4. EXCRETORY PRODUCTS AND THEIR ELIMINATION

Excretion is the elimination of metabolic wastes like **ammonia, urea, uric acid** etc. from the tissues.

Types of excretion

1. **Ammonotelism:** Process of excretion of **NH_3.**
   Ammonotelic animals: Aquatic invertebrates, bony fishes, aquatic amphibians, aquatic insects etc. NH_3 is highly toxic. So excretion needs excess of water.
   NH_3 is readily soluble in water and is excreted by diffusion across body surfaces or through gill surfaces (in fishes) as ammonium ions. Kidneys do not play any significant role in its removal.
2. **Ureotelism:** Process of excretion of **urea.**
   Ureotelic animals: Mammals, terrestrial & semi-aquatic amphibians (frogs, toads etc.), cartilaginous fishes, aquatic or semi-aquatic reptiles (alligators, turtles) etc.
   In liver, NH_3 is converted into less toxic urea. So it requires only moderate quantity of water for excretion.
3. **Uricotelism:** Process of excretion of **uric acid.** It is insoluble in water. So water is not required for excretion.
   Uricotelic animals: Birds, terrestrial reptiles, insects, land snails and some land crustaceans.

Ureotelism & uricotelism are needed for water conservation.

Some excretory organs in animals

- **Protonephridia (flame cells):** In Flatworms, rotifers, some annelids & cephalochordate. Protonephridia are primarily for osmoregulation.
- **Nephridia:** In Annelids. Help in the removal of nitrogenous wastes and osmoregulation.
- **Malpighian tubules:** In Insects. Help in the removal of nitrogenous wastes and osmoregulation.
- **Antennal or green glands:** In Crustaceans (prawn etc.)
- **Kidneys:** In Higher animals.

HUMAN EXCRETORY SYSTEM

It includes a pair of **kidneys,** a pair of **ureters,** a **urinary bladder** and a **urethra.**

Structure of Kidney

- Reddish brown, bean-shaped structures situated between the levels of last thoracic and 3rd lumbar vertebra.
- Length: **10-12 cm,** width: **5-7 cm,** thickness: **2-3 cm.** Average weight: **120-170 gm.**
- It is enclosed in a tough, 3-layered **fibrous renal capsule.**
- On the concave side of kidney, there is an opening (**hilum** or **hilus**) through which blood vessels, nerves, lymphatic ducts and ureter enter the kidney.
- Hilum leads to funnel shaped cavity called **renal pelvis** with projections called **calyces.**
- Each kidney has outer **cortex** and inner **medulla.**
- Medulla has few conical projections called **medullary pyramids (renal pyramids)** projecting into the calyces.
- Cortex extends in between the medullary pyramids as renal columns **(Columns of Bertini).**
- Each kidney has nearly one million tubular **nephrons**.

Nephron

- Nephrons are the structural & functional units of kidney.
- Each nephron has 2 parts: **Glomerulus** & **Renal tubule.**
  - **Glomerulus:** A tuft of capillaries formed by **afferent arteriole** (a fine branch of renal artery). Blood from the glomerulus is carried away by an **efferent arteriole.**
  - **Renal tubule:** It begins with a double walled cup-like **Bowman's capsule**, which encloses the glomerulus.
- **Glomerulus + Bowman's capsule = Malpighian body.**
- The tubule continues with **proximal convoluted tubule (PCT), Henle's loop** & **distal convoluted tubule (DCT).**
- Henle's loop is hairpin-shaped. It has **descending and ascending limbs.**
- The DCTs of many nephrons open into a **collecting duct**. Collecting duct extends from cortex to inner parts of medulla. They converge and open into the **renal pelvis** through **medullary pyramids** in the **calyces.**
- **Malpighian body (Renal corpuscle), PCT** and **DCT** are situated in **renal cortex. Loop of Henle** dips into **medulla.**
- The **efferent arteriole** emerging from glomerulus forms a fine capillary network **(peritubular capillaries)** around the renal tubule. A minute vessel of this network runs parallel to Henle's loop forming a 'U' shaped **vasa recta**.

Types of nephrons

1. **Cortical nephrons** (85%): In this, the Henle's loop is short and extends only very little into the medulla. Vasa recta is absent or highly reduced.
2. **Juxtamedullary nephrons** (15%): In this, Henle's loop is long and runs deep into medulla. Vasa recta present.

URINE FORMATION (PHYSIOLOGY OF KIDNEY)

3 processes: Glomerular filtration, reabsorption & secretion.

1. Glomerular filtration (ultrafiltration)

- The glomerular capillary blood pressure causes filtration of blood through 3 layers, i.e. **endothelium of glomerular blood vessels**, **epithelium of Bowman's capsule** & **a basement membrane** between these 2 layers.
- The epithelial cells **(podocytes)** of the Bowman's capsule are arranged in an intricate manner so as to leave some minute spaces called **filtration slits (slit pores).**
- Almost all constituents of the blood plasma except the proteins pass onto the lumen of the Bowman's capsule.
- About **1100-1200 ml of blood** is filtered by the kidneys per minute. It constitutes **1/5th** of the blood pumped out by each ventricle of the heart in a minute.
- The amount of the filtrate formed per minute is called **Glomerular filtration rate (GFR).**
- **Normal GFR = 125 ml/minute, i.e., 180 litres/day.**

2. Reabsorption

- **180 litres** of glomerular filtrate is produced daily. But about **99%** of this is reabsorbed by the renal tubules.
  So normal volume of urine released is **1.5 litres.**
- From the filtrate, **glucose, amino acids, Na^+,** etc. are reabsorbed **actively** and **nitrogenous wastes** are absorbed by **passive transport**. Passive reabsorption of water occurs in the initial segments of the nephron.
- **PCT** reabsorbs most of the nutrients, and 70-80% of electrolytes & water. Simple cuboidal brush border epithelium of PCT increases surface area for reabsorption.
- In **loop of Henle,** minimum reabsorption takes place. It maintains high osmolarity of medullary interstitial fluid.
  The descending limb is permeable to water but almost impermeable to electrolytes. This concentrates the filtrate.
  The ascending limb is impermeable to water but allows transport of electrolytes. So, the filtrate gets diluted.
- In **DCT,** conditional reabsorption of Na^+ & water takes place.
- **Collecting duct** extends from cortex to inner parts of medulla. It reabsorbs large amount of water to concentrate urine. It also allows passage of small amounts of urea into medullary interstitium to keep up the osmolarity.

3. Tubular Secretion

- Cells of **PCT** & **DCT** maintain **ionic** (Na-K balance) and **acid-base balance (pH)** of body fluids by selective secretion of H^+, K^+ & NH_3 into the filtrate and absorption of HCO_3^- from it.
- **Collecting duct** maintain pH and ionic balance of blood by the secretion of H^+ and K^+ ions.

Mechanism of the concentration of the filtrate

- **Henle's loop** & **vasa recta** help to concentrate the urine.
- The flow of filtrate in the 2 limbs of Henle's loop and the flow of blood through the 2 limbs of vasa recta are in opposite directions (i.e. in a **counter current pattern).**
- The counter current and proximity between the Henle's loop & vasa recta maintain an increasing **osmolarity** towards the **inner medullary interstitium**, i.e., from **300 $mOsmolL^{-1}$** in the **cortex** to about **1200 $mOsmolL^{-1}$** in the **inner medulla**. This gradient is mainly caused by **NaCl** and **urea.**
- NaCl is transported by ascending limb of Henle's loop that is exchanged with descending limb of vasa recta. NaCl is returned to interstitium by ascending limb of vasa recta.
- Similarly, small amount of urea enter the thin segment of the ascending limb of Henle's loop which is transported back to the interstitium by the collecting tubule.
- This transport of substances facilitated by Henle's loop & vasa recta is called **Counter current mechanism.** It maintains a **concentration gradient (interstitial gradient)** in medullary interstitium. It helps in an easy passage of water from collecting tubule to concentrate the filtrate (urine).
- Human kidneys produce urine four times concentrated than the initial filtrate formed.

REGULATION OF THE KIDNEY FUNCTION

- It is done by hormonal feedback mechanisms involving the **hypothalamus, JGA** and the **heart.**
- Changes in **blood volume, body fluid volume** and **ionic concentration** activate **Osmoreceptors** in the body.

1. Regulation by ADH (vasopressin)

- When body fluid level decreases, the **osmoreceptors** stimulate the **hypothalamus antidiuretic hormone (ADH)**. ADH prevents **diuresis** by facilitating water reabsorption from **DCT** and **collecting duct**.
- An increase in fluid volume switches off the osmoreceptors and suppresses the ADH release to complete the feedback.
- ADH constricts blood vessels resulting in an increase of BP. This increases the glomerular blood flow and GFR.

2. Regulation by JGA (Renin-Angiotensin mechanism)

- There is a special sensitive region called **juxta glomerular apparatus (JGA**) formed by cellular modification of **DCT** and the **afferent arteriole** at the location of their contact. JGA regulates the **GFR.**
- A fall in glomerular blood flow/glomerular blood pressure/GFR activates the **JG cells** to release **renin.**
- Renin converts **angiotensinogen** in blood to **angiotensin I** and further to **angiotensin II** (a **vasoconstrictor**). Angiotensin II increases **glomerular blood pressure** and thereby **GFR**. Angiotensin II also activates **adrenal cortex** to release **Aldosterone.**
- Aldosterone causes **reabsorption** of **Na^+** and **water** from the **distal parts** of the tubule. This also leads to an increase in blood pressure and GFR.

3. Regulation by ANF

- ANF check on the renin- angiotensin mechanism.
- An increase in blood flow to the atria of the heart causes the release of **Atrial Natriuretic Factor (ANF).**
- ANF causes **vasodilation** (dilation of blood vessels) and thereby decreases the blood pressure.

MICTURITION

- Gradual filling of urinary bladder causes stretching. As a result, **stretch receptors** on its wall send impulses to CNS. The CNS passes on **motor messages.** It causes the contraction of **smooth muscles** of the bladder and simultaneous relaxation of the **urethral sphincter.** It results in **micturition** (release of urine).
- The neural mechanism causing micturition is called **micturition reflex.**
- An adult human excretes **1 to 1.5 litres** of urine (**25-30 gm urea)** per day.
- Urine is a **light yellow coloured watery fluid**, slightly **acidic (pH-6.0)** and has a characteristic odour.

- Various conditions can affect the characteristics of urine.
- Analysis of urine helps in **clinical diagnosis** of many metabolic disorders and malfunctioning of the kidney.
  E.g. **Glycosuria** (presence of glucose) and **Ketonuria** (ketone bodies) in urine indicates **diabetes mellitus.**

Role of Lungs, liver & skin in Excretion

- **Lungs:** Remove **CO_2 (18 litres/day)** and **water.**
- **Liver:** Secretes bile containing **bilirubin, biliverdin, cholesterol, degraded steroid hormones, vitamins** and **drugs.** Most of them pass out along with digestive wastes.
- **Skin (Sweat glands** & **sebaceous glands): Sweat** contains **water, NaCl, small amounts of urea, lactic acid, etc.**
  Primary function of sweat is to give a **cooling effect** on body surface.
  Sebaceous glands eliminate substances like **sterols, hydrocarbons** and **waxes** through **sebum.** Sebum provides a protective oily covering for the skin.
- **Saliva** eliminates small amounts of nitrogenous wastes.

DISORDERS OF EXCRETORY SYSTEM

- **Uremia**: Accumulation of urea in blood which may lead to **kidney failure.**
- **Renal calculi:** Stone or insoluble mass of crystallized salts **(oxalates, etc.)** formed within the kidney.
- **Glomerulonephritits:** Inflammation of glomeruli.

Hemodialysis

- In patients with uremia, **urea** is removed by **hemodialysis.**
- The **dialyzing unit** (artificial kidney) contains a coiled **cellophane tube** surrounded by **dialyzing fluid.** It has same composition of plasma except nitrogenous wastes.
- Blood drained from a convenient artery is pumped into **dialyzing unit** after adding anticoagulant like **heparin.**
- The porous **cellophane membrane** of the tube allows the passage of molecules based on concentration gradient.
- As nitrogenous wastes are absent in dialyzing fluid, these substances freely move out, thereby clearing the blood.
- The cleared blood is pumped back to the body through a vein after adding **anti-heparin** to it.

Kidney transplantation

- It is the ultimate method in the correction of **acute renal failures.** A functioning kidney is taken from a donor.
- It is better to receive kidney from a close relative to minimize chances of rejection by immune system of host.