Excretory Products and their Elimination

Human Excretory System

Excretion

- Removal of nitrogenous wastes from the body

Nitrogenous wastes

- **Ammonia**
- Most toxic
- Needs more water for getting excreted
- Diffuses across general body surfaces
- Examples of organisms excreting ammonia: fishes, aquatic amphibians and aquatic insects
- Such organisms are called ammonotelic.
- **Urea**
- Less toxic
- Requires less water for excretion
- Terrestrial adaptation for conservation of water
- Ammonia $\xrightarrow{\text{in liver}}$ Urea
- Examples of organisms excreting urea: terrestrial amphibians and marine fishes
- Such organisms are called ureotelic.
- **Uric acid**
- Least toxic
- Eliminated with the least loss of water, as pellets or paste

- Examples of organisms excreting uric acid: birds, reptiles, land snails and insects
- Such organisms are called uricotelic.

Human excretory system

It comprises of:

i. pair of kidneys

ii. pair of ureters

iii. urinary bladder

iv. urethra

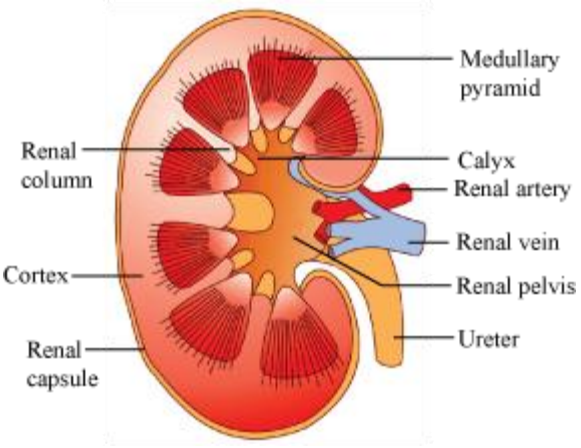
- **Kidney** is divided into outer cortex and inner medullary region.
- **Nephrons** are basic functional units of kidney.

Kidney-Structure

Kidneys

- Location: Between levels of the last thoracic and the third lumbar vertebra
- Measurement: 10–12 cm (length) × 5–7 cm (width) × 2–3 cm (thickness)
- Weight: 120–170 g
- Hilum: A notch present towards the centre of the inner concave surface of the kidney
- Through the hilum, the ureter, blood vessels and nerves enter the kidney.
- On the inside of the hilum, the renal pelvis is present. Renal pelvis has projections called calyces.
- 2 zones in the kidney: Cortex (outer)
  Medulla (inner)

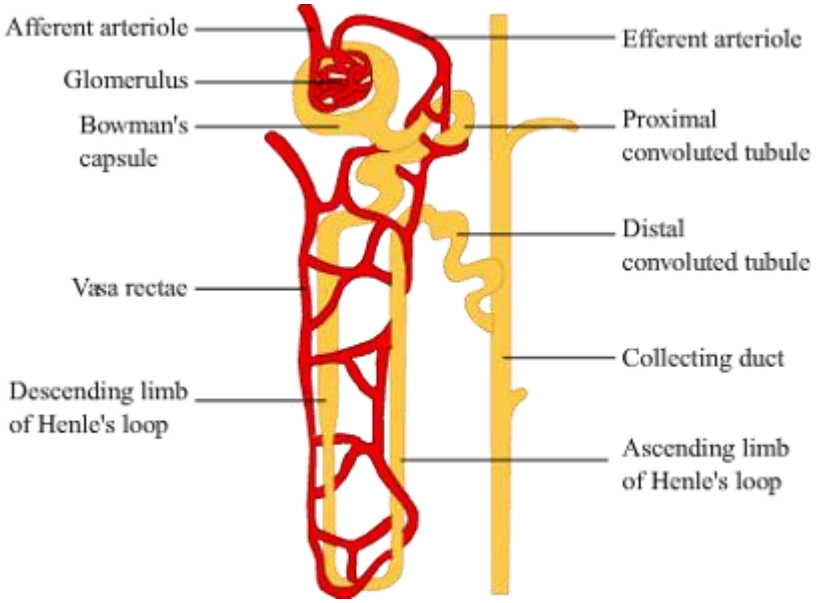
- Medulla divides into medullary pyramids (cone-shaped). These medullary pyramids project into the calyces.
- Cortex is present in between the medullary pyramids as renal columns called the columns of Bertini.



- Each kidney consists of about 1 million nephrons. These are the structural and functional units of the kidneys.

Structure of Nephron

Nephrons



- A Nephron has two parts:
- Glomerulus

- Renal tubule
- Glomerulus
- Tuft of capillaries formed by the afferent arteriole
- Renal Tubule: Has many parts

  Bowman's capsule $\xrightarrow{\text{Continues into}}$ Proximal Convoluted Tubule (PCT) $\xrightarrow{\text{Continues into}}$ Hairpin-shaped Loop of Henle $\xrightarrow{\text{Continues into}}$ Distal Convoluted Tubule (DCT) $\xrightarrow{\text{Opens into}}$ Collecting duct $\xrightarrow{\text{Converges into}}$ Medullary pyramids → Renal pelvis

  Glomerulus + Bowman's Capsule = Malpighian body (Renal Corpuscle)

- **Afferent arteriole:** These are the arterioles that arise from renal arteries and break into numerous capillaries to form glomerulus present inside the Bowman's capsule
- **Efferent arteriole:** These are formed from the reunion of capillaries emerging from the Bowman's capsule. Once formed, they travel a short distance and then break up into the secondary capillary network called **vasa recta**, which surrounds the renal tubule.
- Nephrons are of 2 types:
- **Cortical nephrons**: Here, the loop of Henle is short and confined to the cortex only. Vasa rectae are absent. These nephrons are more common (85%).
- **Juxta medullary nephrons**: Here, the loop of Henle is long and extended to the medulla. Vasa rectae are present. These nephrons are less common (15%).
- Malpighian corpuscle, PCT and DCT are present in the corticle region only.
- Capillary network in a nephron:
- Peritubular capillaries: Emerging from the glomerulus, the efferent arteriole forms a capillary network around the renal tubule called the peritubular capillaries.
- Vasa Recta: A minute vessel of the capillary network present in a nephron runs parallel to Henle's loop to form the U-shaped Vasa Recta.

Excretion in Animals

Excretory Organs in Animal Kingdom

- Protonephridia (flame cells): Excretory structures in platyhelminthes and some cephalochordates like *Amphioxus*
- Nephridia: In earthworms and other annelids
- Malpighian tubules:In insects, including cockroach
- Antennal glands(Green Glands): In crustaceans (prawns)
- Vertebrates and some molluscs have kidneys to perform excretion

Urine Formation and Function of Nephron Tubules

Urine formation and Mechanism of Concentration of Filtrate

Urine Formation

Involves 3 basic steps:

- Glomerular filtration
- Re-absorption
- Secretion

Glomerular filtration

- Kidney filters 1100–1200 mL blood/min

- Filtration of blood occurs as it passes through three layers.

- Endothelium of glomerular blood vessels
- Epithelium of Bowman's capsule
- Basement membrane between these two layers
- Epithelial cells of Bowman's capsule are called podocytes. Arrangement of these podocytes leaves extremely minute spaces called filtration slits or slit pores.
- Ultrafiltration occurs through these slits pores, i.e., all plasma components (except proteins) get filtered into the lumen of the Bowman's capsule.
- Glomerular Filtration Rate (GFR): 125 mL/min or 180 L/day
- The glomerular filtration rate is regulated by the juxtaglomerular apparatus which releases the hormone renin.

Re-absorption

- GFR = 180 L/day; Urine released = 1.5 L/day. Thus, 99% of filtrate is re-absorbed by the renal tubules.
- Re-absorption occurs through the epithelial cells of the various segments of the nephrons.
- Active Re-absorption: Glucose, Na^+, amino acids
- Passive Re-absorption: Nitrogenous waste, water

Secretion

- Tubular cells secrete substances such as H^+, K^+ and ammonia into the filtrate.
- Importance: Maintenance of ionic and acid-base balance of body fluids

Constituents of Urine

Normal adult's urine consists of 95% water and 5% solid waste.

Organic Constituents in (g/L)	Inorganic Constituents in (g/L)
Urea: 2.3	Sodium chloride: 9.0
Creatinine: 1.5	Potassium chloride: 2.5
Uric acid: 0.7	Ammonia: 0.6
Others: 2.6	Others: 2.5

Abnormal constituents of urine:

- **Blood cells:** Blood passes through urine due to infection in urinary tract, kidney stones, or tumour. This condition is known as haematuria.
- **Glucose:** Excess of glucose passes through urine. This condition is known as glycosuria and occurs in the case of diabetes mellitus.
- **Albumin:** Albumin is passed through urine due to high blood pressure or bacterial infection.
- **Bile pigments:** Bile pigments are passed through urine due to anaemia, hepatitis or liver cirrhosis.

Function of the Tubules

- **Proximal Convoluted Tubule**

- Specialised for re-absorption as it is lined by a simple cuboidal brush border epithelium which increases the surface area for absorption
- Re-absorbs all essential nutrients, electrolytes and water
- Secretes H^+, NH_4^+, K^+ ions and $HCO_3^{(-)}$ to maintain pH

- **Henle's Loop**

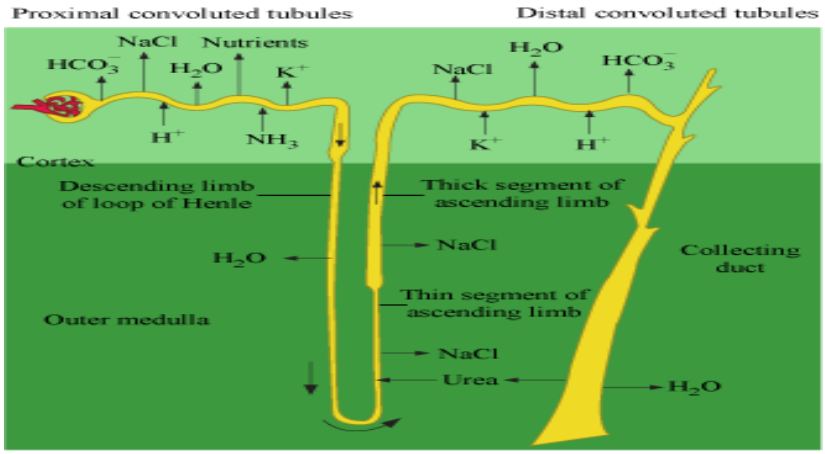
- Minimum re-absorption occurs here
- Helps in maintaining high osmolarity of the medullary fluid
- Descending loop of Henle: Permeable to water and impermeable to electrolytes; Concentrates the filtrate
- Ascending loop of Henle: Impermeable to water and permeable to electrolytes; Dilutes the filtrate

- **DCT**

- Conditional re-absorption of Na^+, water, HCO_3^-
- Selectively secretes H^+, K^+, NH_3
- Maintains pH and Na–K balance in blood

- **Collecting Duct**

- Concentrates the urine by absorbing large amounts of water
- Allows passage of urea into the medullary interstitial fluid to maintain osmolarity
- Secretes H^+ and K^+ ions; hence, maintains pH and ionic balance



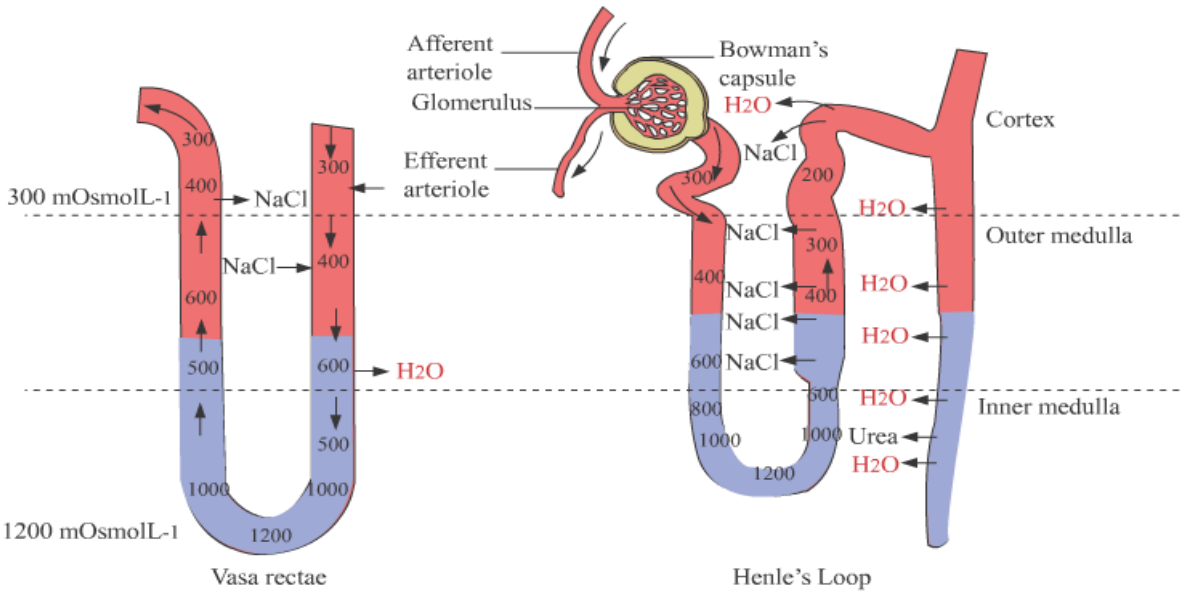
Micturition

- Passing of urine through the opening in the urinary bladder
- Urine is stored in urinary bladder. As the bladder gets filled with urine, it gets stretched.
- Stretch receptors on the walls of the bladder send signals to CNS.
- CNS sends counter signals to initiate contraction of the smooth muscles of the bladder, and relax the urethral sphincter to cause urine to be released (micturition).
- Neural mechanism: Micturition reflex
- Urine: 1–1.5 L/day; pH 6.0; Light yellow in colour
- On an average, 25–30 gm of urea is excreted everyday.
- Presence of glucose and ketone bodies in urine indicates diabetes mellitus.

Mechanism of concentration of filtrate

- Concentration of urine is achieved by the presence of a concentration gradient in the medullary interstitium.
- Such concentration gradient is maintained by a specialised mechanism called the counter-current mechanism.

- The flow of filtrate in the two limbs of Henle's loop is in the opposite direction. Flow of blood in vasa recta is also in the opposite direction. Both these flows form a counter-current.
- Close proximity of Henle's loop and vasa recta as well as the counter-current in them maintains an osmolarity that increases towards the medullary interstitium.
- NaCl and urea play a role in the maintenance of the gradient.
- NaCl: Transported by the ascending limb of Henle's loop and provided to the descending limb of vasa recta
- Urea: Enters the thin segment of the ascending limb of Henle's loop
- NaCl is transported back to the interstitium by the ascending portion of vasa recta and urea is transported back to the interstitium by the collecting tubule.



Hormonal Feedback for Regulation of Kidney Function

Regulation of Kidney Function

- The functioning of kidney is efficiently regulated by hormonal feedback mechanism. It involves – Hypothalamus, Juxtaglomerular apparatus (JGA), and heart.

- **Hypothalamus**

- Antidiuretic hormone or ADH plays an important role in regulation.

- Excessive loss of fluids from the body activates the osmoreceptors and stimulates hypothalamus to release hormone ADH, which helps in water re-absorption and prevents diuresis.

- A further increase in body fluid volume can turn off the osmoreceptors. This inhibits the ADH release, which in turn completes the feedback.

- ADH constricts the blood vessels and causes blood pressure to increase, which in turn increases glomerular blood flow and therefore GFR.

- **Juxtaglomerular Apparatus (Renin-Angiotensin Mechanism)**

- When GFR falls, JG cells release renin.
  Renin plays an important role in the production of angiotensin II.
  $\text{angiotensinogen} \xrightarrow{\text{renin}} \text{angiotensin I} \longrightarrow \text{angiotensin II}$

- Angiotensin II – Constricts blood vessels to increase blood pressure and hence GFR
  It also activates adrenal cortex to release aldosterone that causes re-absorption of Na^+ and water from tubule. This also results in an increase in blood pressure and hence GFR.

Heart

- As the blood flow to the atria increases, atrial Natriuretic Factor (ANF) is released.

- ANF causes vasodilation and decreases blood pressure.

- It checks renin-angiotensin mechanism.

Disorders of the Excretory System

Disorders of Excretory System

- **Uremia**

- Accumulation of urea in blood
- May lead to kidney failure
- Urea is removed by haemodialysis. In acute cases, kidney transplant may be required.

- **Renal Calculi**

- Stones or insoluble mass of crystallised salts are formed within the kidney.

- **Glomerulonephritis**

- Inflammation of glomeruli of kidney

Treatments for Disorders of Excretory System

- **For Uremia - Haemodialysis**

- Blood drained from the convenient artery is pumped into dialysing unit. Anticoagulant (heparin) is added.
- Dialysing unit – Cellophane tube surrounded by dialysing fluid
- Dialysing fluid – Same as the plasma composition except the nitrogenous waste
- Molecules move according to concentration gradient. Nitrogenous wastes are absent in dialysing fluid. Therefore, they are transported to the fluid, thereby cleansing the blood.

- **For Renal Calculi - Kidney Transplantation**

- A functioning kidney from the donor is used for transplantation.
- Donor – close relative to minimize the immune rejection