CHAPTER 19

Excretory Products and Their Elimination

EXCRETORY WASTE

Metabolism → Excess ingestion

Results in accumulation of

- **Nitrogenous wastes** – NH_2, urea, uric acid
- Other contents – CO_2, H_2O, ions (Na^+, K^+, Cl^-, PO_4^{3-}, SO_4^{2-})

Removed ↓

Partially/Completely

NITROGENOUS WASTES

Nature of nitrogenous waste formed and their excretion vary among animals depending on the **habitat/availability of water**.

Major nitrogenous waste	Nature & Examples	Toxicity and water required	Typical
Ammonia	**Ammonotelic** ○ Aquatic insects ○ Many bony fishes ○ Aquatic amphibians	Maximum	○ Diffusion through gills surface or body surface as ammoium (NH_4^+) ions
Urea	**Ureotelic** ○ Marine fishes ○ Many terrestrial amphibians ○ Mammals	Lesser	○ **Kidneys** filter urea from blood
Uric acid	**Uricotelic** ○ Land snails ○ Insects ○ Reptiles ○ Birds	Least	○ Pellet/Paste (Semi-solid)

- Ammonia converts into urea in liver.
- Elimination of urea, uric acid is meant for conservation of water i.e., a type of **terrestrial adaptation**.
- Kidneys do not play a significant role in removal of ammonia.
- Some amount of urea may be retained in the kidney matrix of some animals to maintain desired osmolarity.

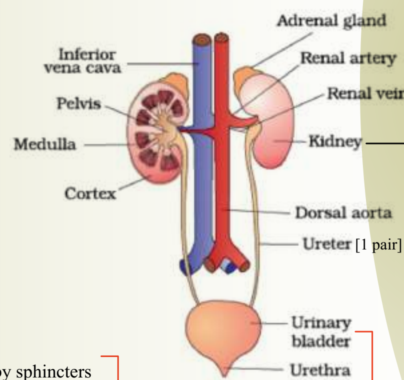
EXCRETORY STRUCTURES

- Most invertebrates – Simple tubular forms.
- Vertebrates – Complex tubular organs called kidneys.

Structures	Examples
○ Protonephridia/flame cells (osmoregulation)	○ Platyhelminthes (*Planaria*) ○ Rotifers ○ Some annelids ○ Cephalochordates (*Amphioxus*)
○ Nephridia	○ Annelids (Earthworms)
○ Malpighian tubules	○ Insects (Cockroaches)
○ Antennal/Green glands	○ Crustaceans (Prawn)

- **Function of excretory structures:**
  - Eliminate nitrogenous wastes.
  - Maintain ionic and acid-base balance of body fluids, i.e., osmoregulation.

HUMAN EXCRETORY SYSTEM



Kidney:
1 pair, bean shaped, reddish brown
Length 10-12 cm,
Width 5-7 cm,
Thickness 2-3 cm
Weight 120-170 g
Between T_{12} - L_3 vertebra, close to dorsal inner wall of abdominal cavity

Urinary bladder:
Have stretch receptors
Store urine till voluntary signals from CNS carries out its release

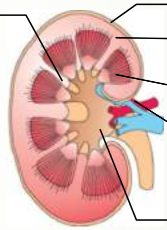
Urethra:
- Guarded by sphincters
- Meant for release of urine

MICTURITION

- Process of release of urine
- Mechanism - **Micturition reflex**

↓
Urinary bladder (Store urine)
↓ Activates
Stretch receptors → signals → CNS (voluntary signals)
↓ Send motor messages
Urimary bladder
Smooth muscles contract
Urethral sphincters relax
↓ Release
Urine

KIDNEY



Columns of Bertini/ Renal columns
- Part of cortex which extends between medullary pyramids

Capsule–outer tough covering

Cortex (Outer)→Malpighian corpuscle, PCT, DCT

Medulla (Inner)→Loop of Henle

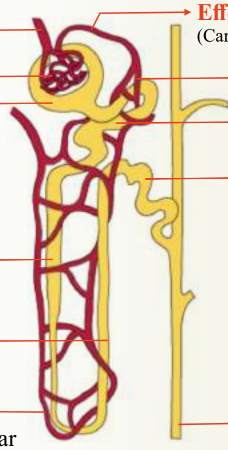
Hilum
- Notch towards concave surface
- Ureter, blood vessels and nerves enter

Renal pelvis
- Funnel shaped space with projections called calyces

Medullary pyramids are conical masses that project into calyces.

NEPHRON

- **Functional unit of kidney**
- Nearly **1 million** complex tubular structure
- Each nephron has two parts—(i) Glomerulus (ii) Renal tubule



Afferent arteriole (Short, wide)
(Carry blood to glomeruli)

Efferent arteriole (Narrow)
(Carry the blood from glomeruli)

Malpighian body/ Renal corpuscle
- Glomerulus
- Bowman's capsule

Peritubular copillaries

Proximal convoluted tubule

Distal convoluted tubule

Henle's loop (Hairpin shaped)
- Descending limb of loop Henle
- Ascending limb of loop Henle

Vasa recta
- Branch of Peritubular capillaries
- Parallel to loop of Henle
- U-shaped

Collecting duct

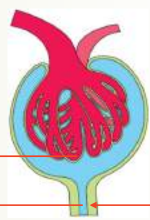
Types of Nephron

Parameters	Cortical	Juxitamedullary
Number	More	Less
Loop of Henle	Too short	Very long
Extension into medulla	Very little	Deep
Vasa recta	Absent/reduced	Present

- **Juxtaglomerular apparatus (JGA):** Sensitive region formed by cellular modifications in **distal convoluted tubule** and **afferent arteriole** at the location of their **contact**.
- JGA is composed of JG Cells and Macula densa.
- Nephrons are dipped in interstitial fluid having specific osmolarity
  – **Cortex** - 300 mOsm/L – **Medulla** - upto 1200 mOsm/L (Gradient)

- **Glomerulus** is a tuft of capillaries formed by **afferent arteriole** - a fine branch of renal artery.
- Many DCTs open into straight tube called **collecting duct**, many of which converge into renal pelvis through medullary pyramids in the calyces.
- **Efferent arteriole** emerging from glomerulus forms **peritubular capillaries** around renal tubule.

URINE FORMATION



Non-selective process (Glomerular filtration)

1. **Glomerular filtration**
   180 L filtrate/day

2. **Tubular reabsorption**
   Nearly **99%** of filtrate get **reabsorbed** by renal tubules

Active process	Passive process
○ Glucose, Na^+ amino acid	○ Nitrogenous wastes, H_2O

3. **Tubular secretion**
   - ○ H^+, K^+ and ammonia secreted into filtrate
   - ○ Maintains ionic and acid base balance

Urine 1-1.5 L/day

Glomerular Filtration/Ultra filtration (Non selective process)

– 1/5th of cardiac output or 1100-1200 ml blood/min is filtered by kidneys

↓

Renal Artery

↓

Arterioles

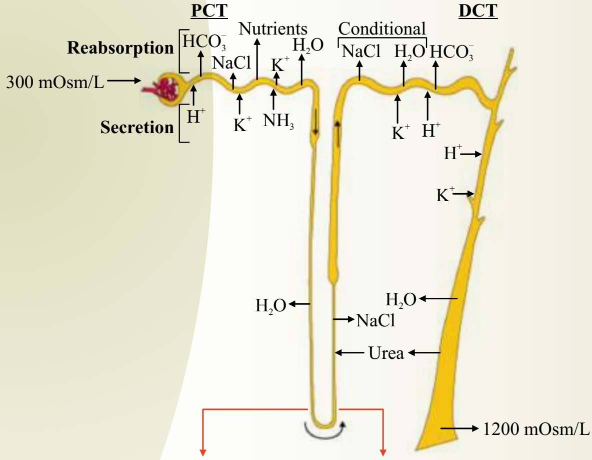
↓

(i) Endothelium of glomerular blood vessels
↓
(ii) Basement membrane
↓
(iii) Epithelium of Bowman's capsule
↓
Glomerular filtrate
(Plasma except proteins)

(i)–(iii): **Filtration membrane**

- **Bowman's** capsule have **podocytes** arranged in intricate manner so as to leave some spaces called slit **pores/filtration slits.**
- Filtration is due to pressure in the glomerular capillaries.
- **Glomerular** filtration rate (GFR) = Filtration/min
  125 ml/min
- Kidney has an ability to regulate GFR.

FUNCTIONS OF THE TUBULES

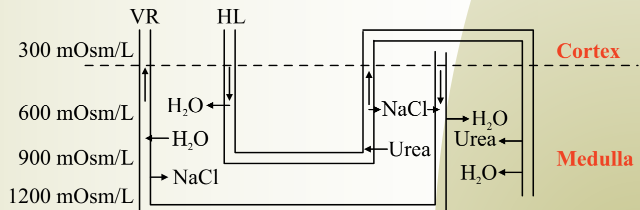


Parameter	Descending limb	Ascending limb
Permeable	Water	Salt
Impermeable	Salt	Water
Filtrate	Concentrated	Diluted
	↓	↓
	Concentrating limb	Diluting (Minimum reabsorption) limb

PCT:
- Lined by **simple cuboidal brush border epithelium**.
- Nearly all essential nutrients, 70-80% electrolytes and water are reabsorbed.
- Major site of reabsorption & for selective secretion.

COUNTER CURRENT MECHANISM TO CONCENTRATE FILTRATE

- Flow of filtrate in different limbs of following structures are opposite direction **(Counter current)**: ○ Loop of Henle ○ Vasa recta
- Proximity of Henle's loop and Vasa recta and counter current in them increase osmolarity towards inner medullary interstitium (300 mOsm/L in cortex to 1200 mOsm/L).
- **Interstitium gradient is caused by NaCl** and **urea**.
- **NaCl** trasported by ascending limb of Henle's loop exchanged with descending limb of vasa recta and is returned to medullary interstitium by ascending limb of Vasa recta.
- **Urea** which enters in thin part of ascending limb of Henle's loop is transported back to interstitium by collecting tubule.
- This mechanism maintain **interstitial concentration gradient** that helps in easy passage of water from collecting tubule thereby concentrating filtrate (urine).



- **Henle's loop primarily** helps to **maintain osmolarity gradient** in kidney interstitium.
- Mammals have ability to produce **concentrated urine**.

REGULATION OF KIDNEY FUNCTION/GLOMERULAR FILTRATION RATE

Hypothalamus

Low blood volume/ Body fluid volume/ Ionic concentration

↓ Activate

Osmoreceptors of hypothalamus to release ADH/Vasopressin from neurohypophysis

↓ Work

○ Constrict blood vessels
○ Increase reabsorption of water from DCT (Prevent diuresis)

↓ Result

JGA

Low GFR/ Glomerular blood flow/Glomerular blood pressure

↓ Activate

JG cells to release **renin**

Angiotensinogen → Angiotensin I

↓ ACE - Angiotensionogen converting enzyme

Angiotensin II

↓ Work

○ Constrict blood vessels
○ Activate adrenal cortex to release aldosterone, that causes reabsorption of Na^+ and water

Heart

Increase blood flow to atria of heart

↓

Release of ANF (Atrial natriuretic factor)

↓ Work

Vasodilation

↓ Result

○ Blood pressure decrease
○ GFR decrease

- Blood volume increases
- Blood pressure increases
- GFR increases

Increase in blood volume

↓ Switch off

Osmoreceptors

↓ Suppress

ADH/Vasopressin

↓ Result

- Blood pressure increase
- GFR increase

(**Renin-Angiotensin** mechanism)

ANF mechanism acts as a check on **Renin-Angiotensin mechanism (RAAS)**

CHARACTERISTICS AND COMPOSITION OF URINE

- **Colour** - Light yellow
- **pH** = 6
- **Odour** - Characteristic
- Human kidneys can produce urine nearly **4 times** concentrated than initial filtrate.
- **Urea** - 25-30 gm/day
- Various conditions can affect characteristics of urine.

Abnormal constituents of urine	Condition	Indicate
Glucose	Glucosuria	Diabetes mellitus
Ketone bodies	Ketonuria	Diabetes mellitus

Analysis of urine helps in clinical diagnosis of many metabolic disorders as well as malfunctioning of the kidneys.

DISORDERS OF EXCRETORY SYSTEM

Disorders	Symptoms or Treatment
Renal calculi	Stone or insoluble mass of crystalised salts (e.g., oxalates)
Glomerulonephritis	Inflammation of glomeruli of kidney
Renal/kidney failure	Malfunctioning of kidneys lead to accumulation of **urea in blood (Uremia)**, highly harmful, may lead to kidney failure. **Treatment** **(i) Haemodialysis: Process to remove urea from blood** Boon for thousands of uremic patients all over the world. Blood drained from artery —Mix with→ **Heparin (Anticoagulant)** → Pumped through

Dialysing unit

Artificial kidney
Porous cellophane tubes surrounded by dialysing fluid

Filtration based on concentration gradient → Clear blood → Mix with → Anti coagulant → Pumped back to body through → Vein

Nitrogenous wastes freely move out

(ii) Kidney transplantation

Ultimate method in correction of **acute renal failure**

- Functional kidney is taken from donor
- To minimize rejection, **close relatives** are **preferred** as donor
- Modern clinical problems have increased success rate of such complicated techniques

Composition of dialysing fluid is same as plasma except the nitrogenous wastes

ROLE OF OTHER ORGANS IN EXCRETION

Accessory structure	Remove	Basic work
Lungs	CO_2, water	○ Remove large amount of CO_2 approximately **200 mL/min** ○ Remove significant quantity of water
Liver (Largest gland)	Bilirubin, vitamins biliverdin, drugs cholesterol, degraded steroid hormones	○ Remove large amount of CO_2 approximately **200 mL/min** ○ Remove significant quantity of water
Skin ○ Sweat gland	Sweat contains ○ NaCl ○ Urea ○ Lactic acid	○ Primary function of sweat is to facilitate **cooling effect** on body surface
○ Sebaceous gland	Sebum contains ○ Sterols ○ Hydrocarbons ○ Waxes	○ Sebum provides a protective oily covering for the skin
Salivary glands		○ Small amount of nitrogenous wastes are eliminated through saliva