Life Sciences, Grade 11, Excretory System

Definitions

Excretion: The process of removing metabolic waste products from the body.

Osmoregulation: The control of water and salt balance in the body.

Glomerulonephritis: Inflammation of the kidney's filtering units.

Polycystic kidney disease: A genetic disorder causing cysts (fluid-filled sacs) in the kidneys.

Kidney stones: Solid masses formed when minerals and salts in the urine crystallize and clump together.

Egestion: The removal of undigested food from the alimentary canal of the body through the anus (this undigested food does not come from cells of the body)

Concepts

What are Metabolic Waste Products?

- Metabolic waste products come from metabolic reactions
    - reactions that occur within living cells/ organisms that are essential for maintenance of life
    - eg. CO_2, excess water and salts and nitrogenous wastes (urea, uric acid)

4 Main excretory substances:

- **Carbon dioxide**
    - waste product of CR
    - Transported in the blood from all the cells in the body to the alveoli of the lungs
    - Excreted in the air that is exhaled
- **Water**
    - produced during CR
    - Consumed in food and drink
    - Excess water is excreted in urine and sweat
- **Bile pigments**

    - produced by the breakdown of haemoglobin which takes place in the liver
    - Excreted in faeces
- **Urea**
    - made in the liver from excess proteins that are consumed
    - Transported by blood
    - Excreted in urine

Deamination

- is the process where an ammonia group (NH2) is removed from an amino acid molecule
- NH2 is cleaved off along with another hydrogen and they together form ammonia (NH3)
- Ammonia is very toxic, so it is converted to urea (less toxic) by the addition of CO2
- The left-over amino acid molecule (without N) is converted to glucose
- Stored as glycogen in the liver

Functions of the Urinary system

- Excretion of nitrogenous waste substances
- Osmoregulation by regulating the water content of body fluids
- Regulates the salt content of body fluids
- Regulates the pH of body fluids

Structure of the Urinary system

- **Kidneys**
    - near the back of your abdomen
    - They are surrounded by fat which insulates the kidneys, keeps them in position and absorbs shock
- **Renal artery**
    - each kidney receives blood via the renal artery adrenal glance
    - Rich in oxygen and glucose
    - Also contains toxins and nitrogenous wastes

- **Renal vein**
    - blood leaves the kidney through the renal vein
    - Deoxygenated blood
    - No glucose, toxins or nitrogenous waste
- **Hilum**
    - where the renal artery, vein and ureter are attached to the kidney
- **Bladder**
    - bladder stores urine temporarily
- **Sphincter muscles**
    - control the opening of the bladder so that elimination of urine can be controlled
- **Urethra**
    - carries urine to the outside of the body
- **Ureter**
    - two narrow tubes that transport urine from the kidneys to the bladder

Macroscopic structure of Kidneys:

- Renal Capsule
    - Connective tissue protects kidney from infection
- Cortex
    - With many renal capsules
- Medulla
    - Area with pyramids
- Nephron
    - Structural and functional unit of kidney
- Renal pelvis
    - Receives urine from calyx
- Renal artery (oxygenated)
    - Carries N2
- Renal vein (deoxygenated)
    - Carries purified blood
- Pyramid
    - Made up of ducts of Bellini (loop of Henle, collecting ducts)
- Renal sinus
    - Space between calyces
- Papilla

    - Where tip of pyramid fits into calyx (ducts of Bellini empty contents here)
- Calyx
    - Receives urine from pyramids
- Ureter
    - Carries urine to bladder

Microscopic structure of a Kidney

- a kidney is made up of many tiny tubules called nephrons
- Nephron = structural and functional unit of kidney
- made up of Malpighian body (renal corpuscle) and renal tubule

- **1. Malphigian Body (Renal Corpuscle)**
    - Made up of
        1. Bowman's capsule
        2. Glomerulus
    - situated in the renal cortex
    - The glomerulus (capillary network) sits inside the Bowman's capsule
        - cup shaped, hollow —> capsular space
    - The Bowman's capsule is made up of specialised cells podocytes
        - The podocytes have filtration slits between them
    - glomerulus filtration takes place here —> a filtration unit
        - It forces waste products out of the blood which passes through the glomerulus

- **Glomerular filtration**
    - blood is carried by the wide afferent arterioles to the glomerulus
    - Efferent arterioles (exiting) is narrower than the afferent (arriving) therefore blood in the glomerulus is under great hydrostatic/ liquid pressure
    - Substances from the blood are filtered and forced out through capillary walls (which have tiny pores) and through the filtration silts of the podocytes and into the cavity of the Bowman' capsule

- Only substances small enough to fit through capillary - or slit pores pass into the capsular space: fatty acids, amino acids, glycerol, glucose, salts, nitrogenous waste and water
- The filtrate that passes into the capsular space = glomerular filtrate
- Glomerular filtration isn't a selective process (ie. The filtrate does not only contain waste procures, but useful ones as well)

- **Adaptations of the Malpighian body for glomerular filtration**
  - **Blood pressure**
    - Blood enters the glomerulus through wider afferent arterioles and leaves through narrower efferent arterioles
    - This builds up hydrostatic pressure in the glomerulus
    - This pressure forces the smaller components of blood plasma through the capillary pores and podocyte slits into the lumen of the bowman's capsule
  - **Thin membranes**
    - glomerulus capillary membranes are made up of a single layer of squamous epithelium capsule
    - The inner lining of Bowman's capsule is also only 1 cell layer thick, therefore there are only 2 layers of cells between the blood in capillaries and the filtrate in the capsule short distance and fast filtering
  - **Large surface area**
    - A cup shaped capsule and branched capillary network of glomerulus provide a large SA for maximum filtration
  - **Porous membrane**
    - capillaries have numerous small porches (act as micro-filters), Allowing only blood plasma to pass through them, therefore proteins and blood calls can't = ultra-fine filtration
  - **Filtration slits**
    - The podocyte layer of capsule has many filtration slits between podocyte cells. The filtered plasma passes easily through these slits into capsular spaces
    - Podocyte cells have 4-6 feet-like projections (major processes) extending sideways and many finer projections (minor processes) that stretch towards the basement membrane

- **2. Renal tubule**
    - Situated in:
        - the cortex - proximal and distal convoluted tubules
        - The medulla - loop of Henle and collecting ducts
    - The renal tubule is lined by cuboidal epithelial cells
    - The renal tubule is made up of the
        - proximal convoluted tubule
        - the loop of Henle (with a descending limb, hairpin bend and an ascending limb)
        - distal convoluted tubule
    - The DCT opens into the collecting duct
    - These collecting ducts join to form the duct of Bellini in a pyramid and open into the calyces of the renal pelvis

- **Tubular reabsorption**
    - As glomerular filtrate passes through the PCT, all the glucose, amino acids, vitamins are actively absorbed back into the peritubular capillaries that surround the PCT
    - Water follows the movement of these particles by osmosis (from a high water pot. inside the PCT to a low water pot. in the blood)
    - After glucose, amino acids etc. have been actively reabsorbe, the glomerular filtrate is now called dilute urine
    - Dilute urine still has a large amount of water as it enters the loop of Henle
    - The loop of Henle's main job is to recover and conserve the amount of water that is needed by the body

- **Adaptations of the Proximal convoluted tubule for tubular reabsorption**
    - Tubules are convoluted
        - This creates a large surface area which maximises absorption and slows down the movement of the filtrate -> allowing more time for absorption
    - Microvilli on the surface of the cuboidal epithelial cells
        - This further increases the surface area for maximum absorption
    - Cuboidal epithelial cells contain a large number of mitochondria •
        - supplies energy for active absorption

- Capillaries are in close contact with the PCT
    - This reduces the distance for reabsorption of useful substances into the capillaries

Blood supply to the Nephron

- Each Bowman's capsule is supplied with blood by a branch of the renal artery, called an afferent arteriole which divides into a tangled network of capillaries called the glomerulus
- The capillaries of the glomerulus rejoin to form the efferent arteriole • The efferent arteriole forms a network of capillaries running closely alongside the PCTs, LofH and DCTs
- This network of capillaries is called the peritubular capillaries which eventually lead to the renal vein

Tubular excretion

- renal tubule cells don't only re absorb useful substances they also excrete wastes such as creatinine, drugs, ammonia, potassium, hydrogen and bicarbonate ions from the blood back into the tubule
- The kidney tubules assist in regulating the pH of the blood

- If the blood becomes too acidic (low pH)
    - The concentration of H-ions in the blood is high
    - The cells of the tubules remove more hydrogen ions from the blood and pass them into the tubule, thus reducing the H-ion concentration in the blood
    - The pH of blood returns to normal
- If the blood becomes too alkaline (high pH)
    - The concentration of bicarbonate ions in the blood is high
    - The cells of the tubules remove more bicarbonate ions from the blood and pass them into the tubule, thus reducing the bicarbonate concentration in the blood
    - The pH of blood returns to normal

The passage of urine to the bladder

- The fluid that leaves the collecting ducts is called urine
- Urine = concentrated solution of urea in water. Also contains salts, uric acid and creatinine

1. Nephrons
2. Collecting ducts of pyramids
3. Renal calyx
4. Renal pelvis
5. Ureter (propelled by peristalsis)
6. Temporarily stored in muscular-walled bladder
7. Internal sphincter (involuntary control)
8. External sphincter (voluntary control)
9. Urethra

The role of loop of henle in conserving water

- Function of the Loop of Henle
    - to recover and conserve the amount of water that is needed by the body
- sodium ions are actively pumped out of the ascending limb of the loop of Henle into the tissue fluid of the medulla
- This creates a lower water potential in the medulla and a high-water potential in the DCT and collecting duct
- Water moves passively out of the DCT and collecting duct (both permeable to water) onto the medulla by osmosis
- The ascending limb of the loop of Henle is impermeable to water
- Water from the medulla is re absorbed back into the blood of the surrounding peritubular capillaries
- The urine in the collecting ducts may be concentrated or dilute depending on whether the body has an excess or shortage of water
- The reabsorption of water from the DCT and CD is regulated by hormone called antidiuretic hormone

1. Na and Cl diffuse out of filtrate, H2O follows by osmosis
2. Na are actively pumped out of the filtrate sodium pump —> hypertonic tissue fluid

3. As walls of ascending limb are impermeable to water, water can't follow —> hypotonic filtrate
4. This results in a diffusion gradient which causes water to move by osmosis out of the distal and collecting ducts into tissue fluid and then into blood capillaries
5. This results in water being kept in the body and urine being highly concentrated

Homeostasis

Process of maintaining a constant, internal environment within narrow limits, despite changes that take place internally and externally

The kidneys maintain homeostasis by:

- Regulating the water content of the body through the action of hormone ADH (osmoregulation)
- Controlling the pH of the blood
- Removing various cellular wastes and substances which are in excess (eg. Salts, uric acid and urea)

- **Osmoregulation**
    - Maintaining a constant internal water balance
    - Hormone: Antidiuretic hormone (ADH)
    - Produced: Hypothalamus
    - Stored: Pituitary Gland
    - Target organ: Kidney —> DCT + CD

    - When the body has too much water —> drinking lots of water/ less sweating/ little exercise:
        - volume of water in the blood increases
        - Osmoreceptors in the hypothalamus are stimulates
        - Impulses are sent to pituitary gland to secrete less ADH into the blood

        - Walls of DCT and CD become less permeable to water • Less water leaves tubule via osmosis
        - More water remains in the tubule
        - More dilute urine which is excreted from the body
        - Less water is reabsorbed by capillaries
        - Level of water in blood decreases back to normal
    - When the body has too little water—> excessive exercise/ hot temperatures/ increase sweating/ or decreased water intake:
        - volume of water in the blood decreases
        - osmoreceptors in the hypothalamus are stimulated
        - Impulses are sent to pituitary gland to secrete more ADH into the blood (ADH increases the number of water permeable channels in DCT and CD membrane)
        - Walls of DCT and CD become more permeable to water
        - More water leaves tubule via osmosis and is reabsorbed by capillaries
        - More concentrated urine
        - Level of water in blood increases back to normal

- **Salt balance**
    - Hormone: Aldosterone
    - Produced: Adrenal gland
    - Target organ: Kidney

    - When there is a shortage of sodium in the blood:

        - More Aldosterone is secreted
        - Aldosterone stimulates the active reabsorption of sodium ions from the filtrate into the blood
        - Therefore, less sodium ions are excreted
        - Therefore, sodium level returns to normal

    - When there is an excess of sodium ions in the blood:
        - secretion of aldosterone decreases
        - Less sodium is reabsorbed by blood capillaries
        - Therefore: more sodium is excreted. When sodium is in a tubule, water follows by osmosis, therefore: the amount of urine excreted increases if the amount of sodium ions increases

- Therefore: the amount of sodium in the blood decreases back to normal