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Urinary System: Reenal Physiology for Medical Students, L1

Reference: Guyton & Hall, Jordanian first edition
Chapter 28

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Color code

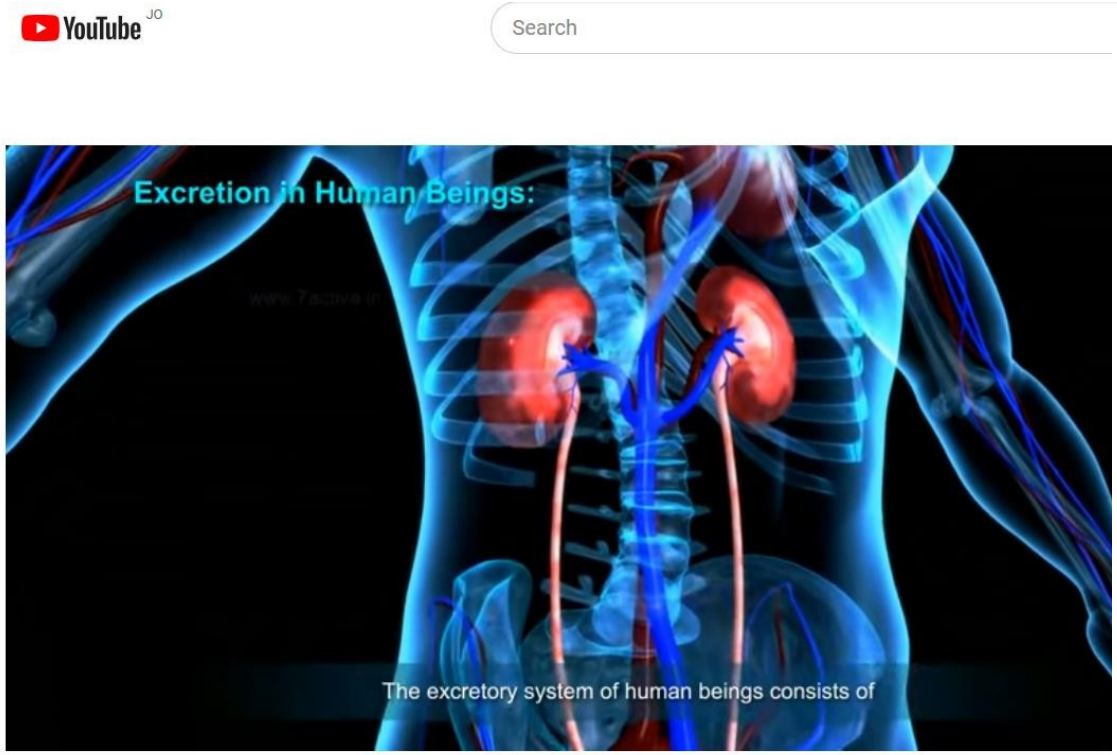
- Slides
- Doctor
- Additional info
- Important

Learning Objectives

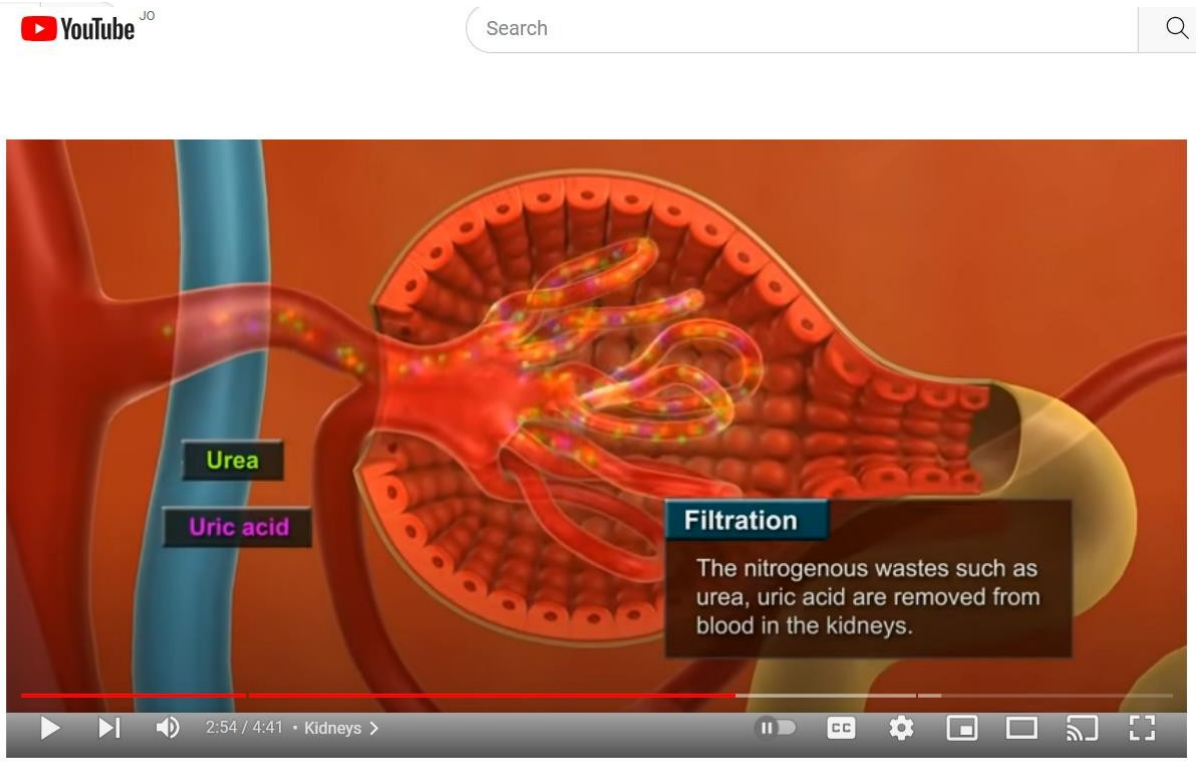
- Identify the functions of the urinary system, particularly the kidneys.
- Describe the external and internal anatomical features of the kidneys.
- Describe the structure of the nephron including the renal corpuscles and the renal tubules.
- Dissect the blood supply of the kidney including nephrons blood supply.
- Understand the relation between the structure and function of the nephron unit.

Please Watch This Video Demonstrating Urinary System Functions

- [Excretion in human - YouTube]



Excretion in human



Excretion in human

The urinary system plays a crucial role in maintaining homeostasis by eliminating metabolic waste products and excess substances from the body.

While the system includes several components, the kidneys perform the majority of its physiological functions. The main component of this system include:

1. **Kidneys** (two in number) – Major organs responsible for filtering blood, forming urine, and regulating fluid and electrolyte balance.

2. **Ureters** (two in number) – Muscular tubes that transport urine from where it was formed (the kidneys) to the urinary bladder (conduction). This conduction is aided by the contractile activity of the wall of the ureter, which propel urine down toward the bladder.

3. **Urinary Bladder** (only one) – A hollow, muscular organ that stores urine until urination.

4. **Urethra** (only one) – A passageway through which urine exits the body.

Each kidney has a **hilum** on its **medial** surface, where the following structures enter or exit:

Renal **artery** (entry of oxygenated blood)

Renal **vein** (exit of filtered blood)

Ureter (exit of formed urine)

Lymphatic vessels and **nerves**

Extra Note: The renal hilum is like the lung hilum and serves as a gateway to the kidney's internal structures like the renal pelvis, calyces, and sinus.

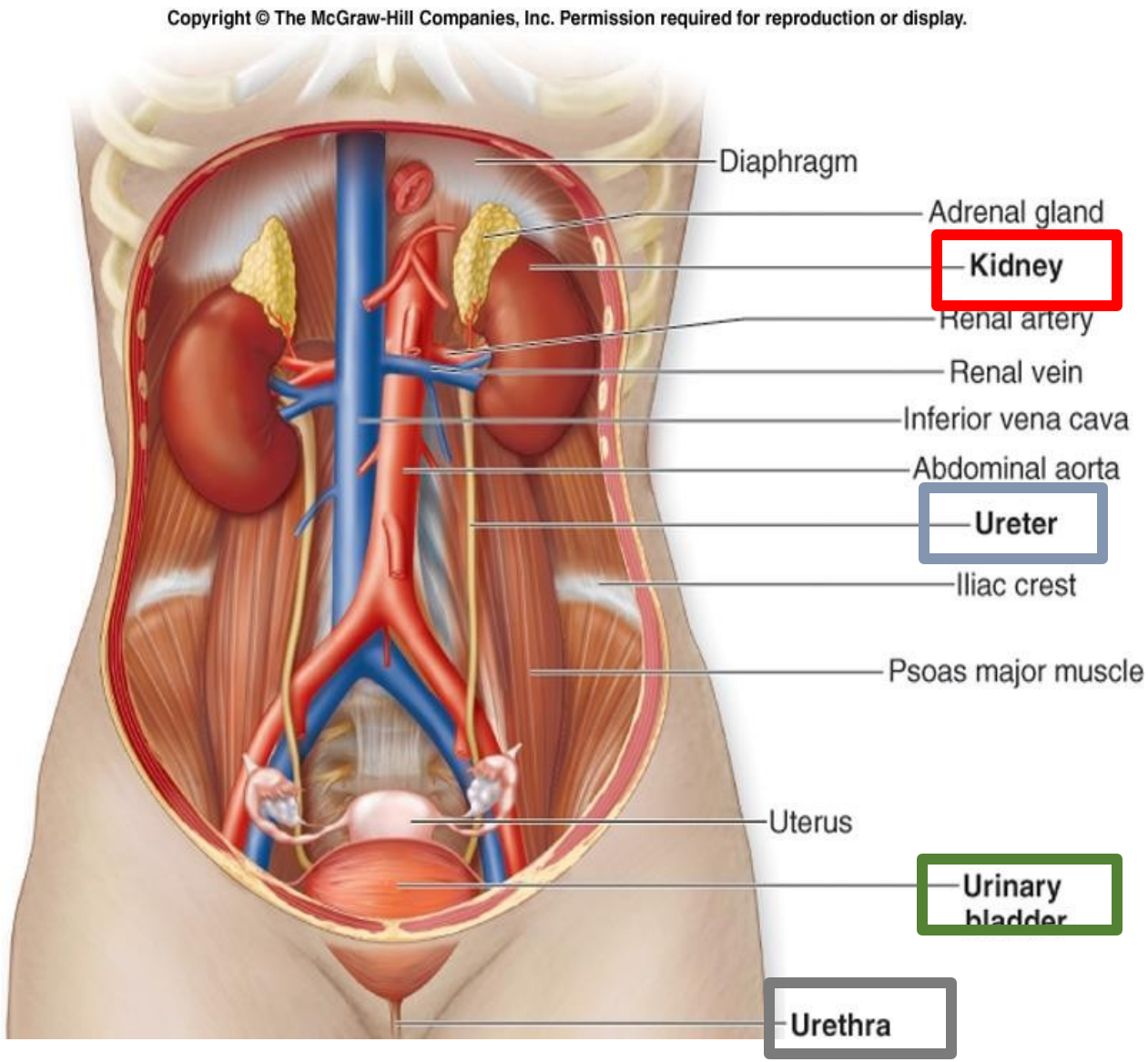
The Urinary System

All was discussed

- The **Kidneys** do most of the work of the urinary system, while other parts serve as passageways or storage organs

- The **ureter** transport urine from the kidneys to the urinary bladder.

- The **urinary bladder** stores urine.
- The **urethra** discharges urine from the body.



Functions of the Urinary System (Mainly by the Kidneys):

1. Excretion of Waste Products:

Maintains electrolyte balance, especially sodium and chloride, and controls water balance and osmolarity.
Removal of nitrogenous wastes (urea, creatinine).
Elimination of foreign substances and drugs.

This is mainly part of the **filtration** function, which is one of the many functions that take place in the kidneys (which will be discussed later).

The next slide contains all the details regarding was removal function, the doctor read it all

Urinary System Function

- **1. Filters Waste Products from Blood**

-Excretion of water and sodium chloride (NaCl) is regulated in conjunction with cardiovascular, endocrine, & central nervous system

-The urinary system eliminates in the urine different waste products such as :

1. **ammonia** and **urea** (both formed when amino acids are broken down),
2. **uric acid** (formed when nucleic acids are broken down),
3. **creatinine** (from muscles).
4. **end products of hemoglobin metabolism, hormone metabolites**
5. **foreign substances**

   (e.g., drugs, pesticides, & other chemicals ingested in the food)

-The blood is filtered by the kidney through 3 processes called **filtration**, **reabsorption**, and **secretion**.

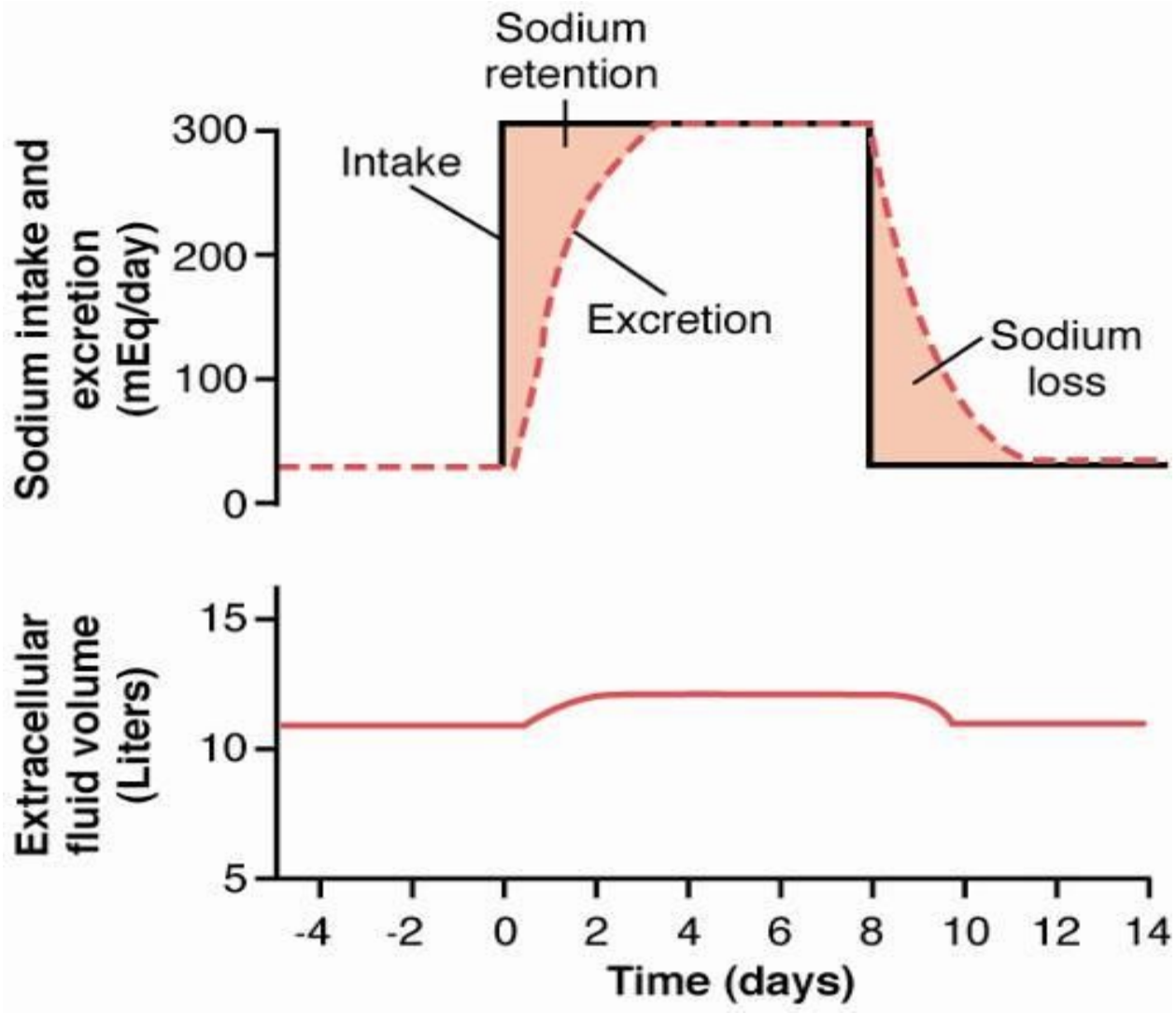
The wastes leave the body as **urine**.

Urinary System Function

- **2. Conserves Valuable Nutrients**
  The urinary system ensures glucose, amino acids and other valuable nutrients are not lost from the urine, by a process called reabsorption. In addition, in long time fasting, kidneys can also use glutamine to release glucose in gluconeogenesis.
- **3. Regulates Ion Levels in the Plasma**
  The urinary system regulates ion (electrolyte) levels in the plasma by regulating the amount of sodium, potassium, chloride and other ions lost in the urine, by controlling the level of ions excreted and reabsorbed.

Effect of increasing sodium intake 10-fold on urinary sodium excretion and extracellular fluid volume

The audio cut off during this part of the lecture but check next slides !



Note: this slide will be explained in the second lecture !

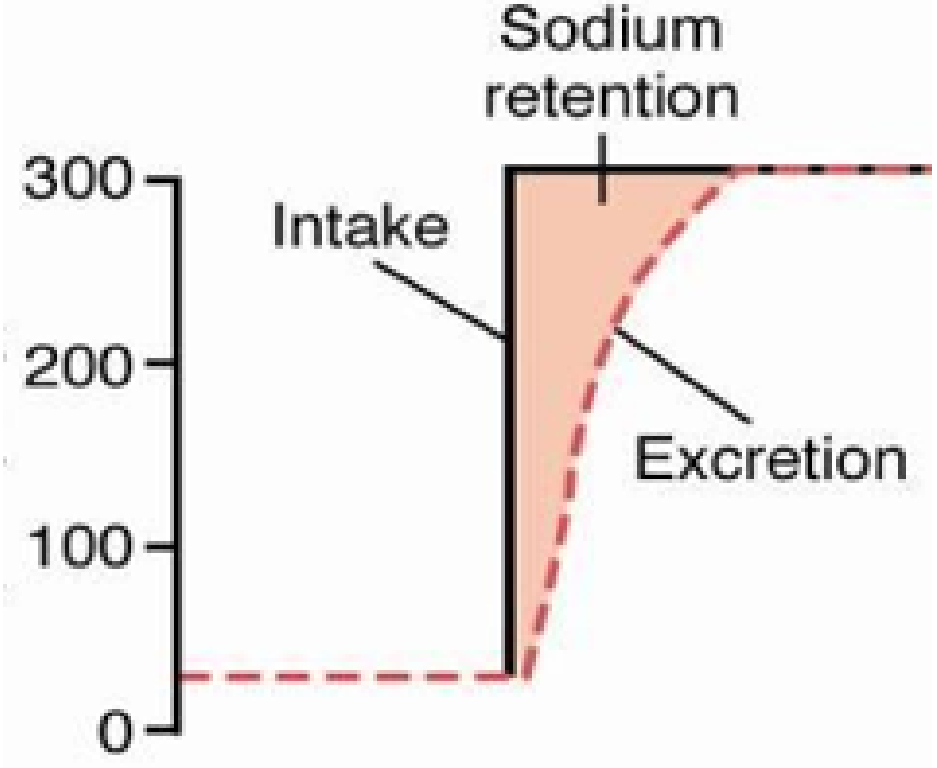
The figure tends to be explaining the effect of sudden sodium increase:

1. Before Day 0: Sodium intake and excretion are balanced at a low, steady level (~30 mEq/day), and extracellular fluid (ECF) volume stays constant (~11 L).

2. Day 0 – Sudden 10x Sodium Increase: Intake jumps to ~300 mEq/day, but excretion lags behind. This creates a gap (orange shaded area labeled "sodium retention") where more sodium is entering than leaving the body.

3. Day 0 to ~Day 5: The kidneys gradually respond by increasing sodium excretion. It takes several days for excretion to match the new intake level (~300 mEq/day). During this time, sodium and water accumulate, causing a slight increase in ECF volume.

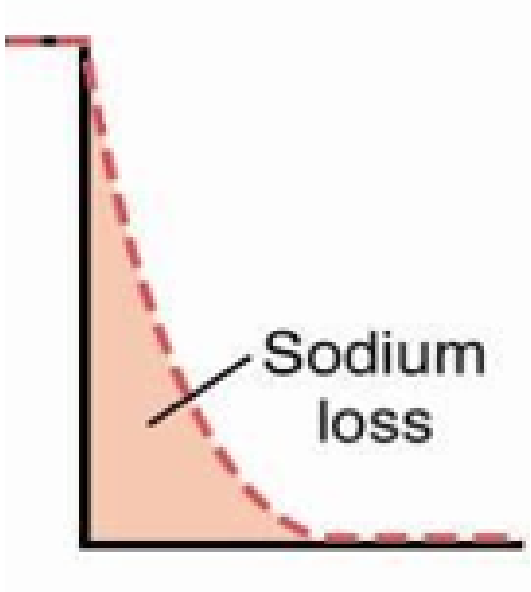
4. Day 5 to Day 9: Sodium intake and excretion are balanced at the higher level, and ECF volume stays elevated but stable.



5. Day 9 – Return to Normal Sodium Intake: Intake drops back to baseline (~100 mEq/day), but the kidneys continue excreting at the high rate briefly. This creates a new gap (labeled "sodium loss") where more sodium is being lost than taken in.

6. Day 9 to ~Day 12: Sodium excretion slowly drops to match intake again, and the previously retained sodium is eliminated. As a result, ECF volume returns to baseline.

So, in summary, the kidneys maintain sodium and fluid balance but take a few days to fully adapt, this will lead to a temporary increase in extra cellular volume during the beginning.



Urinary System Function

- **4. Regulates Blood pH**

  -The urinary system regulates blood pH by regulating the number of H+ and bicarbonate ions (HCO3-) lost in the urine, the rate of elimination is an important factor for this process.

  -The kidneys work in concert with lungs to regulate the pH in a narrow limits of buffers within body fluids.

4. Blood Volume and Blood Pressure Regulation:

By controlling extracellular fluid volume, the kidneys indirectly regulate blood pressure.

In response to low blood pressure, the kidneys release renin, triggering the renin-angiotensin-aldosterone system (RAAS), providing an acute control over blood pressure.

When blood pressure or sodium is low, the kidneys release renin. Renin converts angiotensinogen (from the liver) into angiotensin I. ACE converts angiotensin I into a **vasoactive** peptide, angiotensin II. Angiotensin II causes vasoconstriction and stimulates aldosterone release from the adrenal glands. Aldosterone increases sodium and water reabsorption in the kidneys, raising blood pressure.

Kidneys are also involved in the long-term regulation of blood pressure, which is done through other mechanisms

Urinary System Function

- **5. Regulates Blood Volume and blood pressure**
  The urinary system regulates blood volume and extra cellular fluid, and arterial pressure by:

1) releasing **renin**, a hormone that after a series of reactions eventually restricts salt and water loss at the kidneys.

2) adjusting the volume of water lost in the urine

Urinary System Function

- **6. Regulates RBC Production**
  - If oxygen levels in the blood are low (for example, during hypoxia) , the kidneys release **erythropoietin**, a hormone that stimulates the hemocytoblasts (stem cells in the bone marrow) to increase red blood cell formation (hematopoiesis). Having more RBCs allows the blood to transport more oxygen.

Having a kidney disease or dysfunction will directly affect the level of oxygen in the blood.

Urinary System Function

- **7. Stores Urine**

All the previous functions of the urinary system are mainly handled by the kidneys, but this function is preformed by the bladder. The kidneys produce urine continuously; however, the **bladder** stores the urine until it is convenient to excrete it.

- **8. Excretes Urine:** The **urethra** transports urine from the urinary bladder to the outside of the body when the micturition reflex starts.

Urinary System Function

- **9. Produces and secretes hormones**:

The kidneys can also act as endocrine glands, and secrete some hormones, including:

- **Calcitriol**: the kidneys help to activate vitamin D, producing calcitriol (The active form of vitamin D). Vitamin D increases calcium deposition in bones and increases digestive absorption of calcium.

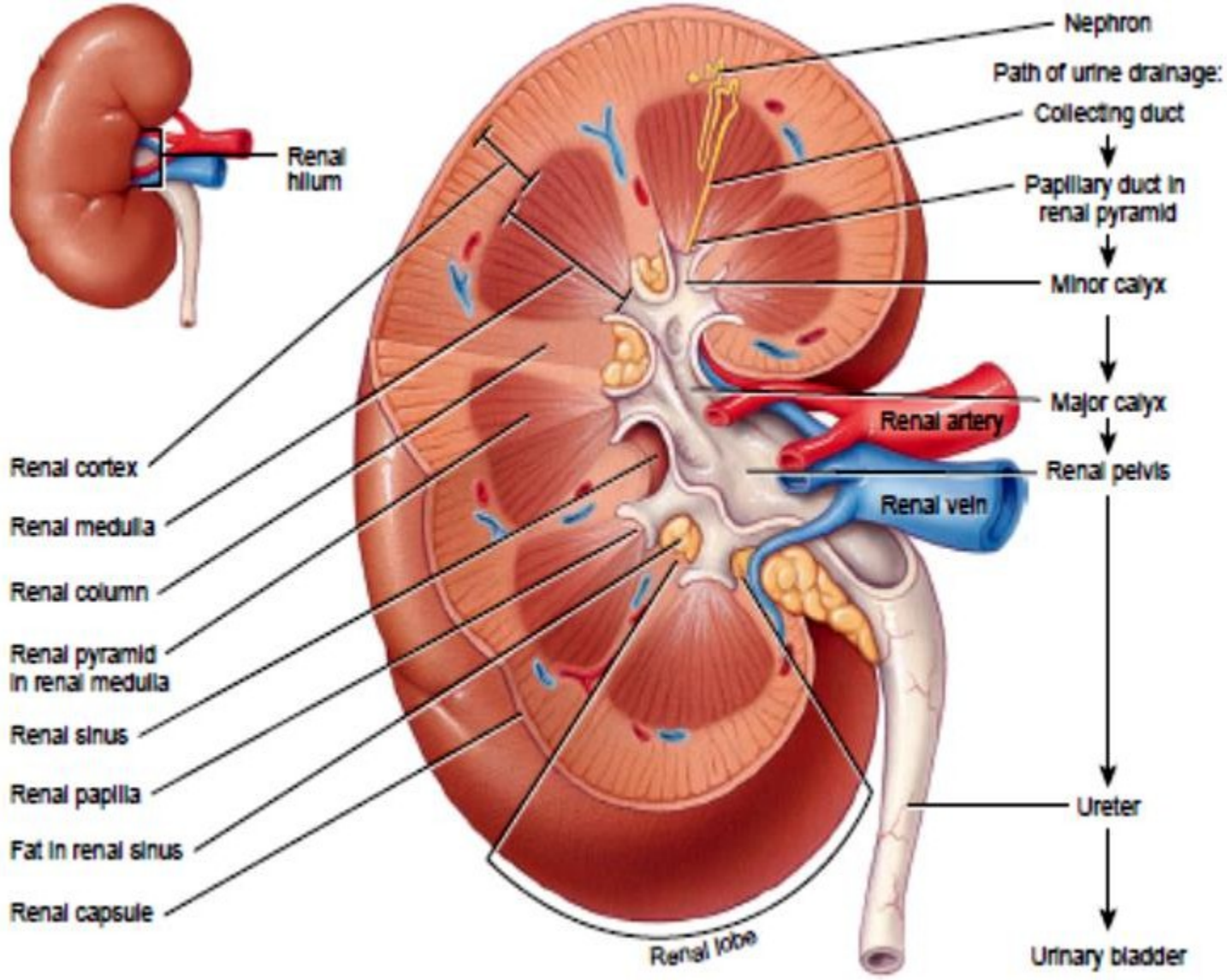
- **Renin:** activates the renin-angiotensin-aldosterone system, thus regulating **blood pressure regulation** & Na+, K+ balance.

- **Prostaglandins/kinins:** bradykinin = vasoactive, leading to modulation of renal blood flow & along with angiotensin II affect the systemic blood flow. Vasoactive substances that cause vasodilation (some prostaglandins) increase renal blood flow and thus increase filtration, people who take prostaglandin inhibitors (like COX inhibitors) should be careful with its effect on the kidneys, especially people with kidney disease

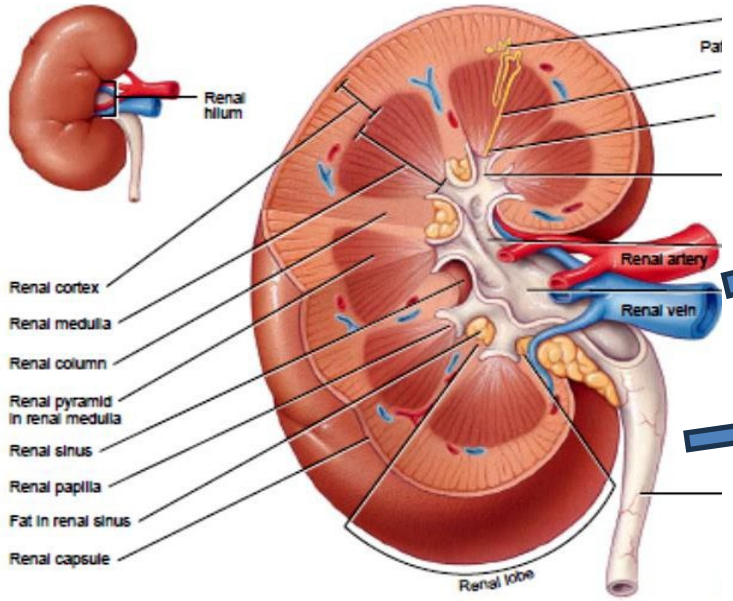
- **Erythropoietin:** stimulates red blood cell formation by bone marrow

Kidney Structure

This is a cross section of the kidney, check next slide !



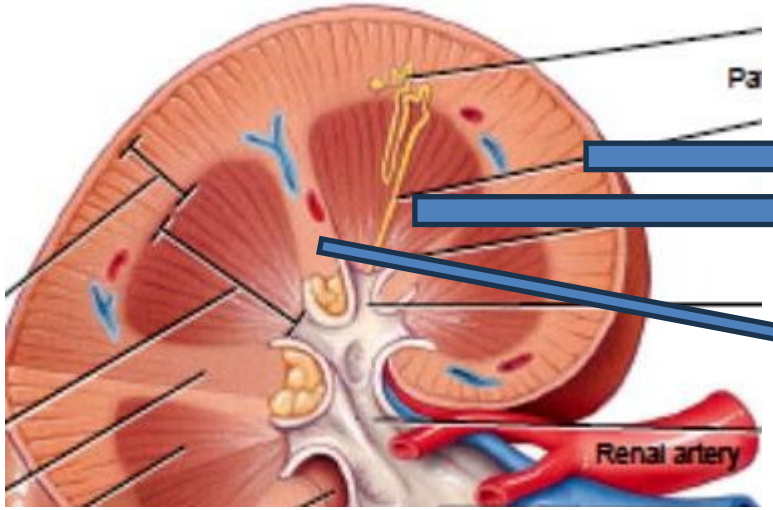
(a) Frontal section of right kidney



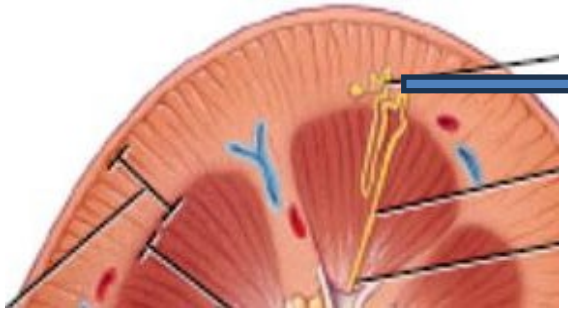
Here you can see hilum of the kidney, which includes:

Renal artery and **renal vein**, that bring blood into and from the kidney.

The ureter, which collects formed urine and transport it to the urinary bladder

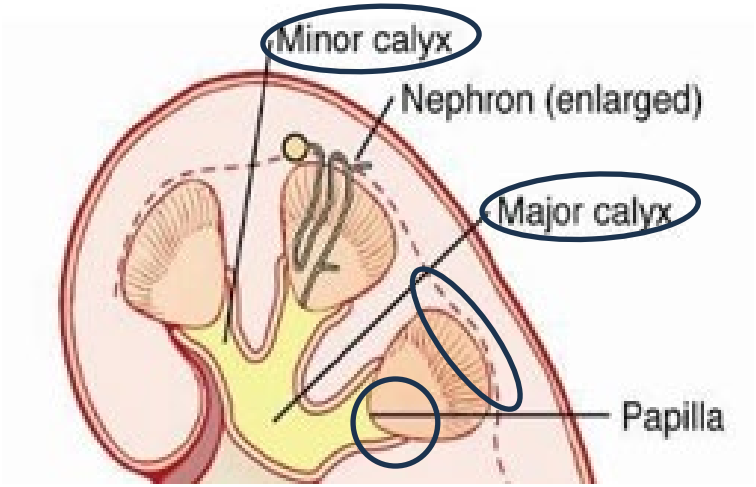


The main structure of the kidney is divided into:
1.The outer **renal cortex**
2.The inner **renal medulla,** which is composed of pyramidal structures called renal pyramids, between these pyramids are the **renal columns.**



Here, you can see a very special structure, the **nephron**, the functional unit of the kidney, which extends from the cortex into the medulla, and preforms most of kidney functions.

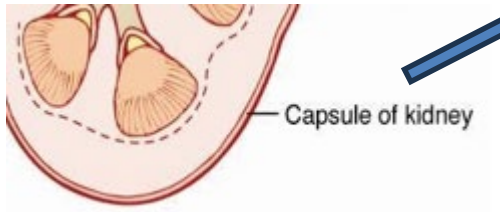
Each kidney has about 1 million nephrons, each one of those nephrons is able to preform filtration, reabsorption and secretion.



Each pyramid has a tip (papilla) and a base (parallel to the border between cortex and medulla).

The papilla is the place where all nephrons and collecting tubes empty their urine, papilla then empty into **minor** and **major calyx,** which represent pools where formed urine is collected.

The kidney also has a strong **capsule** to protect it.



Kidneys and urinary system

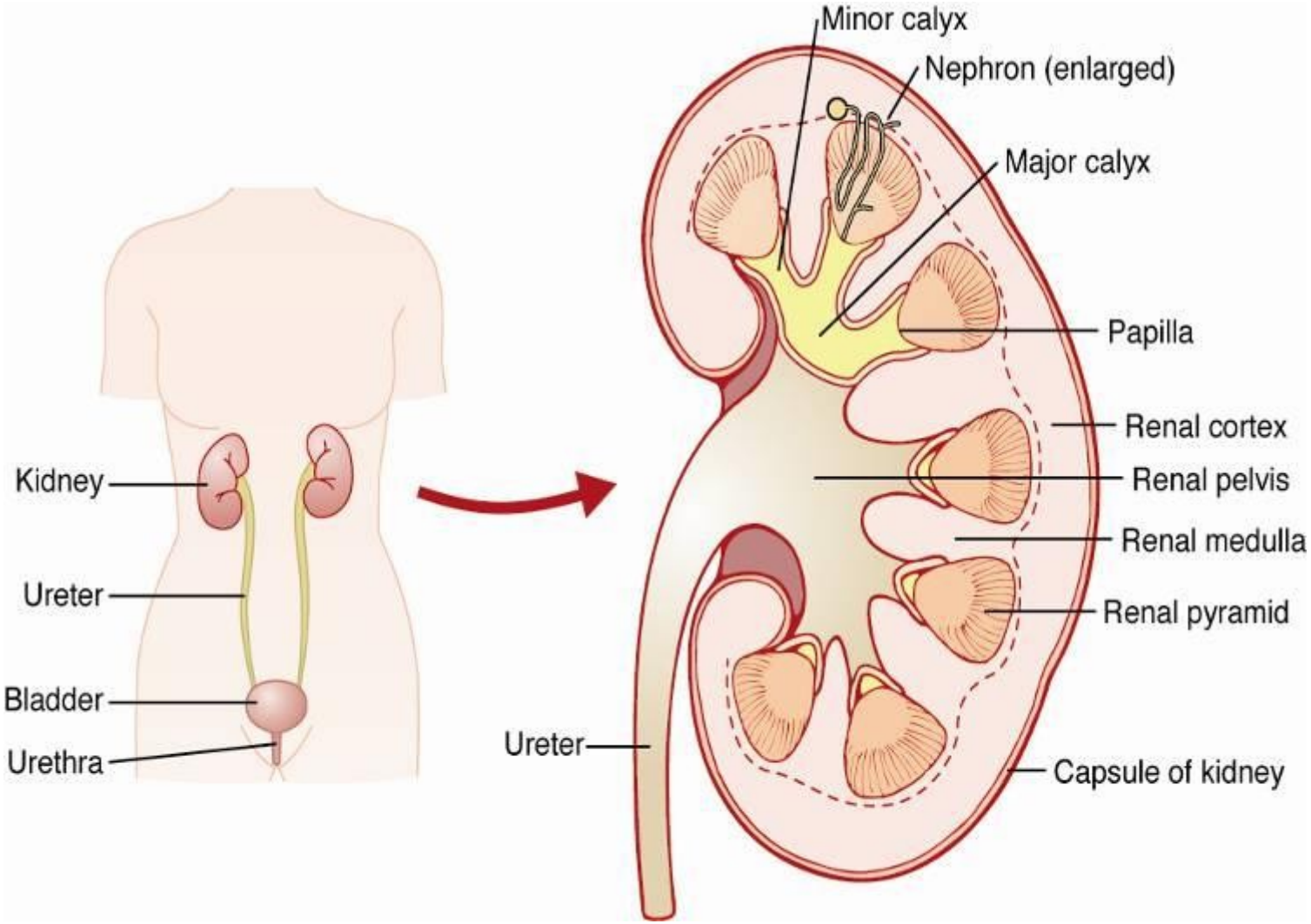


Figure 26-3

Major blood vessels of the kidney

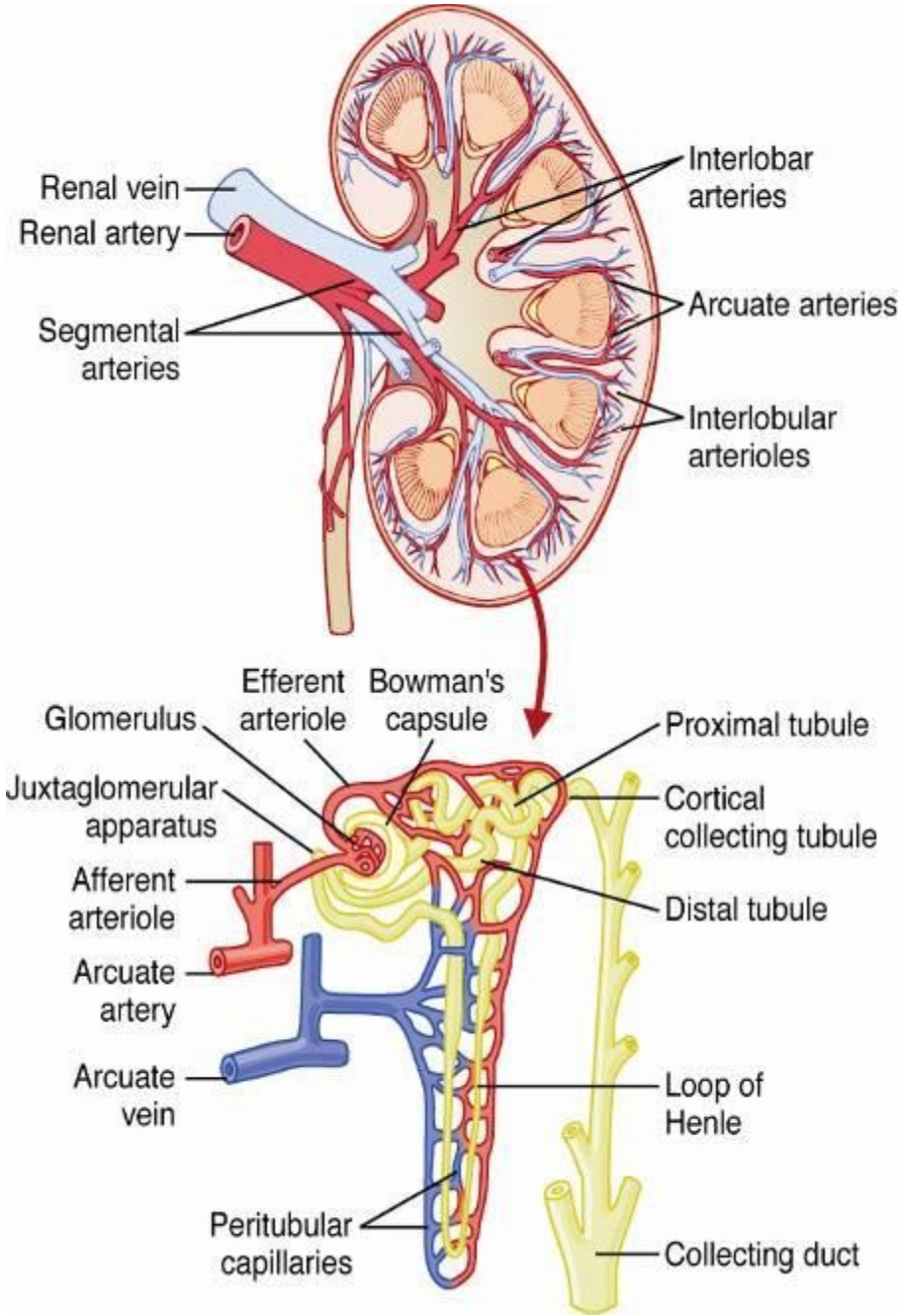


Figure 26-3

Blood supply of the kidney and functional unit:

1. 1/4 of the entire cardiac output reaches the kidneys through the **renal artery.**

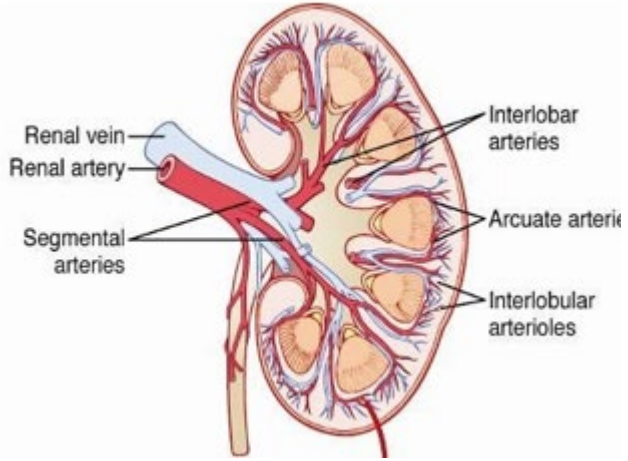
2. Then, the **renal artery** divides into multiple **segmental arteries, Lobar arteries, interlobar, arcuate arteries** and **Interlobular arteries.**

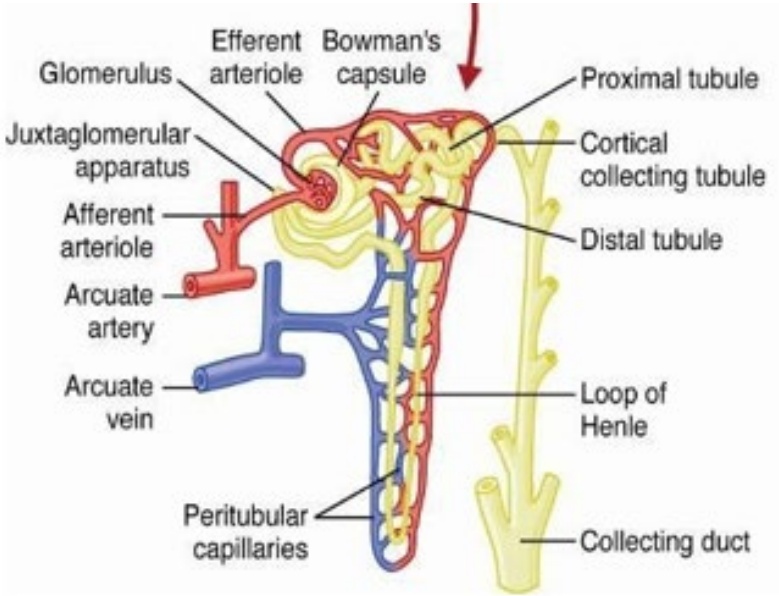
3. **Interlobular arteries** are responsible for blood supply of the nephron, **Interlobular arteries** gives a branch called **Afferent arteriole**, this arteriole brings blood to a capillary bed called **Glomerulus.**

4. Those **capillaries** then coalesce into **efferent arteriole.**

5. The **efferent arteriole** gives rise to another capillary bed, the **Peritubular capillaries**

So, you can note that the structure of the kidney contains two capillary beds which are connected in series, this is a very important characteristic when it comes to understanding the different processes that happen in the kidney.





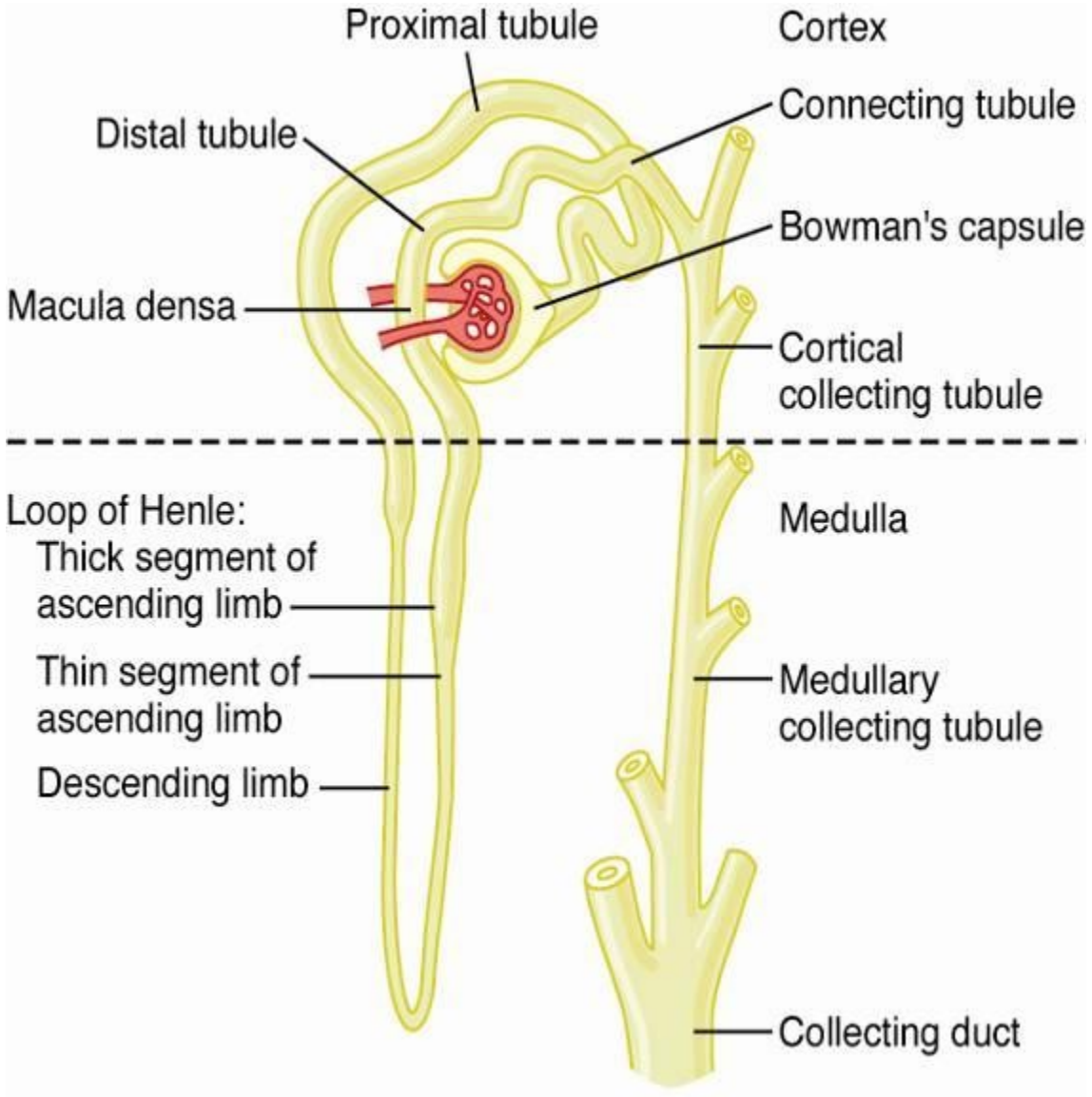

Proximal tubule
Cortex
Distal tubule
Connecting tubule
Bowman's capsule
Macula densa
Cortical
collecting tubule
Loop of Henle:
Thick segment of
ascending limb
Medulla
Thin segment of
ascending limb
Medullary
collecting tubule
Descending limb
Collecting duct

Figure 26-4

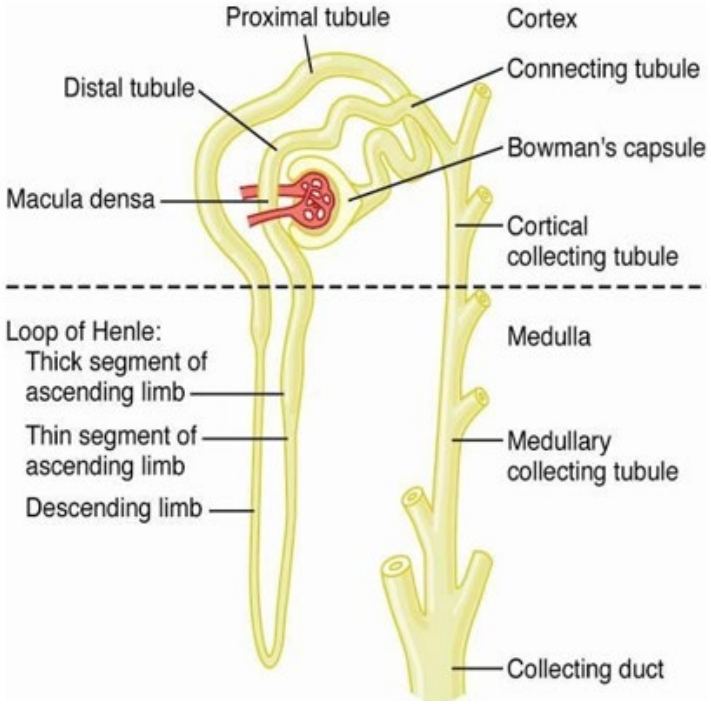
Structure of the nephron:

1. The characteristic blood supply we explained earlier

2. **Bowman's capsule**

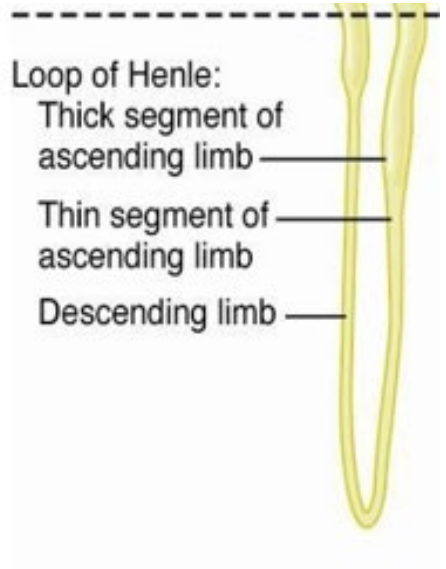
3. **A tubular structure that starts from Proximal tubules, Loop of Henle, Distal tubule, connecting tubule**, and then **collecting tubule.** Collecting tubule is divided into **cortical collecting tubule** (found in the cortex) and **medullary collecting tubule** (found in the medulla).

Finally, all the collecting tubules come together to form a **collecting duct.**



The **loop of Henle** is further divided into **thin descending limb, thin ascending limb** and **thick ascending limb,**

The importance of this division is that each segment (limb) of these has a characteristic histology and permeability towards water and salts.



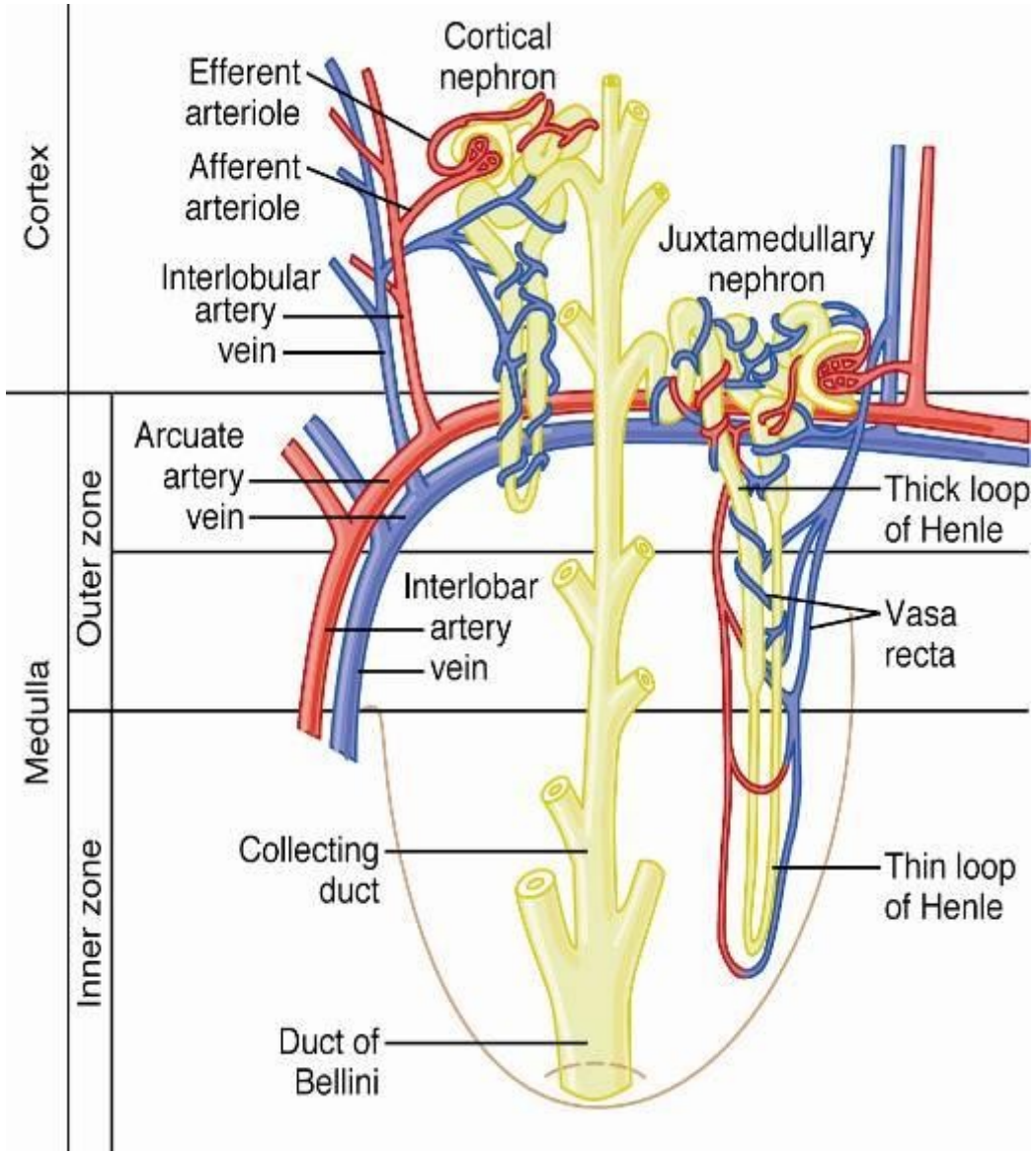
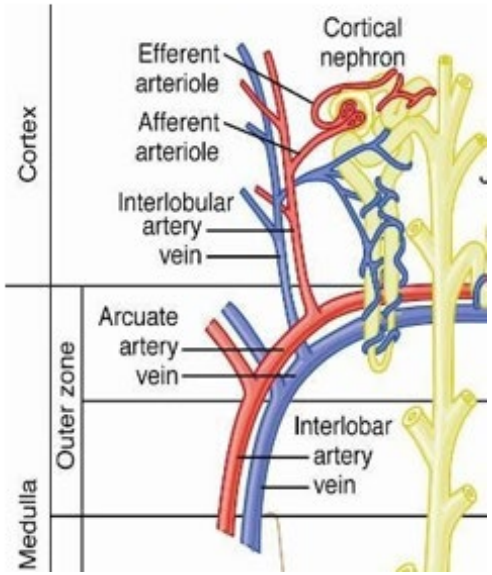
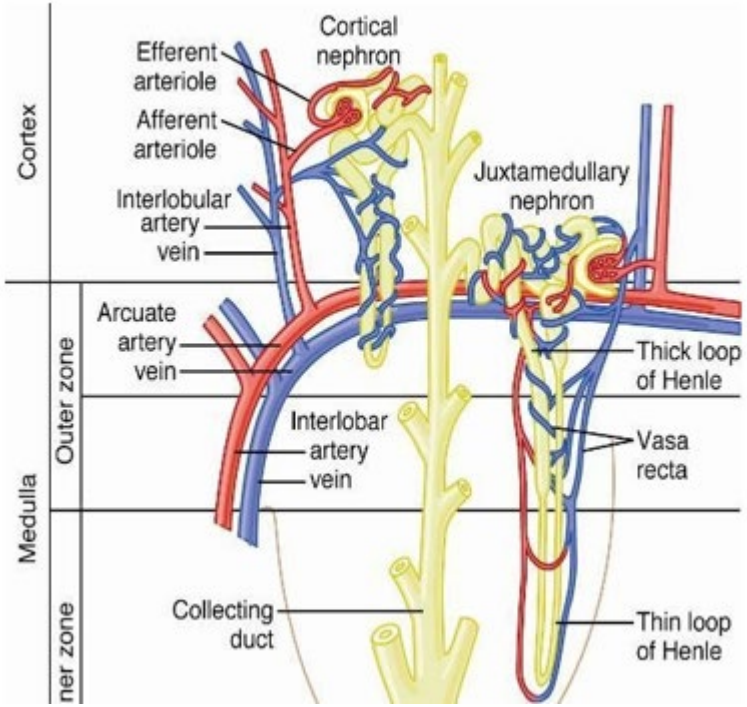

Cortex
Medulla
Outer zone
Inner zone
Cortical nephron
Efferent arteriole
Afferent arteriole
Interlobular artery
vein
Juxtamedullary nephron
Arcuate artery
vein
Thick loop of Henle
Interlobar artery
vein
Vasa recta
Collecting duct
Thin loop of Henle
Duct of Bellini

Figure 26-5





There are two types of nephrons, **cortical nephrons and juxtamedullary nephrons.**

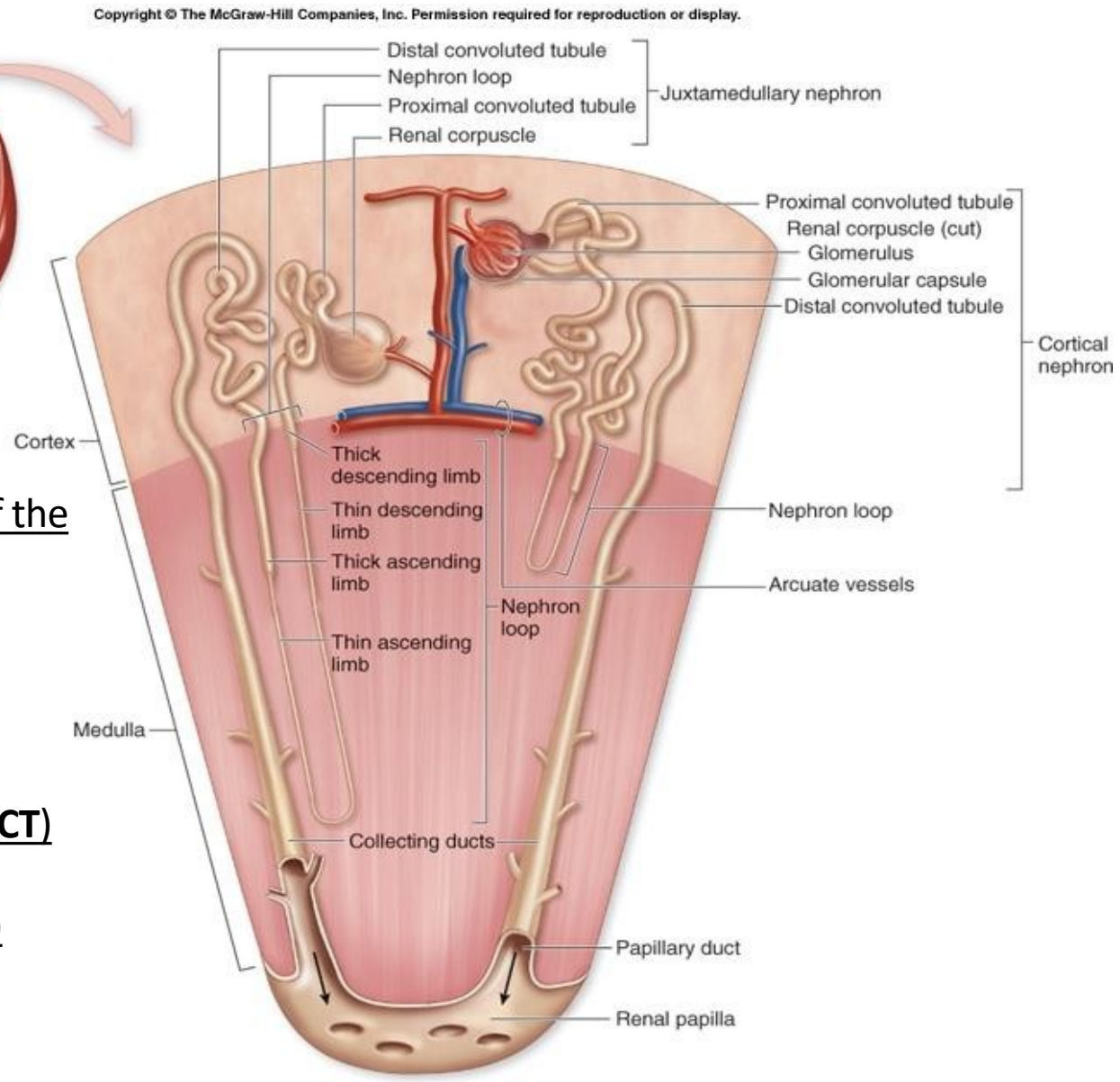
Most of the **Cortical nephron** is situated in the cortex, except for as small part of the loop of Henle and collecting tubule which is found in the medulla.

Juxtamedullary nephrons are found at the border between cortex and medulla, as most of the length of the loop of Henle extends deep in the medulla, it may even reach the tip of the pyramid. Those nephrons are longer than cortical nephrons.
Also, Juxtamedullary nephrons have a unique blood supply, where peritubular capillaries are organized in a way that surround the long loop of Henle, laying side by side. This structure is called **Vasa recta.**

Juxtamedullary nephrons as well as Vasa recta are very important for **concentrating urine**, as we will see later.

The Functional Unit of The Kidney?

Glomerulus: tough of capillaries starts with afferent arteriole > efferent arteriole.



Is the nephron.

- **Each kidney is made up of 1 million of nephrons.**
- Each nephron is made up of the following:

❑ Renal Corpuscle
-Bowman's Capsule
-Glomerulus

❑ Renal Tubules
-Proximal Convoluted Tubule (**PCT**)
-Loop of Henle**(LH)**
-Distal Convoluted Tubule (**DCT**)
-Collecting Duct **(CD)**

Any damage to the nephrons is irreversible, no repair.
After the age of 40, a decrease in number of nephrons will take place due to aging. 10% decrese every 10 years.
This is not mean that the kidney will deteriorate after the age of 40, because other parts of kidney will compensate.

Question

- Can a person live after nephrectomy with one normal kidney?

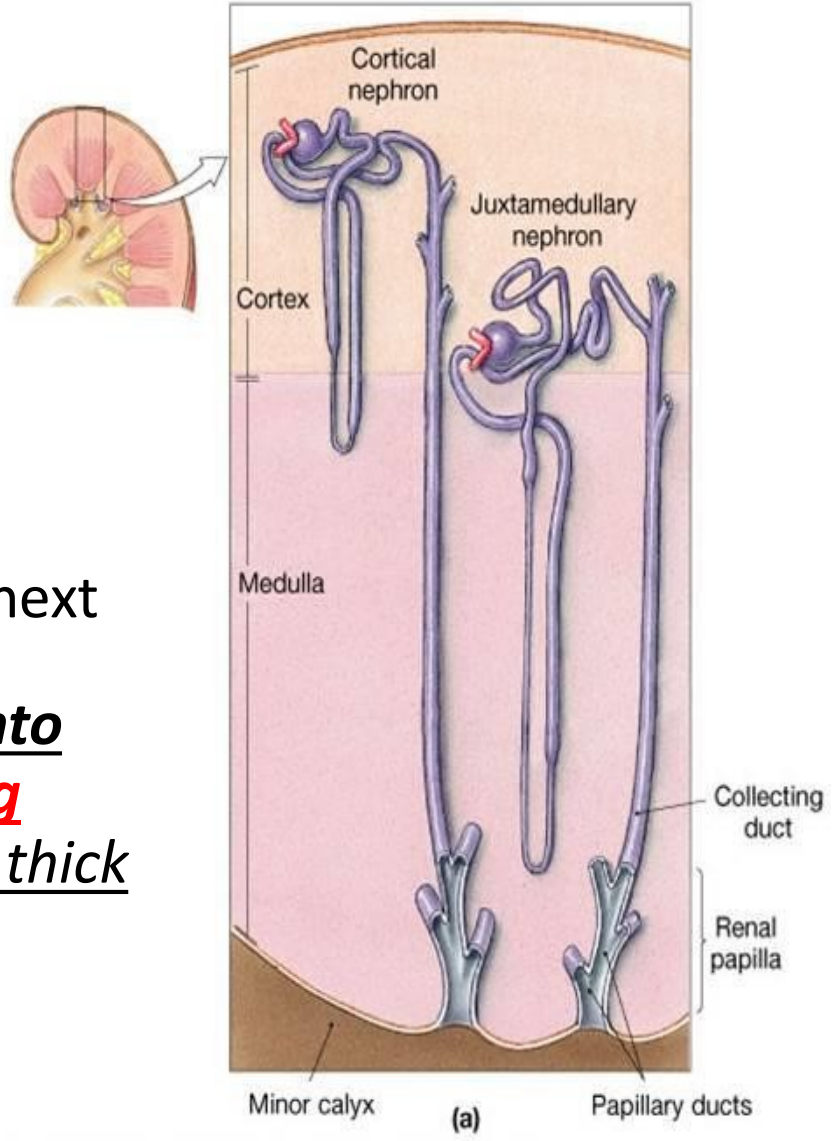
Yes, If the remaining kidney is normal it can just do perfectly the whole job

Types of Nephrons

Juxtamedullary nephrons are important for urine concentration capability that is done by the kidney

- **Cortical nephrons**
  - -~85% of all nephrons.
  - Are located in the cortex.
  - ***short Loop of Henle.***

- **Juxtamedullary nephrons** *15%*
  - Are deep in cortex closer (juxta = next to) the renal medulla.
  - ***The loops of Henle extend deep into the medulla*** (renal pyramids). ***long***
  - *Ascending limb contains thin and thick ascending portions.*



انتبهوا على الأرقام في السلايد القادم

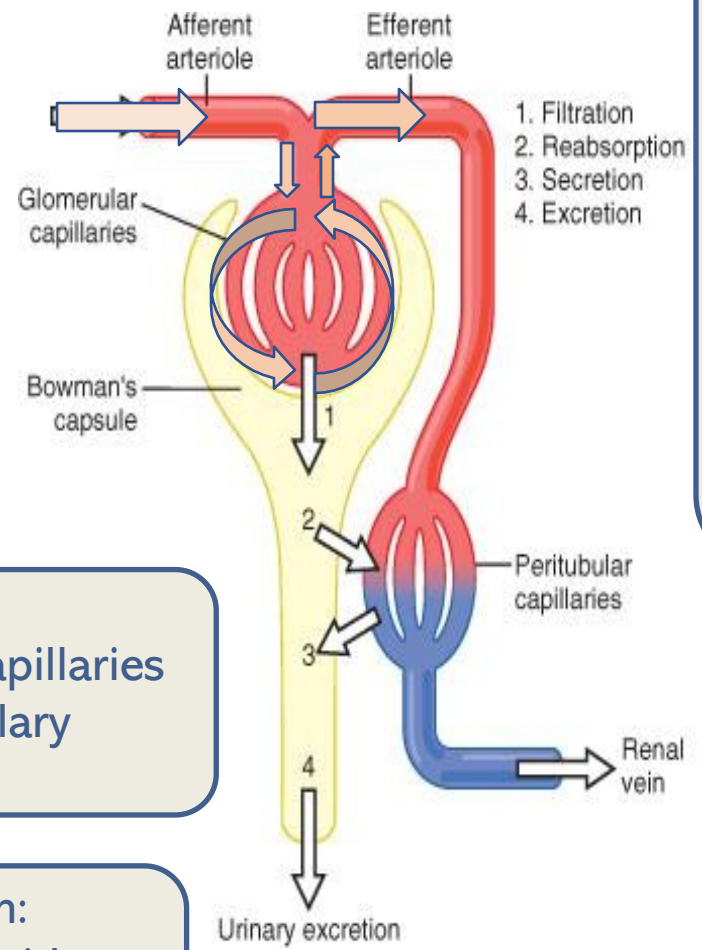
Nephron Blood Supply

- Blood travels from the **afferent arteriole** to a ball of capillaries in the nephron called a **glomerulus**
- Blood leaves the nephron via the **efferent arteriole**
- Blood travels from efferent arteriole to the **peritubular capillaries** and **vasa recta**

3. Secretion: Some substances will move from the peritubular capillaries to tubular part to be eliminated.

1. After the blood enters the glomerulus via afferent arterioloe, filtration process will occur (filtered fluid will enter Bowman's capsule).

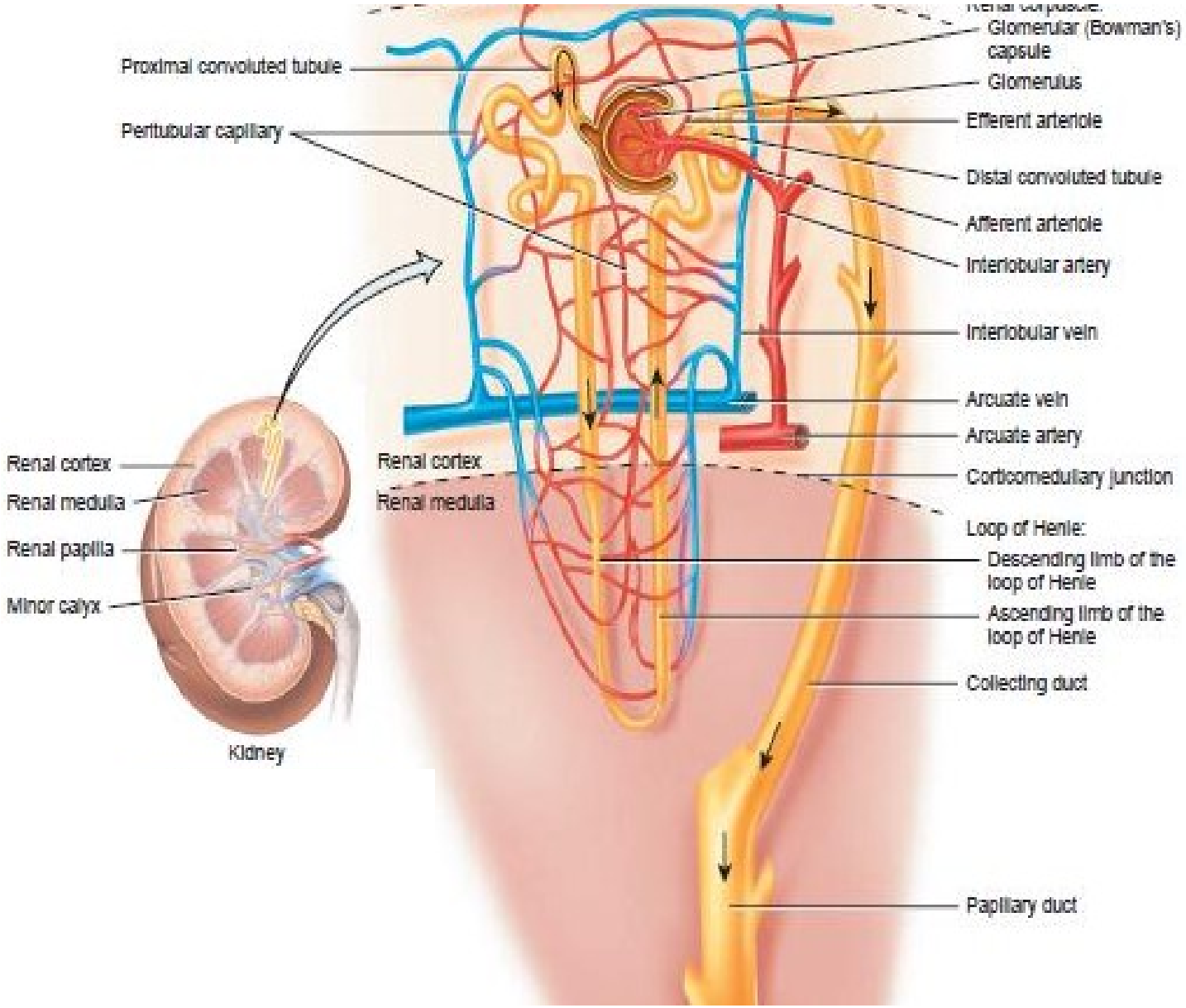
4. Urinary excretion: What is left in the tubule will be urinary excreted



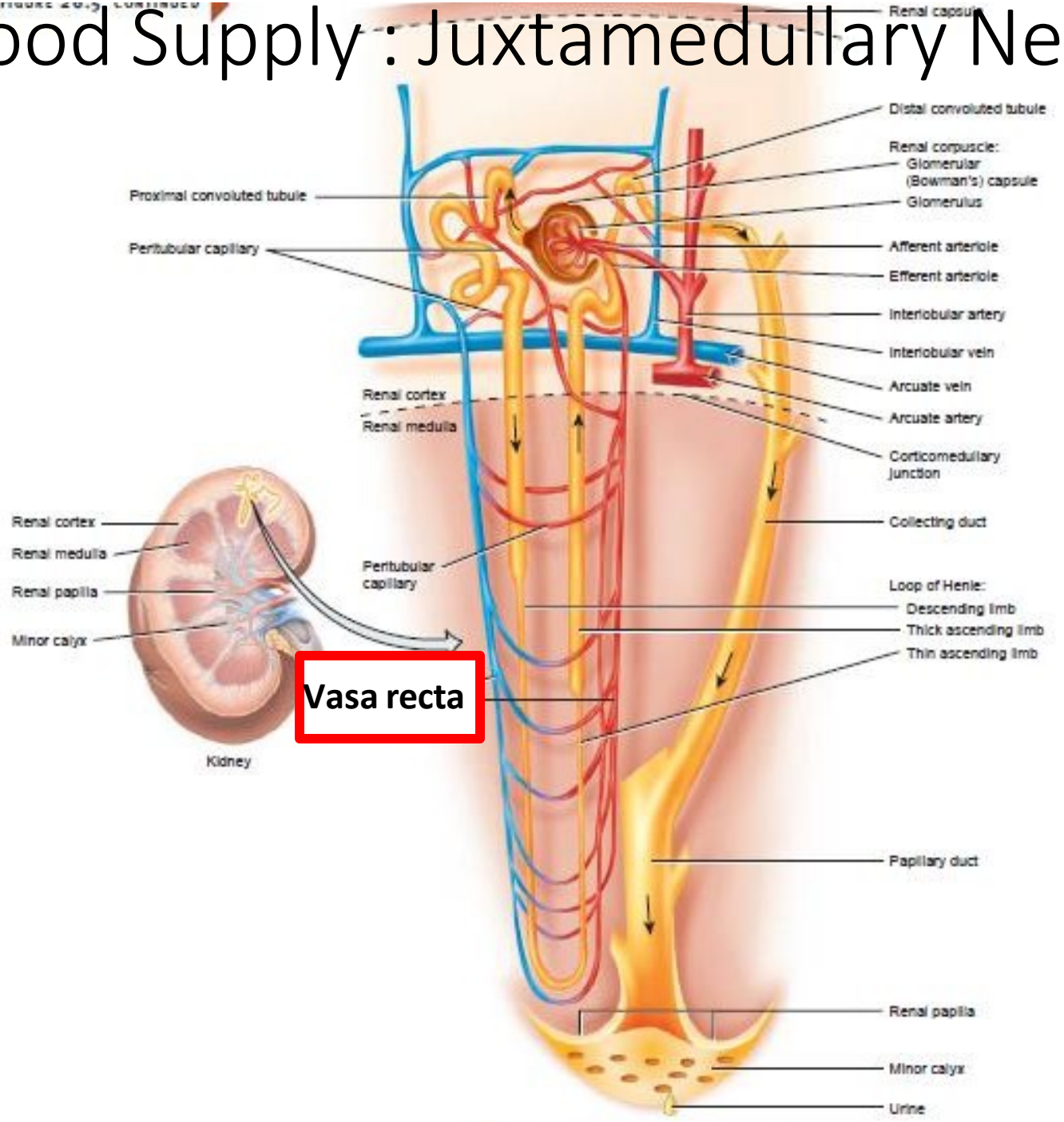
Vasa recta = peritubular capillaries in juxtamedullary nephrones.

2. Reabsorption: Movement of fluid from tubular part back to vascular part

Blood Supply: Cortical Nephron



Blood Supply : Juxtamedullary Nephron



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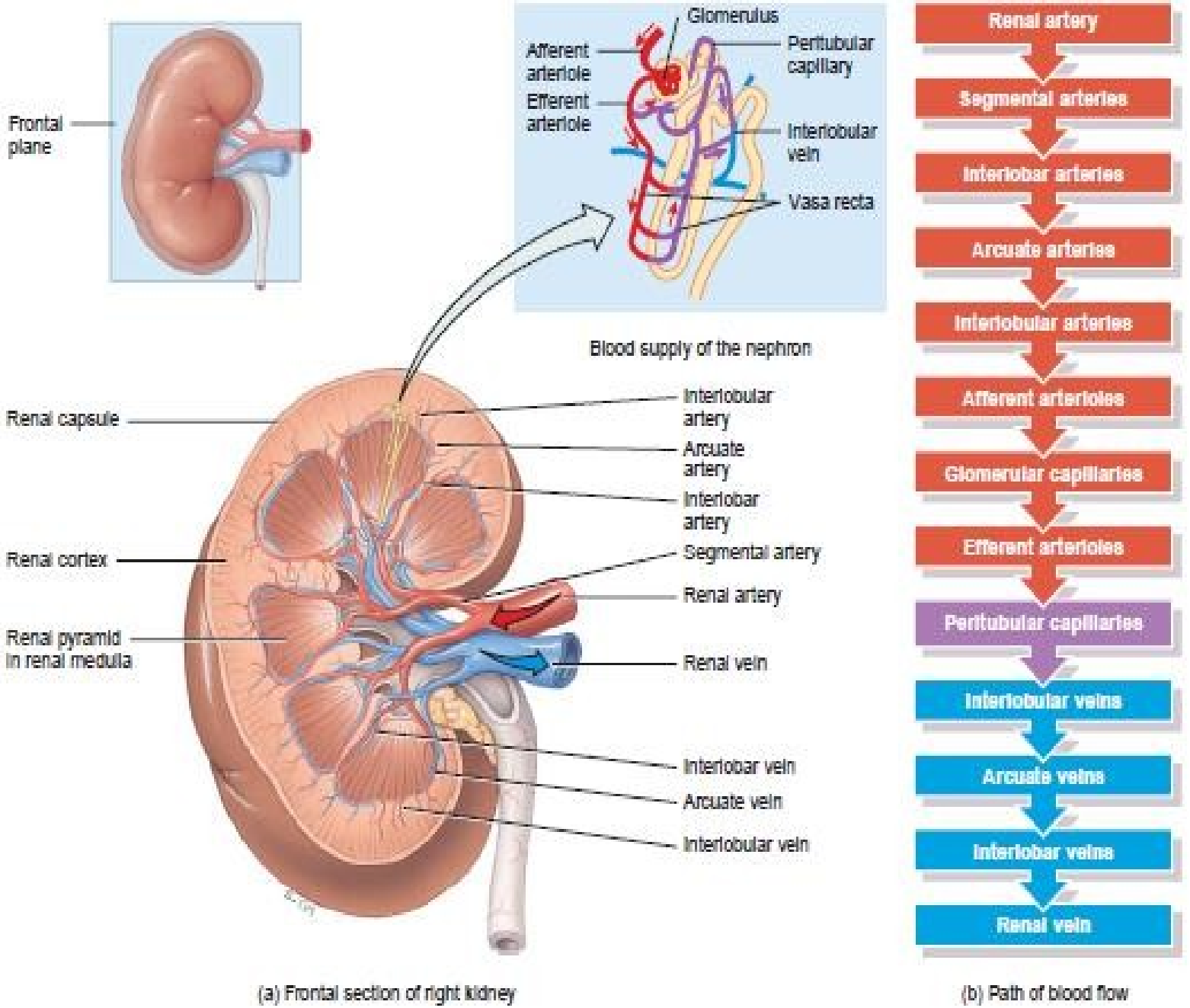

Frontal plane
Glomerulus
Afferent arteriole
Efferent arteriole
Peritubular capillary
Interlobular vein
Vasa recta
Blood supply of the nephron
Renal capsule
Renal cortex
Renal pyramid in renal medulla
Interlobular artery
Arcuate artery
Interlobar artery
Segmental artery
Renal artery
Renal vein
Interlobar vein
Arcuate vein
Interlobular vein
(a) Frontal section of right kidney
Renal artery
Segmental arteries
Interlobar arteries
Arcuate arteries
Interlobular arteries
Afferent arterioles
Glomerular capillaries
Efferent arterioles
Peritubular capillaries
Interlobular veins
Arcuate veins
Interlobar veins
Renal vein
(b) Path of blood flow

Summary:
Blood will enter nephron through afferent arteriole > glomerulus (filtration occur)

1. Blood will be filtered into Bowman's capsule except for proteins and cells.
2. Part of the blood will be reabsorbed into peritubular capillaries.
3. For rapid elimination, some blood will be secreted into the tubules.
4. The remaining will be urinary excreted as urine.

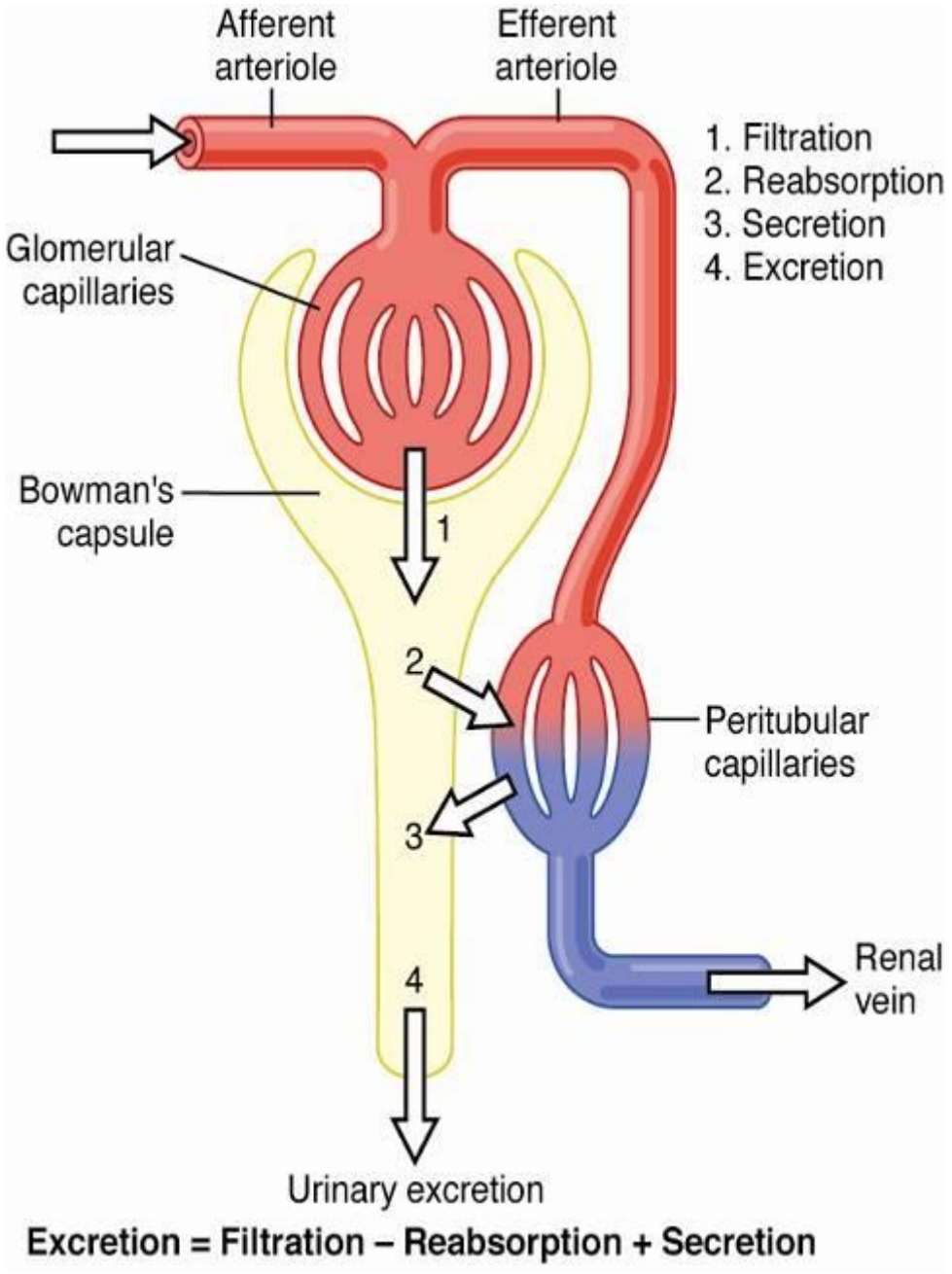


Figure 26-9

Basic Mechanisms of Urine Formation

- (1) Filtration : **(no energy required) (occur in glomerulus)**

Passive, somewhat variable, not selective (except for proteins), averages 20% of renal plasma flow

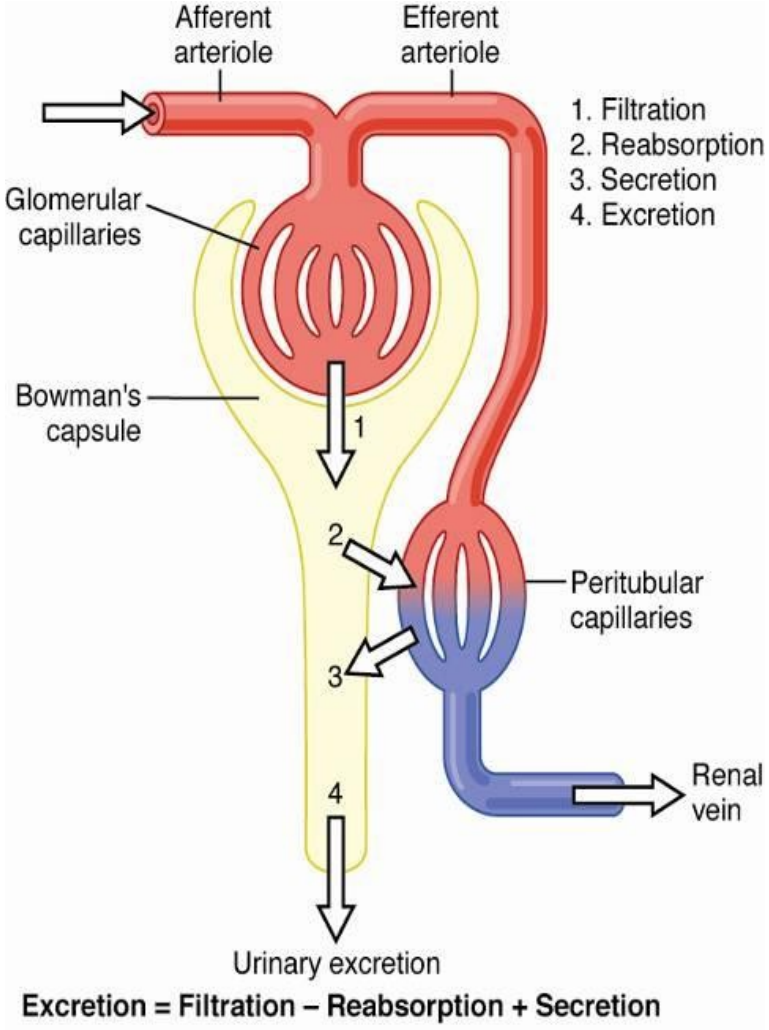
- (2) Reabsorption : **(conservation of substances)**

highly variable and selective

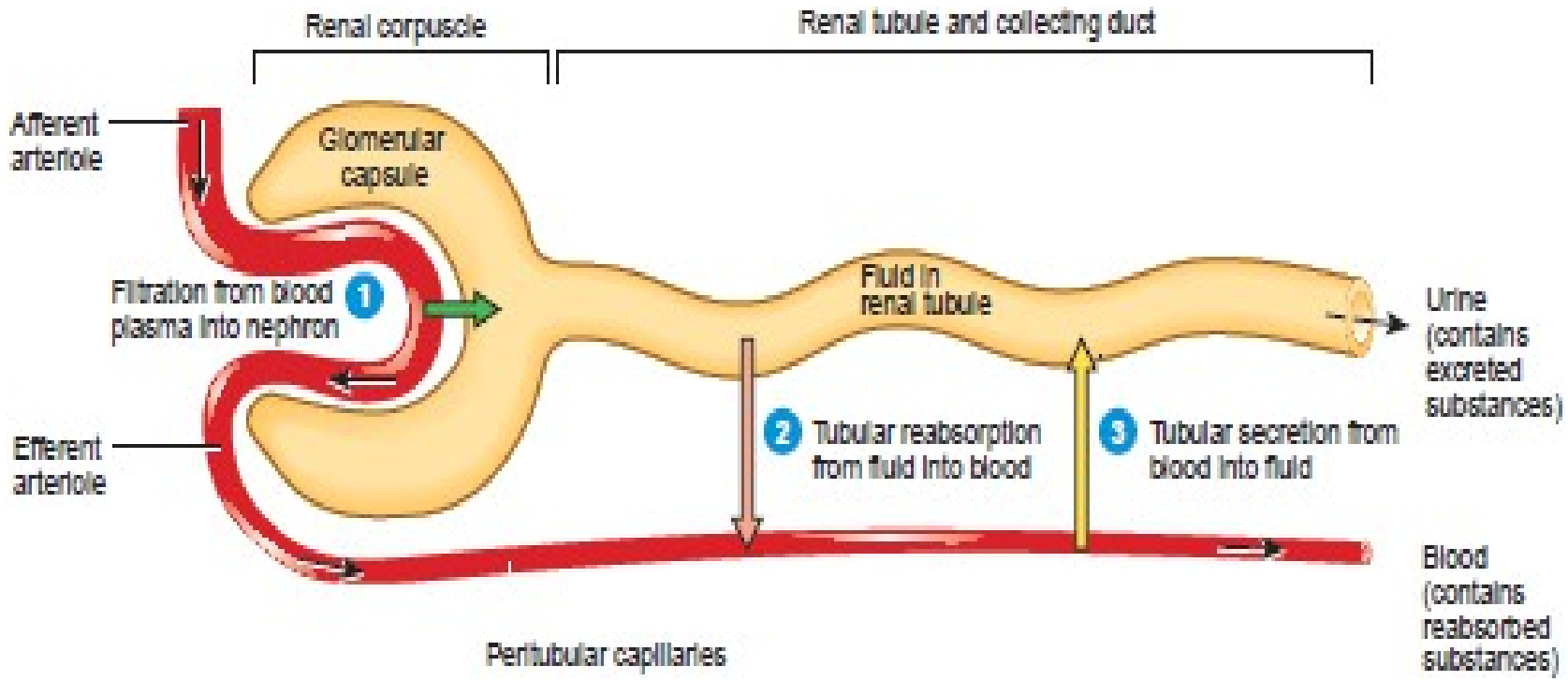
most electrolytes (e.g. Na^+, K^+, Cl^-) and nutritional substances (e.g. glucose) are almost completely reabsorbed; most waste products (e.g. urea) poorly reabsorbed **(Because they are toxic)**

- (3) Secretion : highly variable; important for rapidly excreting some **(High rate) (Active)**

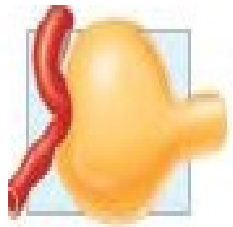
waste products (e.g. H^+), foreign substances (including drugs), and toxins

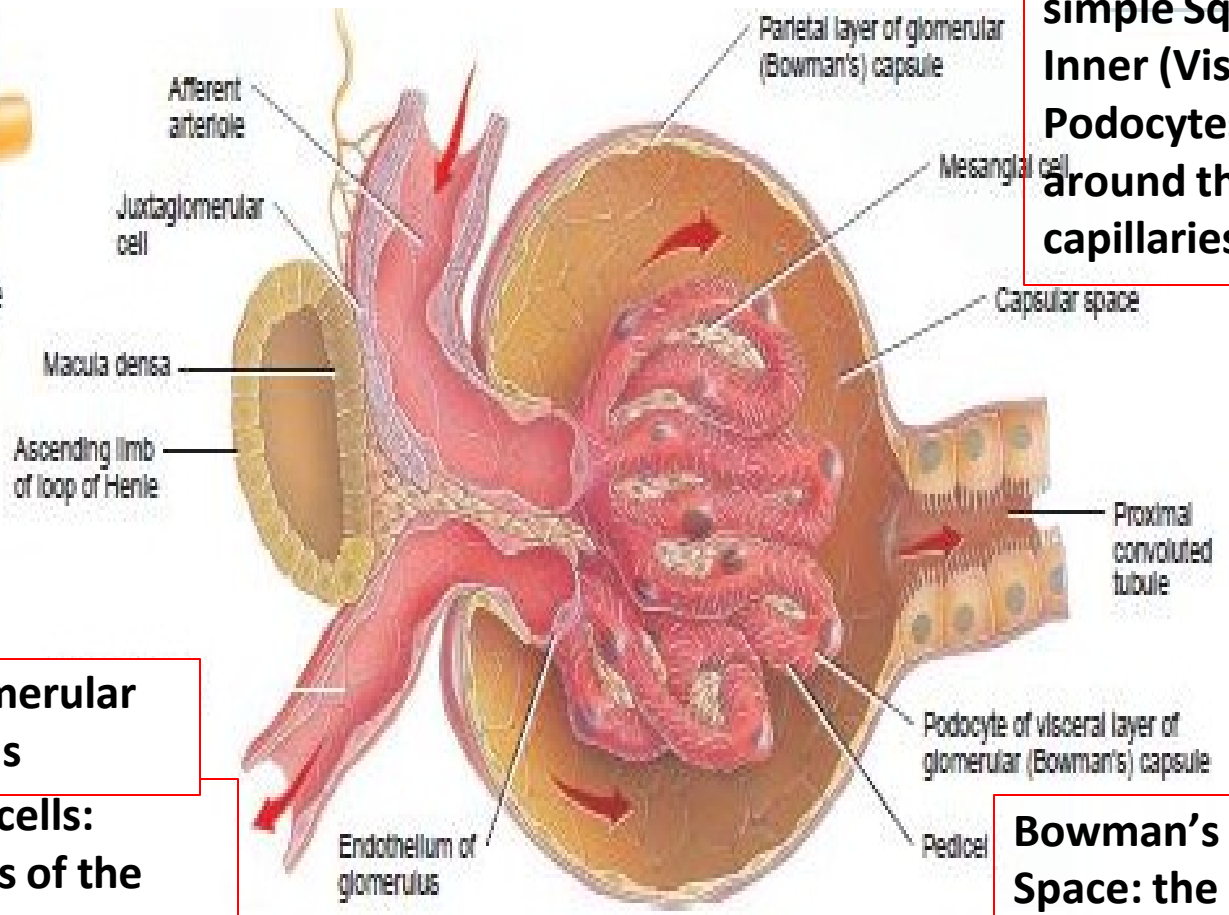


Nephron Structure and Function



Renal Corpuscle





Glomerular or Bowman's Capsule:
Outer:
simple Squamous epith.
Inner (Visceral):
Podocytes that wraps around the glomerular capillaries

Macula Densa: cells in the final part of the ascending loop of Henle

Juxtaglomerular Apparatus

Juxtaglomerular cells: modified SM cells of the wall of afferent (or efferent) arterioles that are proximate to the Macula Densa.

Mesangial cells: are contractile cells lies in the clefts between afferent and efferent arterioles

Bowman's or Capsular Space: the space between the outer and inner layers of the capsule which is filled with the filtered fluids

The Bowman's capsule is made up of 2 layers:

1. Outer (parietal)
2. Inner (visceral layer)

The inner layer is composed of specialized cells = Podocytes (they wrap the glomerular capillaries throgh pedicles).

The outer surface is composed of single layer of simple squamous of epithelial cells

The space between these 2 layers contains the filtered fluid.

As we know, arterioles have a layer of smooth muscle cells.
Afferent arteriole has a modified smooth muscle cells = juxtaglomerular cells.

Juxtaglomerular cells + Macula densa = Juxtaglomerulus apparatus.

Juxtaglomerular apparatus function:
Renal autoregulation process (increase or decrease filtration rate).

Mesangial cells: Contractile cells found in spaces between afferent and efferent arterioles.
Function: Adjusment of blood flow coming into the glomerulus.

Filtration Membrane

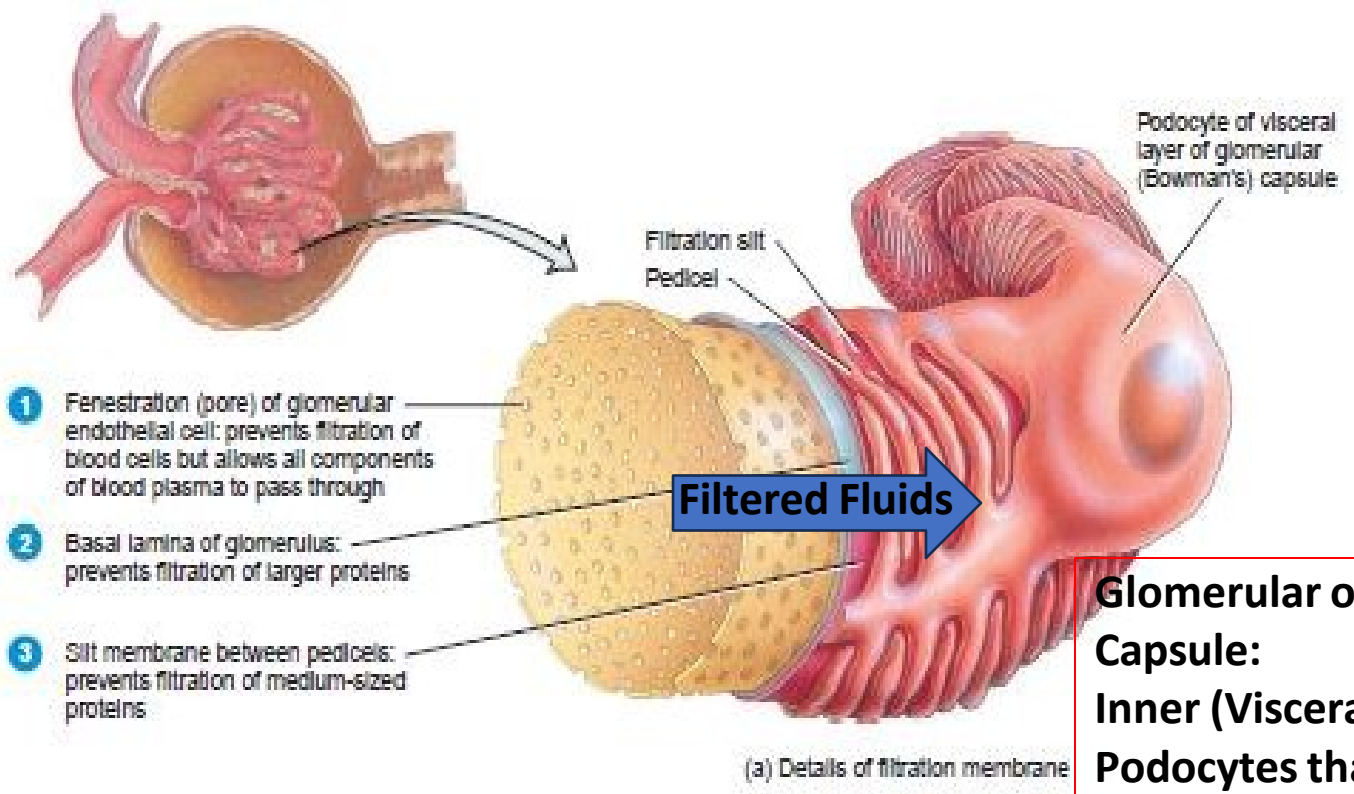
Filtered Fluid from glomeruli Should pass through:

Filtered Fluids

Glomerular Capillaries

Podocytes of Bowman's Capsule

Capsular Space



Glomerular or Bowman's Capsule:
Inner (Visceral):
Podocytes that has projections called pedicles wraps around the glomerular capillaries

Glomerular capillary filtration barrier

Please Watch This Video Demonstrating

[Glomerular Filtration animation - YouTube]

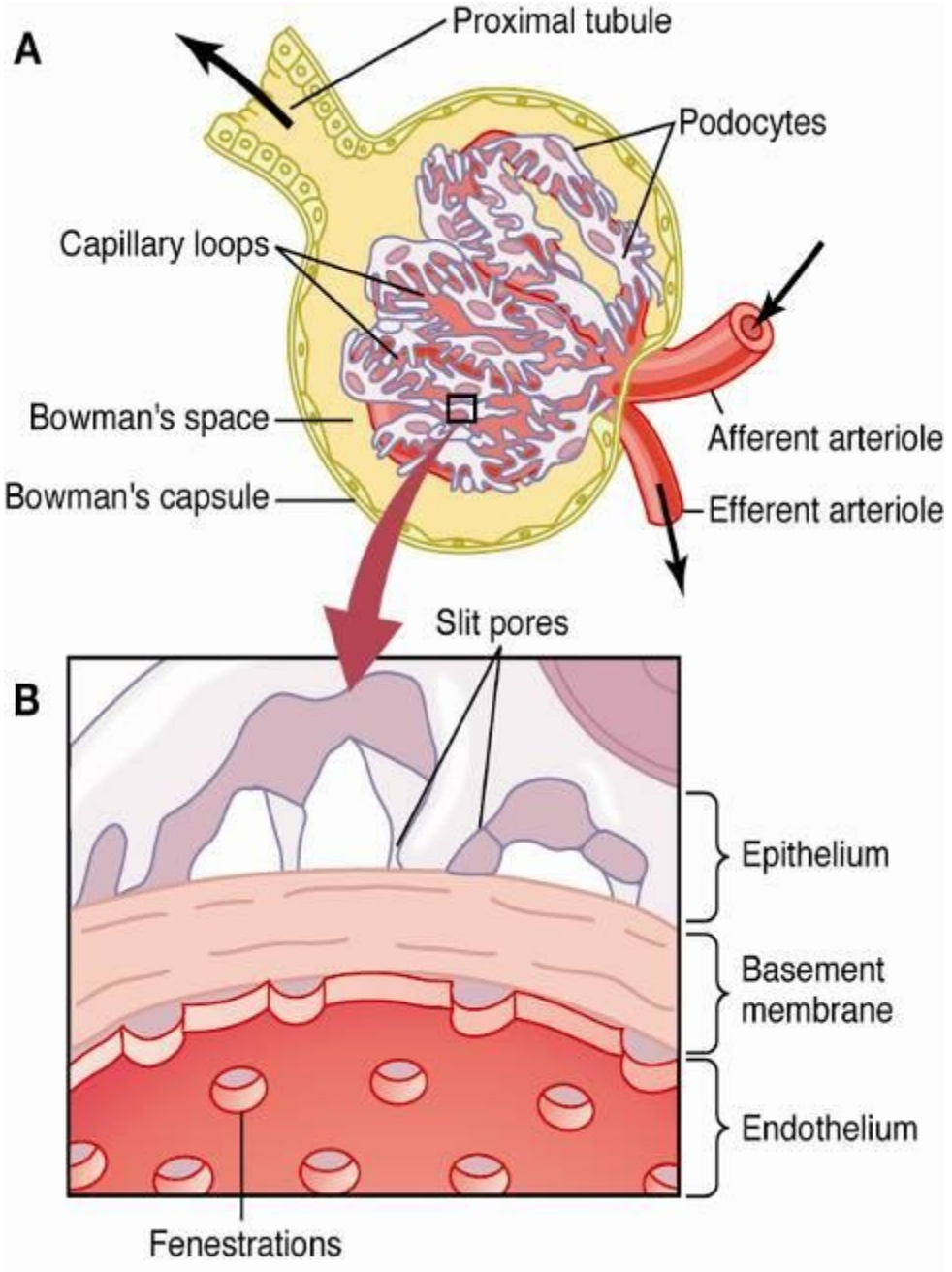


Figure 26-11

Renal Tubules and Collecting Ducts

- **Proximal Convoluted Tubule (PCT):** Simple cuboidal epithelial cells with brush borders.
- **Loop of Henle(LH):** Simple Squamous (thin), Cuboidal(Thick).
- **Distal Convoluted Tubule (DCT):** simple cuboidal.
- **Last part of DCT and Collecting Duct (CD):** Simple cuboidal consisting of:

1. **Principal Cells: contains receptors for ADH and Aldosterone.**
2. **Intercalated Cells : Blood PH regulation**

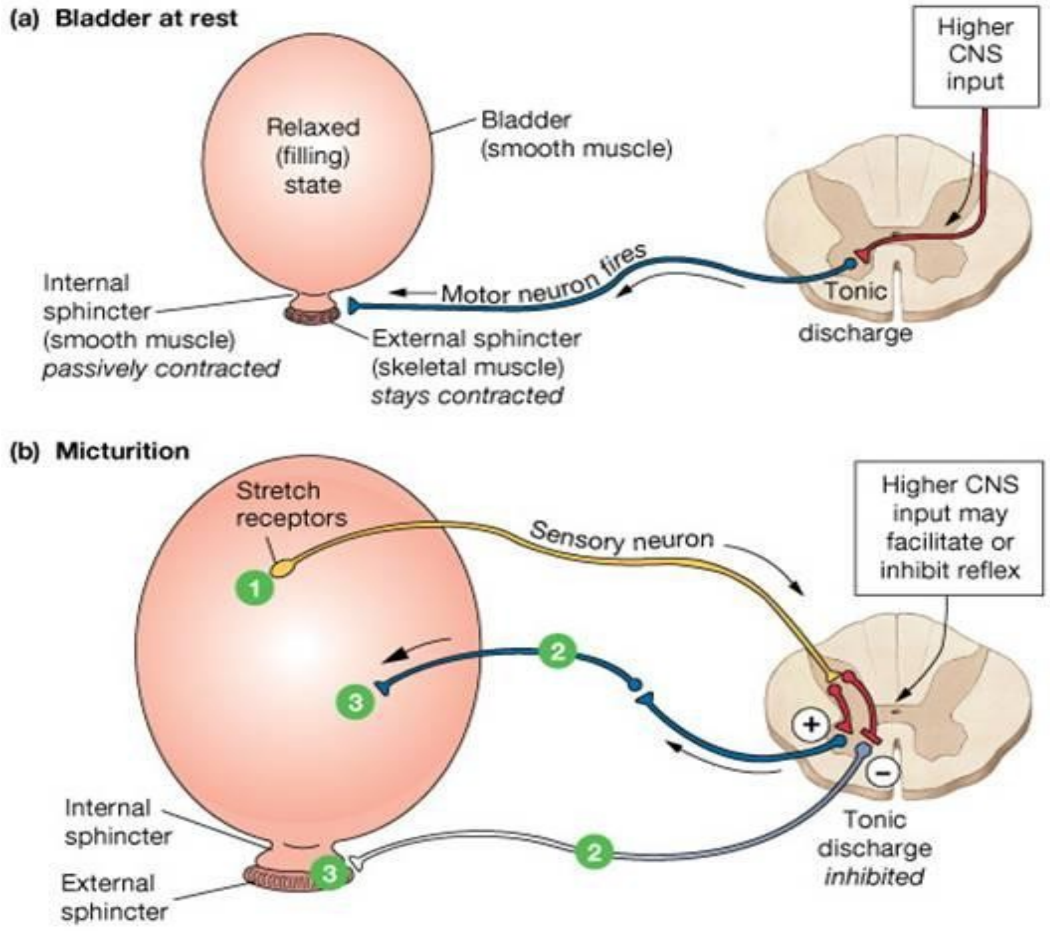
Micturition

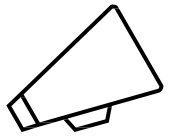
Reflex that is very important to eliminate the urine

- From the kidneys urine flows down the ureters to the bladder propelled by peristaltic contraction of smooth muscle. The bladder is a balloon-like bag of smooth muscle = detrussor muscle, contraction of it empties bladder during micturition.
- **Voluntary** and **involuntary** muscle contractions.
- Bladder can hold 700-800 ml (differes between males and females)
- Volumes exceeding (200-400)stretch bladder walls and initiate micturation reflex:
- ***Spinal reflex (micturition center in the spinal cord)***
  - Parasympathetic impulses from the spinal cord causes ***bladder to contract and the Internal urethral sphincter to relax.*** ***(In normal conditions, there is a tonic contraction).***
  - **Internal sphincter (smooth muscle) opens.**
  - Simultaneously mict. C inhibits the external sphincter (skeletal muscle) and then it relaxes. (This part can be controlled voluntary)

Micturition

Revision of previous slide.





Link To Lect 1 Recording

https://fisjo-my.sharepoint.com/:v:/g/personal/e_zayadneh_ju_edu_jo/Ecdxiv3SB0ZHhKOTIQl6GvoBYDjuKAyoJmjGceUdGBmEtg?e=u8qfyE

End of Lecture 1

Additional sources

1. Ninja nerd

<من صام رمضان ثم أتبعه ستًا من شوال كان كصيام الدهر>

VERSIONS	SLIDE #	BEFORE CORRECTION	AFTER CORRECTION
V1→ V2	28	collecting tubule	connecting tubule
V2→V3	26 44	We change point 2 and 3 Glomerulus	See slide number 26 plz Bowman's capsule

امسح الرمز و شاركنا بأفكارك لتحسين أدائنا !!