

Biology

EXCRETORY PRODUCTS AND THEIR ELIMINATION

CHAPTER 19

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EXCRETORY PRODUCTS AND THEIR ELIMINATION

CHAPTER 19

I. Introduction

- Animals accumulate various substances like ammonia, urea, uric acid, ions, and others from metabolic activities or excessive ingestion.
- Elimination of these substances is essential to prevent toxicity.

2. Nitrogenous Waste Types

- **Ammonia:** Most toxic, needs a lot of water for elimination.
- **Urea:** Less toxic, eliminated with a moderate amount of water.
- **Uric Acid:** Least toxic, requires minimal water for elimination.

3. Excretory Mechanisms

- **Ammonotelism (Ammonia Excretion):**
 - Animals: Many bony fishes, aquatic amphibians, aquatic insects.
 - Process: Diffusion across body or gills as ammonium ions.
 - Kidneys' Role: Insignificant in ammonia elimination.
- **Ureotelism (Urea Excretion):**
 - Animals: Mammals, many terrestrial amphibians, marine fishes.
 - Process: Ammonia converted to urea in the liver, then released into blood. Kidney's filter and excrete it.
 - Special Note: Some urea may be retained in the kidneys for osmolarity.
- **Uricotelism (Uric Acid Excretion):**
 - Animals: Reptiles, birds, land snails, insects.
 - Form: Pellet or paste to minimize water loss.

4. Excretory Structures in the Animal Kingdom

- **Protonephridia or Flame Cells:**
 - Animals: Platyhelminthes (e.g., Planaria), rotifers, some annelids, Amphioxus.
 - Function: Osmoregulation, ionic and fluid volume regulation.
- **Nephridia:**
 - Animals: Earthworms, other annelids.
 - Function: Removal of nitrogenous wastes, osmoregulation.
- **Malpighian Tubules:**
 - Animals: Most insects, including cockroaches.
 - Function: Nitrogenous waste removal, osmoregulation.
- **Antennal or Green Glands:**
 - Animals: Crustaceans (e.g., prawns).
 - Function: Excretion.

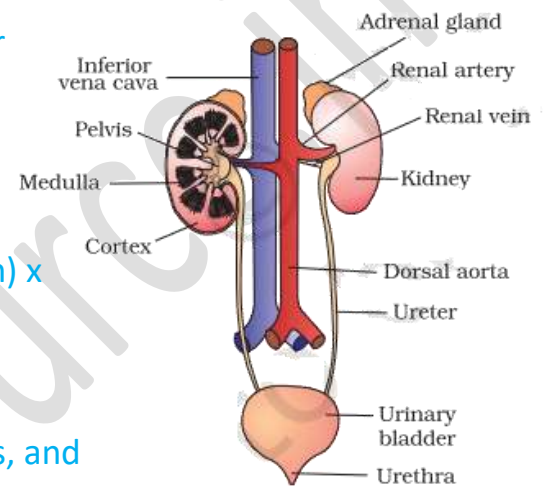
II. HUMAN EXCRETORY SYSTEM

1. Components of the Excretory System

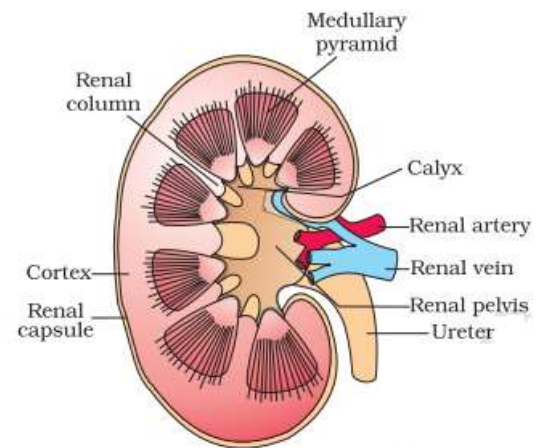
- Kidneys (pair)
- Ureters (pair)
- Urinary Bladder
- Urethra

2. Kidneys

- **Location:** Between the last thoracic and third lumbar vertebra, close to the dorsal inner wall of the abdominal cavity.
- **Description:**
 - Reddish brown, bean-shaped
 - Dimensions: 10-12 cm (length) x 5-7 cm (width) x 2-3 cm (thickness)
 - Average Weight: 120-170g
- **Structure:**
 - **Hilum:** Notch for entry of ureter, blood vessels, and nerves.
 - **Renal Pelvis:** Funnel-shaped space inside hilum. Has projections called calyces.
 - **Layers:**
 - Outer: Tough capsule
 - Cortex (outer layer)
 - Medulla (inner layer): Divided into conical masses (medullary pyramids) that project into calyces.
 - **Columns of Bertini:** Extensions of the cortex between medullary pyramids.



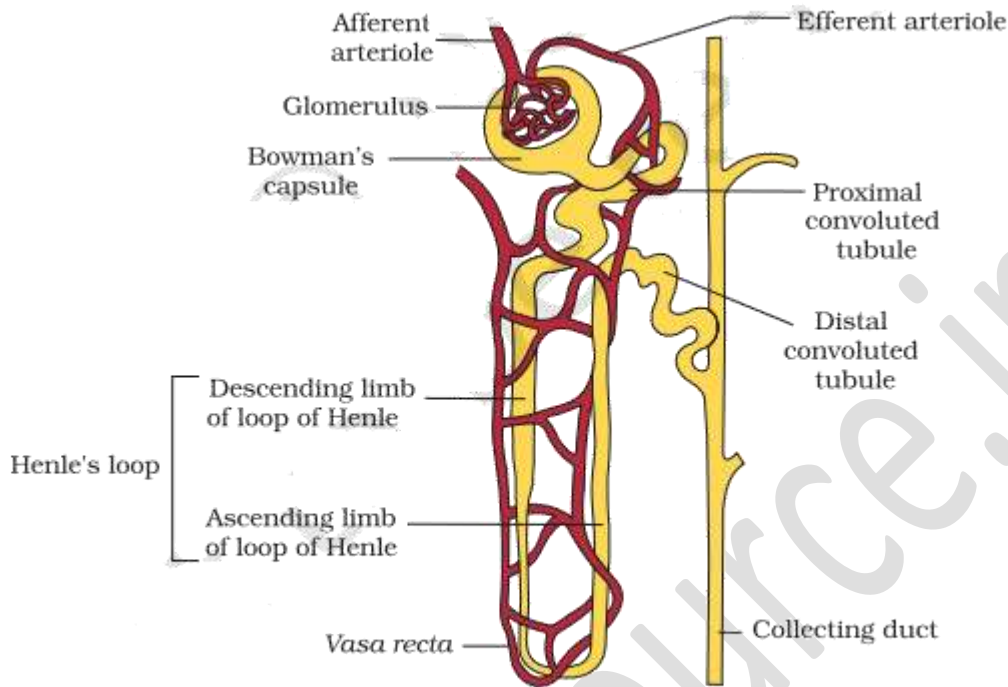
Human Urinary system



Longitudinal section (Diagrammatic) of Kidney

3. Nephrons

- **Count:** About one million per kidney.
- **Description:** Complex tubular structures, functional units of the kidney.
- **Components:**
 - **Glomerulus:** Tuft of capillaries formed by a branch (afferent arteriole) of the renal artery. Drained by efferent arteriole.
 - **Renal Tubule:**
 - **Bowman's Capsule:** Double-walled structure enclosing the glomerulus. Together, they form the Malpighian body/renal corpuscle.



A diagrammatic representation of a nephron showing blood vessels, duct and tubule

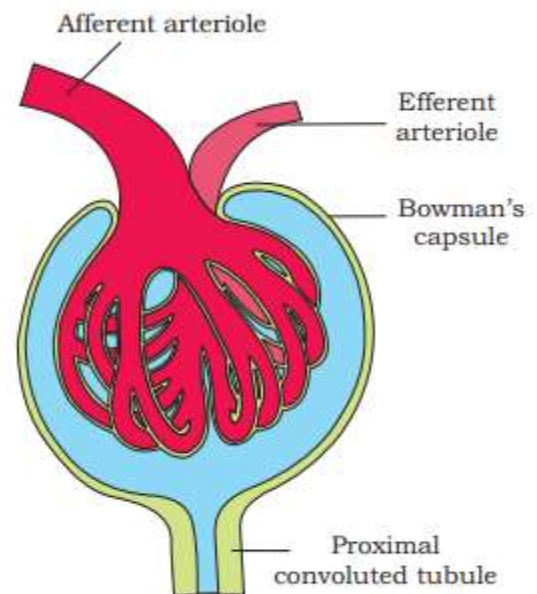
- **Proximal Convoluted Tubule (PCT):** Coiled tubular structure.
- **Henle's Loop:** Hairpin shape with descending and ascending limbs.
- **Distal Convoluted Tubule (DCT):** Coiled tubular structure. Many DCTs open into a collecting duct, which leads to the renal pelvis.

• Location:

- **Cortical Nephrons:** Mostly in the cortex, with a short loop of Henle.
- **Juxta Medullary Nephrons:** Have a long loop of Henle extending deep into the medulla.

4. Blood Supply

- **Peritubular Capillaries:** Fine capillary network formed by the efferent arteriole, surrounds the renal tubule.
- **Vasa Recta:** U-shaped vessel paralleling Henle's loop. Reduced or absent in cortical nephrons.



Malpighian body (renal corpuscle)

III. URINE FORMATION

1. Introduction

- Urine formation in the nephron involves three main processes: glomerular filtration, reabsorption, and secretion.

2. Glomerular Filtration

- First step in urine formation.
- Occurs in the glomerulus.
- On average, 1100-1200 ml of blood is filtered per minute by the kidneys.
- Filtration is due to glomerular capillary blood pressure and takes place through three layers:
 1. Endothelium of glomerular blood vessels.
 2. Epithelium of Bowman's capsule.
 3. Basement membrane between the two layers.
- **Podocytes:** Special epithelial cells in Bowman's capsule. They create filtration slits (slit pores) which enable ultrafiltration, excluding proteins.
- **Glomerular Filtration Rate (GFR):** Amount of filtrate formed by kidneys per minute (about 125 ml/minute or 180 liters per day).

3. Regulation of GFR

- Achieved by **juxta glomerular apparatus (JGA)**.
 - A special sensitive region at the contact point of the distal convoluted tubule and the afferent arteriole.
 - Responds to a fall in GFR by releasing renin, stimulating glomerular blood flow and restoring GFR.

4. Reabsorption

- Approximately 99% of the filtrate (from the 180 liters) is reabsorbed, resulting in about 1.5 liters of urine output per day.
- Reabsorption ensures important substances like glucose, amino acids, and Na^+ are taken back into the body.
 - Active reabsorption for substances like glucose, amino acids, Na^+ .
 - Passive reabsorption for nitrogenous wastes and water in the initial segments of the nephron.

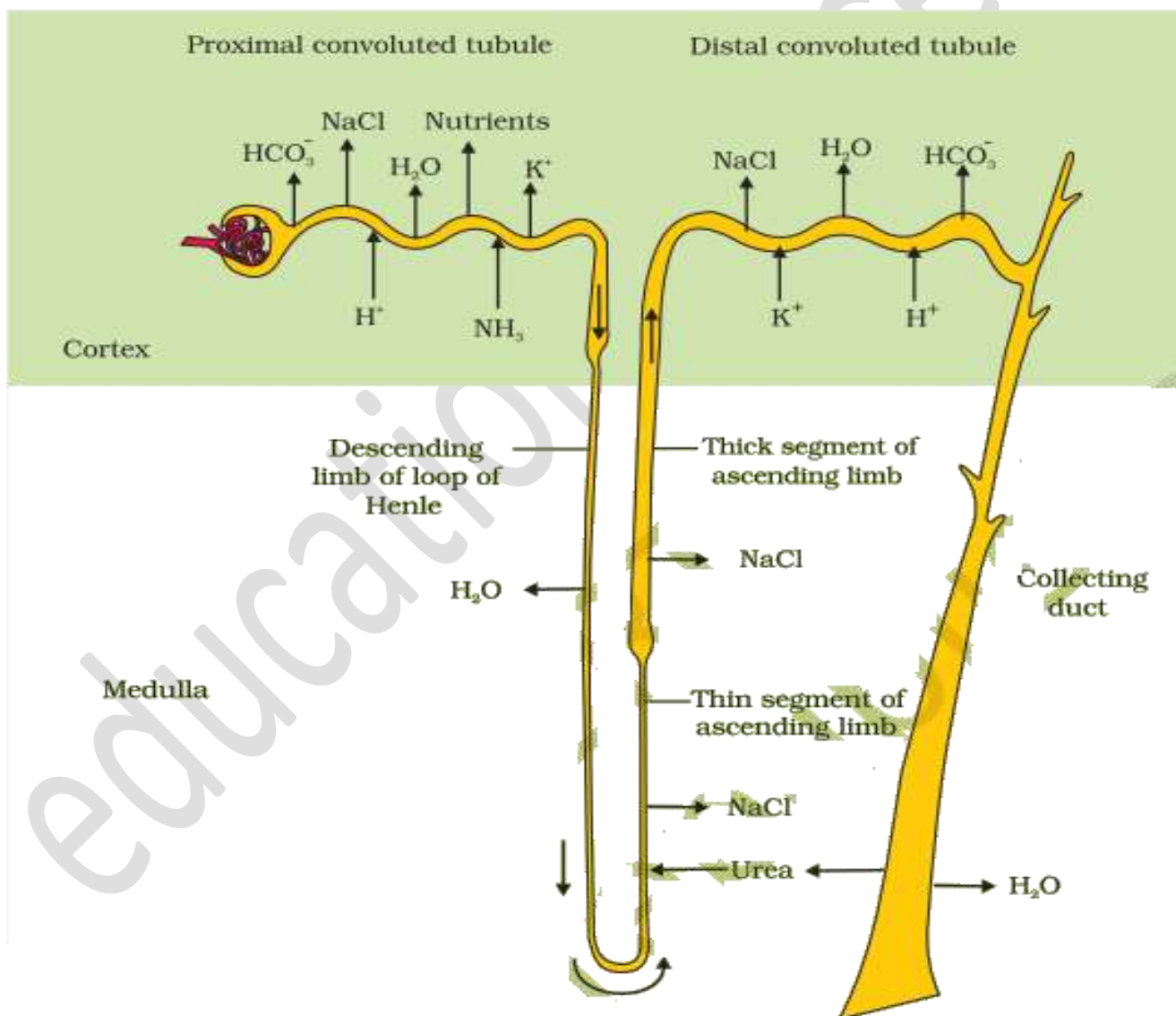
5. Tubular Secretion

- Certain substances (e.g., H^+ , K^+ , ammonia) are secreted from the tubular cells into the filtrate.
- This process is vital for maintaining the ionic and acid-base balance of body fluids.

IV. FUNCTION OF THE TUBULES

1. Proximal Convoluted Tubule (PCT)

- **Structure:** Lined with simple cuboidal brush border epithelium, enhancing surface area for reabsorption.
- **Function:**
 - Major site for reabsorption of essential nutrients, 70-80% of electrolytes, and water.
 - Balances pH and ionic composition of body fluids by:
 - Secreting hydrogen ions and ammonia into the filtrate.
 - Absorbing HCO_3^- from the filtrate.



Reabsorption and secretion of major substances at different parts of the nephron (Arrows indicate direction of movement of materials.)

2. Henle's Loop

- **Function:**

- **Descending Limb:**
 - Water-permeable but almost electrolyte-impermeable.
 - Concentrates the filtrate as it moves downwards.
- **Ascending Limb:**
 - Water-impermeable but allows electrolyte transport.
 - Filtrate becomes diluted due to passage of electrolytes into the medullary fluid.
- Overall, it helps in maintaining high osmolarity of medullary interstitial fluid.

3. Distal Convoluted Tubule (DCT)

- **Function:**

- Conditional reabsorption of Na^+ and water.
- Capable of reabsorbing HCO_3^- .
- Selectively secretes H^+ , K^+ ions, and NH_3 to regulate pH and sodium-potassium balance in blood.

4. Collecting Duct

- **Function:**

- Extends from the kidney's cortex to the deeper parts of the medulla.
- Enables reabsorption of significant amounts of water, producing concentrated urine.
- Permits passage of small amounts of urea into the medullary interstitium for maintaining osmolarity.
- Maintains pH and ionic balance of blood by selectively secreting H^+ and K^+ ions.

V. MECHANISM OF CONCENTRATION OF THE FILTRATE

1. Introduction

- Mammals can produce concentrated urine.
- Henle's loop and vasa recta are crucial for this concentration process.

2. Counter Current Mechanism

- Henle's loop has filtrate flow in two directions: down in the descending limb and up in the ascending limb. This opposite flow creates a counter current.
- Vasa recta also displays a counter current flow pattern in its two limbs.
- The close proximity of Henle's loop and vasa recta, combined with the counter current flow, establishes a gradient in osmolarity in the medullary interstitium.
- Osmolarity increases from the cortex (300 mOsmolL^{-1}) to the inner medulla ($1200 \text{ mOsmolL}^{-1}$).

3. Role of NaCl and Urea in Gradient Formation

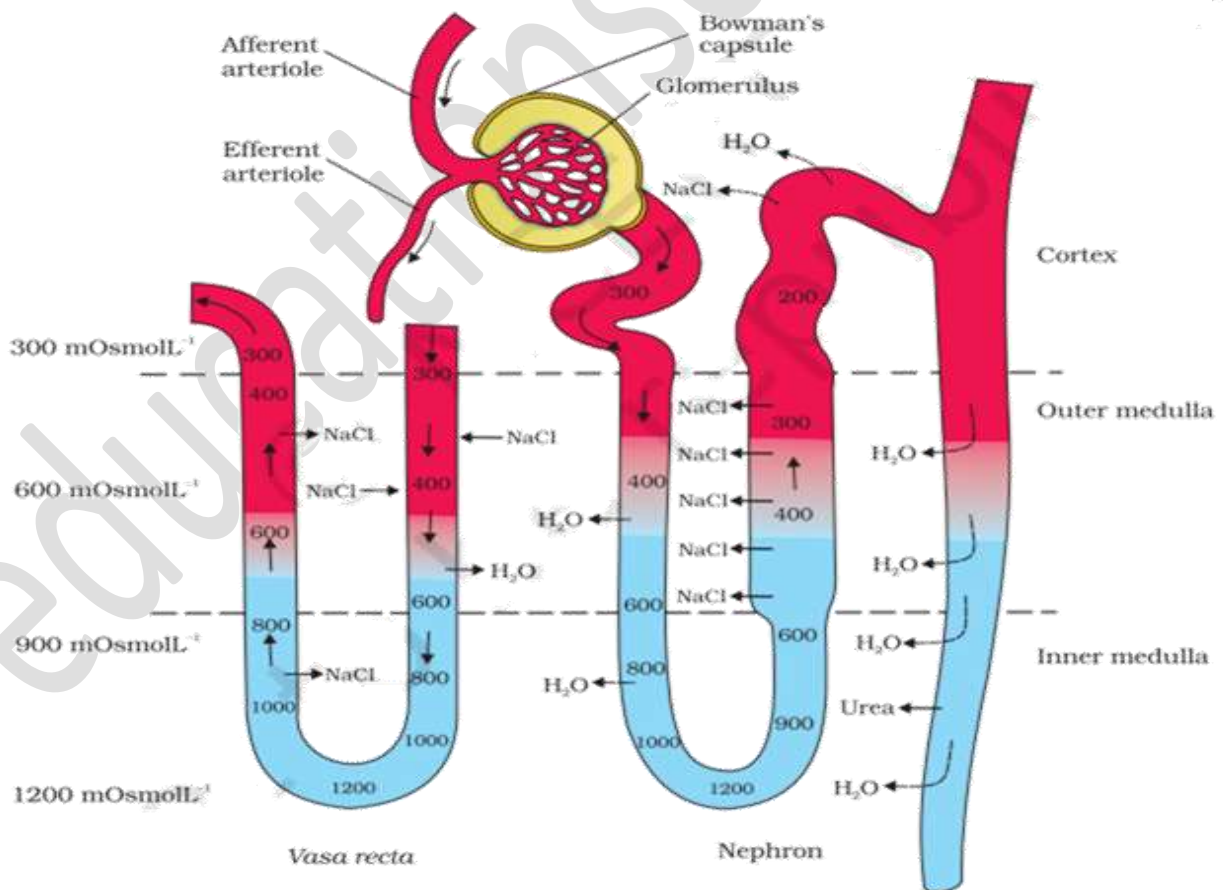
- **NaCl:**
 - Transported by the ascending limb of Henle's loop.
 - Exchanged with the descending limb of vasa recta.
 - Returned to the interstitium by the ascending vasa recta.
- **Urea:**
 - Enters the thin segment of Henle's loop's ascending limb in small amounts.
 - Transported back to the interstitium by the collecting tubule.

4. Result of Counter Current Mechanism

- The unique arrangement of Henle's loop and vasa recta establishes the counter current mechanism.
- This mechanism helps maintain an osmolarity gradient in the medullary interstitium.
- The established gradient enables water to easily pass from the collecting tubule, concentrating the filtrate (urine).

5. Human Urine Concentration

- Human kidneys can concentrate urine to about four times the concentration of the initial filtrate.



Diagrammatic representation of a nephron and vasa recta showing counter current mechanisms

VI. REGULATION OF KIDNEY FUNCTION

Introduction

- Kidney function is regulated by hormonal feedback mechanisms involving the hypothalamus, JGA, and, to some extent, the heart.

2. Role of Osmoreceptors

- **Activation:** By changes in blood volume, body fluid volume, and ionic concentration.
- **Function:** Activation due to excessive fluid loss prompts the hypothalamus to release antidiuretic hormone (ADH) from the neurohypophysis.
 - **ADH:** Promotes water reabsorption from the latter parts of the tubule, preventing excessive urine production (diuresis).
 - If body fluid volume increases, it deactivates osmoreceptors, suppressing ADH release.
 - ADH also constricts blood vessels, raising blood pressure, which in turn can increase the glomerular blood flow and GFR.

3. Role of Juxtaglomerular Apparatus (JGA)

- **Activation:** A drop in glomerular blood flow, blood pressure, or GFR activates JG cells.
- **Function:** Release of renin from JG cells leads to the formation of angiotensin I, which is then converted to angiotensin II.
 - **Angiotensin II:** Powerful vasoconstrictor, raises glomerular blood pressure, thereby elevating GFR.
 - Also triggers the adrenal cortex to release aldosterone, promoting reabsorption of Na⁺ and water, increasing blood pressure and GFR further.
- This cascade is known as the **Renin-Angiotensin Mechanism**.

4. Role of Atrial Natriuretic Factor (ANF)

- **Activation:** Elevated blood flow to the heart's atria.
- **Function:** Induces vasodilation, reducing blood pressure.
- ANF acts as a counter to the renin-angiotensin mechanism, ensuring balance.

VII. MICTURITION

1. Introduction

- Micturition refers to the process of releasing urine from the urinary bladder.

2. Urine Storage and Release

- Urine produced by nephrons is transported to the urinary bladder for storage.
- As the bladder fills, its walls stretch, activating stretch receptors.
- These receptors signal the central nervous system (CNS) about the bladder's fullness.

3. Micturition Reflex

- In response to the stretch receptors' signals:

- The CNS sends motor messages that cause the bladder's smooth muscles to contract.
- Simultaneously, the urethral sphincter relaxes.
- This coordinated response results in urine release.
- The neural mechanisms triggering this process are termed the micturition reflex.

4. Urine Characteristics

- **Volume:** An adult human excretes an average of 1 to 1.5 liters of urine daily.
- **Appearance:** Light yellow, watery fluid.
- **pH:** Slightly acidic, around 6.0.
- **Odor:** Characteristic smell.
- **Urea Content:** 25-30 gm of urea is typically excreted daily.

5. Clinical Significance of Urine Analysis

- Evaluating urine can aid in diagnosing metabolic disorders and kidney malfunctions.
 - **Glycosuria:** Presence of glucose in urine, indicative of diabetes mellitus.
 - **Ketonuria:** Presence of ketone bodies in urine, also suggestive of diabetes mellitus.

VIII. ROLE OF OTHER ORGANS IN EXCRETION

1. Introduction

- Apart from kidneys, various organs like lungs, liver, and skin also play significant roles in excretion.

2. Lungs

- **Function:** Eliminate waste products from the respiratory system.
- **Excretory Products:**
 - Carbon dioxide (CO₂) - Approximately 200 mL/minute.
 - Water - Significant quantities are exhaled daily.

3. Liver

- **Function:** The liver, being the body's largest gland, processes and secretes waste products.
- **Excretory Products:** Bile, which contains:
 - Bilirubin and biliverdin (breakdown products of red blood cells).
 - Cholesterol.
 - Degraded steroid hormones.
 - Vitamins.
 - Drugs.
- Most of these substances are eliminated with digestive wastes.

4. Skin

- **Function:** The skin has sweat and sebaceous glands that help eliminate certain waste products.
- **Excretory Products:**
 - **Sweat Glands:** Produce sweat, a watery fluid that contains:
 - Sodium chloride (NaCl).
 - Small amounts of urea.
 - Lactic acid.
 - While sweating primarily cools the body, it also aids in waste elimination.
 - **Sebaceous Glands:** Release substances like sterols, hydrocarbons, and waxes in the form of sebum, which provides a protective oily layer for the skin.

5. Additional Note

- Small amounts of nitrogenous wastes can also be eliminated via saliva.

IX. DISORDERS OF THE EXCRETORY SYSTEM

1. Uremia

- **Description:** Accumulation of urea in the blood due to malfunctioning kidneys.
- **Consequence:** Can result in kidney failure if not addressed.

2. Hemodialysis

- **Description:** A process used to treat uremic patients by removing urea from the blood.
- **Procedure:**
 - Blood is drained from an artery and sent to a dialysis unit known as an artificial kidney after adding an anticoagulant like heparin.
 - The unit houses a cellophane tube encircled by a dialysing fluid with a composition similar to plasma but devoid of nitrogenous wastes.
 - The porous membrane allows molecules to move based on concentration gradients.
 - Nitrogenous wastes move out due to their absence in the dialysing fluid, effectively cleaning the blood.
 - The purified blood is returned to the body through a vein after the addition of anti-heparin.

3. Kidney Transplantation

- **Description:** A surgical procedure to replace a malfunctioning kidney with a healthy one from a donor.
- **Procedure:**
 - Ideally, the donor is a close relative to minimize chances of organ rejection.

- Modern procedures and immunosuppressive drugs have increased the success rates of these transplants.

4. Renal Calculi

- **Description:** Formation of stones or crystallized salt masses within the kidney, often composed of substances like oxalates.

5. Glomerulonephritis

- **Description:** Inflammation of the kidney's glomeruli.

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