Chapter 6 Physiology of Excretion

Excretion: The process of removal of waste material from the body is termed as Excretion. Waste products are like urea, uric acid CO_2, H_2O, Excess salt etc.

Body has two types of fluids:

1. Intraccllular fluid - also called the cytoplasm.

2. Extracellular fluid = (ECF) This fluid found outside the cells like - tissue fluid Blood-plasma, Body cavity fluid, cerebrospinal fluid, Pleural fluid etc. Max. **Quantity of ECF is in the form of blood plasma**.

Claude - Bernard called the ECF as Milieu Interior or the Internal environment of the body.

Baird Hastings called the cells of the body as Islands and ECF as the internal - Sea.

►There is a continuous exchange of materials between ECF and intracellular fluid e.g. From the ECF Oxygen and many nutrients go into the ICF and many waste materials enter the ECF from the ICF. For the continuous exchange of materials between the ECF and ICF, maintenance of chemical composition of ECF is a must, this process is termed as **Homeostasis. The name Homeostasis was given by *Walter-Cannon.***

⇨Excretory organs help in maintaining the chemical-composition of ECF. They continuously remove the waste-materials formed during metabolism from the ECF , so excretory organ are also termed as **Organs of Homeostasis** –

EXCRETORY ORGANS: FUNCTIONAL TYPES

Generalized excretory organs
Contractile vacuoles of protozoans
Invertebrate nephridial organs
Malphighian tubules of insects
Vertebrate kidneys
Specialized excretory organs
Gills (crustaceans, fish)
Rectal glands (elasmobranches)
Salt glands (reptiles, birds)
Liver (vertebrates)
Intestine (insects)

Osmoconformers and Osmoregulators

An animal may be an osmoconformer or osmoregulator depending on how they balance water loss with water gain.

Osmoconformers = Animals that do not actively adjust their internal osmolarity. **Most marine invertebrates are osmoconformers**.

- Body fluids are isotonic to the environment.
- Body fluid composition usually differs from the external medium due to internal regulation of specific ions.
- Some vertebrates of the Class Agnatha (hagfishes) are also osmoconformers.

Osmoregulators = Animals that regulate internal osmolarity by discharging excess water or taking in additional water.

· Many saltwater animals, all freshwater animals, and terrestrial animals

· Net movement of water in or out, requires a concentration gradient – the maintenance of which requires energy.

· Osmoregulation permits animals to live in a variety of habitats, but the tradeoff is that it requires an energy expenditure by the animal.

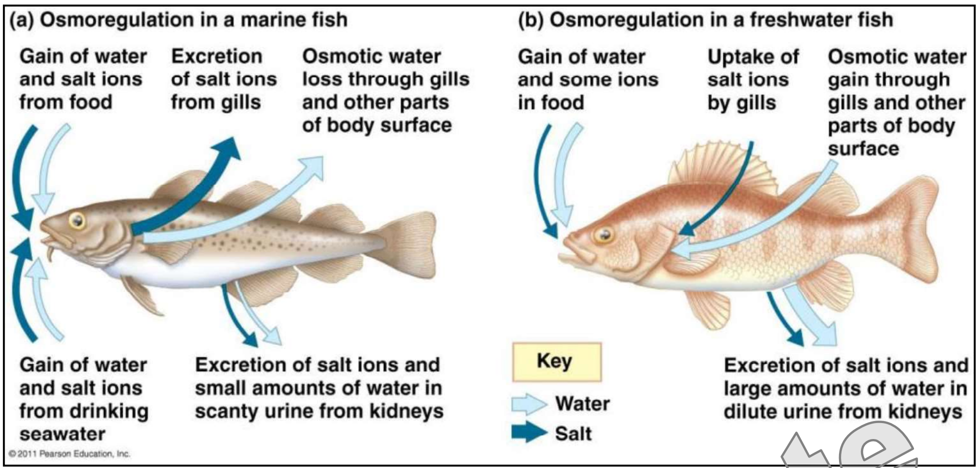
- ⇨Most cartilaginous fishes, including sharks, maintain internal salt concentrations lower than sea water by pumping salt out through rectal glands and through the kidneys, yet their osmolarity is slightly hypertonic to seawater.

a. Sharks retain urea as a dissolved solute in the body fluids.

b. Sharks also produce and retain trimethylamine oxide (TMAO), which protects their proteins from denaturation by urea.

c. Retention of these organic solutes (urea, TMAO) in the body fluids actually makes them slightly hypertonic to seawater.

d. Do not drink water, but balance osmotic uptake of water by excreting urine.Marine bony fishes are hypotonic to seawater.
e. Compensate for osmotic water loss by drinking large amounts of seawater and pumping excess salt out with their gill epithelium.
f. Excrete only a small amount of urine.



TYPE OF ANIMALS ON THE BASIS OF EXCRETION

Ammonotelic

Animals excreting their nitrogenous waste in the form of ammonia are known as ammonotelic. Ammonia is highly soluble in water with which it forms ammonium hydroxide (NH4OH) which injures cells directly by alkaline caustic action. Hence **excretion of ammonia requires large amounts of water to be lost from the body.That is why such amode is suitable for aquatic organisms which have a constant access to water**.

⇨No energy is required to produce ammonia. E.g. **all aquatic invertebrates, bony fishes and aquatic amphibians.**⇨Ammonia is the **first metabolic waste product** of protein metabolism.

⇨In anurans (amphibians) the larval tadpoles excrete ammonia, while the adults produce urea.

Ureotelic

Animals that excrete their nitrogenous waste mainly in the form of urea are known as ureotelic

⇨Urea can be stored in body for considerable periods of time, **and is least toxic**. It is eliminated in the form of urine. Ureotelism is exhibited by semi-terrestrial animals, e.g. some earthworms, adult amphibians, elasmobranch (cartilagineous fishes) and mammals.

⇨Frog like other amphibians is ammonotelic in tadpole state and ureotelic in mature state. Earthworm is similarly ammonotelic when sufficient water is available and ureotelic when water availability is reduced.

Uricotelic: -Animals which excrete their nitrogenous waste mainly in the form of uric acid and urates are known as **uricotelic**. Terrestrial animals like insects, reptiles, and birds excrete uric acid. Uric acid ($C_5H_4N_4O_3$) (which require more energy) is produced by degradation of purines (*e.g.* guanine) in liver and kidneys to some extent.

⇨In uricotelic animals, excess nitrogen is first used in synthesis of purines. A purine is changed to **xanthine** (from hypoxanthine or guanine) which is then **oxidised to uric acid**. Part of uric acid is **oxidised** further to form **allantoin** and **allantoic acid**.

⇨**Teleost fish excrete allantoate or hydration product of allantoin.** In most fishes and amphibians, allantoate is hydrolysed to urea and glyoxylate.

Aminotelism is the excretion of amino acids which cannot be metabolised due to their being in excess. The animals performing aminotelism are called aminotelic, e.g. some molluscs (Pila, Unio, Limnaea) and some echinoderms (starfish, Holothuria)

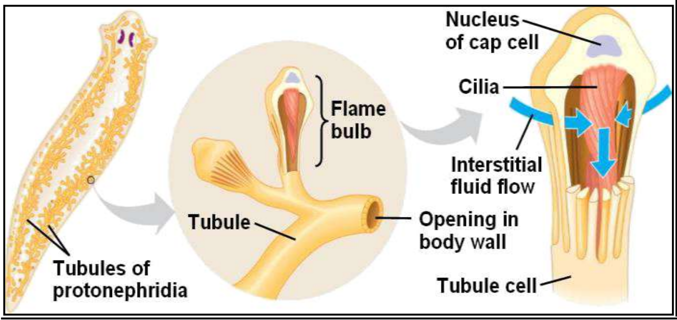
Main Nitrogenous Waste-Materials: Different type of animals excrete nitrogenous waste materials in various forms-like:

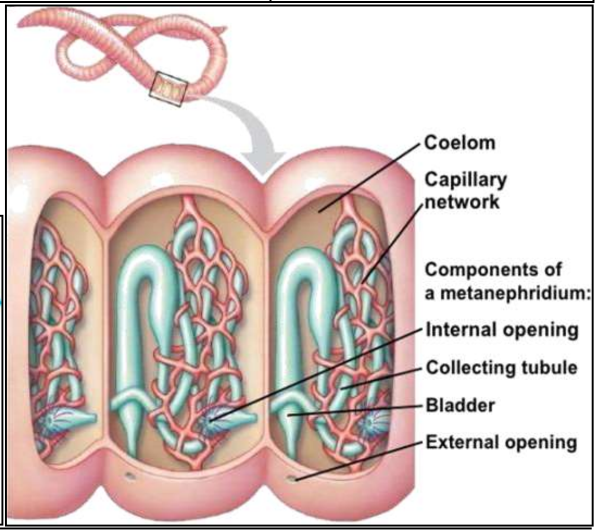
1. **Amino-acids:** Some animals excrete amino-acids. These are termed as Aminotelic e.g. Some molluscs (Unio, Limnia, Snails) Some echinoderms like Asterias
2. **Ammonia:** Majority animals do the deamination of amino-acids. In this process the ammonia (NH_3) is removed from the amino-acids. Majority aquatic animals excrete this ammonia from the body. Such animals are termed as **Ammonotelic.** Ammonia is highly soluble in water so it diffuses rapidly in water. To excrete ammonia, more amount of water is required. To excrete **1 gm of ammonia 300-500 ml. water is required.** Ammonia is highly toxic, so more amount of ammonia can't be kept inside the body.

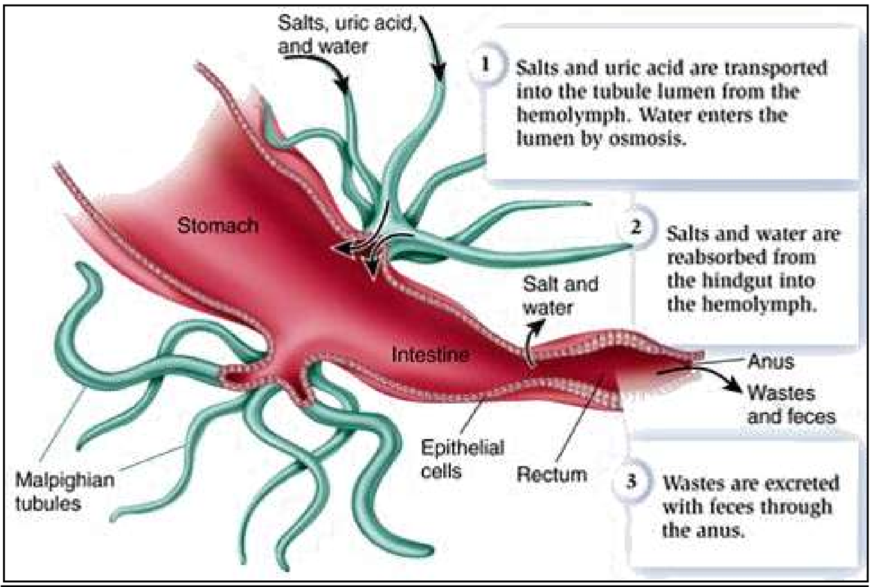
3. **Urea:** Amphibians, Mammals and fishes of the Elasmobranchi group convert the ammonia obtained from deamination into urea. Urea is soluble in water but less soluble as compared to ammonia. Less water is required to excrete urea from the body. To excrete **1 gm of urea, 5O ml of water is required.** Urea is not toxic so some amount of urea can be circulated into the blood before excreting out.
   Urea is taken from the site of formation to the excretory-organ through blood. In human blood 20-40 mg/100 ml urea is present. The amount of ammonia is very less or negligible i.e. 0.0001-0.0003 mg/ 100 ml of blood. This much amount of ammonia is not toxic for the body. Tadpole larva of amphibia is Ammonotelic and adult animal is Ureotelic.
4. **Uric-Acid:** Majority terrestrial animals which have a scarcity of water, convert the ammonia obtained from deamination into uric acid and excrete it in the form of uric-acid. These animals are termed as Uricotelic. Like- Reptiles, Birds and Insects. Uric acid is insoluble in water; so water is not required to excrete it. Uric-acid is excreted in the form of a paste. Uricotelism is an adaptation of the terrestrial habitat. Uric-acid is non-toxic. It is less nontoxic as compared to urea.
5. **Tri-methyl amine-oxide:** Some animals convert the ammonia into non-toxic tri-methyl amine oxide and excrete it. It has a typical fishy-smell, e.g. Marine-fishes, Marine molluscans and Marine crustaceans etc.
6. **Guanine:** Spiders convert ammonia into guanine and then excrete it. It is similar to uric-acid; its structure is same as that of uric acid. It is insoluble in water Guanine is excreted in the form of crystals. It is also an adaptation to check the water-loss.
7. **Allantonin:** Majority mammals convert the Purines and Pyrimidines to Allantonin and then excrete it. In man purines are excreted in the form of uric-acid and pyrimidines in the form of alanine and Iso-butyric acid.
8. **Hippuric-acid:** In mammals, the Benzoic-acid excreted out in the form of Hippuric- acid
   Benzoic acid + Glycine------------------------> Hippuric – acid
   But in birds, the benzole acid is treated with Ornithine amino-acid.
   Benzoic acid + Ornithine--------------------—>Ornithuric acid
9. **Creatinine & Creatine:** Creatinine is the product of the breakdown of creatine. The amount of creatine excreted through the urine by an audit individual is about 1.2 to 1.7 g per 24 hours. **Creatinine** coefficient any be defined as the ratio between the amount excreted in 24 hours and the body weight in kilogram. It is commonly 20 to 26 mg per kg per 24 hours in normal man and 14 to 22 mg per kg in normal woman per 24 hours. **Creatine** is present in the urine of children and in much smaller amounts in a normal adult men. It is observed that normal males excrete about 6% of the total Creatinine output of creatine (60-150 mg/day). In females, this amount is higher than that of in males. Excretion of creatine is increased in pregnancy and is decreased in hypothyroidism. In normal urine, creatine is absent. But in newborn infants, pregnant and lactating females the urine contains creatine. Creatine is obtained in the liver from amino-acids in pathological conditions namely starvation, impaired carbohydrate metabolism, hyperthyroidism and certain myopathies creatinuria is also found.
   Creatinine: It is formed in the muscles. In the muscles a high-energy compound called Phosphocreatinin.
   Creatinine is formed from its reduction. It is excreted along with urine.
10. **Oxalate:** Normal urine contains about 10-30 mg of oxalate per 24 hours. Excretion of oxalic acid is increased in diabetes, in certain liver diseases.
11. **Hippuric acid:** It is chemically benzoyl glycine. It is the detoxication products of benzoic acid with glycine. The quantity of hippuric acid excreted through the urine is about 0.7g (ranges about 0.1 to 1.0 g).
12. **Amino acids:** In adults about 150-200 mg of amino acids are excreted through the urine in 24 hours.

<table>
<tr><th>No.</th><th>Animals</th><th>Excretory organ</th><th>Examples</th></tr>
<tr><td>1.</td><td>Protozoans</td><td>Plasmalemina</td><td>Amoeba</td></tr>
<tr><td>2.</td><td>Porifera</td><td>General body surface</td><td>Sycon</td></tr>
<tr><td>3.</td><td>Coelenterates</td><td>General body surface</td><td>Hydra</td></tr>
<tr><td colspan="4">In the above three, contractile vacuole is also there which is not really an excretory organ.
It is specially for water balance & helps to get rid of extra water that diffuse into the cell.</td></tr>
<tr><td>4.</td><td>Platyhelminthes</td><td>Flame cells (Solenocytes)
Protonephrisium</td><td>Taenia, planaria
Larva of platyhelminth
Miracidium, redia larva</td></tr>
<tr><td>5.</td><td>Aschelminthes</td><td>Renette cell (excretory cell)</td><td>Ascaris</td></tr>
<tr><td>6.</td><td>Annelida</td><td>Nephridia
Chloragogen cells</td><td>Earthworm
Earthworm megascolex</td></tr>
<tr><td>7.</td><td>Arthropoda</td><td>Malphighian tubules, uricose gland,
Urate cells
Coxal gland
Green gland</td><td>Cockroach
Spider,
Scorpian (arachnida)
Prawn (crustacea)</td></tr>
<tr><td colspan="4">Special glands called rectal glands reabsorb water and ions and urine which are mixed with faeces. This is an adaptation of dry habitat.</td></tr>
</table>

8.	Echinoderm	Tubefeet (podia) & dermal branchea (thin walls of gills)	Starfish
9.	Protochordates	Solenocytes Neural gland Glomerulus	Amphioxus Hermania Balanoglossus







<u>LOCATION AND STRUCTURE OF KIDNEYS</u>

A pair of kidneys is present in the dorsal part of the abdominal-cavity & lateral to vertebral column. **In human being right kidney is slightly downwards than the left kidney (approx. 2.5 cm.).**

⇨In mammals, the kidneys are Bean-shaped or concavo-convex type. The small pit like structure is found on the medial surface called as hilum or hilus. **From the Hilus part a ureter comes out.**

⇨Both the ureters open through seprate openings into the urinary-bladder. The openings of these ureters into the bladder are oblique; so they prevent the backward flow of urine into the kidney. Bladder opens into the urethra.

⇨<u>**Opening of urinary bladder is control by external & internal sphincter**. Internal sphincter which is involuntary in nature while external sphincter voluntary nature. Normally it remains contracted; only at the time of micturition it remains relaxed.</u> The diaphragm remains active during micturition and exerts pressure on the bladder. Urethra opens to the outside through the urinogenital aperture.

In human Male urethra is large than female urethra. If approximately 20 cm, & divided into four parts

I. **Urinary urethra (preprostatic urethra).** It is 1.0–1.5 cm long part which lies between urinary bladder and point of union with ejaculatory ducts
II. **Prostatic urethra** - (2.5 cm.) run between prostatic lobe.
III. **Membranous urethra -** (2.5cm.} runs between perineal muscle.
IV. **Penile urethra** - (15 cm.) It is largest part of male urethra & runs in corpuous spongiosum part of penis & open outside in the form of external urethra] orifice. **While female urethra is short approx 4 cm. & open in in anterior part of vaginal vestibule.**

DEVELOPMENT OF KIDNEY

During embryonic development nephrotome plate develops from mesoderm which is made up of fine tubules called **nephros.** Nephrotome develops into kidney while nephros develops into Nephrons or uriniferous tubules.

On the basis of development kidney are of 4 types:

(1) Archinephros: It is the basic and ancestral form. Such kidney is found today in larvae of certain cyclostomes (Myxine), but do not occur in any adult vertebrate. Glomeruili are only present in some of the posterior tubules.

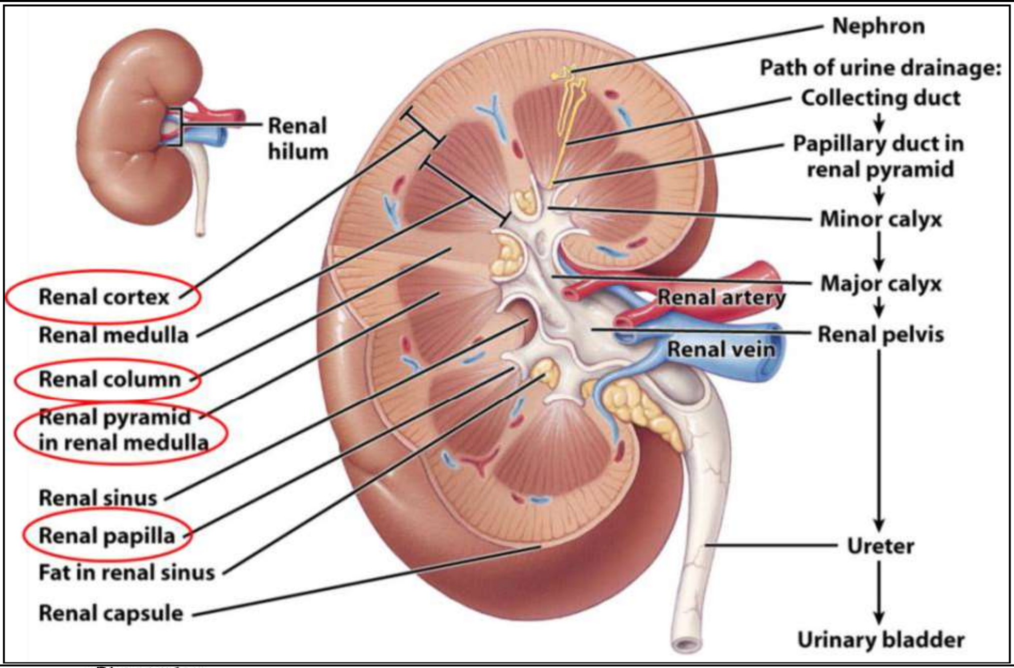
(2) Pronephric Kidney: Pronephros the **most primitive excretory organs** that develop in vertebrate, corresponding to the first stage of kidney development. Develop from **anterior part of Nephrotome plate**. Its nephrons are in simple tubular shape. Nephrons are not differentiated.

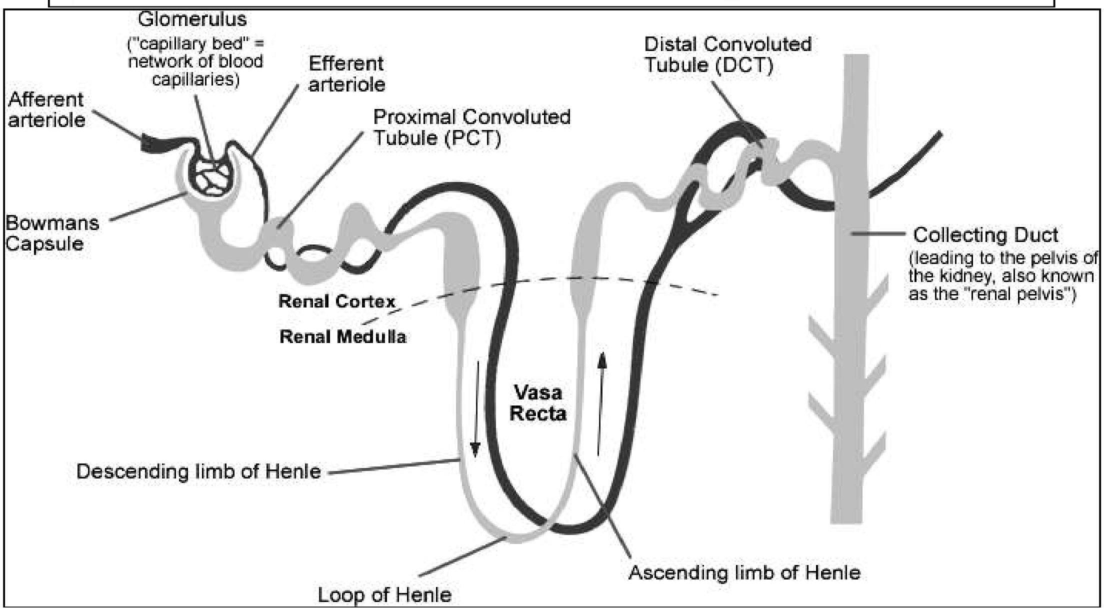
Example: It is present at the embryo of more advanced fish and at the larval stage of amphibians. In human beings, it is rudimentary and replaced by mesonephros after 3.5 weeks.

(3) Mesonephric Kidney or opisthonephros: develop from **middle part of Nephrotome plate**& remaining part of nephtotome is destroyed- Only Bowman's capsule is found in nephrons while remaining part is simple tubular **Example:** Most of the fishes & adult Amphibians but in reptiles, birds and mammals it is functional in embryo

(4) Metanephric Kidney: Develops from **posterior part of nephrotome** while remaining part is destroyed. Nephrons are well differentiated in to Bowman's capsule PCT, DCT & loop of Henle's. **Example:** Reptile, Aves, Mammals

(INTERNAL STRUCTURE OF KIDNEYS)





Around each kidney, there is a coat of white fibrous connective tissue called the **Renal-capsule.** Inside of the kidney is filled with loose connective tissue. This connects tissue is divided into two - **Outer is Cortex and Inner Medulla**. Medulla is raised inside the cortex is the form of a dome shaped structure called the **Pyramid**.

⇨In each kidney of man, 8-12 pyramids are present. Projection of the cortex are embedded into medulla called as **renal column of Bertini**

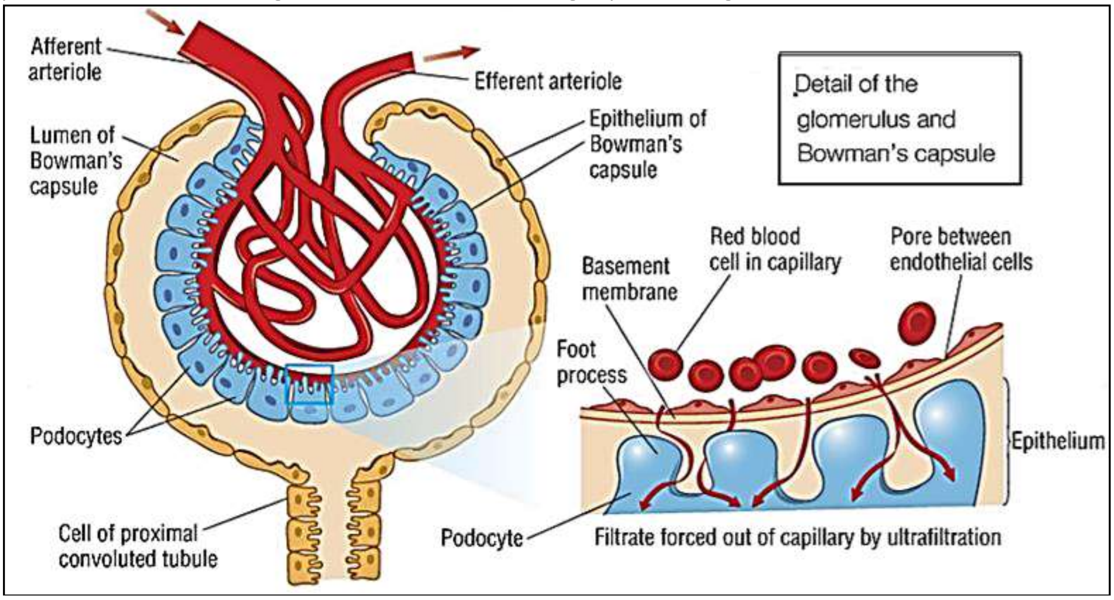
The Proximal part of the ureter is broad and funnel shaped; and is termed as the *pelvis.* Narrow apex of the pyramid called Renal-papilla. Their pelvis is divided into 3 or 4 branches. These branches are termed as Major calyx, Major-calyx is further divided into sub-branches called Minor-calyx. Minor-calyxes are expanded in the pyramids to collect urine.

Minor & major calyxes make the endoskeleton of the kidney

In each kidney of man 10-12 lakh Nephrons are present. Nephron is a **functional & anatomical unit of kidney**Anephron consists of **two parts**– an initial filtering component (the renal corpuscle) and a long tubule (**renal tubule**) – both made of simple cuboidal epithelium

Renal corpuscle: -

- The renal corpuscle **filters out large solutes from the blood, delivering water and small solutes to the renal tubule for modification**. The renal corpuscle (or Malphigian corpuscle) is **composed of a glomerulus and Bowman's capsule**. Where blood is filtered to begin the process of urine formation. The nephron begins as a double-walled blind cup called **Bowman's capsule** (lined by squamous epithelium) which surrounds a network of capillaries known as **glomerulus**.
- **Glomerulus** is a capillary (fenestrated) tuft that **receives its blood supply from an afferent arteriole of the renal circulation**. Blood enters glomerular capillaries through **afferent arteriole** and leaves through **efferent arteriole**. The **diameter of afferent arteriole is much more than that of efferent arteriole**.
- Bowman's capsule is composed of **inner visceral (simple squamous epithelial cells) and outer parietal (simple squamous epithelial cells) layers**. The **visceral layer** lies just beneath the thickened glomerular basement membrane and is **made of podocytes** which send **foot processes** over the length of the glomerulus.
- **Foot processes** interdigitate with one another forming filtration slits that, in contrast to those in the glomerular endothelium, are spanned by diaphragms.
- The size of the filtration slits restricts the passage of large molecules (eg, albumin) and cells (e.g., red blood cells and platelets). As a result, the **filtrate** leaving the Bowman's capsule is very **similar to blood plasma** in composition as it passes into the proximal convoluted tubule. In addition, foot processes **have a negatively charged coat (glycocalyx)** that limits the filtration of negatively-charged molecules, such as albumin. The parietal layer of Bowman's capsule is lined by a single layer of squamous epithelium
- **Unlike the visceral layer, the parietal layer does not function in filtration.**Rather, the filtration barrier is formed by three components: the diaphragms of the filtration slits, the thick glomerular basement membrane, and the glycocalyx secreted by podocytes.
- Podocytes are special, less flattened cells which line the concavity of Bowman's capsule. **Surface of Podocytes bear hooks that help in binding the capillaries of the glomerulus through a basement membrane**. Podocytes prevents filteration of large macromolecules that might pass through basement membrane and endothelium.



⇨After **Bowman's Capsule** the nephron is in the form of a straight tubule called the Neck of Nephron.

After the neck, the remaining part of the nephron is in the form of a highly coiled tubule, termed as the secretory-tubule.