting a series of regular action potentials
- These signals are conducted along the muscle fibres to the **atrioventricular (AV) node**
- Atrial contraction occurs just after these first two stages (this is the atrial systol)
- From there, the signals are passed through the atrioventricular bundle (bundle of His) to the apex of the heart via the bundle branches (the surrounding tissue is insulated)
- From there, the signals are spread throughout the ventricles by the large **purkinje fibres**, producing the famous **'QRS complex'**
- This leads directly to ventricular contraction (the ventricular systole). During this time, the AV valves are closed
- **Systole** refers to the period of contraction, and **diastole** to the period of relaxation

Control of heart rate

- During exercise, heart rate increases from 70 bpm to up to 200 bpm. Stroke volume tends to increase more, from 60 to 200 mL. Combined, these allow for a tenfold increase in cardiac output during exercise
- The cardiovascular centre (CV) in the **medulla oblongata** is primarily responsible for regulating heart rate and stroke volume
- **Baroreceptors** in the aorta, internal carotid arteries, and other large arteries detect changes in pressure, and send signals to the CV to regulate blood pressure
- There are also **chemoreceptors** which detect the concentration of oxygen, carbon dioxide, and protons in the blood, sending signals to the CV which then alters heart rate and breathing rate accordingly
- Sympathetic nerves from the CV innervate the heart via the accelerator nerve, causing an increase in heart rate and contractile force
- Parasympathetic nerves from the CV innervate the heart by the vagus nerve, decreasing heart rate by slowing the excitation of the AV node
- The vasomotor nerves can also cause vasoconstriction and vasodilation to alter blood pressure
- There are also movement receptors (**proprioceptors**) located around the skeletal muscles that can detect increases in movement related to a need for more blood flow

Blood pressure

- Blood pressure is commonly measured in the brachial artery using a **sphygmomanometer**
- This involves inflating a rubber cuff to a high pressure (above 120 or so), so that the artery is closed off
- A stethoscope is then placed just below the cutoff point, and the cuff progressively deflated until a sound is heard
- This sound corresponds to the first spurt of blood passing through, and will occur at the systolic pressure
- As the cuff is deflated further, the sounds become faints until they become inaudible - this point is referred to as the disystolic pressure
- Normal blood pressure is around 120/80

Capillary Exchange

- Blood pressure falls from the arteriole to the venule part of the capillaries, leading to a net filtration of nutrients and water out of the blood vessels in the arteriole portion, and a net filtration of water and wastes into the blood vessels in the venule portion
- These processes are respectively called **ultrafiltration** and **reabsorption**

Oxygen Dissociation Curves

- The higher the partial pressure of oxygen, the more oxygen will be bound to hemoglobin (Hb)
- In the lungs, Hb is nearly saturated with O2 (98%)
- In the tissues at rest, Hb has a lower concentration of O2, about 70%
- In the tissues during exercise, concentrations of O2 can fall as low as 10%
- **Bohr shift** is a phenomenon by which Hb's binding affinity for oxygen falls as the concentration of CO2 rises, and also as pH falls (more acidic)
- This means that in tissues with higher CO2 concentrations, the curve shifts down, hence depositing more O2 in these tissues

Variability in Oxygen Dissociation

- Oxygen dissociation curves differ between species. For example, active fish like the Macherel have lower binding affinities, which means it must live in a higher O2 environment
- Inactive fish like the toadfish have a higher affinity for O2, meaning that they can more easily extract O2 from the environment, but have more difficulty moving it to their tissues, so will be more sluggish
- **Higher temperatures** also **reduce the affinity** for O2, thus active fish with already low affinities cannot live at high temperatures

Characteristics of Blood

- By volume, blood consists of 55% plasma, and 45% formed elements (almost all of which is composed of RBCs)
- The blood plasma is a protein rich fluid that carries wastes, gases, and nutrients. It is about 92% water and 7% protein
- The three types of formed elements are RBCs, WBCs, and platelets
- Hematocrit refers to the percentage of total blood volume occupied by RBCs. Hematocrit of around 40-50 is normal
- Granular leukocytes: **eosinophils** (parasitic worms), **basophils** (inflammatory response), **neutrophils** (phagocytosis)
- Agranular leukocytes: **lymphocytes** (mediate antigen-antibody immune responses) and **monocytes** (mature into macrophages)

Hemostasis

- A three-phase process that stops blood loss and begins repairs to blood vessels
- Phase 1: **vascular spasm** constricts the blood vessel
- Phase 2: **platelet plug** formation
- Phase 3: **clot formation** - cascade of enzymatic reactions leading to the formation of fibrin protein threads, which entangle RBCs and platelets, forming a blood clot

Blood Typing

- This refers to determining which genetically-determined blood proteins are on the surface of RBCs
- It is done by taking a sample of blood and treating it with anti-A serum (which contains antibodies to the A-antigen), and anti-B serum
- A reaction leads to **agglutination**, a clumping together of cells, which indicates the presence of that antigen
- An Rh- mother may develop Rh+ antibodies if blood from an Rh+ child enters her bloodstream during childbirth
- These antibodies may attack the red blood cells of the next Rh+ fetus

Lymphatic System

- The lymphatic system consists of lymph capillaries and vessels that collect water and solutes from interstitial fluid and deliver them to the circulatory system
- Three functions of the lymphatic system:
  - Returns fluids and plasma proteins that **leak out of capillaries** to the circulatory system
  - **Delivers fats** absorbed from the small intestine to the blood
  - Transports **cellular debris, pathogens**, and foreign cells to lymph nodes

- Lymph nodes are organs that filter lymph before it enters blood and identify pathogens
- Important lymph nodes include the **tonsils** (defence against inhaled pathogens), the **spleen** (filters pathogens and worn out RBCs from the blood), and the **thymus gland** (site of T-cell maturation)
- Cytokines: small proteins released by WBCs to help mediate various innate and adaptive immune responses

Respiratory System

The Lung

- The trachea branches into two bronchi, one leading into each lung
- Each bonchus branches into a **bronchial tree**, the ends of which terminate at air sacs called alveoli
- Alveoli are bundled together into sacs called **alveolar sacs**, which share a common opening
- The alveoli are covered with pulmonary capillaries, through which RBCs flow, exchanging oxygen and CO2 with the air in the alveoli via diffusion (alveolar tissue is thin, simple squamous epithelium)
- Alveolar blood pressure is very low (about 6mm Hg), in order to **minimise water loss** to the air in the lungs
- O2 concentration is highest in inhaled air (160 mm Hg) and expired air (120 mm Hg). It decreases in the aveoli and systemic arteries to about 100 mm Hg, falling to about 40 mm Hg by the time the blood returns to the lungs in the pulmonary arteries

Breathing

- During inhalation, the diaphragm and intercostal muscles contract, lifting the ribcage upward and outward and hence expanding the rib cage
- This lowers the **intrapleural pressure**, leading the lungs to expand, and hence drawing air into the lungs
- During exhalation, the **diaphragm** and external **intercostal muscles** return to resting positions, lowering the ribcage, and hence raising intrapleural pressure, leading the lungs to recoil passively
- Exhalation is usually passive, but during exercise forced expiration is possible using the **abdominal muscles**

Lung Capacities

- **Tidal volume**: Volume moved with each breath (500cc)
- **Inspiratory reserve volume** (forced inhalation): Maximum intake above tidal volume (3100cc)
- **Expiratory reserve volume** (forced exhalation): Maximum expiration beyond tidal volume (1300cc)
- **Vital capacity**: Sum of inspiratory and expiratory reserve volumes and tidal volume, 4-5L in young male (less in female)
- **Residual volume** (dead space): Volume that cannot be emptied (1100cc)

Control of Respiration

- The medulla oblongata sends signals every five seconds or so to th**e diaphragm and intercoastal muscles** to contract, initiating each inspiration

- During heavy breathing, the expiratory area of the medulla also becomes active, sending signals to the abdominal muscles to contract for forceful exhalation
- CO_2 chemoreceptors located in the medulla and also the carotid arteries and the aortic arch
- Higher concentrations of CO_2 lead to an increase in the breathing rate
- The sensors in aorta and carotid arteries also detect changes in O_2 levels in the blood and signal the medulla to increase the breathing rate if the levels are too low
- CO_2 combines with H20 in the blood matrix to form **carbonic acid**, which quickly dissociates into HCO_3 and H^+, leading to an decrease in pH

Adaptations to High Altitude

- Hypoxia is a risk at high altitudes owing to the lower partial pressure of oxygen and carbon dioxide
- This can lead to **light-headedness** around **4000m**, dizziness and **sickness** around **6000m**, and **unconsciousness** by **7000m**
- The human body can adapt to high altitude through immediate and long-term acclimatization. At high altitude, in the short term, the lack of oxygen is sensed by the carotid bodies, which causes an increase in the breathing rate (hyperventilation). However, hyperventilation also causes the adverse effect of respiratory alkalosis, inhibiting the respiratory center from enhancing the respiratory rate as much as would be required
- Over a matter of weeks, cardiac output increases permanently, as does the rate of RBC production

Respiration in Fish

- Fish use a counter current exchange system
- Fish gulp water in the mouth, and pump it through the gills, where it passes over the **gill filaments**
- This involves the water brought in by the gills and the blood flowing in opposite directions, thereby permitting extraction of a larger total quantity of the oxygen from the water (up to 80%)
- Fish control this process using a flap that covers the gills, called the opercular valve

Respiration in Birds

- Birds possess a number of inflatable air sacs in two groups - the anterior air sacs and the posterior sacs
- When the bird inhales, some of the air goes to the lungs, and some goes to the posterior air sacs
- Air from the posterior air sacs moves into the lungs, then into the anterior air sacs, and finally is expelled
- The purpose of this system is so that the lungs themselves do not need to inflate, and can **maintain a fixed volume**. The direction of flow of air through the lungs is also kept constant

Respiration in Amphibians

- Amphibians like frogs breath essentially by swallowing air and pushing it into the lungs
- This method of respiration is known is **buccal pumping**

Endocrine System

Hormones

- The endocrine system regulates the activity of target organs at distant sites by means of chemical messengers called hormones, which are excreted into the interstitual fluid surrounding the excretory cells, not into the blood stream directly
- Hormones are molecules secreted by endocrine cells or neurosecretory cells that travel in body fluids to a target cell, where they bind with specific receptors and elicit specific responses
- Arthropods have well-developed endocrine systems. In insects, moulting and development are controlled by interplay between ecdysone and juvenile hormone

Types of Hormones

- **Circulating hormones** travel into the bloodstream and hence throughout the body
- **Local hormones** act locally on neighbouring cells without first entering the bloodstream (e.g. growth factors and neurotransmittors)
- **Steroid hormones** are lipid-soluable, so they can penetrate the plasma membrane of target cells and bind to specific protein receptors, often a hormone-receptor complex in the nucleus that acts to inhibit or enhance gene transcription
- **Peptide hormones** are not lipid-soluable, so instead they bind to a receptor on the cell surface, which via signal transduction triggers a change in enzymatic activity in the cell
- Steroids thus mainly affect the synthesis of proteins, while peptide hormones most often affect the activity of enzymes and other proteins already present in the cell

Messenger Cascades

- Many chemical signals are relayed and amplified by second messengers and protein kinases which are enzymes that catalyse the transfer of a phosphate group from ATP to proteins, the process of phosphorylation. This can either increase or decrease the activity of the protein, depending on its type
- The use of an enzyme cascade by organisms permits the dramatic amplification of the response to the hormone, with the number of activated products much greater with each catalytic step than in the preceding step

Hypothalamus

- The hypothalamus is a small region of the brain located below the thalamus. It produces a number of hormones which control other endocrine glands, especially the pituitary gland
- The pituitary gland is a pea-sized gland at the base of the hypothalamus, which has two lobes; the posterior and anterior
- **Tropic hormones** are hormones that have other endocrine glands as their target. Most tropic hormones are produced and secreted by the anterior pituitary
- The cell bodies of the neuroendocrine cells are often located in the hypothalamus, but the hormones are transported down the axons and released into the capillary beds surrounding the pituitary gland
- **Corticotropin-releasing hormone** (CRH): stimulates release of adrenocortitrophic hormone
- **Growth hormone-releasing hormone** (GH): stimulates release of GHSH from pituitary
- **Thyrotropin-releasing hormone** (TRH): stimulates release of TSH from anterior pituitary
- **Gonadotropin-releasing hormone** (GnRH): stimulates release of FSH and LH from pituitary

Posterior pituitary

- **Antidiuretic hormone** (ADH): controls urine production, sweat and blood pressure. More ADH increases permeability of collecting ducts in nephrons to water, thus leading to greater reuptake of water by the kidneys and hence less, more salty urine
- **Oxytocin**: stimulates contraction of uterus during childbirth and of mammary glands during breastfeeding in response to infant suckling

Anterior pituitary

- **Adrenocorticotropic hormone** (ACTH): stimulates release of cortisol by the adrenal cortex
- **Prolactin** (PRL): promotes milk production by mammary glands
- **Thyrod-stimulating hormone** (TSH): stimulates the synthesis and secretion of thyroid hormones by the thyroid gland
- **Follicle-stimulating hormone** (FSH): stimulates development of oocytes in females and sperm production in males
- **Luteinizing hormone** (LH): stimulates ovulation in females and testosterone production in males
- **Growth hormone** (GH): acts on many organs and tissues to promote growth and protein synthesis

Thyroid Glands

- The thyroid gland produces iodine-containing hormones (**T3 and T4 or thyroxine**) that stimulate metabolism and influence development and maturation in vertebrates
- The production of thyroxine is controlled by a **negative feedback mechanism**
- Low levels of T3 and T4 stimulate the hypothalamus to secrete TRH, which in turn stimulates the anterior pituitary to secrete TSH, which finally stimulates the thyroid gland to produce more T3 and T4
- A goiter is a swelling of the thyroid gland around the neck. It can be caused by conditions which either cause an overproduction (hyperthyroidism) or underproduction (hypothyroidism) of T3 and T4 hormones
- The thyroid gland also produces **calcitonin**, which lowers calcium levels in the blood as part of calcium homeostasis. It works alongside PTH

Parathyroid Glands

- The parathyroid glands are several small, round glands located on the posterior surface of the thyroid gland
- **Parathyroid hormone** (PTH) is the main regulator of calcium in the blood
- It is secreted when calcium levels drop, and causes bone cells to digest bone tissue and release calcium, thereby increasing blood calcium levels
- PTH also stimulates calcium reabsorption by the kidneys and absorption by the gut

Thymus Gland

- The thymus secretes **thymosin** and other chemical messengers-stimulate the development and differentiation of T lymphocytes

Pancreatic Islets

- The endocrine portion of the pancreas consists of **islet cells** (islets of Langerhans)
- The **alpha cells** secrete the peptide hormone glucagon, and the **beta cells** secrete the hormone insulin

- High blood glucose levels stimulate the release of **insulin**, which increases the cellular uptake of glucose, promotes the formation and storage of glycogen in the liver
- Low blood glucose levels trigger **glucagon** release, which increases blood glucose by stimulating the conversion of glycogen to glucose in the liver and increasing the breakdown of fat and protein
- Type I diabetes mellitus is an auto-immune disorder resulting in a lack of insulin. Type II diabetes (non-insulin dependent) is usually caused by the loss of responsiveness of target cells to insulin

Adrenal Glands

- The adrenal gland consists of an outer cortex and an inner medulla
- **Aldosterone**: promotes secretion of H+, and regulates blood concentrations of Na+ and K+
- **Cortisol**: stimulated by ACTH from the anterior pituitary. Acts in opposition to insulin, inhibiting glucose uptake and converting free amino acids and fats to glucose
- **Epinephrine and norepinephrine**: produce effects that enhance those of the sympathetic nervous system. Excreted by the adrenal medulla

Reproductive Organs

- **Testosterone**: produced by the testes; stimulates development of male secondary sexual characteristics and regulates sperm production, also inhibits GnRH
- **Estrogens**: produced by the ovarian follicles; promotes development of female secondary sexual characteristics, inhibits GnRH, FSH and LH
- **Progesterone**: produced by the corpus luteum and (a similar hormone) by a growing fetus; maintains endometrium, inhibits GnRH, LH and FSH
- **Inhibin**: secreted by the testes and the ovaries; inhibits the secretion of FSH and LH from the anterior pituitary
- **Relaxin**: produced by the corpus luteum and the placenta, relaxes uterine smooth muscle for implantation of embryo and delivery of fetus

Reproduction

Asexual Reproduction

- **Fission**: involves the separation of a parent into two or more individuals of about equal size
- **Budding**: occurs when a new individual splits off from an existing one. Found in hydra
- **Fragmentation**: the breaking of the body into several pieces, each of which develops into a complete adult. Found in sponges, cnidarians, polychaete annelids, and tunicates. Most be accompanied by regeneration of lost body parts (e.g. sea stars)
- Advantages of asexual reproduction include the ability of sessile animals to reproduce without needing to seek a mate, and the ability to produce many offspring rapidly
- Most advantageous in stable, favourable environments because it easily perpetuates successful genotypes

Sexual Reproduction

- Requires the fusion of male and female gametes to form a diploid zygote
- The female gamete (ovum) is usually larger and nonmotile
- The male gamete (spermatozoon) is usually a smaller, flagellated cell

- Sexual reproduction increases genetic variability, and is thus advantageous in a fluctuating environment
- **Parthenogenesis** is the development of an egg without fertilisation. Some animals can use this method to alternate between sexual and asexual reproduction depending on environmental circumstances (e.g. aphids, rotifers)
- **Hermaphroditism**, in which each individual has both male and female reproductive systems, is a solution found in many animals which have difficulty finding a member of the opposite sex
- Solves the problem of finding a mate of the opposite sex for some sessile, burrowing, and parasitic animals. Some **self-fertilise**, but most mate with another; each gives and receives sperm doubling potential offspring from one mating
- Sequential hemaphroditism occurs in some species, in which an individual reverses its sex during its lifetime

Fertilization

- The fusion of gametes to initiate the development of a new individual organism
- In animals, the process involves the fusion of an ovum with a sperm, which eventually leads to the development of an embryo
- Depending on the animal species, the process can occur within the body of the female in **internal fertilisation**, or outside in **external fertilisation**
- In external fertilisation, eggs are shed by a female and fertilised by a male in the environment
- External fertilisation occurs almost exclusively in **moist habitats** where development can occur without desiccation or heat stress
- Some aquatic invertebrates release their eggs and sperm into the surrounding water with no contact occurring between the parents
- Internal fertilisation occurs when sperm are deposited in or near the female reproductive tract and fertilisation occurs within the female's body
- For internal fertilisation to be able to occur, **copulatory organs** for sperm delivery and receptacles for sperm storage and transport must be present
- Mating behaviours must include specific reproductive signals for copulation to occur
- Most mammals have separate openings for digestive, excretory, and reproductive tracts while many nonmammals have only a common opening, the **cloaca**

Male Reproductive Anatomy

- The human male reproductive system includes external genitalia and the internal reproductive organs
- **External genitalia** include the scrotum and penis. Internal reproductive organs consist of the gonads (testes), accessory glands, and associated ducts
- The penis serves as the male copulatory organ. The ejaculatory duct joins the urethra (from the excretory system) which opens at the tip of the penis
- The movement of semen through the urethra during copulation results in the sperm being deposited directly in the female system
- The **testes** are highly coiled tubes surrounded by layers of connective tissue. The tubules, or **seminiferous tubules** are where sperm form
- Sperm pass from the seminiferous tubules into tubules of **epididymis**, where sperm are stored and mature
- At ejaculation, sperm are forced through the **vas deferens** which is a muscular duct running from epididymis to the ejaculatory duct

- The ejaculatory duct forms by the joining of the two vas deferens ducts (one from each testes) with the duct from the seminal vesicles; it opens into the tube called the **urethra**

Accessory Glands

- **Seminal Vesicles**: empty into the ejaculatory duct and secrete **seminal fluid** containing mucus, **amino acids** (causes semen to coagulate after deposited in female), **fructose** (provides energy for sperm) and prostaglandins (stimulate uterine contractions to help move semen to the uterus)
- **Prostate Gland**: a large gland that surrounds the upper portion of, and empties directly into, the urethra. It produces a thin, milky alkaline fluid that contains several **enzymes** to deal with the acidity of the urine and the vagina
- **Bulbourethral glands**: a pair of small glands below the prostate that empty into the urethra at the base of the penis. Secrete viscous fluid of **unknown function** before sperm ejaculation

Spermatogenesis

- A continuous process in adult males and may result in 250-400 million sperm cells per ejaculate
- Begins with the differentiation of primordial germ cells by mitosis into spermatogonia in embryonic testes. Both of these types of cells are diploid
- The **spermatogonia** are located near the outer wall of the seminiferous tubules. They increase in numbers through repeated mitosis throughout development and early life
- When the male matures, spermatogonia begin to differentiate into **diploid primary spermatocytes**
- Each primary spermatocyte undergoes **meiosis I** to produce two **haploid secondary spermatocytes**
- Each secondary spermatocyte undergoes **meiosis II** to form **two spermatids**
- All four spermatids from each primary spermatocyte differentiate into **mature spermatoozoa**
- **Sertoli cells**: Line the seminiferous tubules and nourish the developing sperm
- **Leydig cells**: Lie between the seminiferous tubules and secrete testosterone

Female Reproductive Anatomy

- Each **ovary contains many follicles** (one egg cell surrounded by follicle cells, which nourish and protect the developing egg). All follicles are formed at birth
- Starting a puberty, and continuing to menopause, one follicle matures and releases its egg cell during each menstrual cycle
- During ovulation, the egg is expelled from the follicle. The remaining follicular tissue forms the **corpus luteum**, which secretes progesterone (maintains the uterine lining) and additional oestrogen (that is, additional to that produced by the follicle cells)
- If the egg is not fertilised, the **corpus luteum degenerates**, progesterone is no longer produced, and the uterine lining sloughs off
- The egg cell is expelled into the abdominal cavity near the opening of the **oviduct**, and cilia lining the oviduct draw in the egg cell and convey it to the uterus
- The inner uterine lining, the **endometrium**, is richly supplied with blood vessels
- Cervix: The neck of the uterus which opens into the vagina
- Vagina: Thin walled chamber that is the repository for semen during copulation and forms the birth canal
- Hymen: a vascularised membrane, usually covers the vaginal opening from birth until ruptured by vigorous physical activity or sexual intercourse

Menstrual Cycle

- The fertile period for a human female occurs on a cyclic basis, each cycle lasting about 28 days
- Each girl is born with primary oocytes already in the ovaries, having entered Meiosis I but not yet having divided into haploid cells
- **Meiosis resumes,** one oocyte at a time**, with the first menstrual cycle**
- During the **completion of Meiosis I**, the primary oocyte divides into the secondary oocyte and the first polar body (which can further divide)
- **Meiosis II** in the secondary oocyte then **halts again until after fertilization**, at which time the secondary oocyte splits into one ovum and one secondary polar body

Oogenesis

- **Oogenesis** is the development of ova; mature, unfertilised egg cells
- Begins in the embryo when primordial germ cells undergo mitotic divisions to produce diploid **oogonia**. Each oogonium will develop into a primary oocyte by the time of birth of the female, resulting in all potential ova being present in the ovaries at birth
- Between birth and puberty, primary oocytes enlarge and their surrounding follicles grow. They replicate their DNA and enter prophase I and remain there until activated by hormones
- After puberty, during each ovarian cycle, FSH stimulates a follicle to enlarge and the **primary oocyte** within completes meiosis I to produce a haploid secondary oocyte and the first polar body (which usually degenerates)
- LH triggers ovulation and the secondary oocyte is released from the follicle
- If a sperm cell penetrates the secondary oocyte's membrane, meiosis II will occur and the second polar body will separate from the ovum, which completes oogenesis

Male Hormonal Control

- Androgens are steroid hormones produced primarily by the interstitial tissues of the testes. Testosterone is the most important androgen produced
- Gonadotropin releasing hormone (GnRH) from the hypothalamus stimulates the pituitary to release LH (stimulates androgen production) and FSH, which acts on seminiferous tubules to increase sperm production
- Production of testosterone, sperm and inhibin inhibits the hypothalamus and hence reduces FSH and LH levels

Female Hormonal Control

- Female mammals display two different types of cycles: oestrous cycles and menstrual cycles
- **Oestrous cycles** occur in non-primate mammals. Oestrus is the period of sexual activity surrounding ovulation and is the only time most mammals will copulate; the length and frequency of oestrus varies widely among species
- **Menstrual cycles** occur in humans and many other primates. 'Menstrual cycle' refers to changes that occur in the uterus during the reproductive cycle
- Five hormones work together (by positive and negative feedback mechanisms) to coordinate the menstrual and ovarian cycles
- At **puberty**, the hypothalamus secretes increasing amounts of GnRH, leading to higher FSH and LH levels. These gonadotropins trigger maturation of the reproductive system and development of secondary sex characteristics

Menstrual Cycle Control

- The **menstrual flow phase** is the time during which most of the endometrium is being lost from the uterus (menstruation). Persists only a few days
- The **proliferative phase** lasts for one to two weeks and involves the regeneration and thickening of the endometrium
- The **secretory phase** lasts about 2 weeks; is time when endometrium continues to develop
- If no embryo implants by the end of this period, menstruation begins

Ovarian Cycle Control

- The **follicular phase** begins this cycle and is a time during which several follicles in the ovaries begin to grow. The egg cells within the follicles enlarge and the follicle cell coat becomes multilayered. Only one of the growing follicles will continue to mature while the others will degenerate
- The **ovulatory phase** consists of that time when ovulation occurs. The follicle and adjacent wall of the ovary rupture, releasing the egg cell
- The **luteal phase** begins after ovulation. Follicular tissue remaining in the ovary after ovulation forms a corpus luteum, which secretes female hormones

Female Reproductive Hormones

- During the follicular phase of the ovarian cycle, GnRH secreted by the hypothalamus stimulates the anterior pituitary to secrete small quantities of FSH and LH
- **FSH stimulates the immature follicles** in the ovary to grow and these follicle cells secrete increasing amounts of oestrogen
- Increasing amounts of oestrogen secreted by growing follicles **stimulate the endometrium** lining the uterus to thicken in preparation for the embryo
- The high concentration of oestrogen also stimulates the hypothalamus to **increase secretion of GnRH** which results in a sudden increase in FSH and LH secretion
- The **sudden surge in LH** concentration stimulates final maturation of the follicle and **ovulation**. The high LH concentration also stimulates the ruptured follicular tissue to transform into the corpus luteum
- The presence of LH during the luteal phase of the ovarian cycle stimulates the **corpus luteum to continue to secrete oestrogen**, but also to secrete increasing amounts of **progesterone** the oestrogen and progesterone secreted by the corpus luteum stimulate continued development and maintenance and vascularisation of the endometrium
- Increasing concentrations of oestrogen and **progesterone inhibit GnRH secretion** by the hypothalamus resulting in a decrease in FSH and LH, thereby causing the **corpus luteum to atrophy**
- Atrophy of the corpus luteum leads to decreasing levels of oestrogen and progesterone, which **removes the inhibition** exerted on the hypothalamus, which begins to secrete small amounts of GnRH that stimulates the anterior pituitary to secrete low levels of FSH and LH, thus beginning a **new follicular phase** begins at this point
- Decreasing concentrations of oestrogen and progesterone due to the disintegration of the corpus luteum reduce blood flow to the endometrium. The **endometrium breaks down** and passes out to the uterus as the menstrual flow

Pregnancy

- In placental mammals, pregnancy (gestation) is the condition of carrying one or more developing embryos in the uterus
- Following fertilization and zygote formation, the growing blastocyst attaches to the endometrium and begins to burrow into the maternal tissues
- The blastocyst then begins secreting a hormone called human **Chorionic Gonadotropic** (hCG), which stimulates the corpus luteum to keep making progesterone and estrogens. This maintains endometrium, prevents menstruation
- This hormone can be detected by week 3 with a home pregnancy test
- High progesterone levels also stimulate: formation of a protective mucous plug in the cervix, growth of the maternal part of the placenta, and uterus enlargement
- During the second trimester, the **corpus luteum finally degenerates**, however by this time the placenta is able to secrete its own progesterone to maintain the pregnancy
- **High oestrogen levels** during the last weeks of pregnancy trigger the formation of oxytocin receptors on the uterus. **Oxytocin** (from the foetus and maternal posterior pituitary) stimulate the smooth muscles of the uterus to contract
- The physical and emotional stresses caused by the **uterine muscle contractions** stimulate secretion of additional oxytocin and prostaglandins
- Decreasing levels of progesterone after birth remove the inhibition from the anterior pituitary which allows prolactin secretion, which stimulates milk production
- Actual milk release is controlled by oxytocin from the mammary glands

Homeostasis

Introduction

- Homeostasis refers to maintenance of the constancy of the internal environment of the body

Fish Fluid Regulation

- Freshwater fish are hypertonic to medium, meaning that they tend to absorb water through the gills and other body surfaces. This means they need to excrete large amounts of water in dilute urine, and replace salts by uptake from the gills
- Saltwater fish are hypotonic to medium, meaning that they tend to lose water through gills and other body surfaces. This means that they conserve water in concentrated urine, and replace lost water by gulping sea water and excreting salt from the gills
- Sharks maintain (almost) isotonic tissues

Osmoregulation

- Osmoconformers: Internal salt concentrations parallel changes in the external environment
- Osmoregulators: Maintain their internal concentrations at a constant level
- Part conformers, part regulators, regulate osmolarity over some range of salinity, but conform for more extreme ranges
- **Stenohaline**: Limited tolerance to changes in external environment (narrow range of regulation)
- **Euryhaline**: Can tolerate a wide range of osmotic environments (wide range of regulation)
- Osmoregulators can be either **ionic regulators**, in which internal volume is kept constant and ions are excreted or absorbed as needed, or **volume regulators**, in which internal salt concentration is kept the same by altering the water volume

Temperature Homeostasis

- Life operates in environments from -2 C to 95 C
- Poikilotherms: body temperatures fluctuate with environmental changes
- Homeotherms: body temperature is kept mostly constant (birds and mammals)
- Ectotherms: use external heat source and behaviour to trap energy. Usually poikilotherms, but not always (e.g. deep sea creatures where temperature is constant)
- Endotherms: use internal regulated metabolic heat (usually homeotherms, but not always)

Metabolic Rates and Temperature

- Metabolic rate varies with temperature, and so standard metabolic rate measurements must be with reference to a particular temperature
- Large animals have larger heat production per unit of surface area than smaller animals, but a smaller heat production per unit of weight
- Core body temperature in humans is maintained at about 37 degrees in major organs. In peripheral tissues temperatures are lower, around 32 degrees
- Temperature is monitored continuously by thermoreceptors in the skin, membranes and deep organs, and also by blood passing through the hypothalamus
- The hypothalamus controls vasoconstriction and vasodilation, metabolic rate, respiration, and sweating

Temperature Zones

- Zone of hypothermia: Body cannot regulate and core temperature falls
- Zone of **homeothermy**: Core temperature can be maintained, either by additional heat production or by sweating at higher temperatures
- Zone of **thermal neutrality**: Metabolism not required for temperature equilibrium
- Zone of **physical regulation**: Panting or sweating maintains body temperature
- Zone of hyperthermia: Body cannot regulate and temperature increases

Kidneys and Water Balance

Osmoregulation

- Osmosis is the spontaneous net movement of solvent molecules through a partially permeable membrane into a region of higher solute concentration, in the direction that tends to equalize the solute concentrations on the two sides
- **Osmotic pressure** is the pressure which needs to be applied to a solution to prevent the inward flow of water across a semipermeable membrane. It is also defined as the minimum pressure needed to nullify osmosis
- Osmolarity refers to the number of active solute particles per litre

The Kidney

- The kidney is primitively the organ responsible for osmoregulation. Only terrestrial vertebrates also use it for water excretion
- In addition to removing excess water, the kidneys also remove excess salts and urea
- The afferent artery carries blood into a bed of capillaries in the glomerulus
- Blood plasma is pushed by the pressure of the blood out of the capillaries and into the proximal convoluted tubule

- This passes through the descending and ascending portions of the loop of Henle, which in turn connects to the distal convoluted tubutle and finally drains into the collecting duct
- Bowman's capsule and the tubules are located in the renal cortex, while the Loop of Henle and the collecting duct are contained in the medulla

Production of Urine

- Ultrafiltration: water and most blood plasma solutes are moved into the renal tubule from the glomerular capillaries. This is a non-selective process
- Tubular reabsorption: many solutes and most of the water is reabsorbed by cells in the proximal tubule
- Tubular secretion: excess ions, wastes, drugs, and other compounds are secreted by the tubulues and duct cells as the filtrate moves along
- The loop of Henle creates a concentration gradient for the reabsorption of both water and solutes
- The **descending loop** is impermeable to NaCl, so water is lost is osmolarity increases. Conversely, the **ascending loop** is impermeable to water, so salts are lost and osmolarity falls
- The collecting duct has a variable permeability to water, allowing urine to be concentrated or dilute

Control of Urine Excretion

- **Anti-diuretic hormone** is produced by the hypothalamus in response to salty blood. It increases the permeability of the collecting ducts to water, thereby producing a lower volume of more concentrated urine
- The adrenal cortex produces **aldosterone** if salt concentrations become too low. It increases the active transport of sodium ions out of the tubules, which draws water out along with it, thus reducing urine volume

Regulation of Blood pH

- Kidneys also maintain the acid-base balance
- H+ is a major product of metabolism, and so needs to be excreted into the proximal and distal tubules in exchange for sodium ions

Excretion Systems in Different Animals

- **Nephridia**: an invertebrate organ which occurs in pairs and performs a function similar to the vertebrate kidney. Nephridia remove metabolic wastes from an animal's body. They work by the action of cilia or flagella, rather than fluid pressure
- **Protonephridia**: found in animals like flatwords and rotifers that lack blood vessels
- **Metanephridia**: found in many vertebrates, it is the origin of the vertebrate kidney. The ultrafiltrate is sent into the coelom, and is reabsorbed by a separate tubule. This is a primitive version of Bowman's capsule