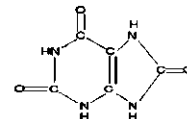


Excretory Products & Their Elimination

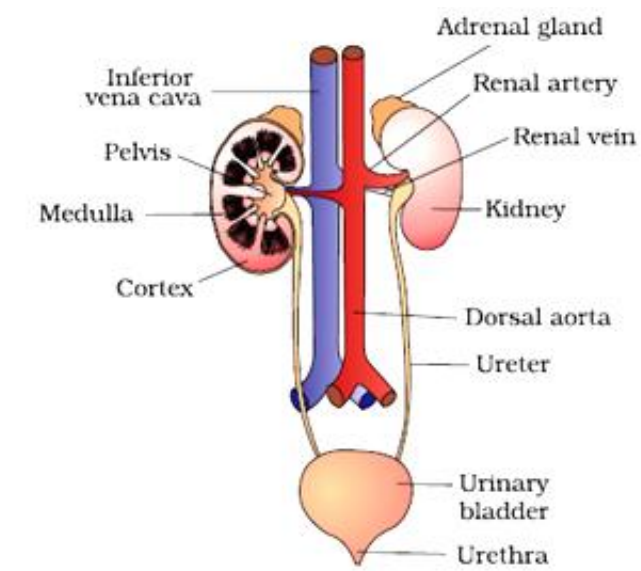
- **Excretion:** Elimination of metabolic waste products from the animal body to regulate the composition of body fluids and tissues.
These waste products include ammonia, uric acid, urea, carbon dioxide and ions like Na^+ , K^+ , Cl^- and phosphates and sulphate.
- **Osmolarity** :The concentration of solutes in a solution, expressed as osmoles per liter of solvent.

Types of Excretion:

Ammoniotelic	Ureotelic	Uricotelic
• Excrete Ammonia/NH_3 • Ammonia is the most toxic • Readily soluble in water • Requires large amount of water for its elimination. • Excreted by Diffusion through Body surface or gills as ammonium ion. • Kidney do not play significant role. • Ex- Bony fishes, Aquatic amphibians (Tadpole) and aquatic invertebrates.	• Excrete Urea ($NH_2 CO NH_2$) • Less toxic than ammonia • Ammonia is converted into Urea in Liver. • Require moderate amount of water for elimination • Kidney play significant role in elimination. • Some amount of urea may retain in kidney to maintain osmolarity. • Ex: Cartilaginous fishes (Shark), Mammals, Terrestrial Amphibians (Adult Frog) and Marine Fishes aquatic insects	• Excrete Uric Acid • Uric Acid Least toxic • Insoluble in water • Do not require water for elimination. • Contribute to water conservation. • Produce concentrated Urine (Uric Acid in form of Pallet or Paste). • Ex: Reptiles, birds, land snails, crustaceans and insects



Animals	Excretory organs
Flatworms (Planaria), Rotifers some annelids & cephalochordates.	Protonephridia or flame cells.
Aschelminthes (Nematoda)	Renette Cells or Excretory Canal
Annelida (Earthworm)	Nephridia
Arthropods (Insects- cockroaches)	Malpighian Tubule
Crustaceans (Arthropods) (prawns, Crabs)	Antennal glands or Green glands
Mollusca	Metanephridia
Hemichordate (Balanoglossus)	Proboscis Gland / (Glomerulus)
Chordates (Mammals)	Kidney



Human Excretory System

According to the chapter on excretory products and their elimination, the human excretory system consists of:

1. **A pair of Kidneys:** Situated between the Thoracic – 12(last) and Lumber - 3 vertebra, bean-shaped and reddish-brown in colour.
 - Covered by a single layer of tough fibrous capsule.
 - Located towards Dorsal side of the Body.
 - 10-12 cm long, 5-7 cm wide, 2-3 cm thick with an average weight of 120- 170 g.
 - The left kidney is larger and positioned higher (upper) in the human body because in right side Liver is present.
 - Divided into 2 layers: the outer cortex and an inner medulla.
2. **A pair of ureters:** Muscular Tube carry urine from the kidneys to the bladder. Approximately 25-30 cm long consist of smooth muscle. Lined by transitional epithelium/urothelium.
3. **A urinary bladder-** A hollow, muscular organ that temporary stores the urine. Capacity 400-500ml. Consist of 4 layers.
 - i) **Mucosa** (innermost) layer with folds,
 - ii) **Submucosa** contains blood vessels,
 - iii) **Muscularis-** Smooth/Detrusor muscles responsible for contraction of bladder
 - iv) **Serosa-** outermost fibrous
4. **A urethra:** A tube that carries urine from the urinary bladder to the external environment. In females it is 3-4 cm long. In males it is 20-25 cm long and serve as common passage for semen & urine.

Urethral Segment	Type of Epithelium
Proximal Part (<i>Near the bladder</i>)	Transitional epithelium (<i>Urothelium</i>)
Middle Part (In Males)	Pseudostratified columnar epithelium (<i>and stratified columnar</i>)
Distal/Penile Part (<i>Near the external opening</i>)	Stratified squamous epithelium

Human Kidney-

Renal Cortex: The outer region of the kidney containing nephrons and renal corpuscles, where filtration of blood occurs. Malpighian body, PCT & DCT lies in Cortex region.

Renal Medulla: The inner region of the kidney containing renal pyramids and collecting ducts, responsible for the concentration and transportation of urine. 8-18 pyramids present in each kidney. Henle's loop lies in Medullary region.

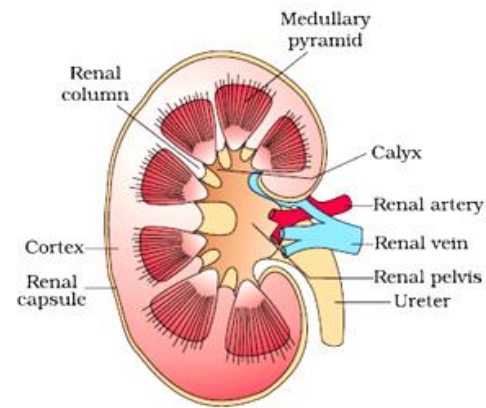
Renal Capsule: A tough fibrous tissue covering that act as a barrier to the kidney.

Hilum- **Notch present on concave side** of kidney through which the ureter, blood vessels, and nerves enter the kidney.

Columns of Bertini : The renal columns formed when the **cortex extends between the medullary pyramids.**

Renal pelvis: A broad funnel shaped space inner to hilum that collects urine from calyces

Calyces (Sing: Calyx): Funnel shape projections from renal pelvis that collects the urine from renal pyramids.



Nephrons: The structural & functional unit of kidney. Each kidney has an average of 1 million nephrons. It consists of :

1. **Malpighian Body** or **Renal corpuscle** (glomerulus)

- **Bowman's capsule:** A double-walled cup-like structure at the beginning of the renal tubule, which encloses the glomerulus
- **Glomerulus:** A cluster of capillaries formed by the arteriole within Bowman's capsule.

Afferent Arteriole: Brings blood to glomerulus.

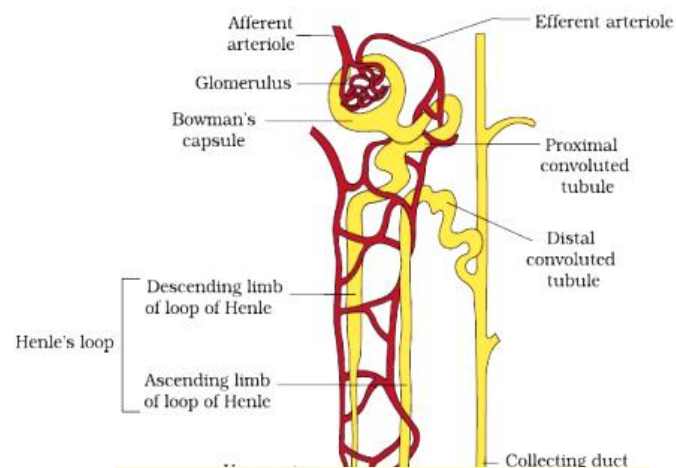
Efferent Arteriole: Takes away blood from

Glomerulus.

Renal tubule

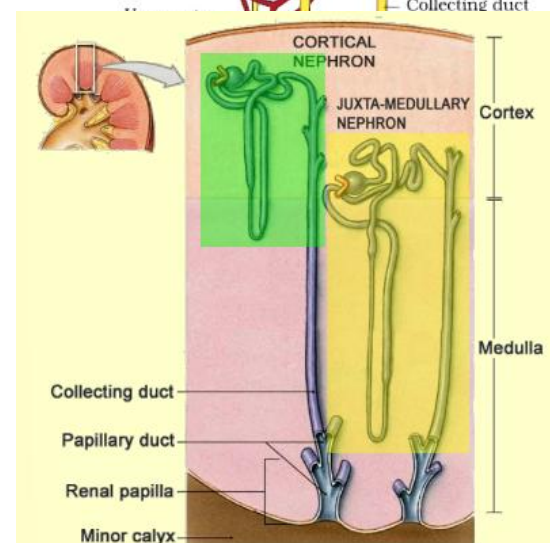
- **Proximal Convoluted Tubule :** A highly coiled tubular structure that carries the filtrate from Bowman's Capsule.
- **Henle's loop:** U shaped tube that extends from PCT & descends into renal medulla. It has an ascending and descending limb.
- **Distal convoluted tubule:** Another highly tubular coiled into which ascending limb of Henle's open.

- ❖ **Vasa recta:** U - shaped blood vessel emerges from Efferent Arteriole that runs parallel to Henle's loop.
- ❖ **Peritubular capillaries:** The fine network of capillaries emerging from glomerulus' efferent arteriole that surrounds the renal tubule.
- ❖ **Collecting Duct:** Straight tube in which DCTs of many (6) nephrons opens.



Types of Nephrons:

1. **Cortical Nephron (85%):** In this Henle's loop is short and extends only very little into medulla. Vasa recta is absent or highly reduced.
2. **Juxtamedullary Nephron (15%):** In this Henle's loop is long and runs deep into medulla. Vasa recta is present. It plays a crucial role in establishing the concentration gradient necessary for water reabsorption and urine concentration.



Urine Formation: Involves 3 main processes namely:

1. **Glomerular Filtration (ultrafiltration)**

- Filtration of blood in glomerulus.
- An average of 1100-1200 ml (1/5 of blood pumped by each ventricle per min) of blood is filtered by the kidneys per minute.

- Almost all the constituents except proteins are filtered onto the lumen of Bowman's capsule.
- Blood Filter through three layers, **endothelium** of blood vessels, the **epithelium** (also called podocytes are arranged in an intricate manner leaving some minute spaces called filtration slits or slit pores) of Bowman's capsule and a **basement membrane** between these two layers.
- Glomerular filtration rate (GFR)- amount of the filtrate formed by the kidneys per minute (approx 125 ml/minute, i.e., 180 litres per day).

➤ **Juxta glomerular apparatus (JGA):**

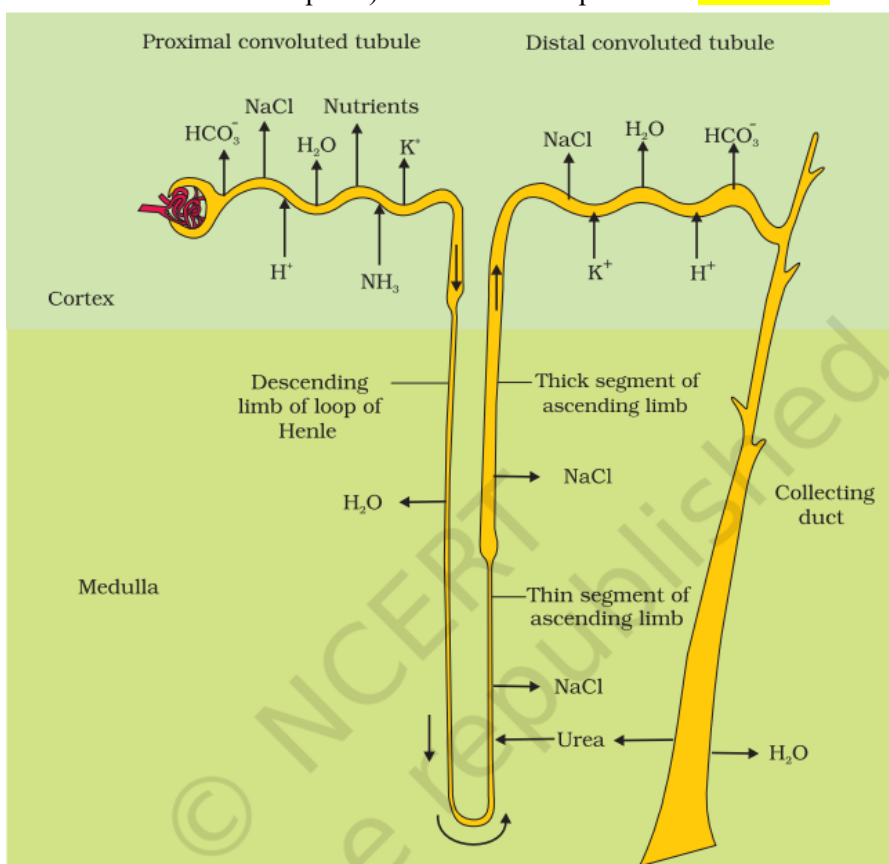
Sensitive region formed at contact of DCT and afferent arteriole. Fall in GFR activates JG cells to release **Renin** which increase Blood flow & bring GFR to normal.

2. Selective Reabsorption

- 180 litres of filtrate formed every day out of which 99% is reabsorbed. 1.5 litres of urine is produced.
- Glucose, amino acids, Na^+ , etc., in the filtrate are reabsorbed actively whereas the nitrogenous wastes are absorbed passively.
- Reabsorption of water passively.

3. Tubular Secretion

- H^+ , K^+ and ammonia into the filtrate during urine formation. Maintenance ionic and acid base balance of body fluids.

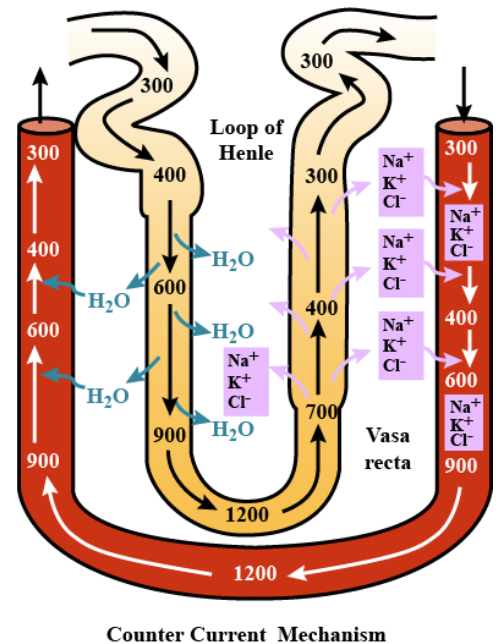
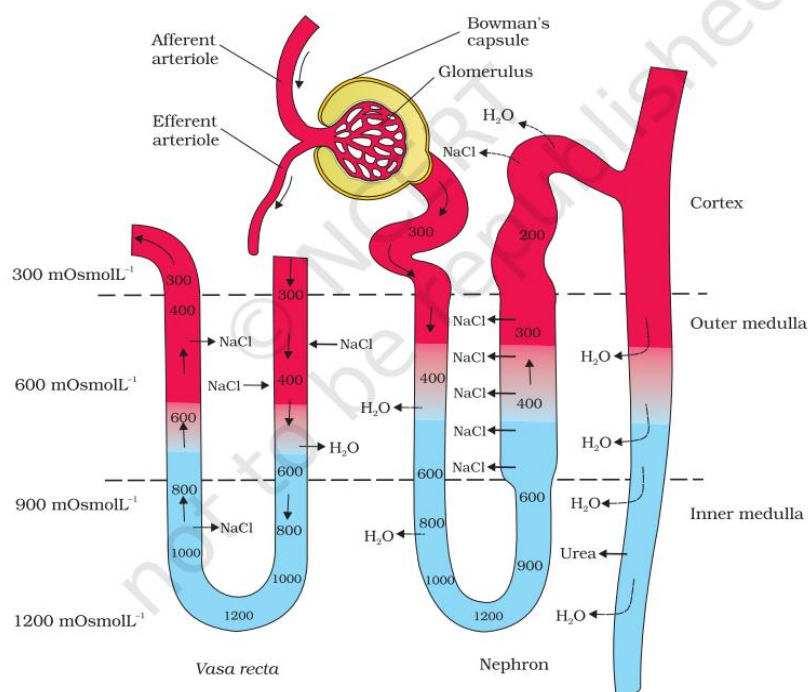


Function of Tubules-

Proximal Convoluted Tubule	Henle's Loop		Distal Convoluted Tubule
- Lined by simple cuboidal brush border epithelium to increase surface area. - Present in Cortex region. 70-80 percent of nutrients, electrolytes and water are reabsorbed. Glucose, Amino Acids, Na^+, Phosphate & Sulphate are absorbed actively. - Maintain pH and ionic balance through Selective secretion of H^+ (actively) and NH_3 (Passively) into the filtrate and by absorption of HCO_3^- (Indirectly & actively) from it. - Absorption of Cl^-, NaCl is both actively and passively. K^+ & Some amount of urea is reabsorbed Passively. - Uric Acid, Creatinine, Antibodies, drugs, pigments & diuretics are secreted actively.	- U- shaped or Hair Pin Shaped tubule extends to Medulla. - Lined by simple squamous epithelium in its thin segments and simple cuboidal epithelium in its thick segments. - As the concentrated filtrate passes upward, it gets diluted due to the passage of electrolytes to the medullary fluid.		- Present in Cortex region. Conditional reabsorption of Na^+ and water. - Capable of reabsorption of HCO_3^- (actively) - Selective secretion of H^+ (actively), K^+ is (actively) & NH_3 (Passively) - Maintains the pH and sodium-potassium balance.
	Descending - Thin part is permeable to water but impermeable to electrolytes. - Reabsorption of water take place.	Ascending Limb Impermeable to water & permeable to ions through entire length. In Thick part Active reabsorption of electrolytes -Na^+, K^+, Cl^- take place. - In Thin Part reabsorption of NaCl (Passively) take place. - Maintains high osmolarity of medullary interstitial fluid. - In Thin part Secretion of Urea take place as it is permeable to Urea and Thick part is Impermeable.	

Collecting Duct: It extends from the cortex to medulla & approx 6 nephron drains in each.

- Reabsorb large amount of water to produce a concentrated urine.
- Maintains osmolarity by allowing the passage of small amounts of urea into the medullary interstitium.
- Selectively secretes H^+ (actively) and K^+ (actively) ions and maintains pH and ionic balance of the body.



Mechanism of Concentration of Filtrate

- Mammals produce concentrated urine through Henle's loop and vasa recta.
- Filtrate flows in opposite directions in Henle's loop than blood flows in vasa recta forming a counter current, aiding reabsorption, secretion and maintains concentration gradient in medullary interstitium.
- Maintains an increasing osmolarity from **cortex (300 mOsmolL⁻¹)** to inner medulla (1200 mOsmolL⁻¹).
- **Gradient caused by NaCl and urea; NaCl transported by ascending limb of Henle's loop and exchanged with descending limb of vasa recta.**
- Urea enters thin segment of ascending limb of Henle's Loop, transported back to interstitium by collecting tubule.
- Interstitial gradient aids easy water passage from collecting tubule, concentrating urine.
- **Human kidneys can produce urine nearly four times more concentrated than the**

Regulation of Kidney Function

Case I: ADH / Vasopressin Mechanism

- **Trigger:** Excessive fluid loss (dehydration, loose motions, sweating).
- **Activation:** Low fluid volume & high osmolality activate **osmoreceptors** (Hypothalamus & Carotid Artery).
- **Hypothalamus sends signal to:**
 - **Thirst Center (Hypothalamus):** Triggers thirst → increases water intake.
 - **Neurohypophysis (Posterior Pituitary):** Releases Antidiuretic Hormone (ADH) / Vasopressin.
- **ADH / Vasopressin- Target DCT & Collecting Duct (CT):** Increases water reabsorption → prevents **diuresis**.
 - Also act as Vasoconstriction → raises blood pressure.
- **Feedback:** Increased body fluid volume suppresses osmoreceptors (negative feedback).

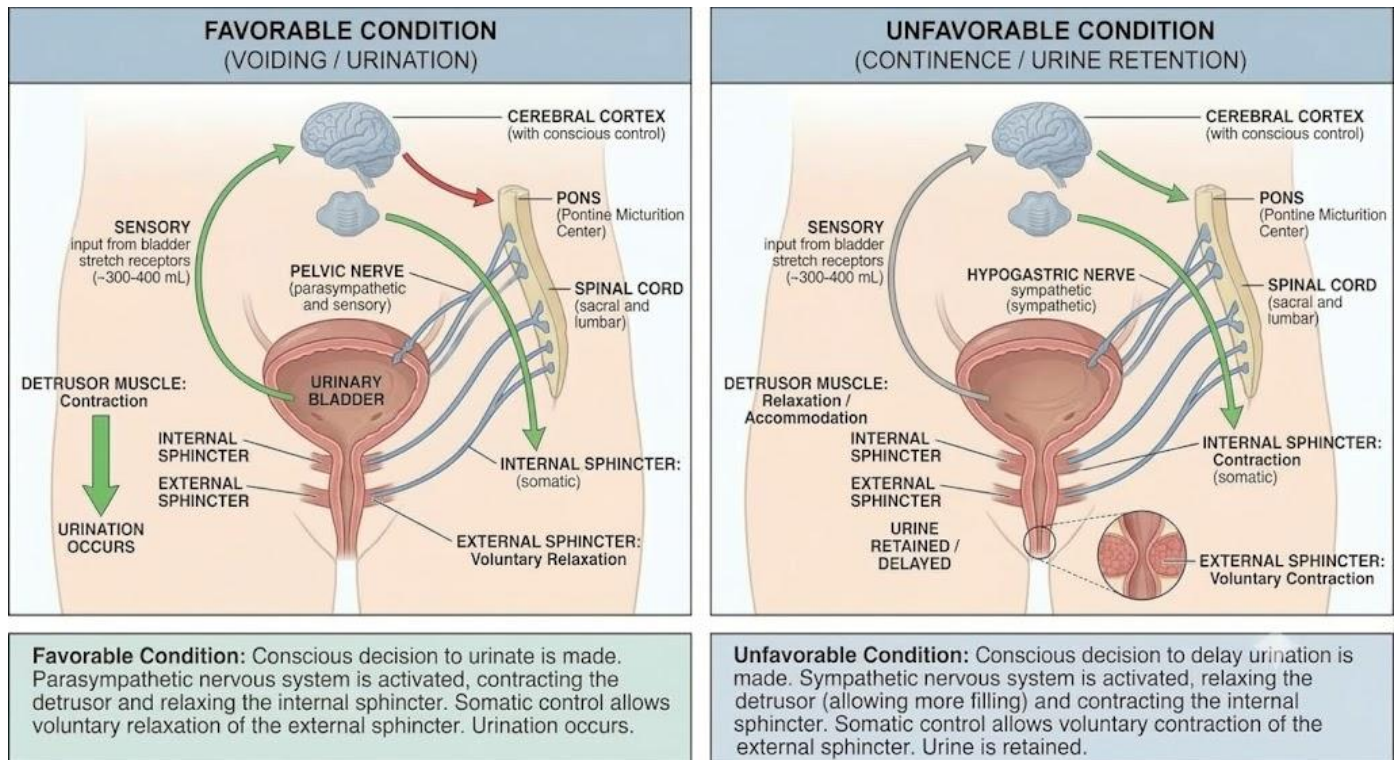
Case II: Renin-Angiotensin-Aldosterone System (RAAS)

- **Trigger:** Fall in Blood Pressure (BP) or Glomerular Filtration Rate (GFR).
- **Activation:** **Juxtaglomerular (JG) cells** (found at Juxta Glomerular Apparatus- at junction of Afferent arteriole-DCT) release **Renin** (Enzymatic Hormone).
- **Cascade:** **Angiotensinogen** (a serum protein released by Liver) $\xrightarrow{\text{Renin}}$ **Angiotensin I** $\xrightarrow{\text{ACE}}$ **Angiotensin II**
(Angiotensin Converting Enzyme (ACE) released from inner lining of Endothelium (Blood Vessel) of Kidney & Lungs.)
- **Angiotensin II Actions:**
 - Powerful **vasoconstrictor** → increases BP & GFR.
 - Increases Na^+ & H_2O reabsorption in **PCT**, DCT and CT.
 - Stimulates **Adrenal Cortex** (Zona Glomerulosa) to release **Aldosterone** (Mineralocorticoid).
- **Aldosterone Action:** Promotes Na^+ & H_2O reabsorption from **DCT & CT** → restores BP & GFR.

Case III: ANF Mechanism (Check on RAAS)

- **Trigger:** High blood pressure / increased blood flow to heart atria.
- **Activation:** **Atrial Myocytes** (cardiac cells) release **Atrial Natriuretic Factor/Peptide (ANF / ANP)**.
- **Action:** Direct **vasodilation** (dilates blood vessels) → lowers BP.
- **Feedback:** Inhibits Renin & Aldosterone release (opposes RAAS).

Micturition: The process of expulsion of urine from the urinary bladder. An adult human excretes, on an average, 1 to 1.5 litres of urine per day



Micturition Reflex

1. Initial State & Sensory Signal

- **Filling:** Urine accumulates to **300–400 mL**, stretching the bladder wall and activating **stretch receptors**.
- **Signal Transmission:** Sensory signals travel to the **Spinal Cord**, which routes them to the **Pons (Pontine Micturition Center)** and up to the **Cerebrum (Cerebral Cortex)**.

2. Case I: Favourable Condition (Urination / Voiding)

- **Roles of Brain & Spinal Cord Centers:**
 - **Cerebrum (Somatic Control):** Decides it is safe to urinate and sends an **inhibitory signal** (not to contract) to relax the external sphincter.
 - **Pons & Sacral Spinal Cord (Autonomic Control):** The **Pons** acts as the main switching center; it triggers the sacral spinal cord to activate **Parasympathetic** output.
- **Muscle Actions:**
 - **Detrusor Muscle (Smooth):** **Contracts** → driven by the **Parasympathetic System** (activated via Pons & Sacral Spinal Cord).
 - **Internal Urethral Sphincter (Smooth):** **Relaxes** → driven by the **Autonomic System** (via Pons signaling).
 - **External Urethral Sphincter (Skeletal):** **Relaxes** → controlled voluntarily by the **Cerebrum** (via Somatic inhibition).

3. Case II: Unfavourable Condition (Urine Retention)

- **Roles of Brain & Spinal Cord Centers:**
 - **Cerebrum (Somatic Control):** Decides it is NOT safe to urinate and sends an **excitatory signal** to contract the external sphincter, overriding the voiding reflex.
 - **Pons & Thoracolumbar Spinal Cord (Autonomic Control):** The **Pons** suppresses parasympathetic output and activates **Sympathetic** output via the spinal cord.
- **Muscle Actions:**
 - **External Urethral Sphincter (Skeletal):** **Contracts** → driven voluntarily by the **Cerebrum** (via Somatic stimulation) to block urine exit.
 - **Detrusor Muscle (Smooth):** **Relaxes / Dilates** → driven by the **Sympathetic System** (via Spinal Cord signals under higher center guidance) to allow bladder filling.
 - **Internal Urethral Sphincter (Smooth):** **Contracts** → driven by the **Sympathetic System** (via Spinal Cord) to seal the bladder neck.

Urine Constituent: pH of Urine is 6 (slightly acidic), colour is pale yellow due to presence of Urochrome.
 It constitute approximately 95% water, with the remaining 5% comprising urea, creatinine, electrolytes (sodium, potassium, chloride, bicarbonate), uric acid, ammonia, and trace elements.
 On an average, 25-30 gm of urea is excreted out per day.
 The presence of glucose (glycosuria) and ketone bodies (ketonuria) in urine is indicative of diabetes mellitus,

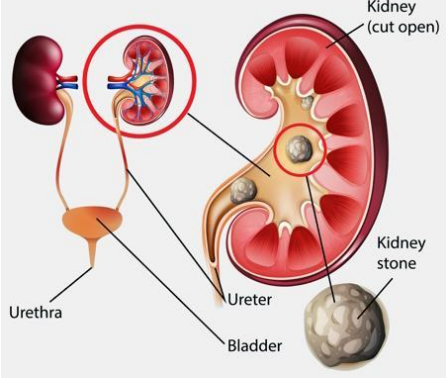
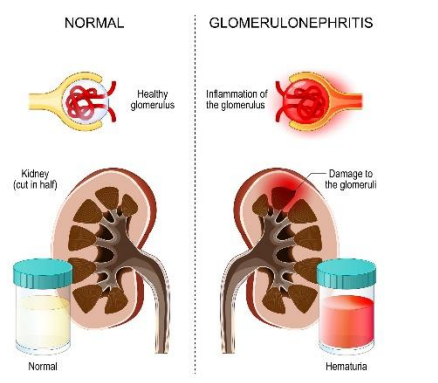
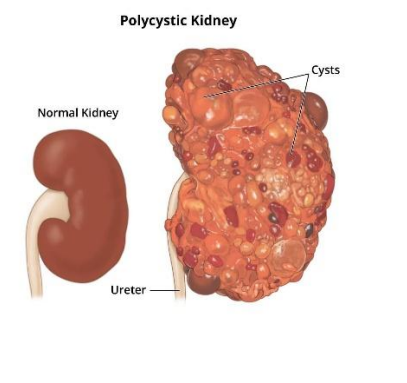
ROLE OF OTHER ORGANS IN EXCRETION

- Lungs remove about 200mL/minute of CO₂ and significant water daily.
- Liver secretes bile with bilirubin, biliverdin, cholesterol, hormones, vitamins, & drugs which are pass out with digestive wastes.
- Skin's sweat glands eliminate NaCl, urea, and lactic acid, facilitating cooling and waste removal.
- Sebaceous glands in the skin release sebum containing sterols, hydrocarbons, and waxes for protective covering.
- Saliva also eliminate small amounts of nitrogenous wastes (urea).

Disorders of the Excretory System

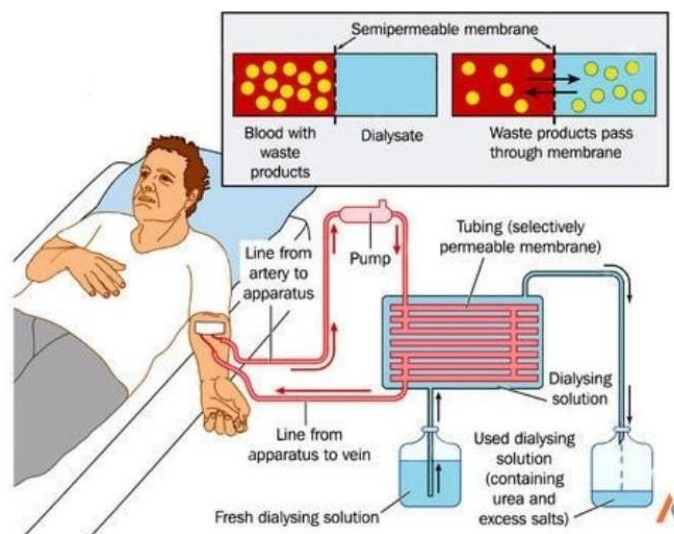
Towards the end of the chapter on excretory products and their elimination, we find out about the disorders of the excretory system. They are as follows:

- **Renal failure** – Kidneys cannot adequately remove wastes or regulate fluid and electrolyte balance. Severe cases may require dialysis or transplantation (Donor, preferably a close relative, to minimise its chances of rejection by the immune system of the host.).
- **Uremia**- Accumulation of urea in blood due to malfunctioning of kidneys. This can lead to kidney failures. Remedy haemodialysis

Renal calculi – Stones or insoluble salts are formed within the kidney.	Glomerulonephritis (Bright’s Disease) – Inflammation of glomeruli in the kidneys. It occurs due to the entry of RBCs or proteins.	Polycystic kidney disease Formation of multiple fluid-filled cysts in the kidneys; some inherited forms progressively impair renal function.
		

Haemodialysis: (Recommended when a patient suffers from acute renal failure or severe uremia)

- **Blood Extraction:** Blood is drawn from a convenient artery (such as the **Radial Artery**).
- **Anticoagulation:** The extracted blood is mixed with **heparin** (an anticoagulant) and cooled before entering the machine.
- **Dialysing Unit:** The blood passes through a coiled **cellophane tube** (semi-permeable membrane) suspended in a **dialysing fluid**.
- **Fluid Composition:** The dialysing fluid has the **exact same composition as normal blood plasma, EXCEPT it lacks nitrogenous wastes**.
- **Waste Removal:** Nitrogenous wastes (urea, uric acid, creatinine, and excess salts) diffuse out of the blood across the cellophane membrane into the dialysing fluid along the concentration gradient.
- **Blood Return:** The cleared blood is warmed back to **body temperature**, mixed with **anti-heparin** (to neutralize heparin), and pumped back into the body through a vein (such as the **Radial Vein**).



Important Terms

Diabetes Mellitus (Sugar Disease): A metabolic disorder characterized by **hyperglycaemia** (persistently high blood glucose levels) caused by the **hyposecretion** (deficiency) of **insulin**.

Key Symptoms & Indicators:

- **Glycosuria:** Excretion of glucose in urine, occurring when blood glucose concentration exceeds the **renal threshold** (approx. 180 mg/dL).
- **Ketonuria:** Presence of ketone bodies in urine due to incomplete breakdown and **increased metabolism of fats**. May occur in uncontrolled diabetes mellitus or prolonged fasting
- **Polyuria:** Excessive urination resulting from osmotic diuresis caused by unabsorbed glucose in nephron tubules.

Diabetes Insipidus

Definition & Cause: Disorder causing excretion of large volumes of dilute urine due to hyposecretion (deficiency) of ADH / Vasopressin.

Key Symptoms:

Polyuria: Excessive urination due to failed water reabsorption in DCT and Collecting Duct.

Polydipsia: Excessive thirst caused by dehydration and high blood osmolality.

Proteinuria	Excess protein in urine	May indicate glomerular damage.
Hematuria	Blood/RBCs in urine	May occur with stones, infection or renal disease.
Albuminuria	Albumin in urine	Can indicate kidney damage.
Polyuria	Excessive urine volume	May occur in diabetes mellitus or diabetes insipidus.
Oliguria	Abnormally low urine output	May occur with dehydration or renal dysfunction.
Anuria	Almost complete absence of urine production	Can occur in severe renal dysfunction or urinary obstruction.
Nocturia	Excessive urination at night	Can occur in several urinary or systemic conditions.

Role of PTH & Calcitonin in Excretion

1. Parathyroid Hormone (PTH)

- **Nature:** Hypercalcemic hormone (increases blood Ca^{2+} levels).
- **Action on Kidney Tubules:**
 - **Increases Ca^{2+} reabsorption** in the Distal Convolutd Tubule (DCT).
 - **Decreases Phosphate (HPO_4^{2-}) reabsorption** in the Proximal Convolutd Tubule (PCT), promoting its excretion in urine.

2. Calcitonin (Thyrocalcitonin / TCT)

- **Nature:** Hypocalcemic hormone (decreases blood Ca^{2+} levels); acts as an antagonist to PTH.
- **Source:** Secreted by Parafollicular (C cells) of the Thyroid gland.
- **Action on Kidney Tubules:**
 - **Inhibits Ca^{2+} and Phosphate reabsorption** in renal tubules, increasing their excretion in urine.