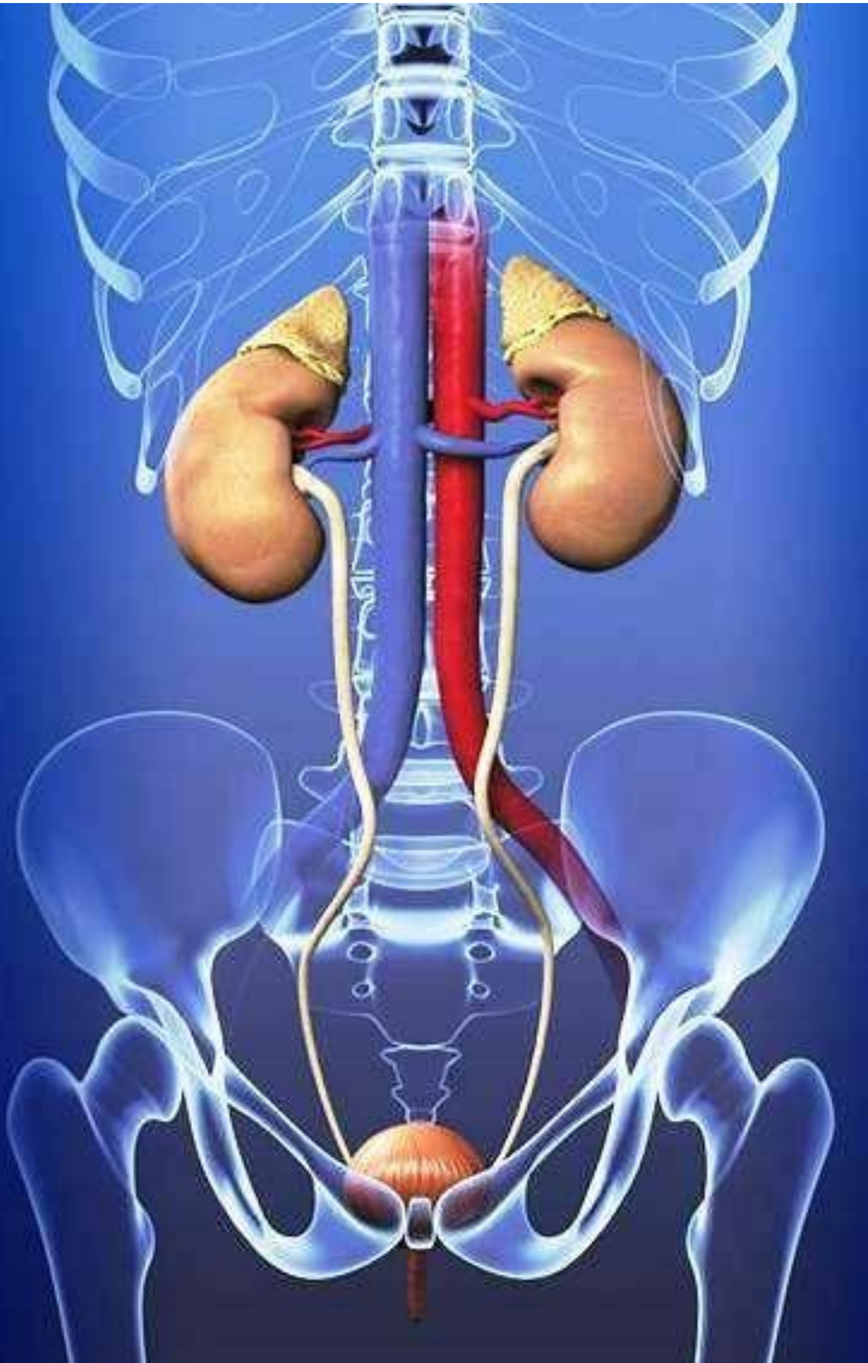
EXCRETION



Tr Amati Ronald
0762567194
Science clinic

INTRODUCTION

Excreti
on

The process of removal of **waste products** generated by **metabolic reactions** inside body cells.

It is not **egetion**-eliminating undigested food

Waste products are formed due to **catabolism** of **amino acids, glucose, glycerol and fatty acids**.

Unwanted substances like

Drugs, pigments, excessive vitamins, CO_2, H_2O

Excess of inorganic salts, hormones

Bilirubin and biliverdin.

Kidneys play a major role as an excretory organ in all vertebrates.

Skin helps in elimination of urea; inorganic salts and water through sweat glands.

Lungs help in the elimination of CO_2 and H_2O

INTRODUCTION

Osmoregulatio n

The process by which the **relative proportion of water and solutes** (salts, glucose, etc) in **the body-fluids** and **cells** are *kept constant.*

Osmoregulation controls the **osmotic pressure of body fluids** and maintains the **volume of blood constant**

Osmoregulation maintains the necessary required **concentration of electrolytes** in the body fluids

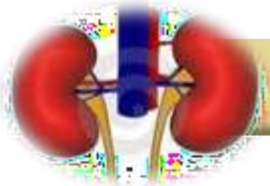
Significance / importance of excretion

- Enables removal of unwanted **by-products** of **metabolic pathways** to prevent unbalancing the **chemical equilibria** of reactions.

- Removes **toxic wastes** that if accumulated would affect the metabolic activities of organisms e.g. may act as **enzyme inhibitors**.

Excretory and homeostatic organs in various animals

Animal	Excretory and homeostatic structures
Platyhelminthes e.g. planaria, liverfluke, tapeworm	Flame cells (solenocytes)
Annelids	Nephridia
Insects, millipedes	Malpighian tubules
Arachnids	Book lungs
Fish	Gills and kidneys
Amphibians	Lungs, kidneys, liver and gills
Birds and Reptiles	Lungs, kidneys and liver
Mammals	Lungs, kidneys, liver and skin
Unicellular organisms	Cell surface membrane
Crustaceans	Antennal glands
Roundworm	Excretory cell



Types of Excretion

AMMONOTELISM	UREOTELISM	URICOTELISM
Nitrogenous waste in the form of **ammonia**	Nitrogenous waste in the form of **urea**	Nitrogenous waste in the form of **uric-acid**
formed in the liver by **deamination** of amino-acids	formed in liver by **ornithine cycle.** (NH_2-CO-NH_2)	formed in the liver by the **ionosinic pathway**.
least expenditure of energy.	relatively more expenditure of energy.	high expenditure of energy.
highly toxic	comparatively less-toxic	Uric-acid is **non-toxic**.
highly soluble in water.	a good **solubility** in water.	is insoluble water.
excreted rapidly in urine	excreted at a (comparatively) slower rate.	excreted very slowly
Dilute urine 500 ml of water is Required for elimination Of 1 gm of ammonia	concentrated urine 50 ml of water for elimination of 1 gm of urea.	of *thick paste or semi-solid pellets* 10 ml of water for elimination of one gm uric acid.

Types of Excretion

AMMONOTELISM	UREOTELISM	URICOTELISM
Aquatic invertebrates *sponges ,bonyfish, jelly-fish aquatic amphibians, aquatic insects etc*	***mammals*** like man,whale, ***amphibians*** like frog,aquatic **reptiles** like turtles and tortoise and *cartilagenous fish*.	*land-animals* like **birds**, ***reptiles*** (lizard, snakes), *land snails* and *insects*

FACTORS THAT INFLUENCE EXCRETION OF NITROGENOUS WASTES

- Ammonia is **highly toxic** hence its excretion requires a lot of water for dilution. Being highly soluble and readily difusable, it is excreted by **fresh water bony fish, protozoa, porifera, Cnidarians** which live in abundance of water. Such animals are said to be ammoniotelic.

- Urea is relatively toxic and very soluble hence can be easily diluted before elimination, so it is excreted by some **terrestrial animals** like mammals and **marine** ones whose **body fluids** are **hypotonic** to seawater. Animals that excrete mainly urea are said to be **ureotelic**

continuation

- **Uric acid** is almost non-toxic and highly insoluble, requiring very little water for its elimination so it is excreted by animals living in very **arid conditions** e.g. birds, insects and reptiles, which live in water shortage. These animals are said to be **ureotelic**
- **Trimethylamine oxide** is soluble but non-toxic, requiring relatively less water for its elimination, so is excreted by **marine bony fishes** suffering from water shortage.
- **Guanine** is less soluble than uric acid and requires no water for its elimination, hence is excreted by **terrestrial spiders** that live in scarcity of water

Note: nitrogenous wastes are produced by the breakdown of proteins, nucleic acids and excess amino acids

Role of Skin & Lungs

SKIN AS AN EXCRETORY ORGAN :

- The skin is **double-layered** i.e. **outer *epidermis*** and **inner *dermis***.

Within the *dermis* are present **hair-follicle**s, **sweat glands** and **sebaceous glands**.

- **SWEAT-GLANDS :**

- They are highly coiled glands found more in forehead, armpits, palms and soles of feet.

The **secretory part** (coiled) lies deep below in the dermis and is connected to the skin surface as perspiration pore via a long, narrow duct. They are simple, unbranched, tubular glands.

Functions :

- ✓ They secrete a colourless salty-fluid called sweat carrying excessive water, sodium-chloride, urea, uric-acid, lactic acid, glucose and amino-acids.
- ✓ Thus it *regulates* the **water-balance, salt-balance, excretion (little urea)** and *cools down the body* (**thermoregulation**) i.e. water converted into vapour by excessive heat.

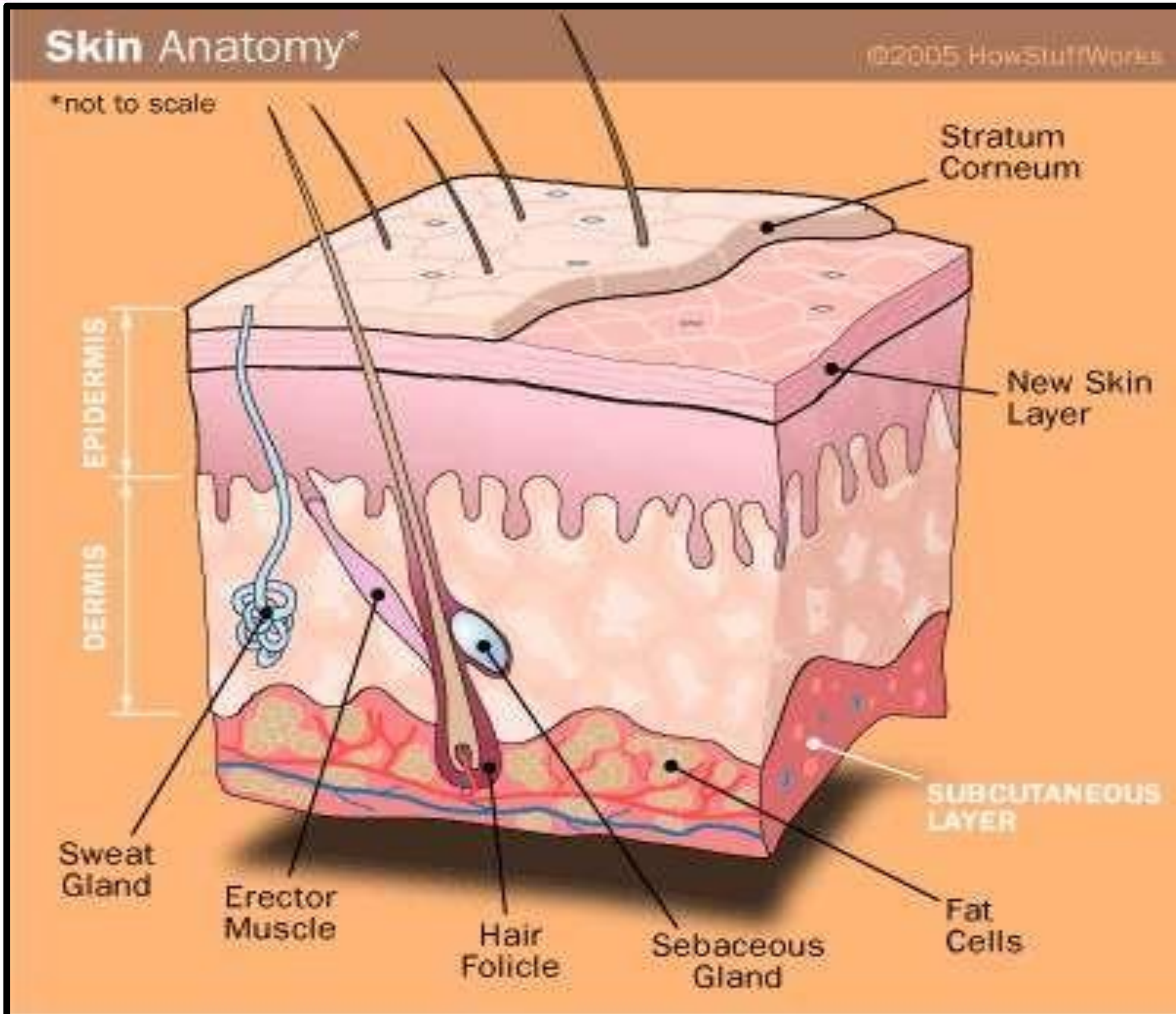
- **SEBACEOUS GLANDS :**

They are alveolar glands present in connection with the hair follicles.

Functions :

- ✓ They secrete **'sebum',** which is rich in waxes, sterols, hydro-carbons and fatty acids. Sebum makes the skin water-proof (due to wax) and has an **antiviral & antibacterial activity.**

Role of Skin & Lungs



Role of Skin & Lungs

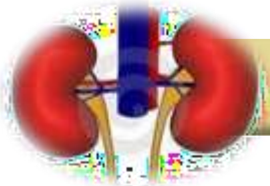
LUNGS AS EXCRETORY-ORGANS :

- The **byproducts** of **cellular respiration** are **water**&**CO_2**.
- The **partial pressure** of CO_2 is higher in the **deoxygenated** blood of **alveolar capillaries** of lungs, brought from all the parts of the body, than in the alveolar air. Hence it diffuses into the alveoli and is exhaled out.Our lungs remove large amounts of CO_2 (18 litres/day).
- Water is also lost from the lung surface by **evaporation** (**Vapour**). This has a cooling effect (**thermoregulation**) in many animals.

LIVER :

- The largest **gland** in our body, secretes bile-containing substances like

bilirubin, biliverdin, **cholesterol, degraded steroid hormones, vitamins and drugs**.
Most of these substances ultimately pass out alongwith digestive wastes and some in urine



EXCRETORY SYSTEMS

- In man and other mammals, small quantity of **uric acid** is formed in the body by breakdown of ***purine*** and ***pyrimidine*** nitrogen bases of nucleic acid.

- In some persons, due to defective metabolism, excess uric acid is produced which gets deposited in **joints** of bones causing painful arthritis called **gout.**

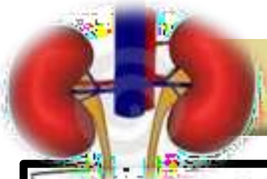
- **GUANOTELISM** – ***Arachnids*** (spiders, scorpions) and ***penguins*** excrete mostly guanine (nitrogen base) and hence are called guanotelic.

Protonephridia or flame cells -- Platyhelminthes (Flatworms, e.g., *Planaria*), rotifers, some annelids and the cephalochordate – *Amphioxus*

Nephridia -- Earthworms and other annelids..

Malpighian tubules -- most of the insects including cockroaches..

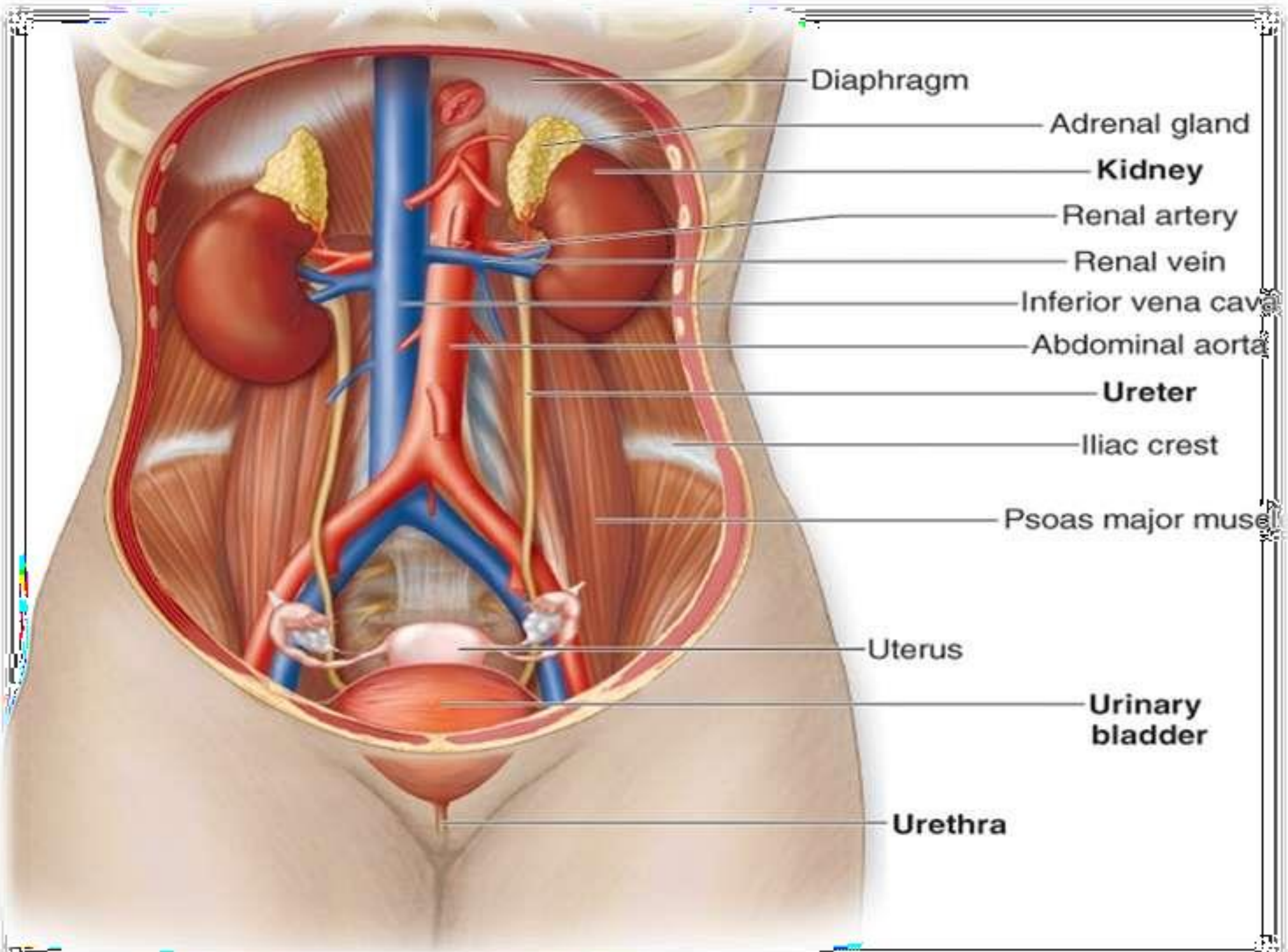
Antennal glands or **green glands** -- crustaceans like prawns



Excretory Systems in Diff. Organisms

	Animal groups	Excretory organs	Main nitrogenous waste
1.	Protozoans	Plasmalemma, pellicle	Ammonia
2.	Poriferans	General body surface	Ammonia
3.	Coelenterates	General body surface	Ammonia
4.	Platyhelminths	Protonephridium with flame cells	Ammonia
5.	Aschelminths	Renette cells (in *Ascaris*)	Ammonia, urea
6.	Annelids	Metanephridia (in *Nereis* and leech)	Ammonia
		Metanephridia and chloragogen cells (in earthworm)	Ammonia, urea on land
7.	Molluscs	Renal gland or organ of Bojanus (in *Pila* and *Unio*) and Keber's organ (in *Unio*)	Ammonia in aquatic and uric acid in land forms, Amino acids in *Unio*.
8.	Arthropods	Malpighian tubules, uricose gland, urate cells, nephrocytes	Uric acid in land forms and ammonia in aquatic forms
		Malpighian tubules, coxal gland, hepatopancreas and nephrocytes (in spiders and scorpions)	Guanine, some xanthine and uric acid
		Green glands or antennary glands (in crustaceans)	Ammonia
9.	Echinoderms	Tubefeet (podia) and dermal branchiae (thin walls of gills)	Ammonia, Amino acids in *Asterias*.
10.	Hemichordates	Glomerulus (in *Balanoglossus*)	
11.	Chordates		
	(i) Urochordates	Neural gland (in *Herdmania*)	
	(ii) Cephalochordates	Pharyngeal nephridia and Hatschek's nephridium (in *Amphioxus*)	
	(iii) Vertebrates	One pair of kidneys are main excretory organs. Lungs, liver, skin and intestine are accessory excretory organs in many vertebrates.	Ammonia, urea, uric acid

Excretory System In Man



Excretory System In Man

Kidneys

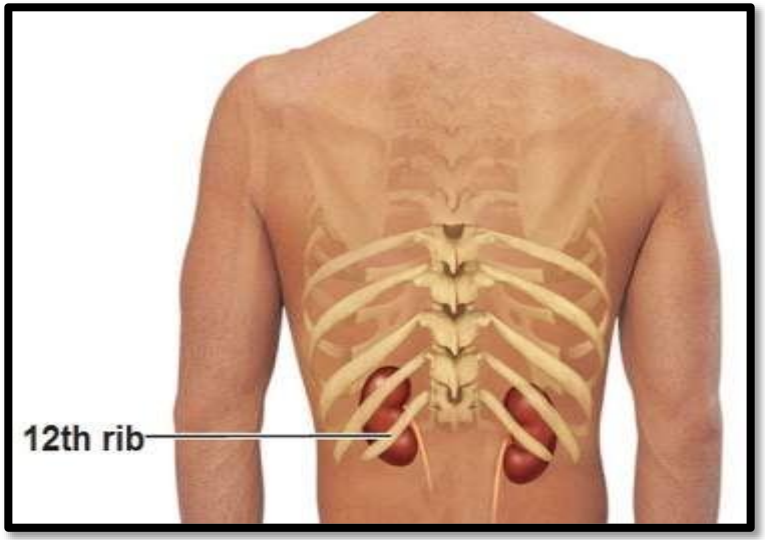
- Pair of **bean shaped, chocolate brown** structures situated in the **dorsal side of the abdominal cavity**

- one on *either side* of the **vertebral-column** between the 12th thoracic and 3rd lumbar **vertebrae.**

- The right kidney is slightly lower than the left kidney

-11 cms long, 6 cms broad and 3 cms thick

-150 grams in males and 135 grams in females

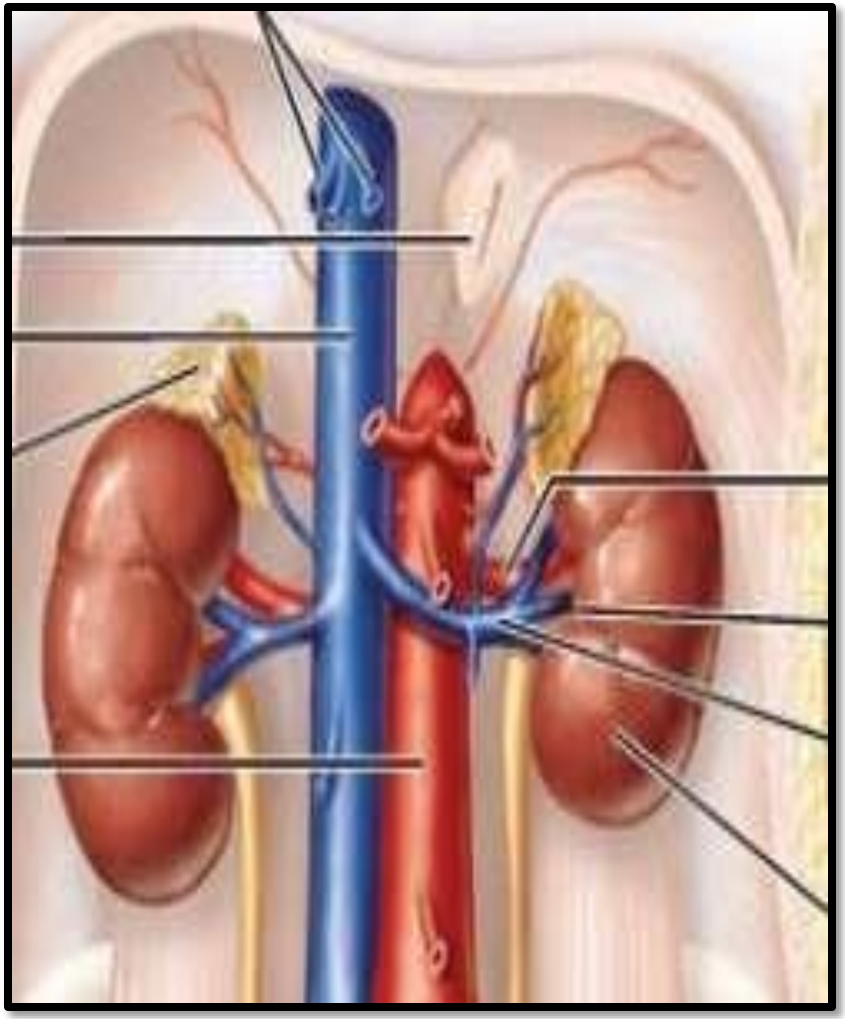


Kidneys

- Each kidney is covered by a **fibrous capsule,** over which lies a layer of **adipose tissue (*peri-renal fat*)** and the outermost fibrous sheath (*renal-fascia*)

- The outer margin of both kidneys is **convex**. The inner margin **is concave** and shows a notch, called hilum.

- The *renal-artery, renal-vein, lymphatic- vessels, nerves, renal-pelvis* (upper expanded end of the ureter) enter the kidney through the hilum. The upper part of each kidney is broad and has an **adrenal (suprarenal) gland** attached to it

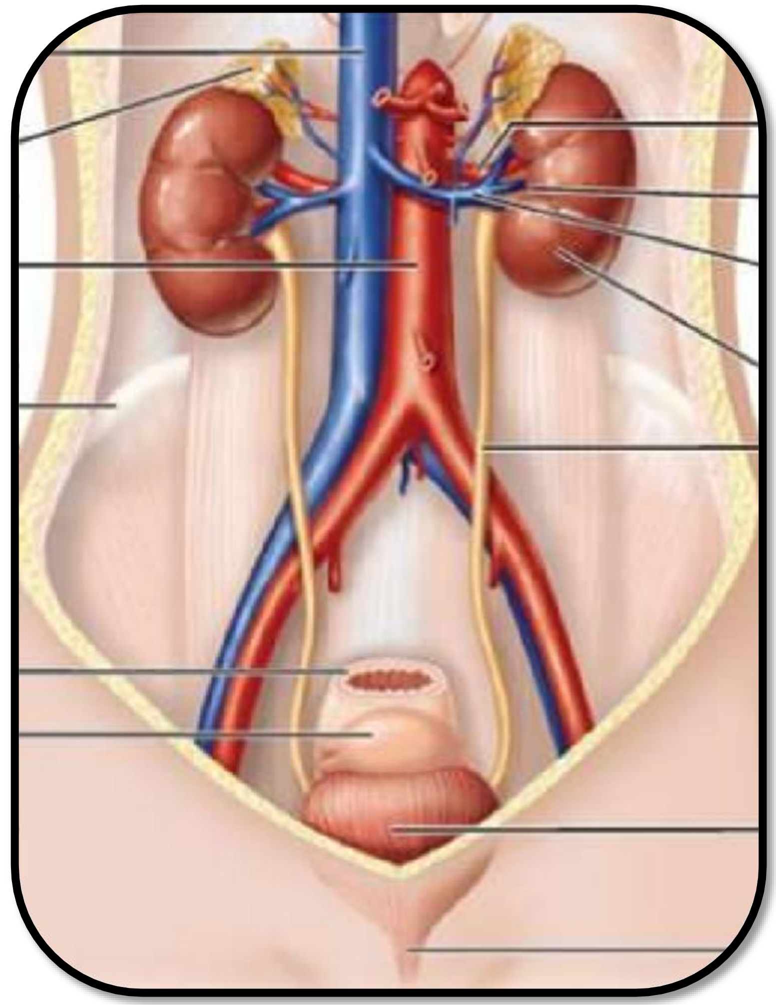


Ureters

- Each ureter arises from the *hilum* of the kidney by forming a funnel shaped expanded ***renal-pelvis***, runs downwards, enters the **bladder wall** obliquely (on the dorsal side) and opens into it.

Structure : They are a pair of narrow, thin-walled muscular tubes measuring about 25 cms in length and 3-6 mm in diameter.

Function: They carry urine from the kidneys to the urinary bladder by rhythmic contraction of its muscle- walls (**peristaltic movements**).



Bladder

- ***Position* :** It is situated in the **pelvic-cavity** **in front** of the *rectum* in the male and in front of the *uterus* in the *female*. (i.e. the womb, which lies between the bladder & the rectum). ***Structure* :**

- It is a *median* (central), single, hollow, ovoid or *pear shaped*, distensible muscular sac.It also shows a thick layer of smooth muscles called **detrusor muscles** lined by that allows expansion. **transitional epithelium**

***Function* :**

- It acts as a temporary **reservoir** for the storage of urine.

- It helps in **micturition** (**urination**). (The process of voiding of urine by contraction of the bladder wall and relaxation of the urethral sphincters).

Urethra

- **Males :**
- ✓ Urethra is 20 cms long extends from the lower end (neck) of the bladder to the tip of the penis

- In **females**
- ✓ it is 4 cms long it *opens separately* just in front of vagina.

- **Females:**

- ✓ it carries urine only.

- In males the urethra joins with the ejaculatory duct (to form the **urinogenital duct**) and carries both urine & semen.

Nervous Control of Micturation

- Urine formed by the nephrons is ultimately carried to the urinary bladder where it is stored till a **voluntary signal** is given by the **central nervous system** (**CNS**).

- This signal is initiated by the stretching of the urinary bladder as it gets filled with urine. In response, the **stretch receptors** on the walls of the bladder send signals to the CNS

- The **CNS** passes on **motor messages** to initiate the contraction of **smooth muscles** of the bladder and simultaneous relaxation of the **urethral sphincter** causing the release of urine.

- The process of release of urine is called **micturition** and the neural mechanisms causing it is called the **micturition reflex**

FUNCTIONS OF KIDNEY:

- By **excretion**, they eliminate *poisonous nitrogenous waste* products (like urea, uric-acid, ammonia) in the urine.

- During **excretion**, they remove unwanted substances like drugs, pigments excessive vitamins etc. from the body.

- By **Osmoregulation**, they regulate the amount of water and salts i.e. the osmotic pressure of body fluids and maintain the *volume of blood constant*.

- By **Osmoregulation**, they maintain a necessary required **concentration of electrolytes** (Na^+, K^+, Cl^-, Ca^+) in the blood.

- They regulate the *pH and acid base* balance of the body by removing excessive acidic or basic substances (H^+ ions concentration) from it.

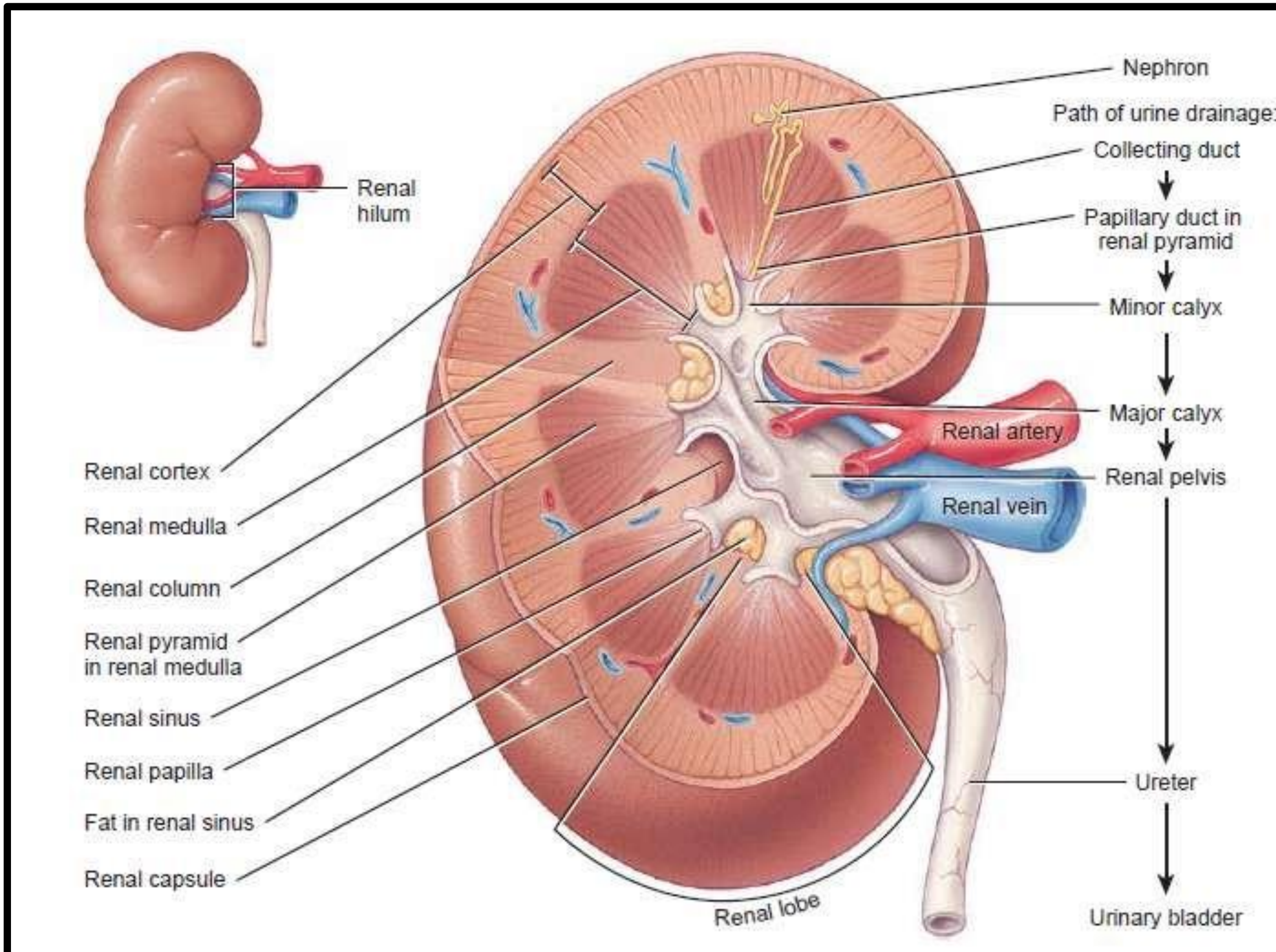
continuation

- During hypotension (low B.P.), they maintain the *pressure of the blood constant* by secreting enzyme renin from it which increases the B.P.

- They help in *production of R.B.C.s* (erythropoiesis by secreting ‘ renal-erythropoietic factor (**REF**) i.e. **erythropoietin** into the blood.

- They help in formation of **active form of Vit-D** (1,25 dihydroxy cholecalciferol

HISTOLOGY OF THE KIDNEY



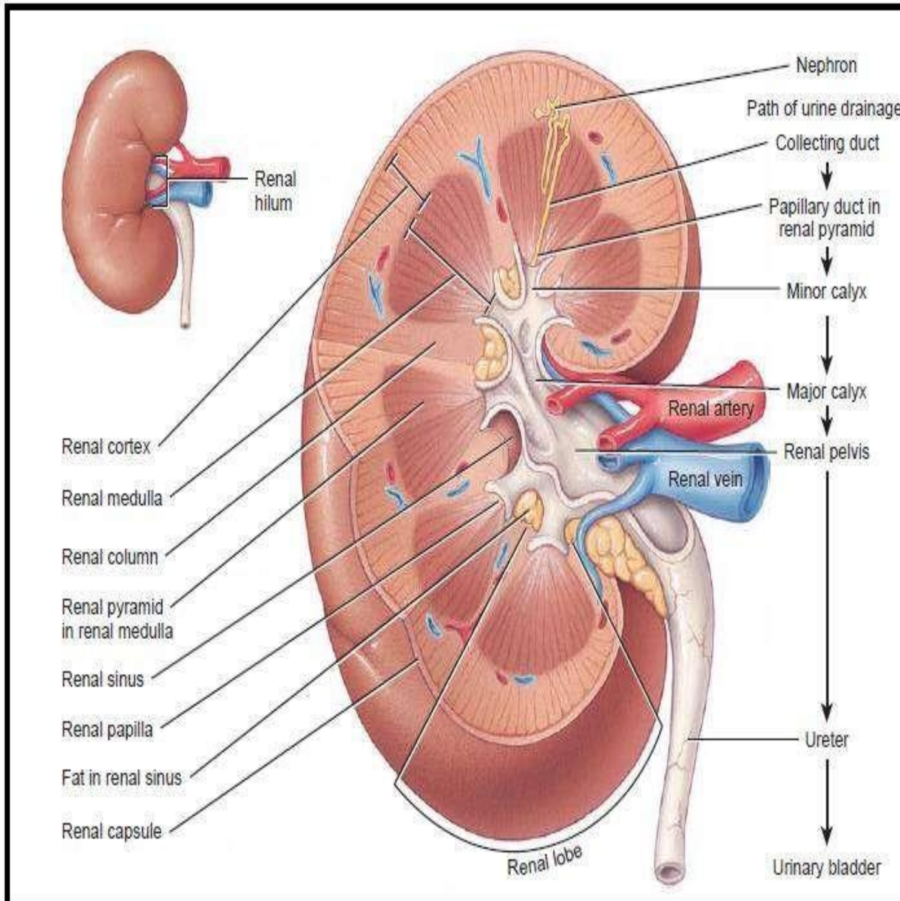
HISTOLOGY OF THE KIDNEY

A longitudinal section through the kidney shows the following parts from outside in :

1) The outer *reddish brown* **cortex,**

2) The inner *pale* **medulla** and

3) The ***renal-sinus***



A) <u>MEDULLA</u> :

- It is the inner, pale, striated part.

  It is made up of **renal pyramids**.

  Each pyramid has its base directed outwards (towards the cortex) and its apex inwards (called **renal-papillae**).

B) **<u>CORTEX</u> :**

It forms the outer (peripheral), reddish-brown, granular part.

- Parts of the cortical tissue invade the medulla and lie between adjacent pyramids and are called **renal-columns (Bertini's columns).**

C) <u>RENAL-SINUS</u> :

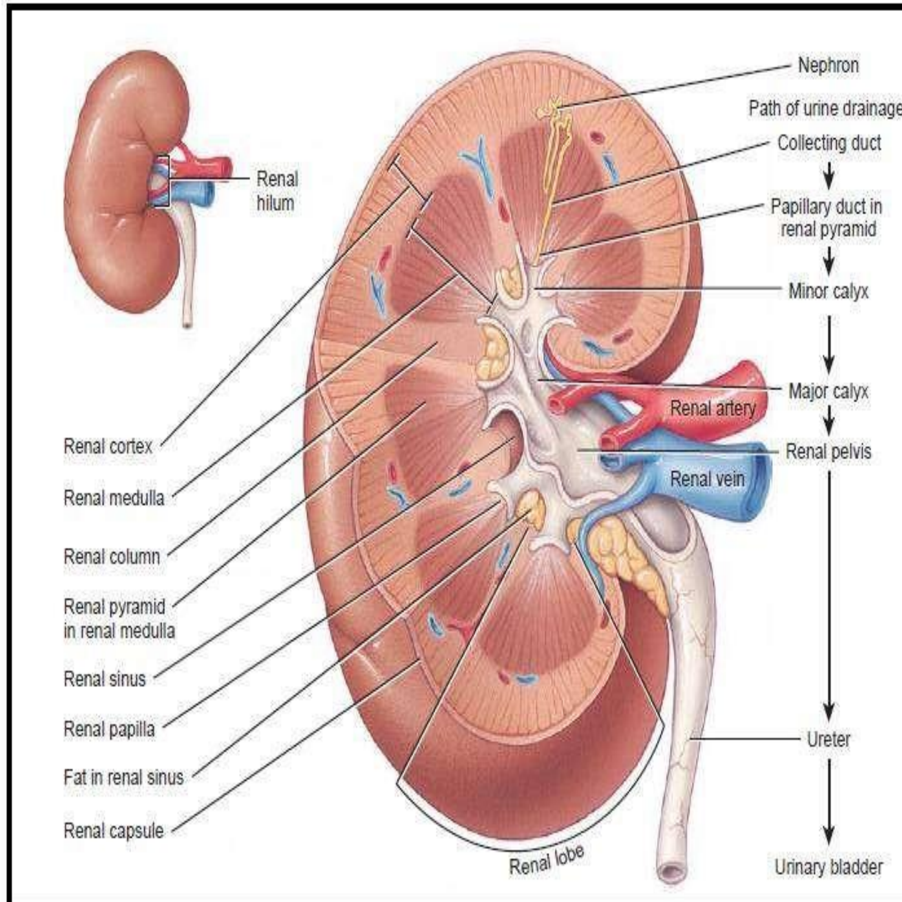
Internally, the *hilum leads* to a space called the **renal-sinus**, which is occupied by the upper, expanded part of the ureter called the **renal-pelvis**.

The renal-pelvis divides into two or three parts called **major-calices** (single calyx→ cup of a flower).

Each *major calyx* divides into 6-20**minor-calices**. Each minor-calyx is shaped like a cup.

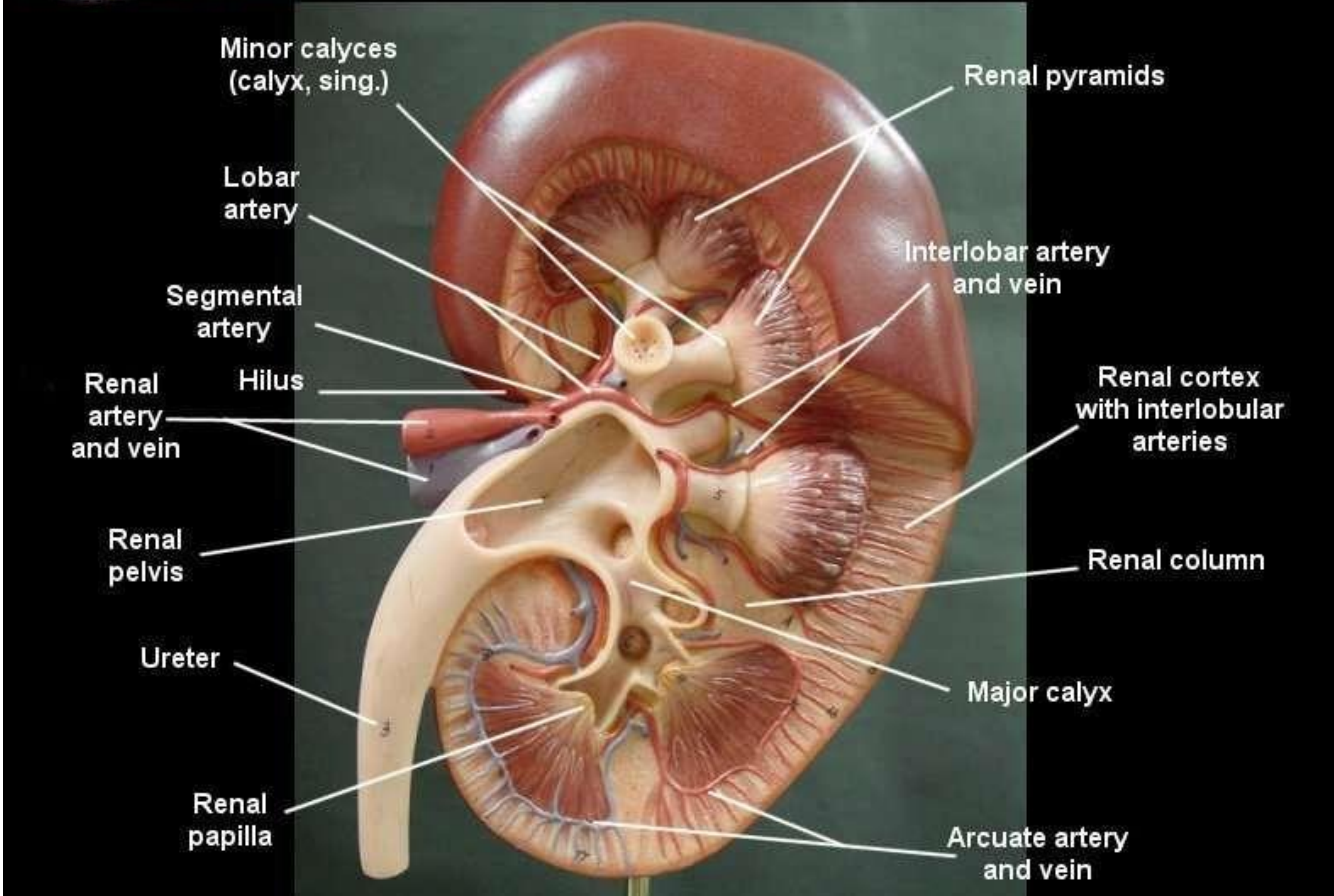
- The **papilla** of a medullary pyramid fits *into* the minor calyx.

Each kidney consists of closely packed microscopic coiled tubular structures called **nephrons**. The nephrons are the structural and functional units of the kidney. There are about *1.2 million* nephrons in each kidney.



HISTOLOGY OF THE KIDNEY

Kidney, Coronal Section

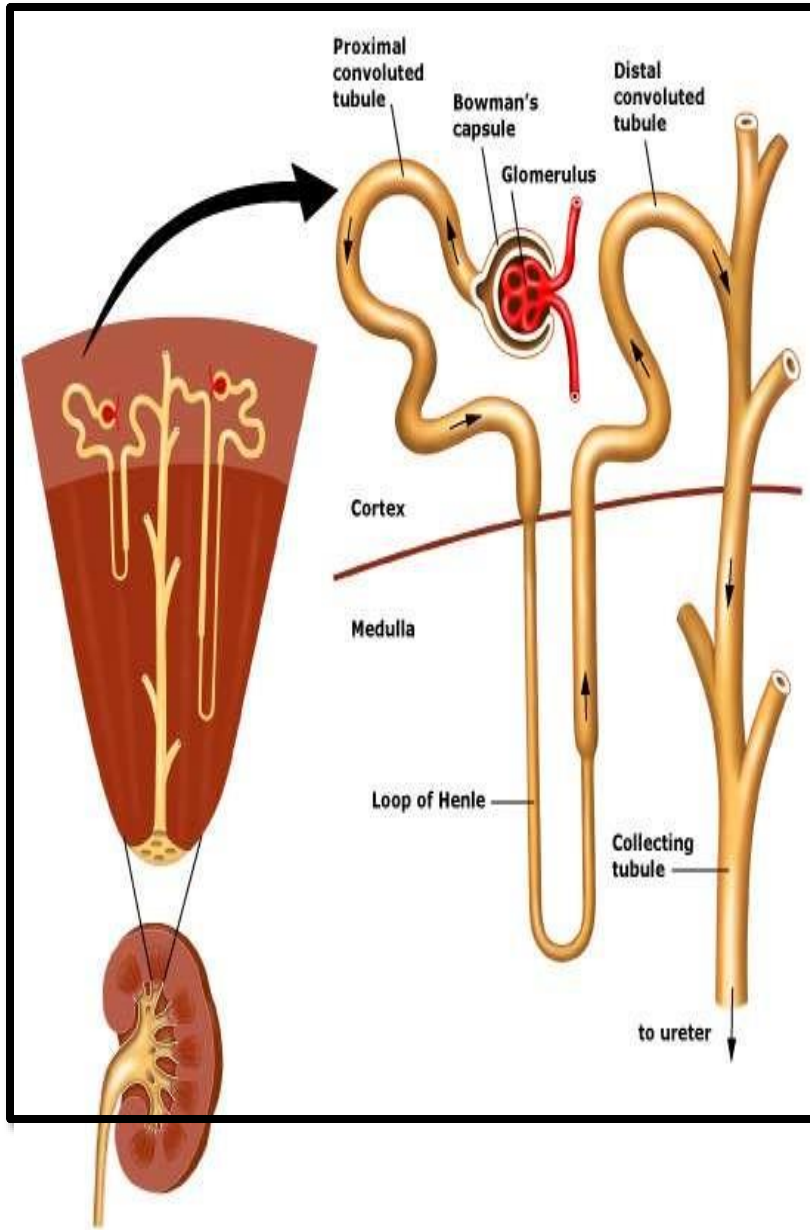


STRUCTURE OF NEPHRON

NEPHRON : 1. Malphigian body
2. Renal Tubule

Malphigian body : 1. Bowman's capsule
2. Glomerulus

Renal Tubule : 1. Proximal convoluted tubule (PCT)
2. Loop of Henle
3. Distal convoluted tubule (DCT)

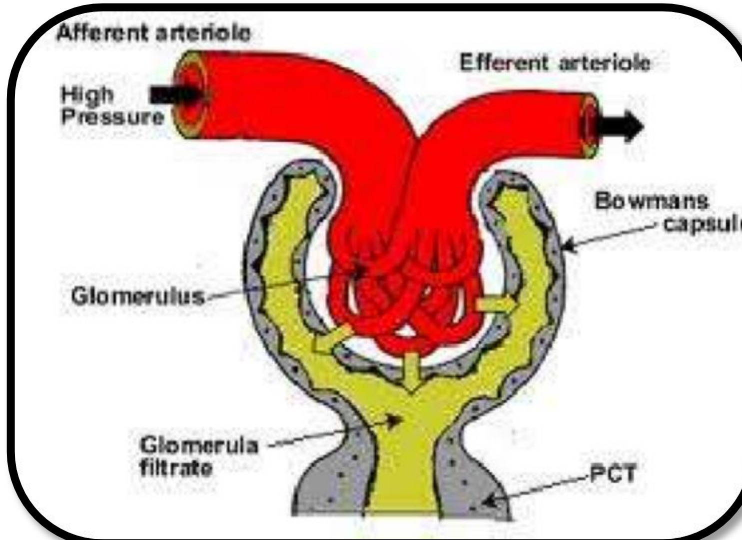


STRUCTURE OF NEPHRON

malphigian body

It is **double-walled, cup shaped** blind-opening in the **cortex**. It is about 1.2 mm in width

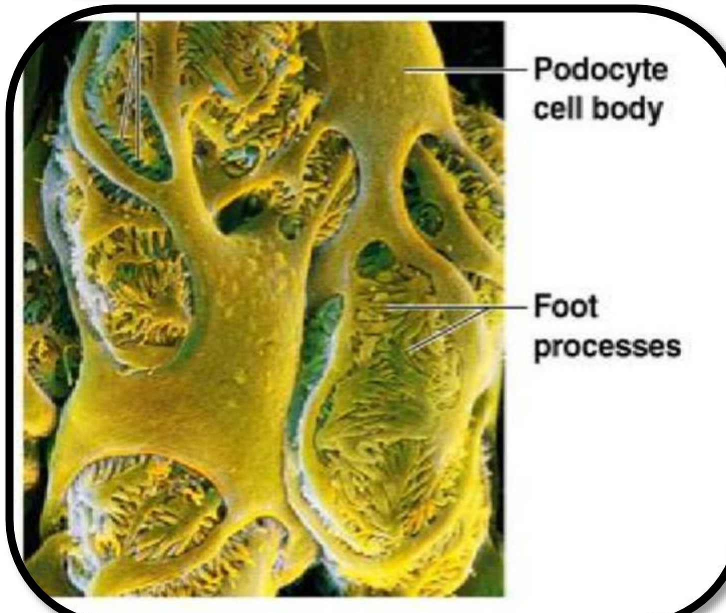
Outer wall : **PARIETAL LAYER** : squampous epithelium
Inner wall : **VISCERAL LAYER** : special squamous cells called **PODOCYTES**



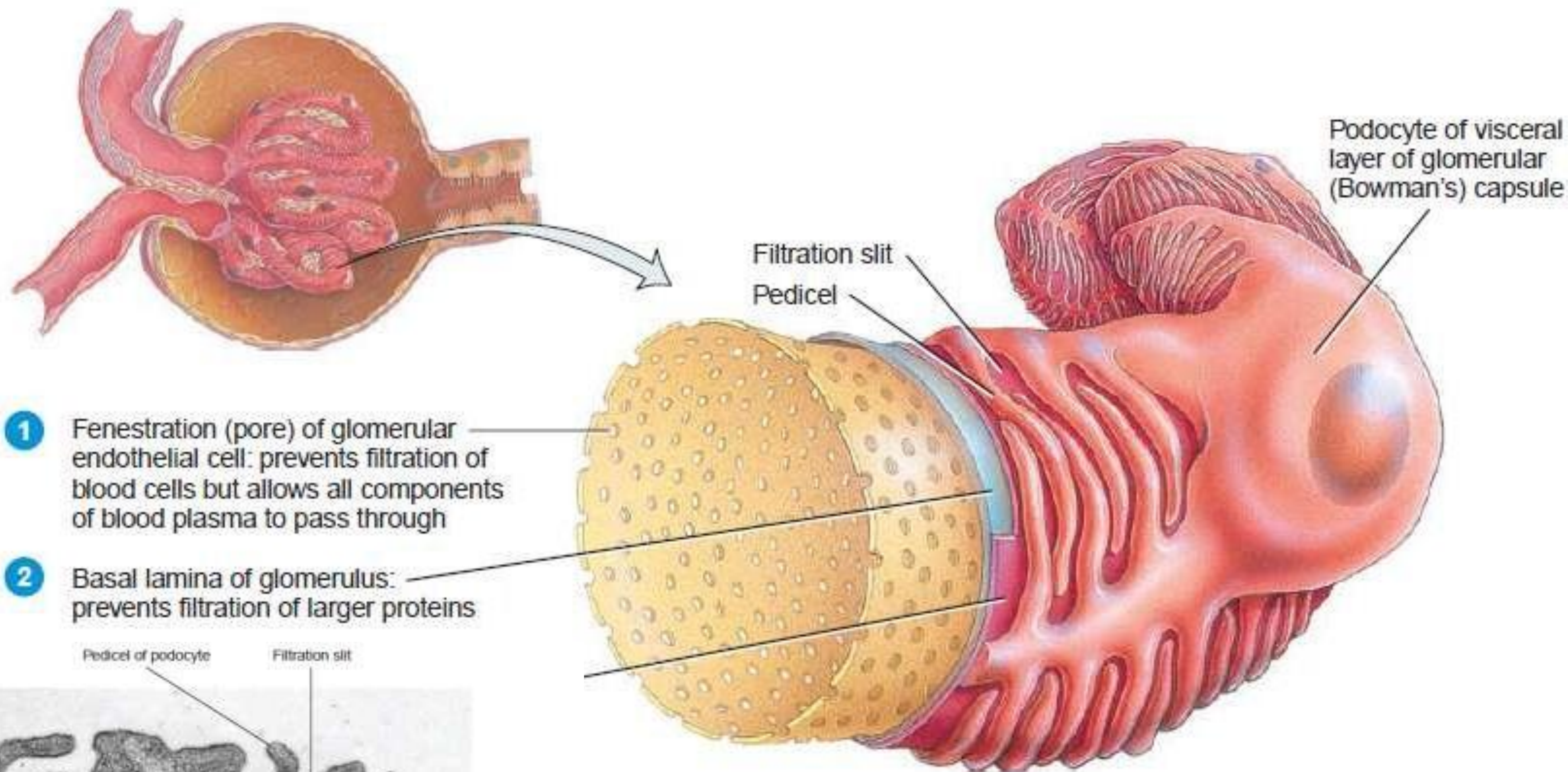
The body of the podocytes rest on feet like processes called '**pedicels**'.

The individual legs, have **foot processes**.

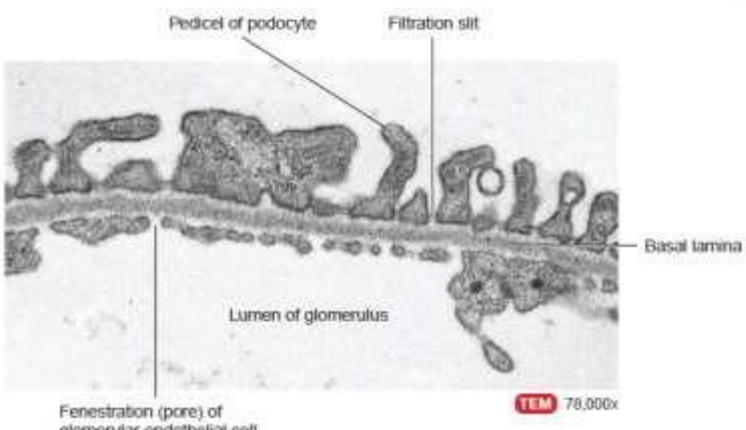
The gaps (**slits**) between the foot processes are in *intimate contact with* **pores**in the endothelium of blood capillaries, through a permeable basement membrane



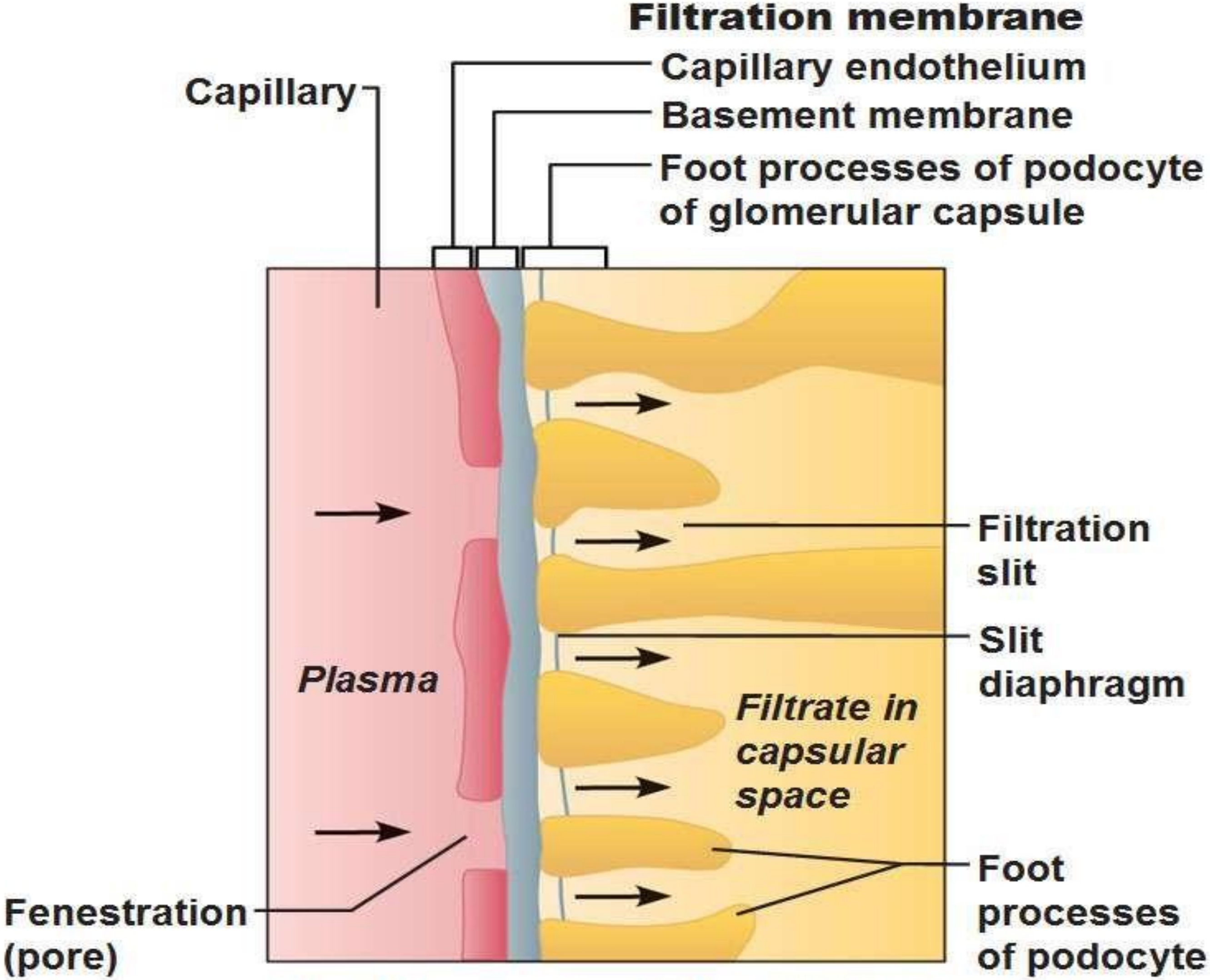
STRUCTURE OF NEPHRON



(a) Details of filtration membrane



Filtration Membrane



(d) Three parts of the filtration membrane

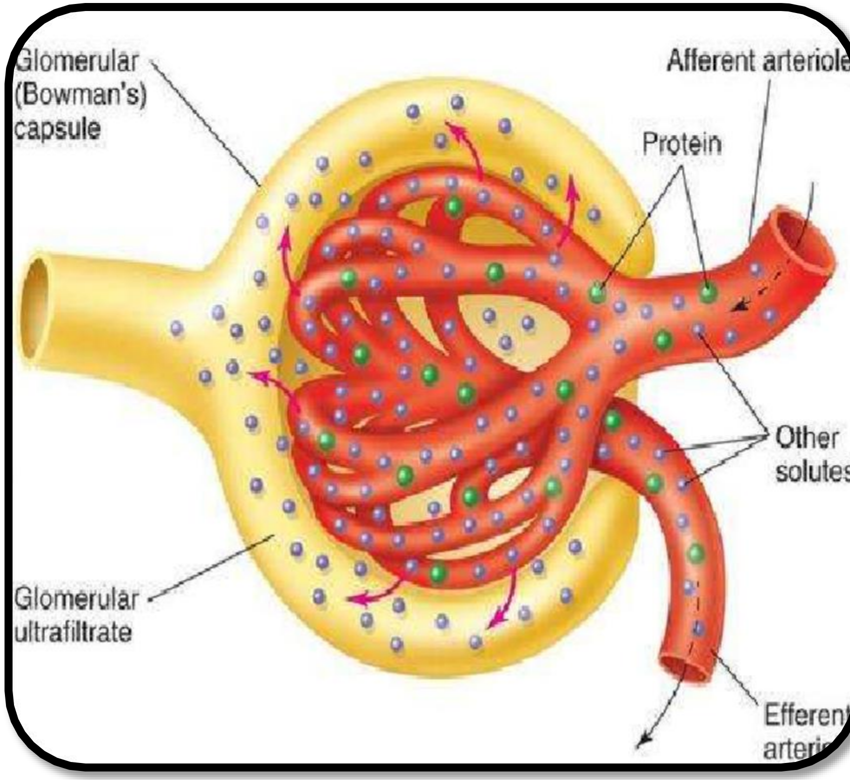
STRUCTURE OF NEPHRON

GLOMERULUS (BLOOD-SUPPLY) :

It is a **rounded tuft of blood capillariesfound** in the **cup** of the *Bowman's capsule*.

The **renal artery**(a branch of the abdominal aorta) enters through the hilus, divides and re-divides to form many branches. One branch called the **afferent renal arteriole** enters the cup and divides to form the **Glomerulus**
.

- The capillaries reunite to form the **efferent renal arteriole**. It leaves the glomerulus.
- *The diameter of the efferent arteriole is lesser than that of the afferent one*.



Renal Tubule

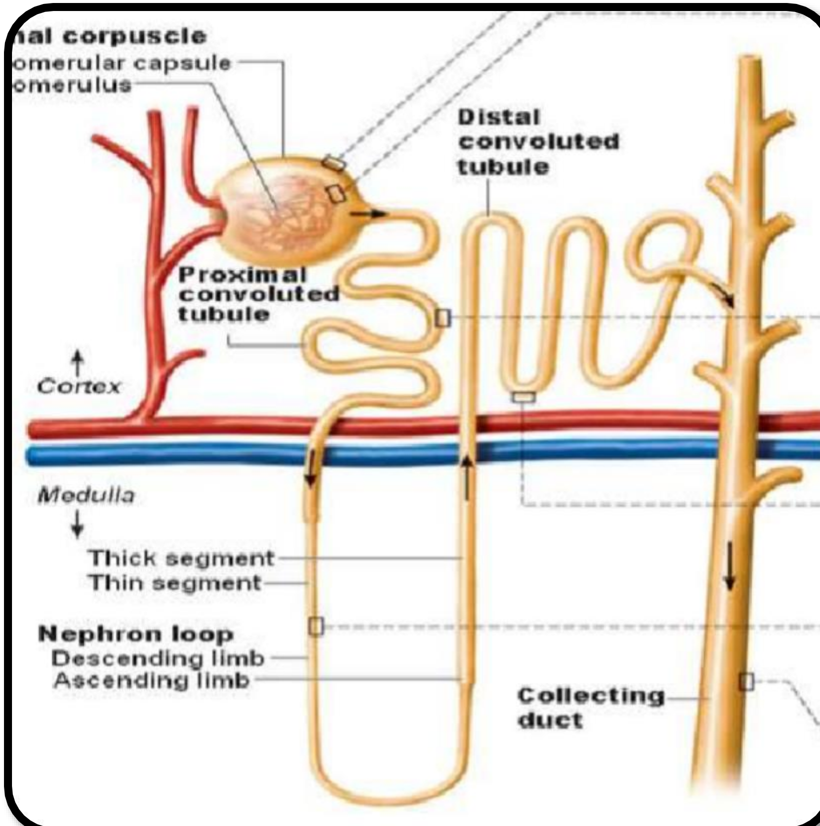
<u>THE PROXIMAL CONVOLUTED TUBULE (P.C.T)</u>

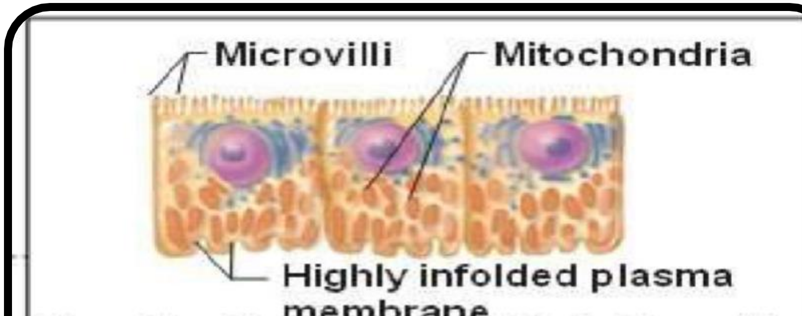
It is a highly coiled structure, connected to the neck and lies in the **cortex**.

It is lined by **cuboidal cells**, rich in *mitochondria*, and having **microvilli** (**brush border** to increase surface area) and thus help in **active reabsorption**.

Quick check

How is the proximal convoluted tubule suited to its function?





Proximal convoluted tubule cells

STRUCTURE OF NEPHRON

Renal Tubule

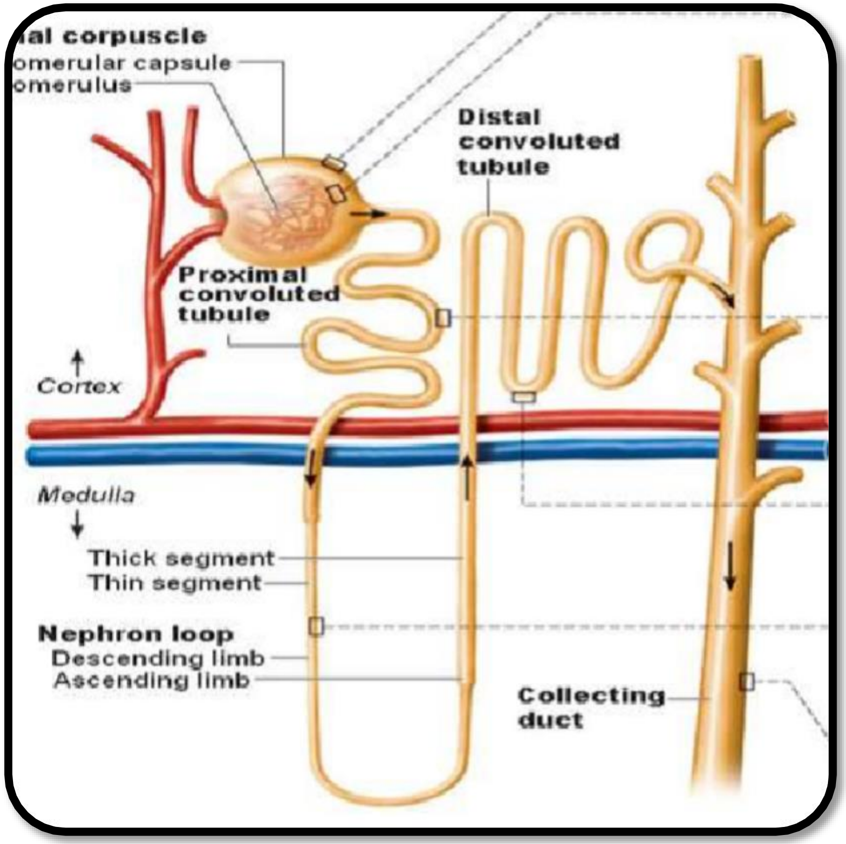
B) **<u>THE MIDDLE LOOP OF HENLE :</u>**

The renal tubule now descends into the **medulla** (thin walled **descending limb**),takes a hair pin turn (*the U-shaped* **loop**) and ascends back towards the cortex (thick walled **ascending-limb**).

The ascending limb is not permeable to water.

The Henle's loop is mainly meant for concentration of urine.

Quick check. What is the function of the loop of Henle and how is it adapted to its function

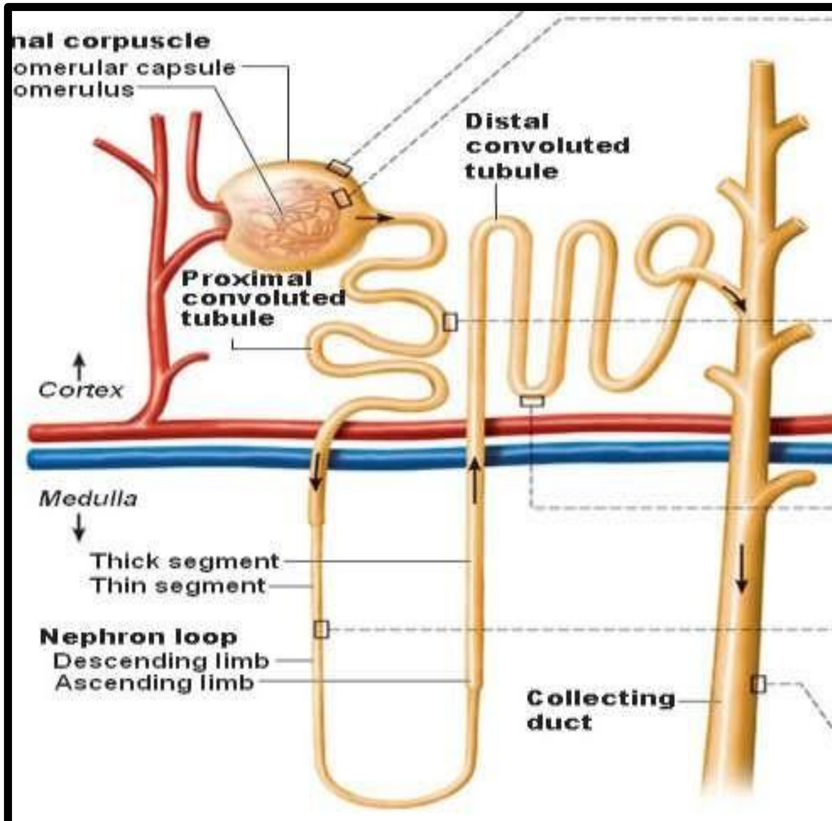


Renal Tubule

THE DISTAL CONVOLUTED TUBULE (P.C.T)

The D.C.T leads to a straight, large **collecting-tubule**. Many nephrons open into the same collecting tubule. Many collecting tubules join to form a **collecting duct** which descends into the medullary pyramids.

The *medullary pyramids* are basically a bunch of these collecting ducts. About 7-8 collecting ducts draining different nephrons join to form **ducts of Bellini**, each of which opens into a minor calyx at the apex (**papilla**) of a medullary pyramid.



Distal convoluted tubule cells

STRUCTURE OF NEPHRON

<u>BLOOD SUPPLY :</u>

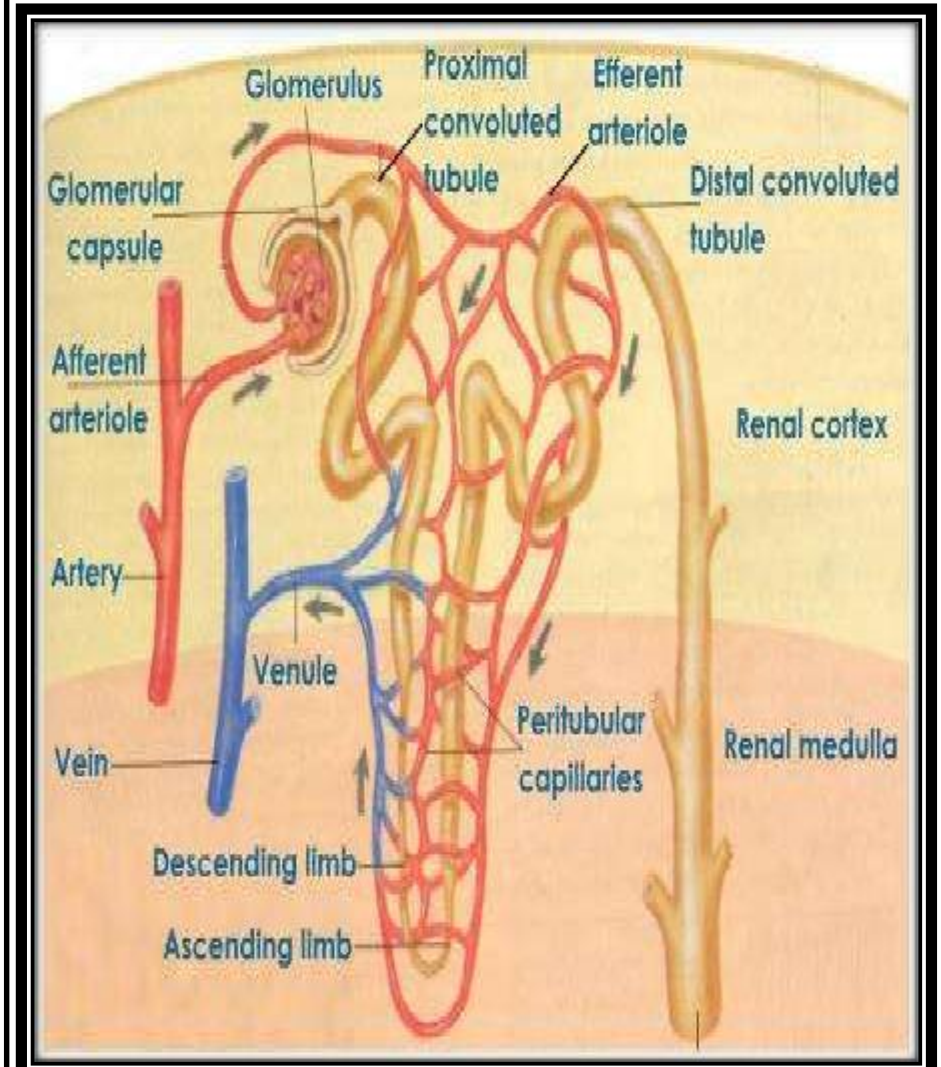
The efferent renal arteriole which leaves the Bowman's capsule breaks to form peritubular-capillaries around the whole renal tubule.

<u>The capillaries around the loop of Henle are called as vasa rectae</u>.

The capillaries reunite to form a renal venule and carry the blood away from the nephrons. The renal venules join to form the renal-vein, which passes out of the kidney to join the inferior vena cava.

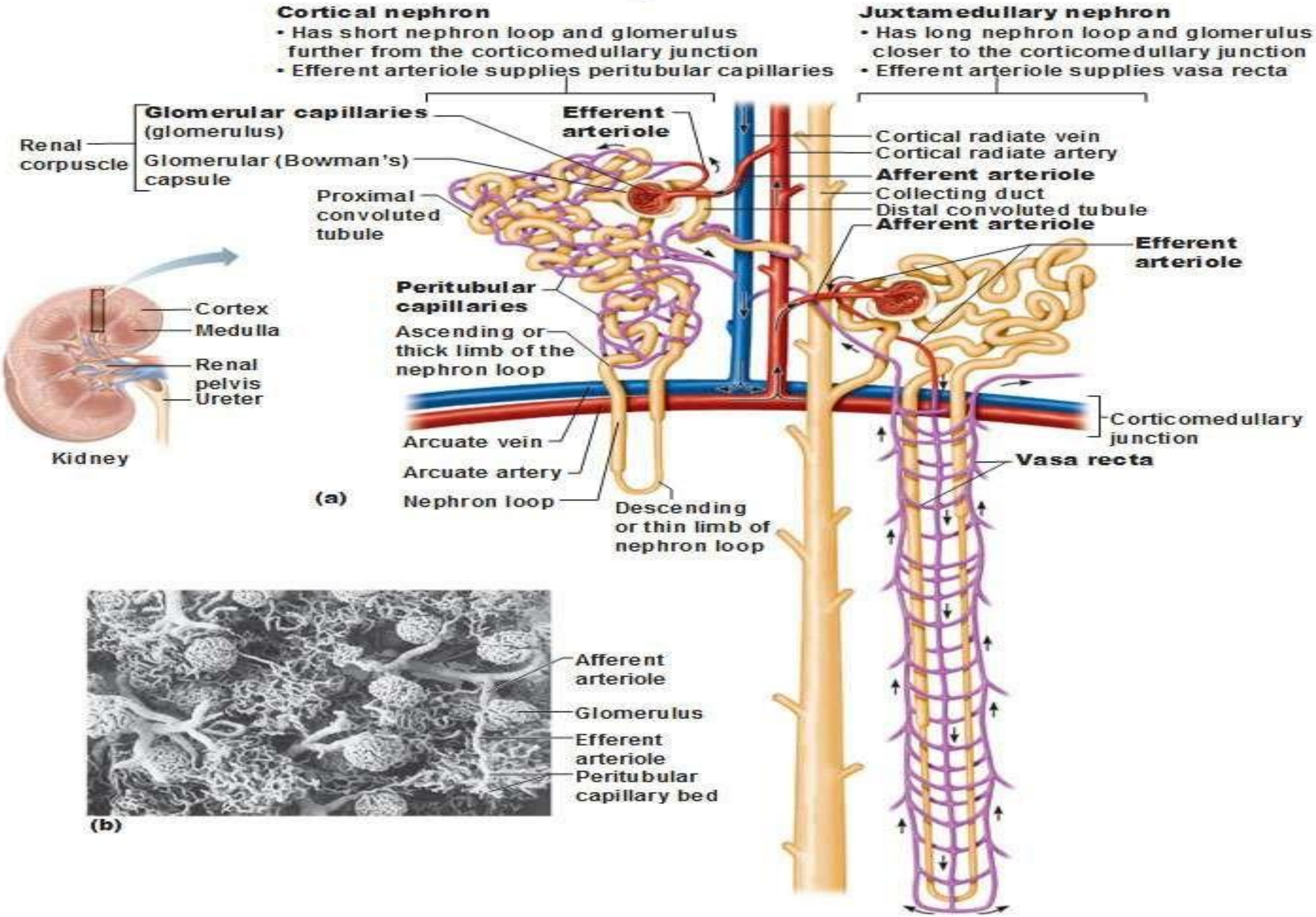
<u>Functions of the renal-tubule :</u>

- Helps in the *selective reabsorption* of essential substances like H_2O, glucose, salts etc.
- Helps in the *tubular-secretion* of unwanted substances.



TYPES OF NEPHRON

Classes of Nephrons



continuation

- **Afferent arterial** entering the **Bowman's capsule** has wider lumen than that of **efferent arterial** leaving it, resulting into high **hydrostatic pressure** that causes **ultrafiltration** to occur.
- The glomerular capillaries are highly coiled to increase the surface area for ultrafiltration to occur.

- The structural arrangement of the three layers of glomerular capillary enables the diaphragms of slit pores formed by foot-like projections of podocytes to offer selective filtration while blood cells and the negatively charged large plasma protein are retained by endothelium and basement membrane respectively.

- The Bowman's capsule is funnel-shaped to direct the renal filtrate into the proximal convoluted tubule.

continuation

- The proximal convoluted tubule cells:

- ✓ Bear numerous **microvilli** at the free end to increase the surface area for reabsorption of substances like glucose, amino acids, vitamins, NaCl, water.
- ✓ Contain numerous **mitochondria** to form ATP that provide energy required in active transport of glucose, amino acids, Na+, H2PO4 - and HCO3 - into the blood capillaries
- ✓ The cell surface membrane is **indented** to form a large area of intercellular spaces bathed with fluid.
- ✓ Contain numerous **pinocytic vesicles**, which enable the digestion of small protein molecules from the renal filtrate.
- ✓ Form a thin thickness of one cell layer to ease reabsorption of substances

continuation

- The loop of Henle is U-shaped with parallel, opposite flows of **tubular fluid** in its limbs to provide a **multiplier effect** that create a concentration gradient, which enables increased water reabsorption.

- The capillaries of **vasa recta** form loops that accompany the loops of Henle resulting into **countercurrent exchange** of solute and water between ascending and descending blood.

- The capillaries of vasa recta are in close proximity with tubules to increase the reabsorption of useful substances from the filtrate.

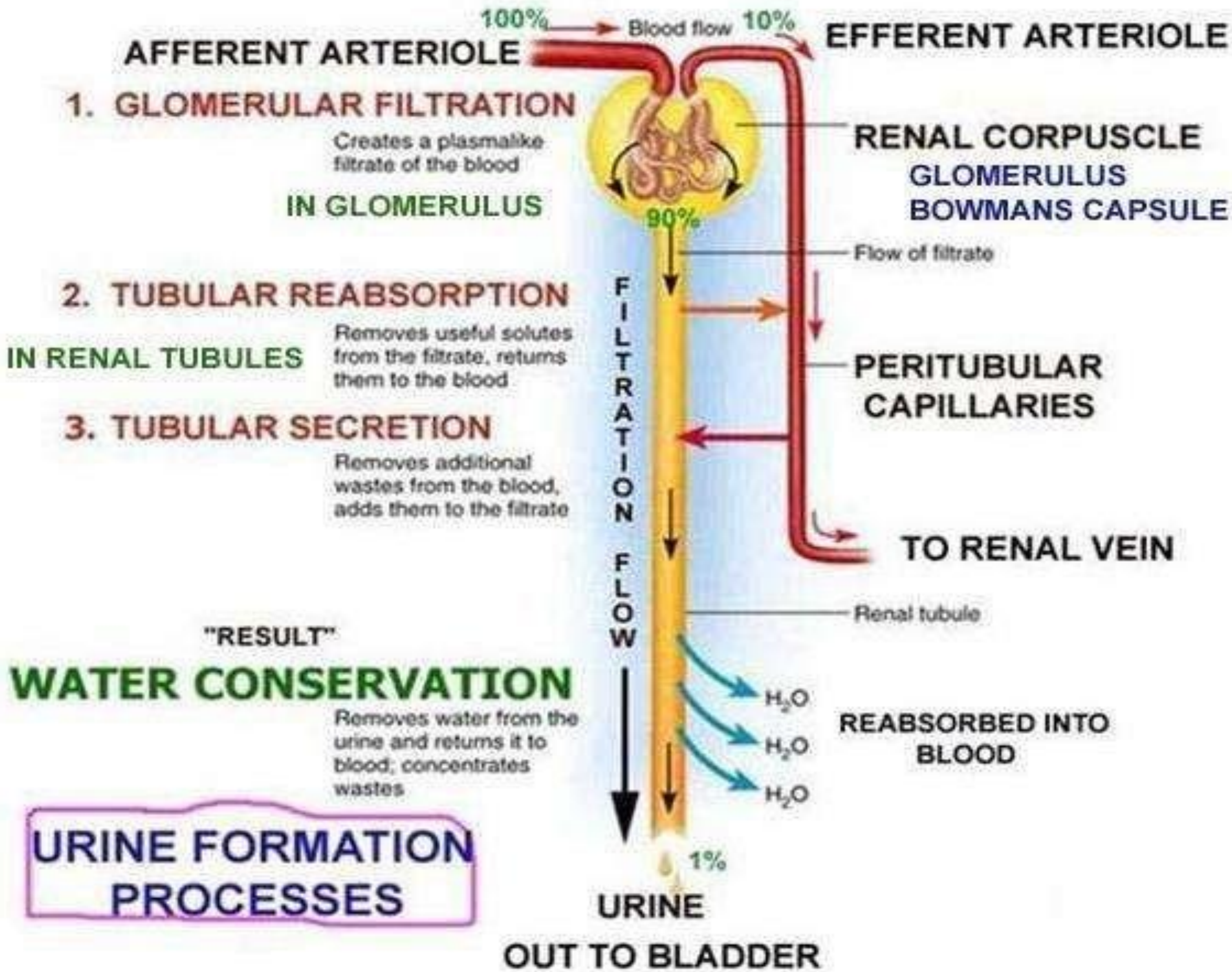
continuation

- The distal convoluted tubule is long and coiled to increase the surface area for reabsorption of water and mineral salts.

- The distal and proximal convoluted tubules are coiled to slow down the movement of renal filtrate to allow more time for efficient reabsorption of substances like water, mineral salts

Physiology of Excretion

FUNCTION OF NEPHRON - URINE FORMATION



Physiology of Excretion - Ultrafiltration

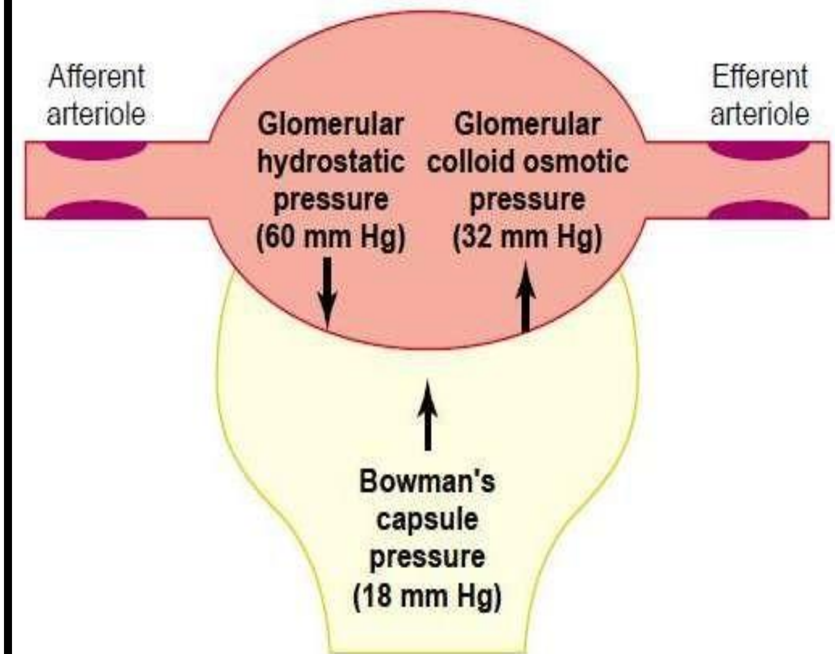
Site **:** In the **malpighian body**

Principle: It is a physical process.The diameter of the afferent arteriole is **bigger** than the efferent arteriole thus creating pressure in the glomerulus.

The ***glomerular hydrostatic pressure*** is the blood pressure in the glomerular capillaries which is about **55mm of Hg**.

The ***colloidal osmotic pressure*** of blood which is **30 mm of Hg** due to the presence of plasma proteins. It opposes the glomerular (capillary) hydrostatic pressure.

The ***capsular (filtrate) hydrostatic pressure*** of glomerular capsule is caused by filtrate thatreaches into the Bowman's capsule. It is about **15 mm of Hg**.It also opposes the glomerularhydrostatic pressure



The net (effective) filtration pressure

EFP = GHP-(BCOP + CHP)

=55 - (30 + 15)

= **10 mm of Hg**

Physiology of Excretion - Ultrafiltration

The afferent arteriole brings in blood at 625 ml/min.
$1/5^{th}$ of it gets filtered.
i.e. the ultrafiltration rate is **125 ml/min** or about 180 litres/day
This rate of formation of filtrate is called **glomerular filtrate rate (GFR)**

Process **:** The epithelial cells of the visceral layer of the Bowman's cup are called **podocytes**. The body of the podocytes rest on feet like processes called '**pedicels**'. The individual legs, have **foot processes**. The gaps (*slits*) between the foot processes are in *intimate contact* with *pores* in the endothelium of blood capillaries*, through the permeable basement membrane*. This arrangement facilitates the transfer of fluids.

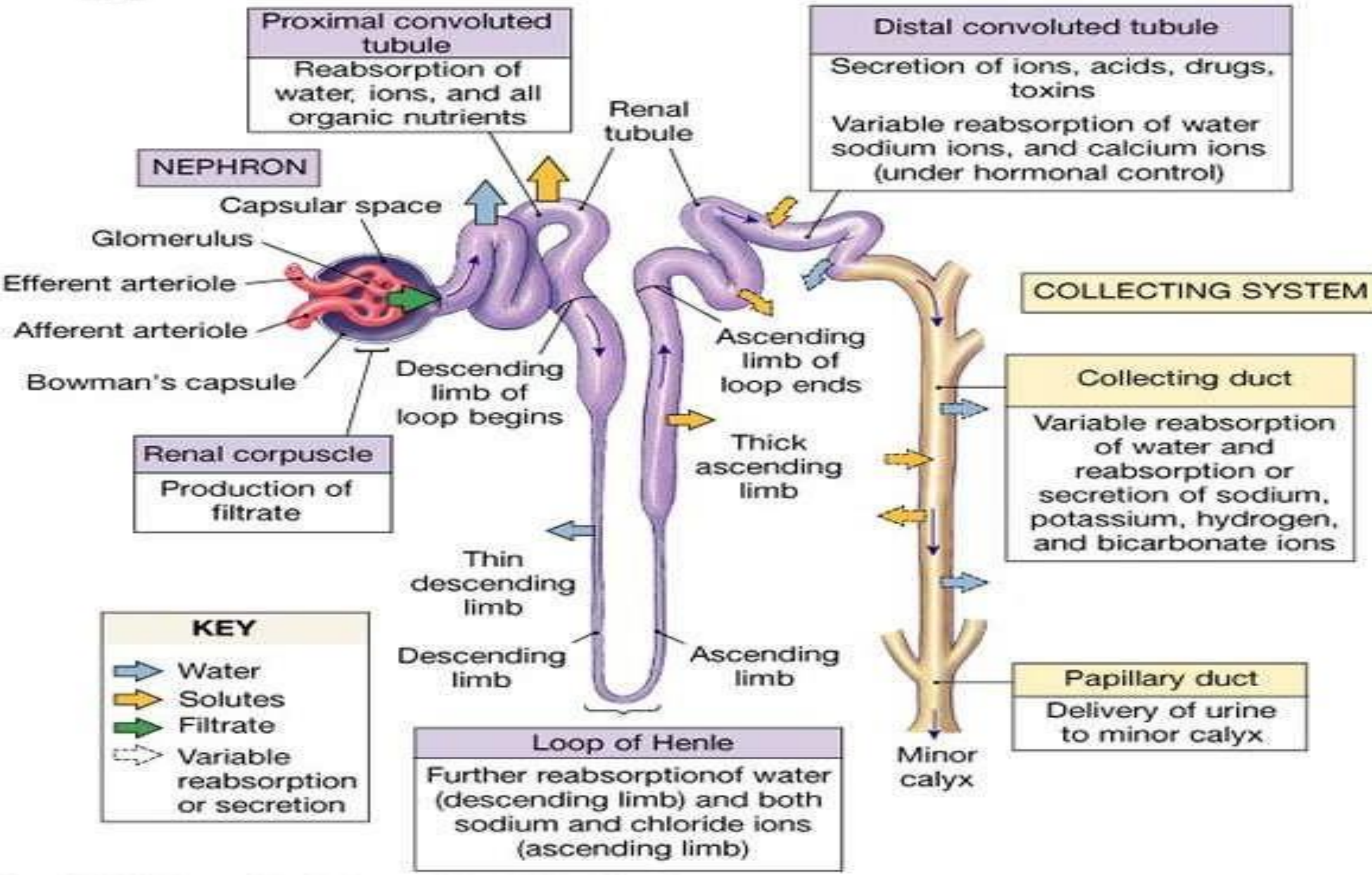
Because of the high blood pressure, about $1/5^{th}$ of the blood (plasma) gets filtered via these filtration paths into the urinary space of the Bowman's capsule.

Final product **:** The **glomerular filtrate**, which contains all the constituents of blood (i.e. glucose, amino-acid, salts, water, urea etc.) *except blood-cells, plasma-proteins and fats*(too big for the pore-size), hence called as **deproteinized plasma**.

Concentrations of substances in the blood and in the glomerular filtrate.

Substance	Concentration in blood plasma / g dm^{-3}	Concentration in glomerular filtrate / g dm^{3}
water	900	900
proteins	80.0	0.05
amino acids	0.5	0.5
glucose	1.0	1.0
urea	0.3	0.3
uric acid	0.04	0.04
creatinine	0.01	0.01
inorganic ions (mainly Na^{+}, K^{+} and Cl^{-})	7.2	7.2

Physiology of Excretion – Selective reabsorption



Reabsorption: The Proximal Tubule

Where does the process of filtrate reabsorption begin?-

- Proximal convoluted tubule

- The filtrate inside this tubule contains water, small solutes such as urea, glucose, amino acids, vitamins, and electrolytes.

- Some of these solutes are **waste products**; others are valuable nutrients

What molecular mechanisms are involved in selective reabsorption in the proximal convoluted tubule?

- Active transport creates Na+ gradient- **Na+/K ATPase** in the **basolateral membrane** moves Na+ from the interior of epithelial cells surrounding the **lumen** of the proximal tubule to the **interstitial fluid.**

- The active transport of Na+ out of the cells creates a **concentration gradient** favoring the entry of Na+ from the **lumen.**

continuation

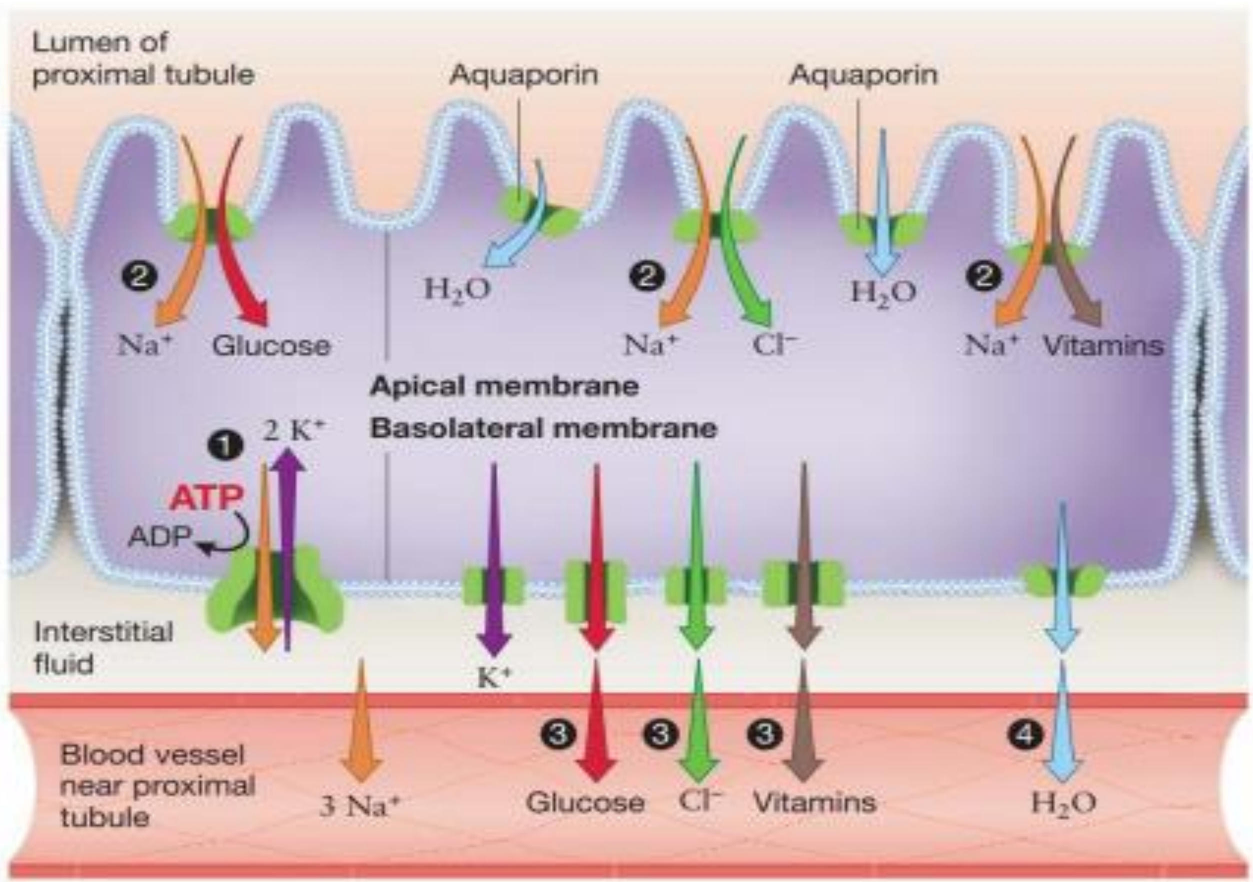
- **Na+ gradient** is used to remove solutes from filtrate - **Na+ dependent cotransporters** in the **apical membrane** use the Na+ gradient to remove ions and nutrients (e.g. c1-, glucose, vitamins) **selectively** from the filtrate in the lumen.
- The movement of Na+ into the cell, down its **electrochemical gradient**, provides the means for moving other **solutes against their gradients**
- Removed substances **diffuse** into blood- The solutes that move from the lumen into the cell diffuse across the **basolateral membrane** into the **interstitial fluid** and then into nearby blood vessels.
- Water moves into blood **by osmosis**- Water follows the movement of solutes from the proximal tubule into the cell and then out of the cell and into blood vessels.
- Recall that water moves by osmosis across the membranes of these epithelial cells through membrane proteins called **aquaporins**

continuation

- Almost all of the **nutrients**, along with about two- thirds of the NaCl and water that is originally filtered by the renal corpuscle, are reabsorbed in the proximal tubule.
- The **osmolarity** of the **tubular fluid** is unchanged despite this huge change in volume, however, because water reabsorption is proportional to solute reabsorption .
- The **pumps** and **cotransporters** in the proximal tubule reabsorb nutrients, electrolytes, and water but leave wastes.

- As the filtrate flows into the loop of Henle, it has a relatively high concentration of waste molecules and a relatively low concentration of nutrients.

Model of selective reabsorption in proximal tubule



Counter – Current Mechanism

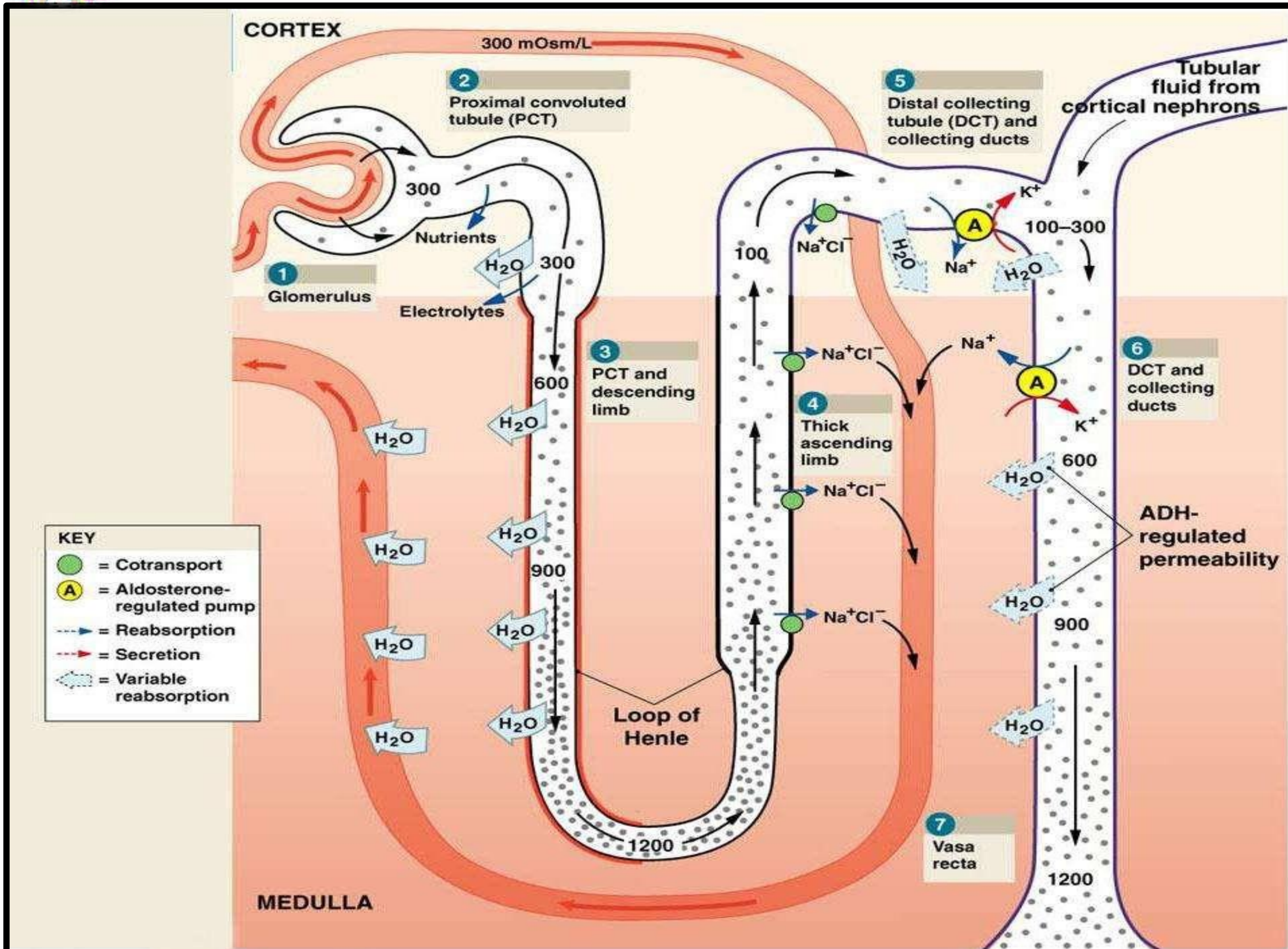
The **Henle's loop** and ***vasa recta*** play a significant role in this.

The flow of filtrate in the two limbs of Henle's loop is in opposite directions and thus forms a counter current.

The flow of blood through the two limbs of vasa recta is also in a counter current pattern.

- The proximity between the Henle's loop and *vasa recta*, as well as the **counter current** in them help in maintaining an increasing **osmolarity** towards the inner **medullary interstitium**, i.e., from 300 $mOsmolL^{-1}$ in the cortex to about 1200 $mOsmolL^{-1}$in the inner medulla. This gradient is mainly caused by **NaCl and urea**.
- NaCl is transported by the **ascending limb of Henle's loop** which is exchanged with the **descending limb of *vasa recta***. NaCl is returned to the medullary interstitium by the ascending portion of *vasa recta*. Similarly, small amounts of urea enter the thin segment of the ascending limb of Henle's loop which is transported back to the medullary interstitium by the collecting tubule. The above described transport of substances facilitated by the special arrangement of Henle's loop and *vasa recta* is called the **counter current mechanism**.
- This mechanism helps to maintain a **concentration gradient** in the medullary interstitium. Presence of such interstitial gradient helps in an easy passage of water from the collecting tubule thereby concentrating the filtrate (urine). Human kidneys can produce urine nearly four times concentrated than the initial filtrate formed.

Counter - Current Mechanism



continuation

- In **mammals**, the fluid that emerges from the proximal tubule enters the loop of Henle-named for Jacob Henle, who described it in the early 1860s.

- In most nephrons, the loop is short and barely enters the medulla. But in about 20 percent of the nephrons present in a human kidney, the loop is long and plunges from the cortex of the kidney deep into the medulla

- The loop of Henle has three distinct regions: the descending limb, the **thin ascending limb**, and the **thick ascending limb**

- The thin and thick ascending limbs differ in the thickness of their walls.

Do the three regions also differ in their permeability to water and solutes?

How the loop of Henle works-water conservation mechanism

- **Descending limb**: **passive** transport of water- As fluid flows down the descending limb, the fluid inside the loop loses water to the interstitial fluid surrounding the nephron.

- This movement of water is **passive**-it does not require an expenditure of **ATP**

- The water follows an **osmotic gradient** created by the **ascending limb**.

- At the bottom of the **loop**-in the inner medulla-the fluids inside and outside the nephron have high **osmolarity**.

- The filtrate does not continue to lose water, though, because the membrane in the **ascending limb** is nearly impermeable to water.

continuation

- **Thin ascending limb**: **Passive transport** of Na+ and Cl -.
  - ✓ The fluid inside the nephron loses Na+ and Cl- in the thin ascending limb.
  - ✓ The ions move passively, down their electrochemical gradient.

- **Thick ascending limb**: **Active transport** of Na+ and Cl-.
  - ✓ Near the cortex, the **osmolarity** of the surrounding **interstitial fluid** is low. Additional Na+ and Cl- are actively transported out of the nephron in the thick ascending limb.

- Movement of NaCl from the ascending limb into surrounding tissue increases the osmolarity of the fluid outside the descending limb, which results in an outward flow of water across the **water-permeable epithelium** of the descending limb via **osmosis**.

- This loss of water in the descending limb increases the **osmolarity** of the fluid entering the ascending limb. The high concentration of salt in the fluid at the base of the ascending limb triggers a **passive flow of ions** out-reinforcing the **osmotic gradient** .

continuation

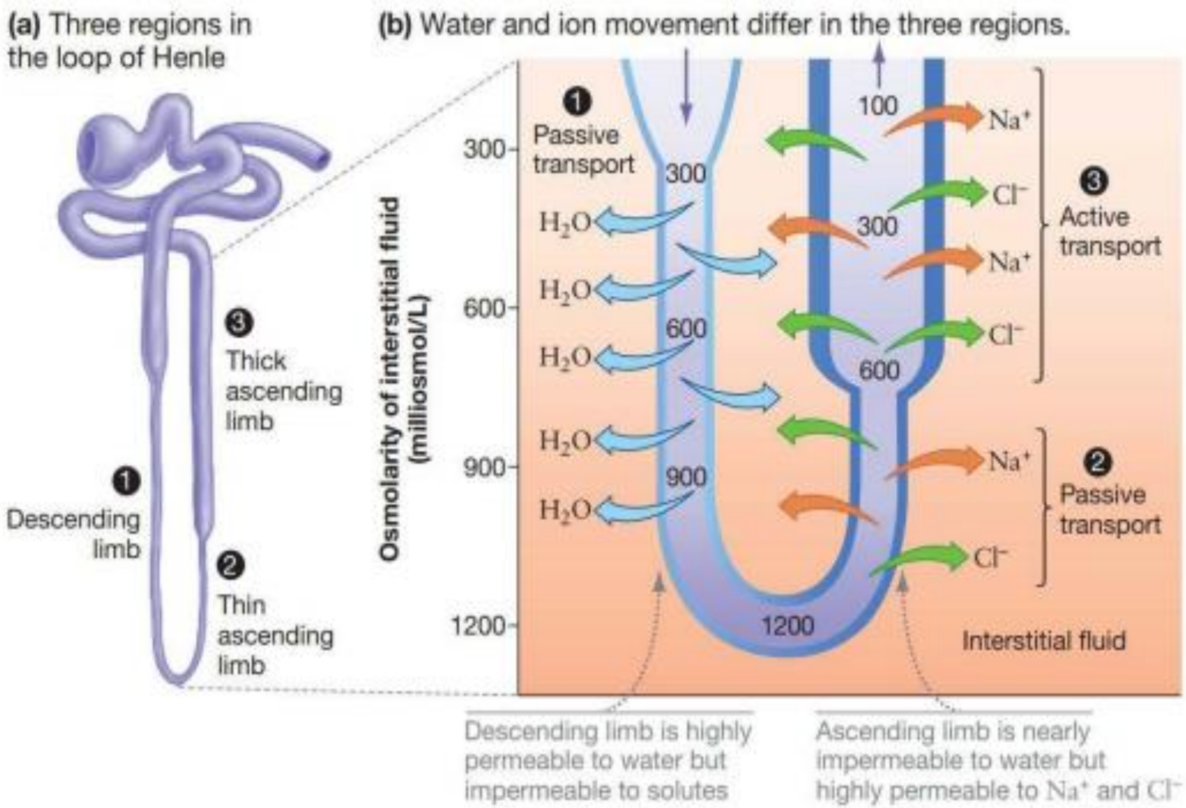


Figure 40.12 The Loop of Henle Maintains an Osmotic Gradient Because Water Leaves the Descending Limb and Salt Leaves the Ascending Limb. The values inside the loop in part (b) represent the osmolarity of the filtrate.

continuation

What happens to the water and salt that move out of the loop from the filtrate into the interstitial fluid?

- They diffuse into the **vasa recta**, a network of blood vessels that runs along the loop. As a result, the reabsorbed water and **electrolytes** are returned to the bloodstream instead of being excreted in **urine**

- The vasa recta is the **counter current exchanger** while the loop of Henle is the **counter current multiplier**

- The vasa recta joins up with small veins at the top of the medulla, which prevents the reabsorption of water and electrolytes from disrupting the concentration gradient in the medulla.

- The removal of water that leaves the descending limb is particularly important. If it were not drawn off into the bloodstream, it would dilute the concentrated fluid outside the loop of Henle and quickly destroy the **osmotic gradient.**

Loop of Henle and the vasa recta

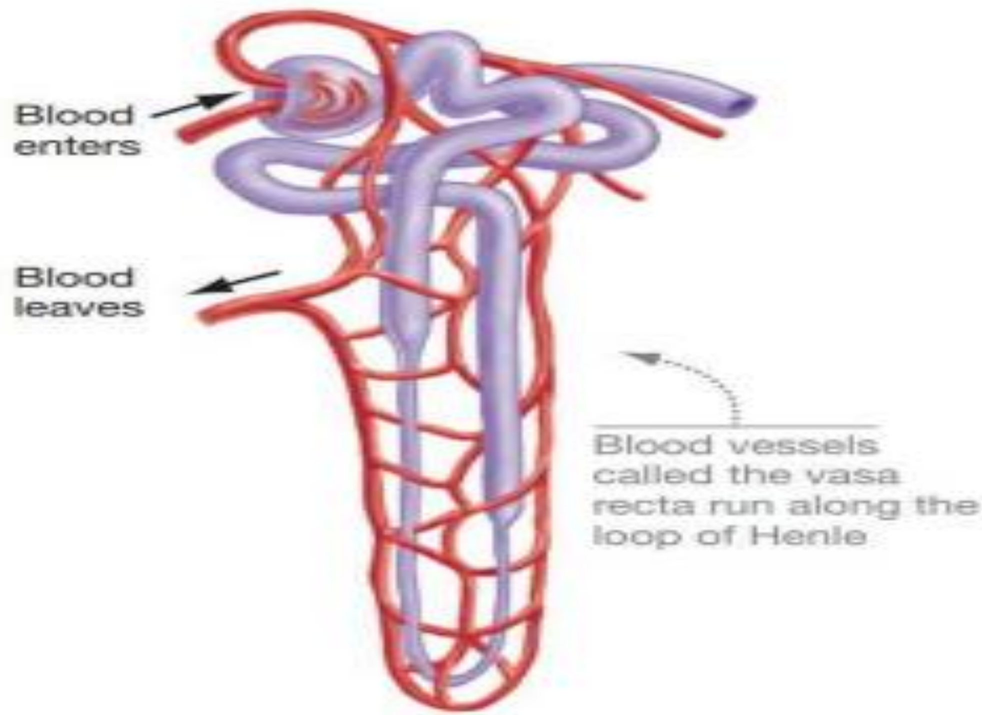


Figure 40.13 Blood Vessels Are Closely Associated with the Nephron. Water and solutes reabsorbed from the loop of Henle enter a system of blood vessels, the vasa recta.

Urea from the Collecting Duct Adds to the Medullary Osmotic Gradient

- **Urea** is also involved in creating the **medullary osmotic gradient**.

- The concentration of urea in the **interstitial fluid** is higher in the **inner medulla** and lower in the **outer medulla**.

- This gradient exists because the innermost section of the collecting duct is permeable to urea

- Therefore ,the **loop of Henle** ,**vasa recta** and **collecting duct** are important in creating and maintaining a **strong osmotic gradient**

Regulating Water and Electrolyte Balance: The Distal Tubule and Collecting Duct

- The first three steps in urine formation-**ultra filtration**, **selective reabsorption**, and establishment of an **osmotic gradien**t-result in a filtrate that is slightly hyposmotic to blood.

- Once the filtrate has passed through the loop of Henle, the major **solutes** that it contains are **urea** and other wastes along with a low concentration of **ions**

- The filtrate that enters the **distal tubule** is always dilute.

- In contrast, the urine that leaves the collecting duct can be highly concentrated when the individual is dehydrated.

How is this possible?

continuation

- Further reabsorption that takes place in the distal tubule and collecting duct:
  - ✓ It is highly **regulated**, and
  - ✓ it is altered in response to **osmotic stress**

- The amount of Na+, Cl-,   and water reabsorbed in the distal tubule and collecting duct varies with the **animal's hydration**

- In addition, **selective secretion of ions** and other molecules into the distal tubule from the surrounding blood vessels may occur when levels of those molecules are high in the blood.

- All of these processes can lead to a final urine that is very different in composition from the filtrate leaving the loop of Henle.

continuation

- Changes in the distal tubule and collecting duct are controlled by hormones-signaling molecules in the blood. Specifically:

- If the Na+ level in the blood is low the **adrenal glands** release the hormone **aldosterone**, which leads to activation of **sodium-potassium pumps**, causing reabsorption of Na+ and secretion of K+ in the distal tubule. Water is reabsorbed by osmosis.

- **Aldosterone** saves Na+ and water and causes excretion of K+.

- It also activates **sodium-proton antiporters** at facilitate reabsorption of Na+ from the distal tubule into the blood and secretion of H+ from the blood into distal tubule.
- The latter helps to regulate blood **pH**.

continuation

- If an individual is **dehydrated** the brain releases antidiuretic hormone **(ADH).** (The term “**diuresis**” refers to increased urine production, so **antidiuresis** means inhibited urine production.) ADH saves water

How Does ADH Work?

- **Epithelial cells** of the collecting duct are impermeable to water and solutes

- ADH triggers the insertion of **aquaporins** into the **apical membrane**. As a result, cells become much more permeable to water and large amounts of water are reabsorbed.

- ADH increases the cells' permeability to urea, which is reabsorbed into the surrounding fluid. This helps create a concentration gradient favoring water reabsorption from the filtrate.

continuation

- water leaves the collecting duct **passively**-following the medullary **osmotic gradient** maintained by the **loop of Henle**.
- When ADH is present, water is conserved by the body, and the urine is strongly **hyperosmotic** to the blood.
- The **collecting duct** is the final place where the composition of filtrate can be altered.
- When ADH is absent, however, few **aquaporins** are found in the epithelium of the collecting duct, and the structure is relatively impermeable to water In this case, a larger quantity of **hyposmotic** urine is produced.
- Urine exiting the collecting ducts moves from the kidneys into **ureters** and then is stored in the **bladder** until urination.

continuation

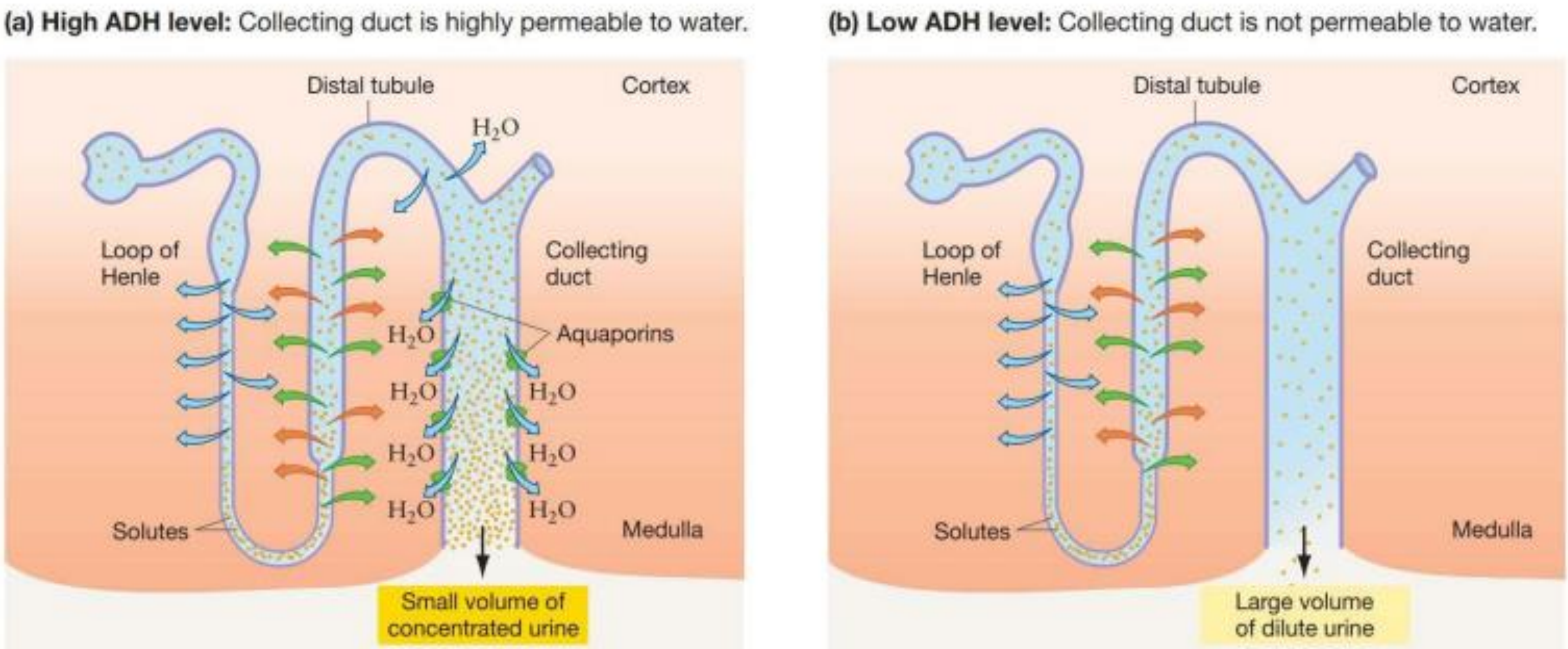


Figure 40.14 ADH Regulates Water Reabsorption by the Collecting Duct.

Quick check

- If you understand ADH’ s effect on the collecting duct, predict how urine formation is affected by ethanol which inhibits ADH release, and by nicotine, which stimulates ADH release.

Physiology of Excretion – Selective reabsorption

P.C.T	Active reabsorption	Glucose, Amino acids, Vitamins, Na^+, K^+, Ca^+, PO_4^-
	Passive reabsorption	Water (75%), Urea and Cl^- (ISOTONIC)
Desc. Limb H2O : Permeable Solutes : Impermeable	Passive reabsorption (Due to Increased medullary tissue osmotic pressure)	Water (5%) (HYPERTONIC) At the bend
Asc. Limb H2O : Impermeable Solutes : Permeable	Passive reabsorption	First Na^+ followed by both Na^+ and Cl^-
	Active reabsorption	Cl^-, K^+ (HYPOTONIC)
D.C.T C.T	Passive reabsorption (under the influence of ADH)	Water (15%) Water (4%) (HYPERTONIC)

dr.aari

Physiology of Excretion – Tubular Secretion

Site **: Proximal and Distal convoluted tubule and partially in the collecting tubule.**

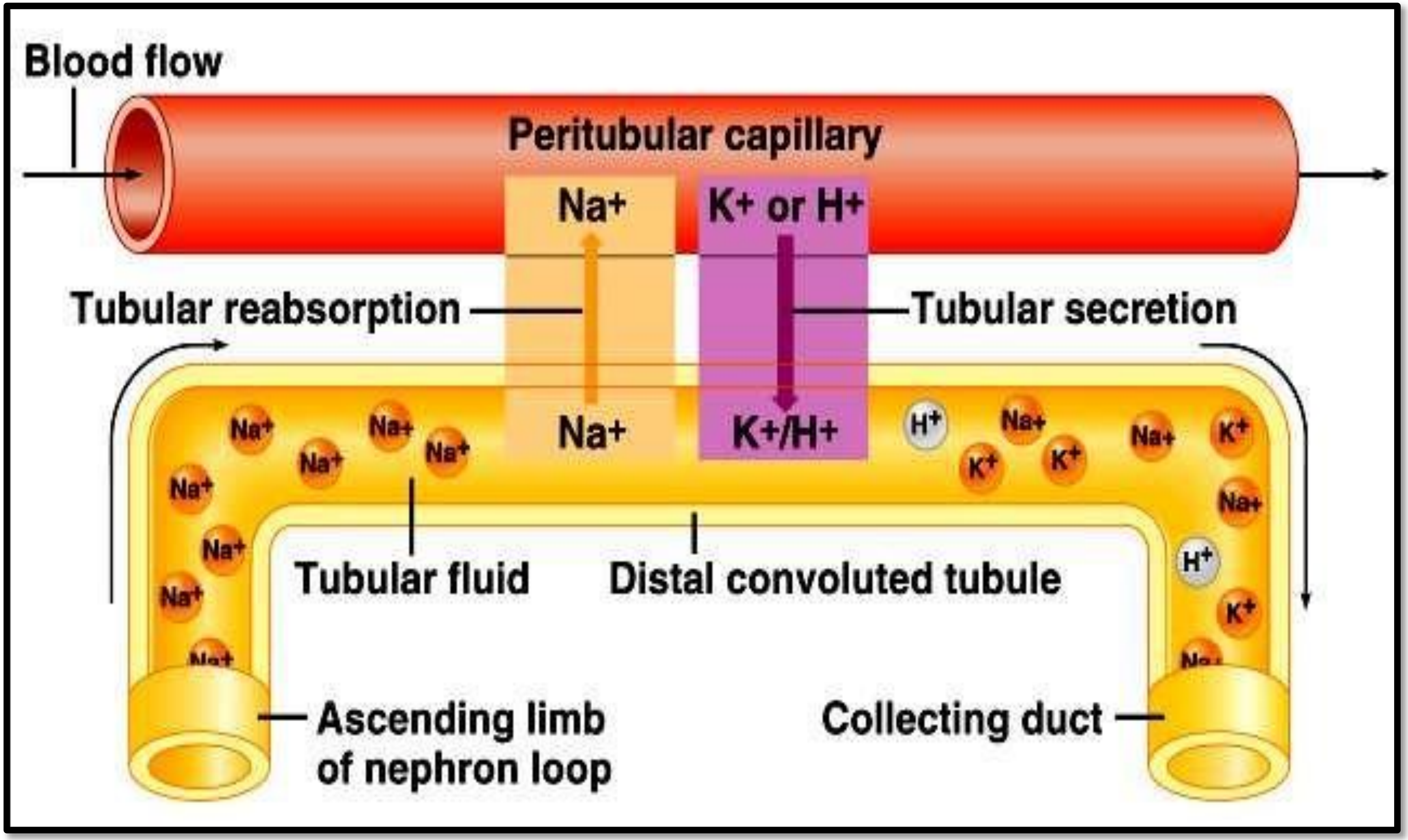
Principle **: Some substances that escape ultra filtration are taken to the peritubular capillaries and *excreted in the filtrate*.**

Process **: Ammonia, Creatinine, K^+, H^+, drugs (e.g penicillin) are excreted in this process.**

- **For every K^+ or H^+ ion excreted a Na^+ ion is reabsorbed.**
- **The H^+ ion concentration (& thus acid-base balance) can be maintained.**

Final product**: Concentrated Urine, containing 50% of urea found in glomerular filtrate.**

Physiology of Excretion – Tubular Secretion



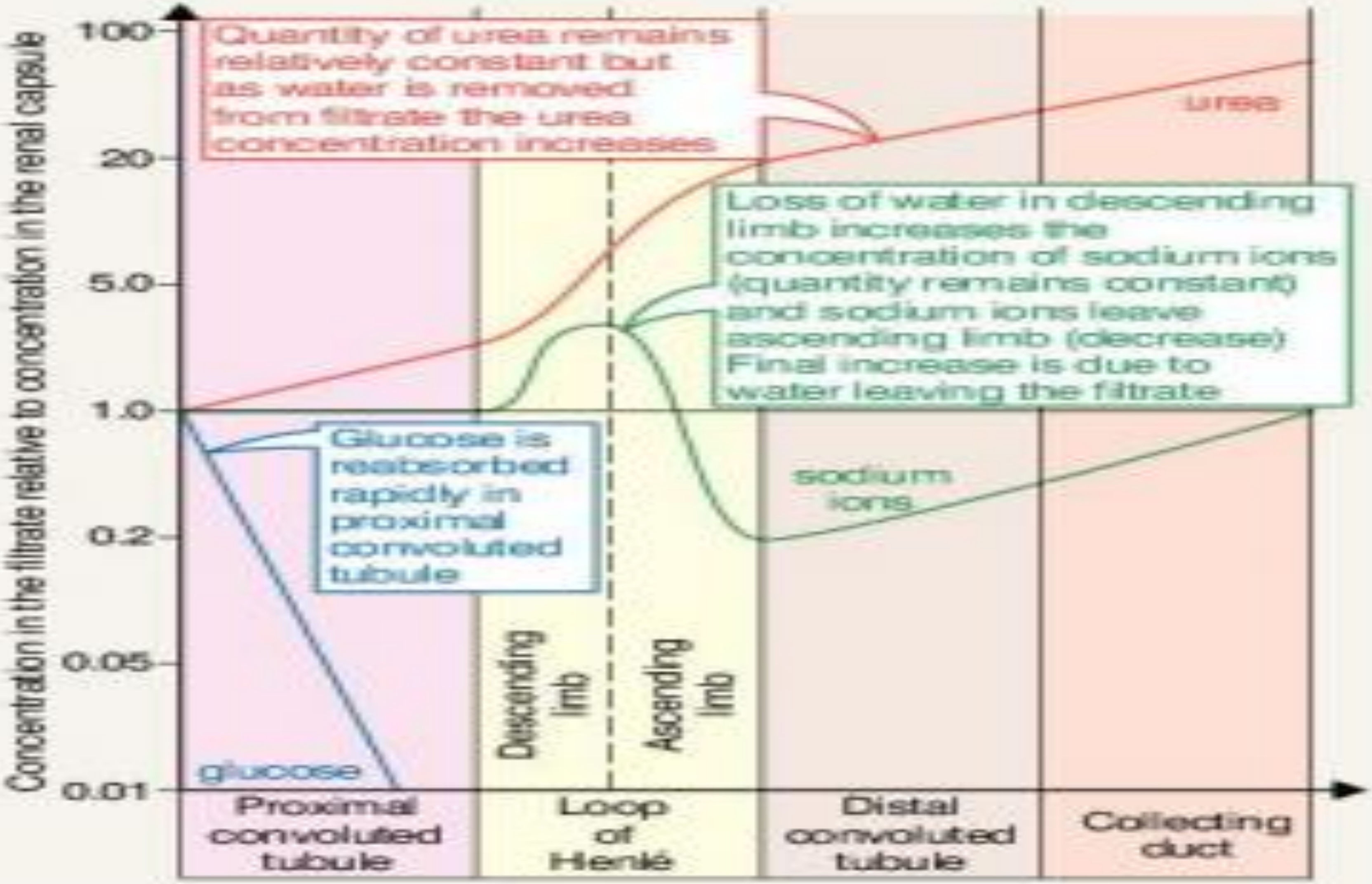


Figure 2 *Relative concentrations of three substances in the filtrate as it passes along a nephron. NB Scale is not linear.*

Kidney and blood pH control:
Acid-base balance

- The body produces more **acids** than **bases,** causing the blood PH usually to lower (become acidic) from the normal PH of 7.4 due to high concentration of H+ ions that result from **metabolic processes**

- In the cells of distal convoluted tubules, the CO2 from **aerobic respiration**, catalysed by **carbonic anhydrase enzyme** reacts with water to form **carbonic acid**, which dissociates into H+ and HCO3 - ions.

- The H+ ions are pumped into the lumen where they are **buffered** by hydrogen phosphate (HPO4 2-) as it takes up H+ ions to form sodium **dihydrogen phosphate (NaH2PO4)**, which is excreted in urine while the **HCO3 - ions** are absorbed and retained in blood.

continuation

- Exceptional lowering of PH causes the cells lining the distal tubule to **deaminate glutamine** amino acid to form ammonia, which on combining with H+ ions forms ammonium ions, which are excreted.

- Blood PH rises (becomes less acidic) due to absorption of HCO_3^- that result from dissociation of carbonic acid.

- In order to control PH, the HCO_3^- are excreted while H+ ions are retained

Within plasma, hydrogen carbonate (HCO_3^-), protein and hydrogen phosphate (HPO_4^{2-})act as PH buffers by temporarily taking up any excess H+ ions and at the same time keeping the PH constant.

continuation

- The body maintains constant PH by :

  - ✓ lungs expelling CO_2,which would accumulate and react with water to form carbonic acid
  - ✓ The **buffering mechanism** involving **plasma protein** in blood
  - ✓ The kidneys expelling H^+ and retaining HCO_3^-

- Therefore PH (acid-base balance) is controlled by the lungs, blood and kidneys

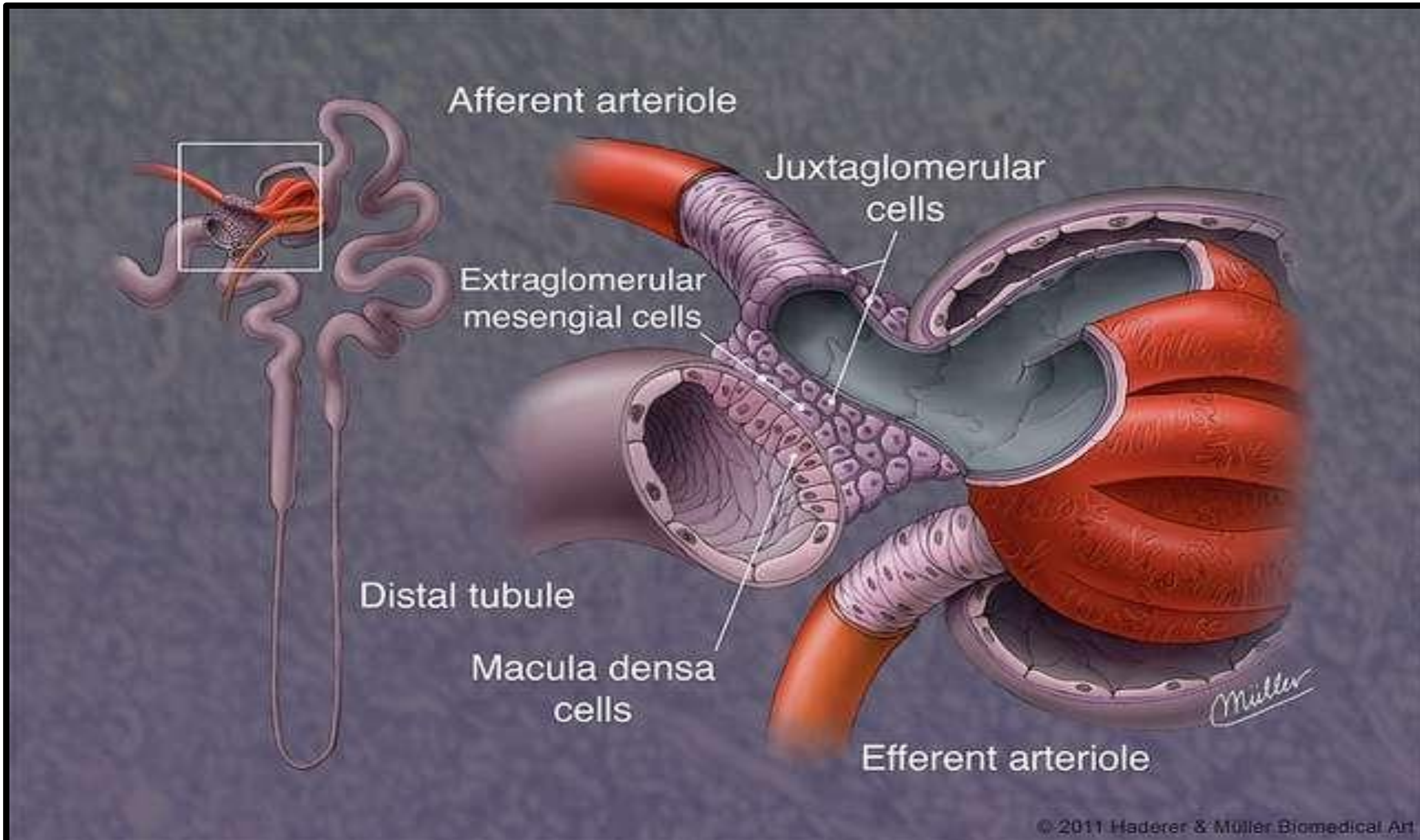
Kidney and blood pressure control/blood volume control

- **Blood pressure** control is by the **Rennin –angiotensin-aldosterone mechanism**
- Blood pressure is required for sufficient **tissue perfusion**
- High blood pressure(**Hypertension**) can cause damage to organs like the kidney, lungs
- Low blood pressure(**hypotension**) compromises rate of delivery of essential materials to tissues and organs, removal of waste products of metabolism from tissues.

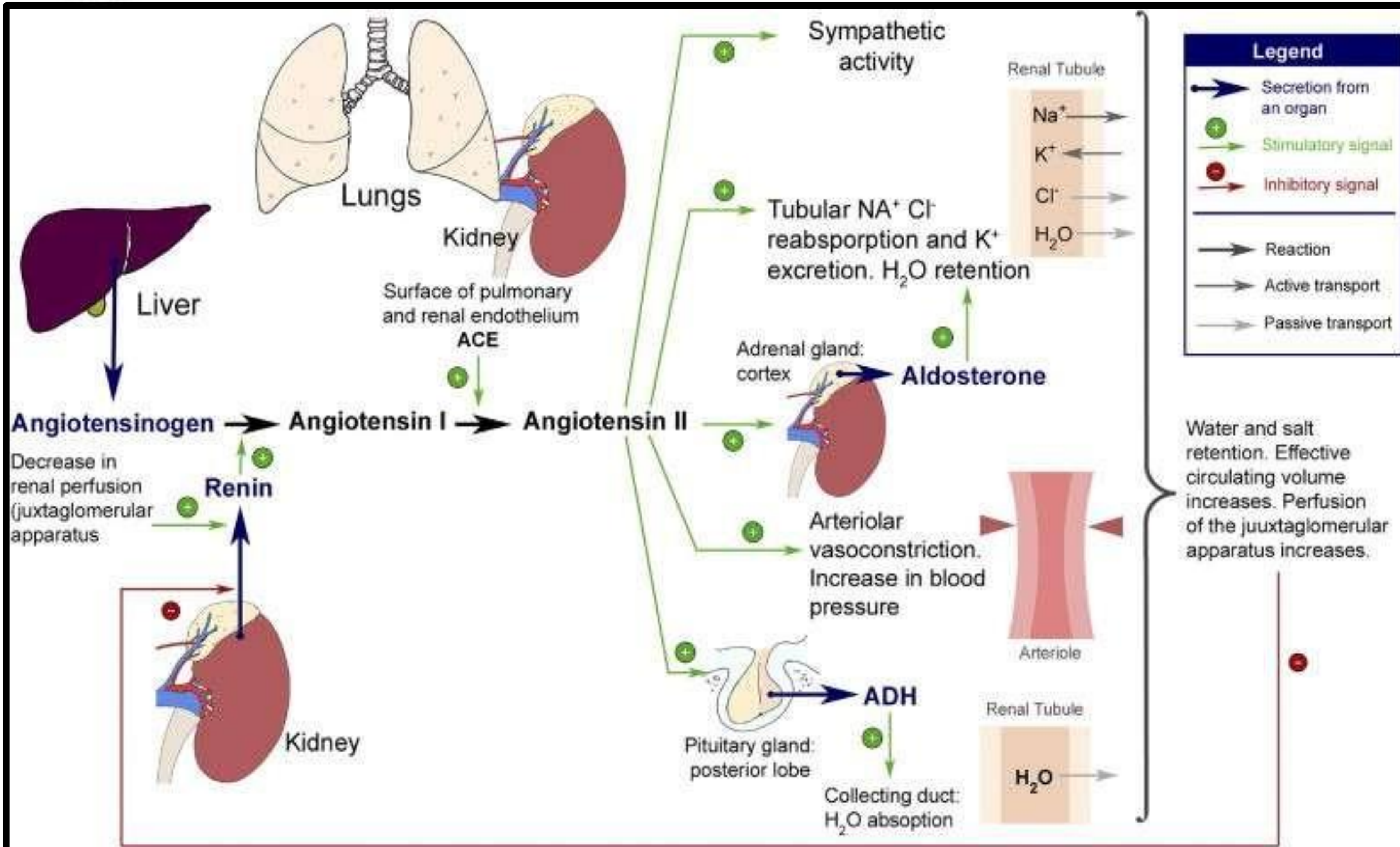
But how is the kidney involved in the control of blood pressure?

- The kidney regulates the relative amounts of solutes and water in blood
- The **Juxtaglomerular apparatus** play key role in this.

Juxta - Glomerular Apparatus (JGA)



Renin – Angiotensin – Aldosterone system



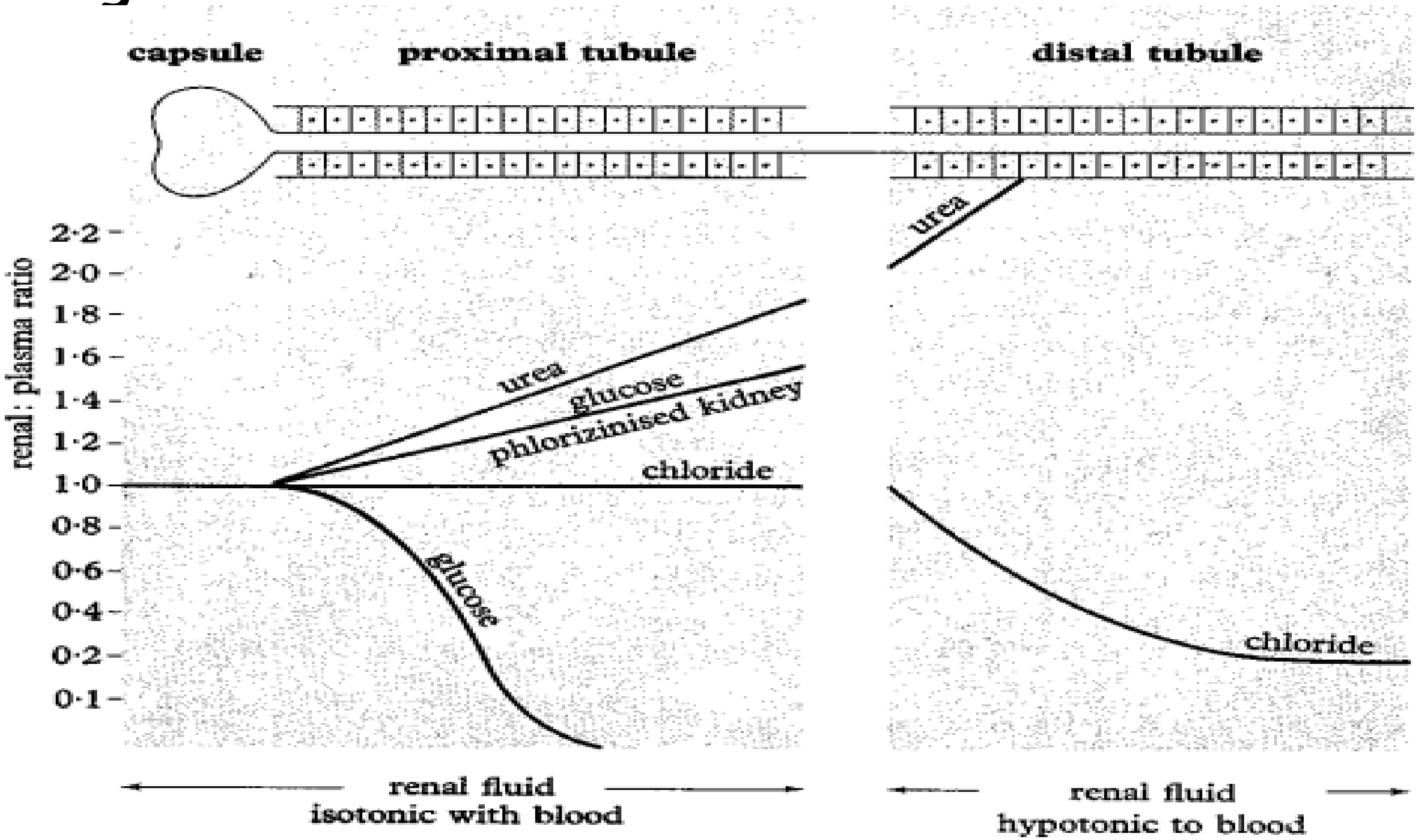
Renal –plasma ratio

What is the composition of the renal fluid as it flows along the nephron?

- Using amphibian kidneys, A N Richards extracted the renal fluid from the proximal convoluted and distal convoluted tubules and analyzed their chemical composition
- The composition of the renal fluid may be conveniently expressed interms of Renal- plasma ratio

- This refers to the concentration of a particular constitute ,say glucose of the renal fluid divided by the concentration of the same constitute in the plasma

Changes in the renal plasma ratio of urea, glucose and chloride in the kidney of the frog



continuation

- The data in the preceding slide tells us whether a substance is absorbed or not as the renal fluid flows along the tubules
- Renal plasma of 1.0- concentrations are the same in both the renal fluid and plasma
- If the ratio is more than 1.0-concntation is greater in the renal fluid than the plasma
- If the ratio is less than 1.0- concentration is lower in the renal fluid than the plasma

Deductions from the graph

- The concentration of all components is the same in the renal fluid (glomerular filtrate) and the blood plasma at Bowman's capsule, thus the ratio of 1.0 ;
- ✓ Re-absorption has not yet occurred

- Chloride concentration remains almost constant in the renal fluid and the blood plasma at the capsular and at the proximal tubule;
- ✓ Equal amounts of the salts and water are reabsorbed

- Renal-plasma ratio of more than 1 for urea
- ✓ The concentration of the component is greater in the renal fluid (glomerular filtrate) than in the plasma. Urea's concentration in the renal fluid increases rapidly mainly because large volume of water is reabsorbed into capillaries ,Urea is actively secreted into tubules from blood.

continuation

- Renal-plasma ratio of more than 1.0 glucose in the phlorizinised kidney.

- ✓ Glucose concentration in the **phlorizinised** kidney increases in the proximal tubule because phlorizin inhibits reabsorption of glucose, large volume of water is reabsorbed into capillaries.

- Renal-plasma ratio of less than 1.0 for glucose in the non-phlorizinised proximal tubule of kidney

- ✓ The concentration of the component is lower in the renal fluid (glomerular filtrate) than in the plasma. The glucose concentration in the proximal tubule decreases rapidly to zero because all the glucose is actively reabsorbed into blood capillaries surrounding the proximal tubule

continuation

- Renal-plasma ratio of less than 1.0 for glucose in the non-phlorizinised proximal tubule of kidney and chloride in the distal tubule.
- ✓ The chloride concentration decreases rapidly and remains at a low constant because Cl- are reabsorbed passively following the active reabsorption of Na+

Quick check

a) Outline the main features of the kidney nephron.
b) Explain how the mammalian kidney produces urine that is hypertonic to blood
c) Describe how the nephron regulates the PH of blood.

Excretion in other organisms

Insects

- Insects rely on excretory organs called **Malpighian tubules** and on their hindgut posterior portion of their digestive tract.

- Malpighian tubules have a large surface area, are in direct contact with the **hemolymph**, and empty into the **hindgut**.

- The Malpighian tubules are responsible for forming a filtrate, a filtered liquid, from the hemolymph.

- This "pre-urine" then passes into the hindgut, where it is processed and modified before excretion

Location of malpighian tubules

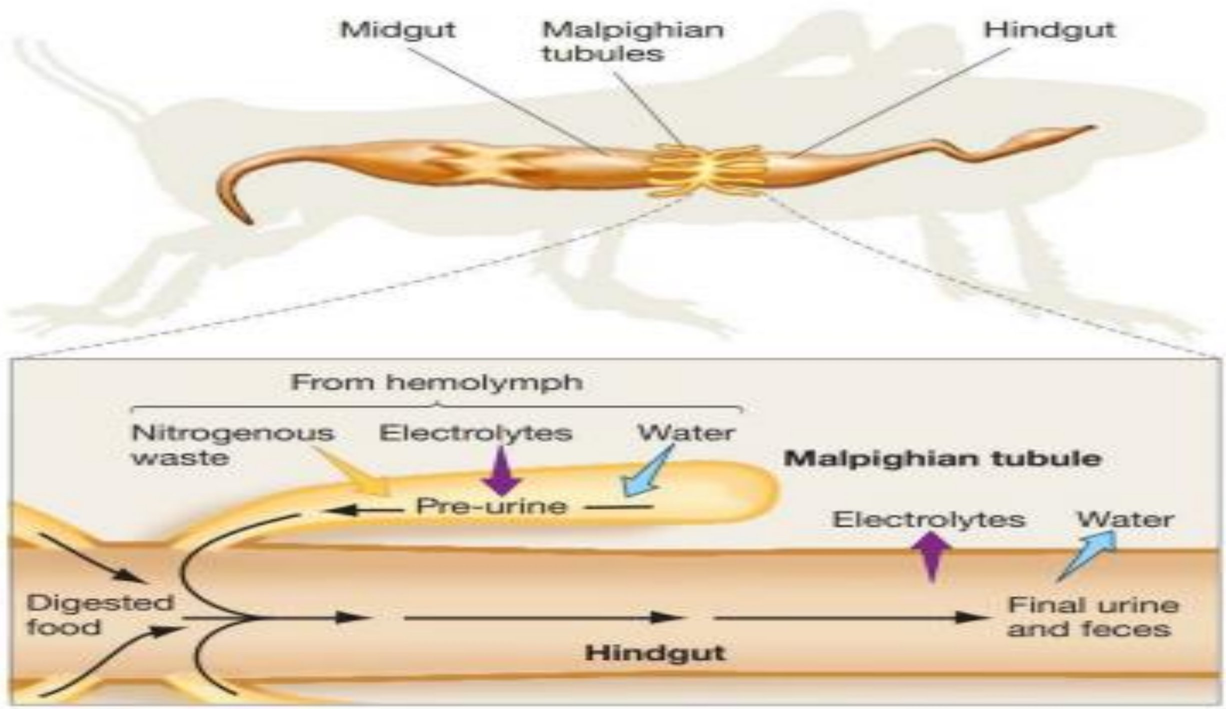
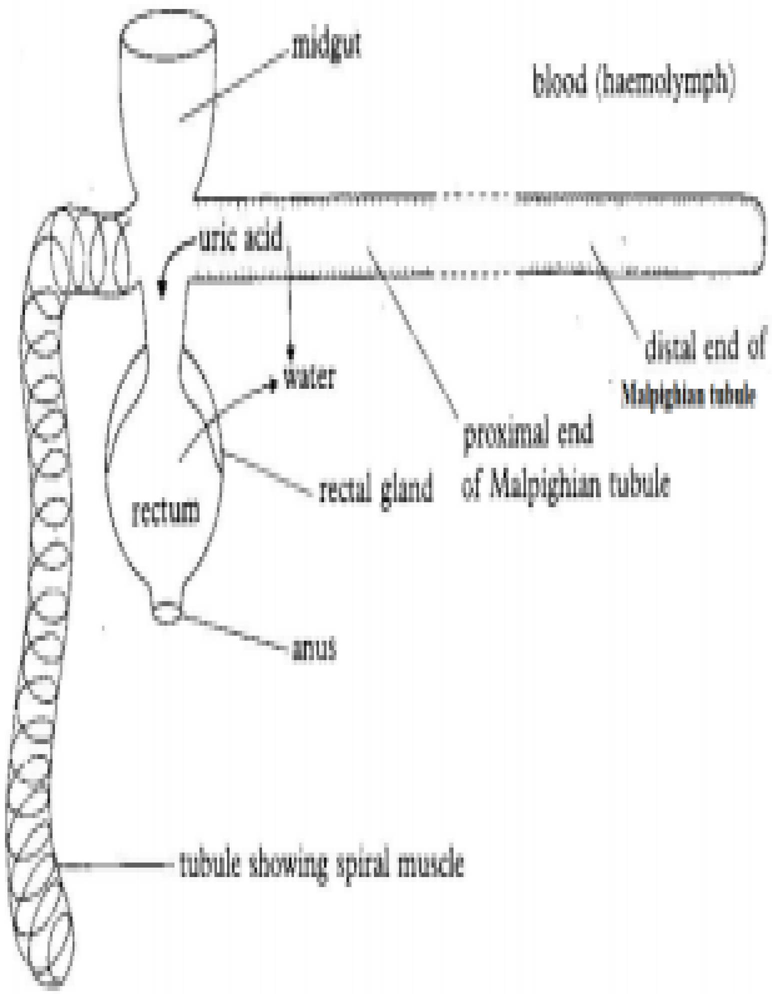


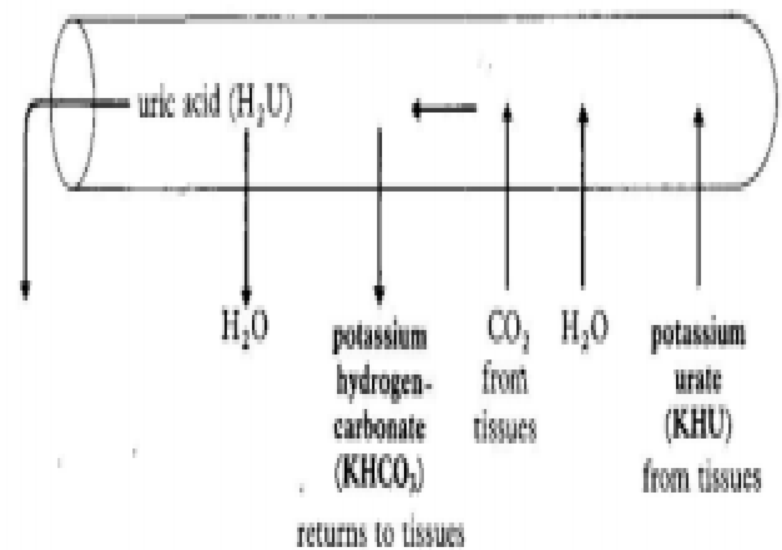
Figure 40.6 In Insects, Urine Forms in the Malpighian Tubules and Is Modified in the Hindgut. The isosmotic filtrate that forms in the Malpighian tubules empties into the hindgut, where it mixes with fecal material. Valuable substances such as electrolytes and water are selectively reabsorbed from the hindgut, leaving wastes to be excreted with feces.

How is the filtrate formed?

- The **peristaltic** movements of malpighian tubules stir up the haemolymph (blood) enabling **epithelial cells** to absorb nitrogenous wastes like sodium and potassium urate.
- Within the tubule cells, Water and CO2 react with potassium urate to form potassium hydrogen carbonate and uric acid.
- Potassium hydrogen carbonate is absorbed back into blood while uric acid is deposited in the tubule lumen.
- As the uric acid moves from **distal** to **proximal** end of the malpighian tubule, water is vigorously back into blood while solid crystals of uric acid are deposited in the lumen and later rectum to be passed out.

Draw figures 14.14 **A** and **B** Roberts MBV: Biology a functional approach, 4th ed. Page 226





overall equation:

$$KHU + H_2O + CO_2 \longrightarrow KHCO_3 + H_2U \downarrow$$

Urine Formation in Non mammalian Vertebrates

- The loop of Henle is an important adaptation in mammals and some birds. Water loss is reduced because these animals can produce urine that is **hyperosmotic** to their blood.

- In contrast, the nephrons of fishes, amphibians, and non-avian reptiles lack loops of Henle, and their kidneys are therefore unable to produce concentrated urine

- Many fishes and amphibians do not need to produce concentrated urine. But conserving water is important in reptiles, especially those inhabiting deserts. Recall that reptiles produce nitrogenous wastes in the form of uric acid, which is excreted with very little water in urine that is hyperosmotic to their body tissues.

- In most reptiles, the ureters empty **isosmotic urine** into the **cloaca**, a cavity into which the urinary, gastrointestinal, and reproductive tracts all empty

continuation

- Reptiles are able to absorb water from urine across the wall of the cloaca into the bloodstream. Eventually, a semisolid uric acid paste is excreted along with the feces.
- Some reptiles also have a bladder at collects the isosmotic urine from the ureters and stores it before emptying it into the cloaca.
- When water is available, these reptiles drink a lot, and their bladders fill up with dilute urine
- Research indicates that the bladder can indeed allow lizards to carry a water supply that they can access when water is scarce.
- As water is reabsorbed from the bladder, the urine becomes more and more concentrated, but the osmolality of the blood remains low

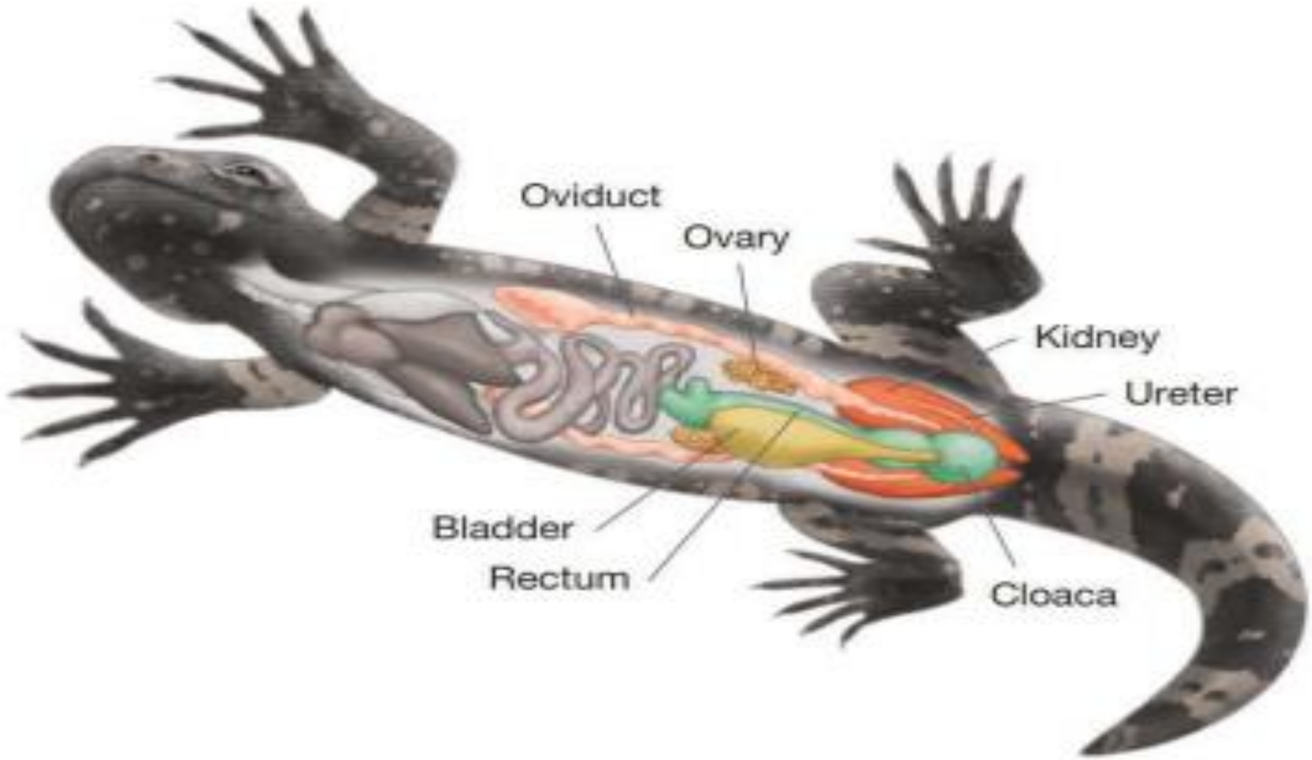


Figure 40.15 **The Cloaca of Reptiles Is a Cavity into Which the Urinary, Gastrointestinal, and Reproductive Tracts Empty.**

EXCRETION IN PLANTS

- The following account for the absence of complex/elaborate excretory systems in plants as those in animals:

- ✓ Toxic wastes do not accumulate because they are utilized by the plant e.g. CO_2 and water are raw materials for photosynthesis while oxygen participates in respiration

- ✓ Extra gaseous wastes are removed from plant bodies by simple diffusion through the stomata and lenticels

- ✓ Most of the organic waste substances formed in plants are non harmful and can be stored in the plant tissues which are removed periodically e.g. leaves and bark

continuation

- ✓ Some plants store other wastes such as resins in organs that later fall off e.g. leaves
- ✓ Excess water and dissolved gases are removed by transpiration through the stomata
- ✓ In some plants, guttation occurs i.e. excess water with dissolved salts ooze out through hydathodes at leaf surfaces
- ✓ Organic acids which would be harmful to plants often combine with excess cations and precipitate as insoluble crystals which can be safely stored in plant cells. E.g. excess Ca2+ combines with oxalic and pectic acids to form the non-toxic calcium oxalate and calcium pectate

Thank you

You have the capacity to learn anything!