النادي الطلابي
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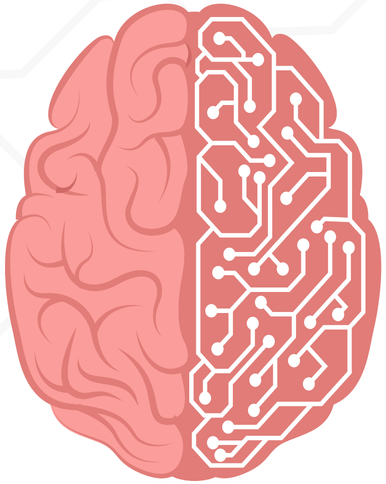

Physiology - GUS

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Urinary System: Renal Physiology for Medical Students

Reference: Guyton

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Learning Objectives

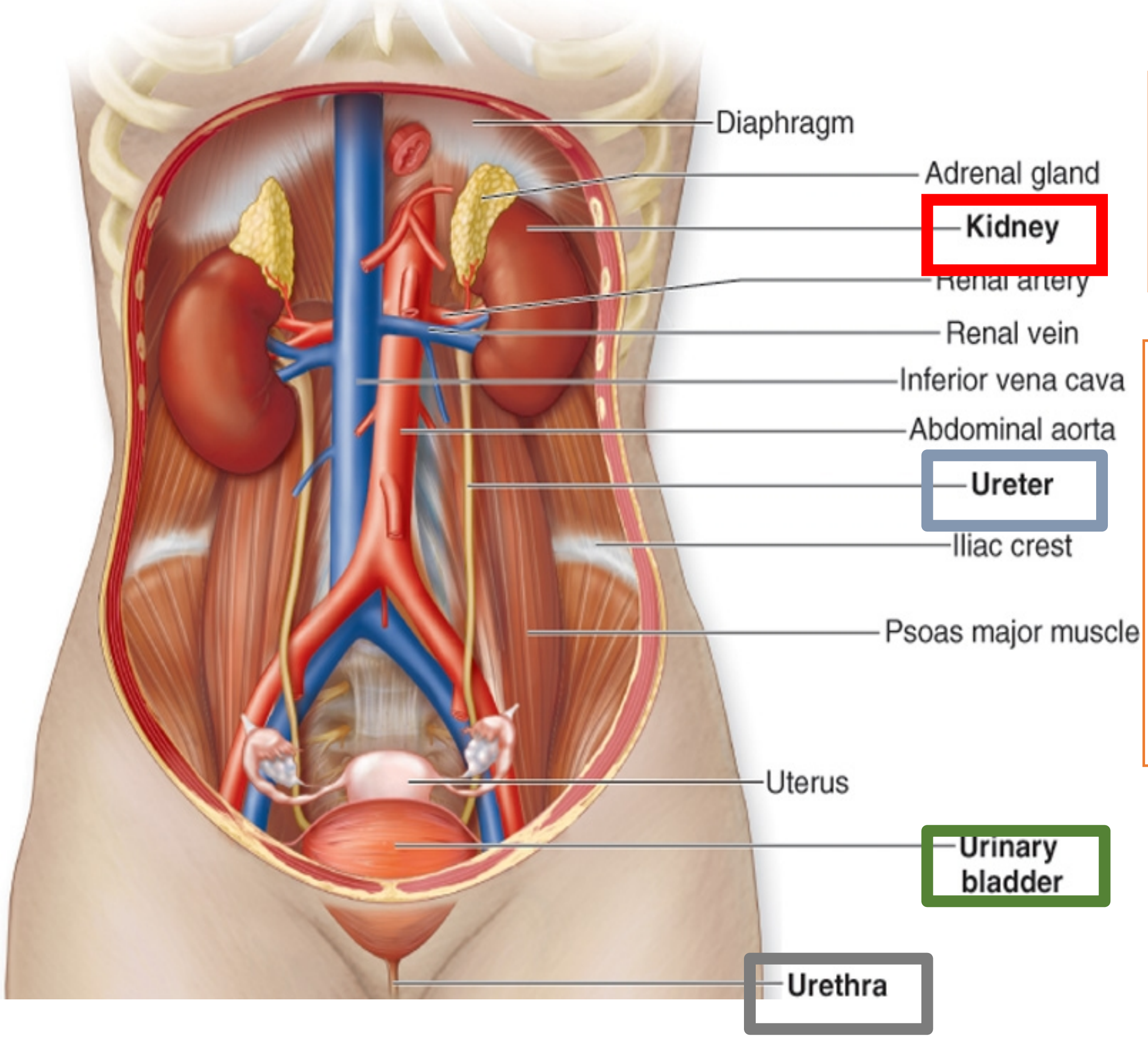
- Identify the functions of the urinary system, particularly the kidneys.
- Describe the external and internal anatomical features of the kidneys.
- Describe the structure of the nephron including the renal corpuscles and the renal tubules.
- Dissect the blood supply of the kidney including nephrons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

The Urinary System

- 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.



The blood supply of the kidneys is composed of two renal arteries and two renal veins.

Urine formation is a continuous process and so the urinary bladder stores the urine until it is convenient for the person to urinate which is called MICTURITION in physiology.

Urinary System Function

- **Filters Waste Products from Blood** Excretion of excess substances and fluids

-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**

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**.

Urine formation is excretion

Urinary System Function

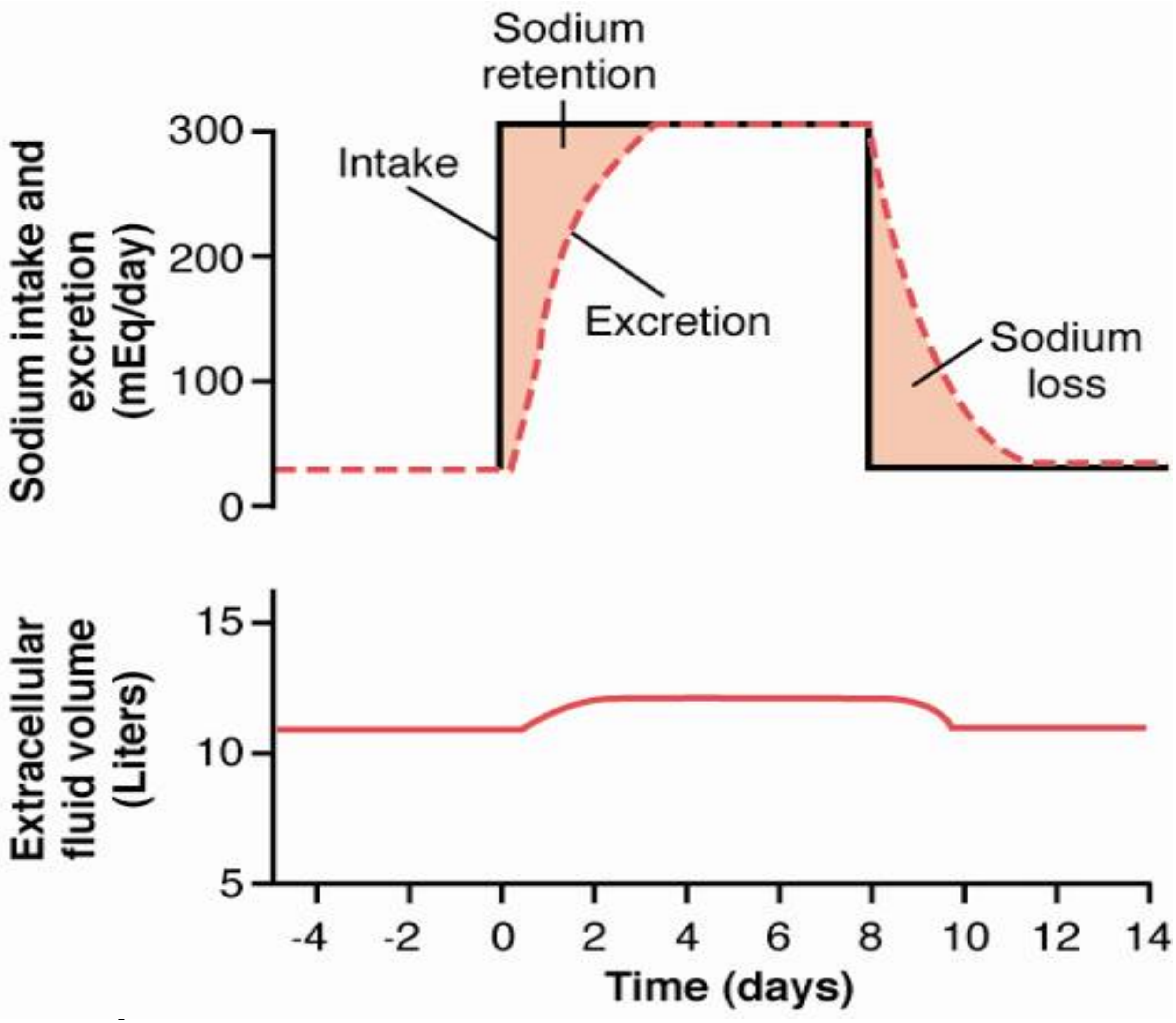
The kidney might filter some of the nutrients from the bloods and since lots of energy is spent in order to gain these nutrients, the urinary system ensures they do not get excreted with the urine by reabsorption, and none of them exit the body through the urine.

- **Conserves Valuable Nutrients**
  The urinary system ensures glucose, amino acids and other valuable nutrients are not lost from the urine. Kidneys can also use glutamine to release glucose in gluconeogenesis.

Because the kidney is a highly demanding organ and it needs a source of energy, it has the ability to convert some amino acids like glutamine into glucose to use as an energy source if the body was running out of glucose or other resources.

- **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.

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



Urinary System Function

- **Regulates Blood pH**
  -The urinary system regulates blood pH by regulating the number of H+ and bicarbonate ions (HCO_3^-) lost in the urine.

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

Urinary System Function

The kidneys have a very important function in fluid homeostasis by adjusting the amount of fluid that is going to be excreted; they adjust the volume of the ECF, and this is done via the renin-angiontensin system

- **Regulates Blood Volume**
  The urinary system regulates blood volume 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

After many steps, renin results in the formation of angiotensin II, and one of its functions is to retain salt and then as a result retain water and decrease the loss of water and increase blood volume

Urinary System Function

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

We consider this an endocrine function because the kidney serves as an endocrine gland that secretes erythropoietin which is a growth factor for the bone marrow to produce differentially and specifically RBCs.

Erythropoietin is important for the regulation of the formation of RBCS, so whenever there is hypoxia (reduction in the oxygen delivery to the body), the kidney will increase the production of erythropoietin and will release it into the blood which in turn will go to the bone marrow and induce the production of RBCs from the proerythroblasts to increase the number of RBCs and correct the hypoxia.

Urinary System Function

- **Stores Urine**
  - The **bladder** stores the urine until it is convenient to excrete it.
- **Excretes Urine:** The **urethra** transports urine from the urinary bladder to the outside of the body.

Urinary System Function

The activation of vitamin D takes place in the kidney and this hormone is important for the calcium absorption in the digestive system

- **Produces and secretes hormones**:

- **Calcitriol**: The active form of vitamin D.
- **Renin:** activates the renin-angiotensin-aldosterone system, thus regulating **blood pressure regulation** & Na+, K+ balance.

Renin results in the production of angiotensin II which regulates the volumes of fluids as well as blood pressure

- **Prostaglandins/kinins:** bradykinin = vasoactive, leading to modulation of renal blood flow & along with angiotensin II affect the systemic blood flow

Kinins are vasodilators, and when there is vasodilation, we increase blood flow to the organ or to the nephron and that is their main function, enhancing blood flow to the kidneys. That is why it is contraindicated to take any medications that might block the production of prostaglandins in patients with reduced kidney function, these drugs include NSAIDs.

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

Kidneys and urinary system

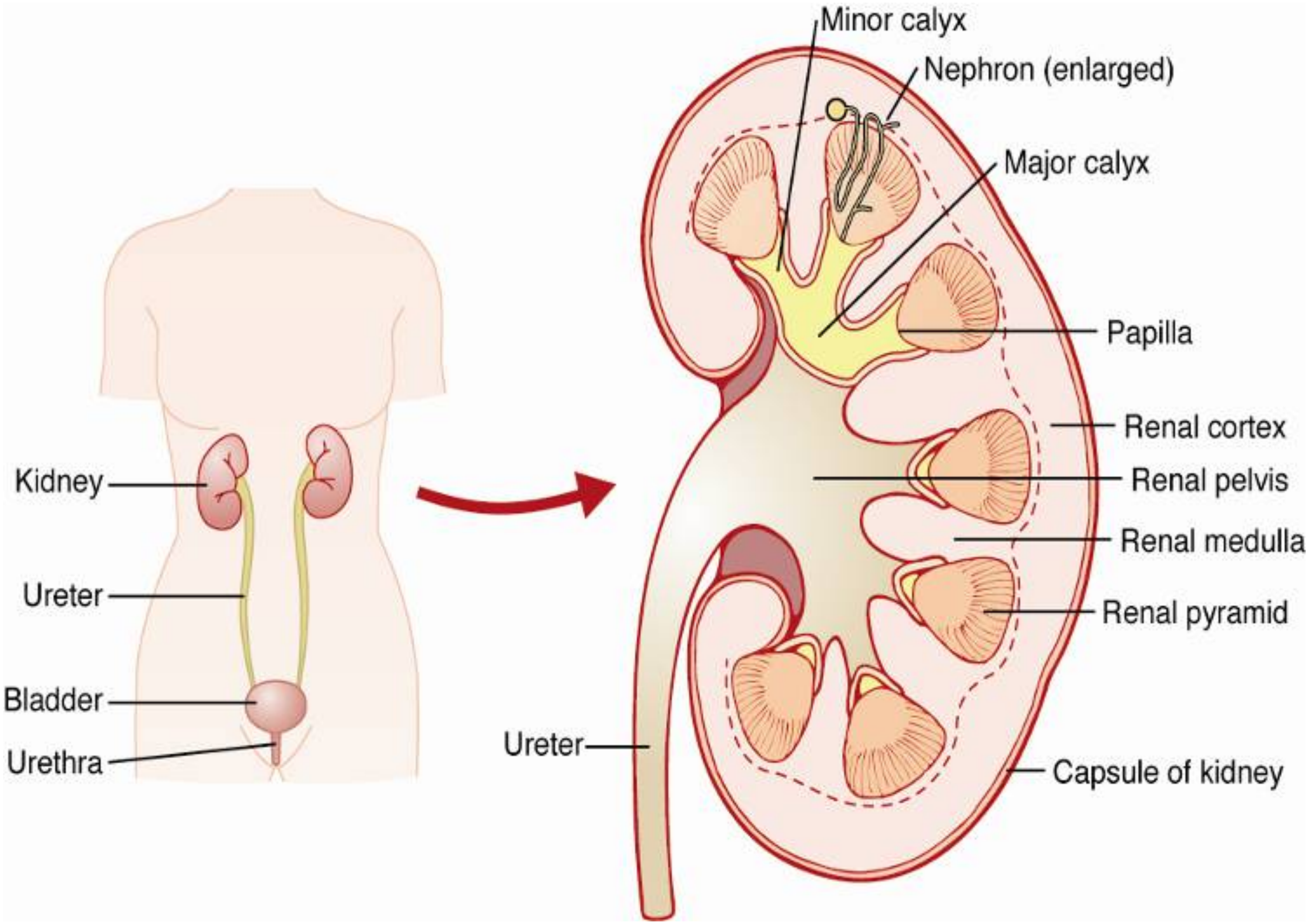
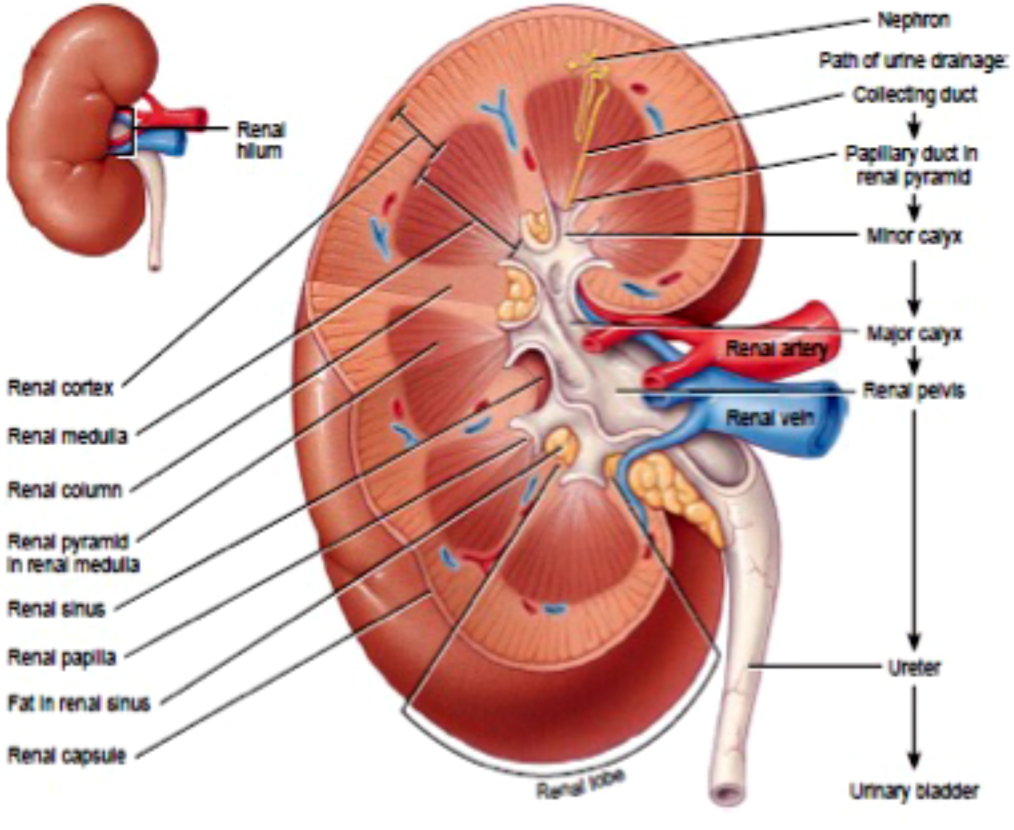


Figure 26-3

Kidney Structure



(a) Frontal section of right kidney

This is a frontal section of the kidney, it is composed of an outer structure which is lighter in color and dense, and an inner structure.
The outer structure is called the kidney cortex and the inner layer is called the medulla of the kidney.

In the medulla, we have pyramidal shapes; these pyramids have a tip that we call the renal papilla which are the end of the papillary ducts. The urine that has been formed in the functional unit, the nephron, ends with the papillary duct that empties at the renal papilla into the minor and major calyces (chambers of the kidney through which urine passes), and then we have a larger container for the urine which is the renal pelvis.
The renal pelvis empties all the urine inside it through the ureters to be stored in the urinary bladder.

In the hilum of the kidney, we have the renal artery and the renal vein, so there is a circuit of blood. Blood comes from the renal artery which will supply the structures of the kidney and then this blood will return via venules and veins to be collected in a renal vein to go back in the circulation and end up in the inferior vena cava to the heart.

We have other structures such as:

- the renal columns which separate the pyramids
- the renal capsule which is the connective tissue covering the kidney.

Major blood vessels of the kidney

There is a renal artery for each kidney and a renal vein, and we notice in the distribution of blood that blood vessels get smaller and smaller and branch to distribute blood all over the kidney.
The small veins anastomose and join to form bigger veins until they form the renal vein in the end.

The arcuate artery will give rise to afferent arterioles which end in the nephron and give to a capillary system called the glomerulus. The renal glomerulus will then give rise to an efferent arteriole. This is an exception to capillary beds which often start with an arteriole and then a venule. Here, we have an afferent and an efferent arteriole.

In the glomerulus, filtration will take place.
If we follow the efferent arteriole, we can see that it will give rise to many other capillaries, and these are called peritubular arterioles because they are close to the tubular system of the nephron.

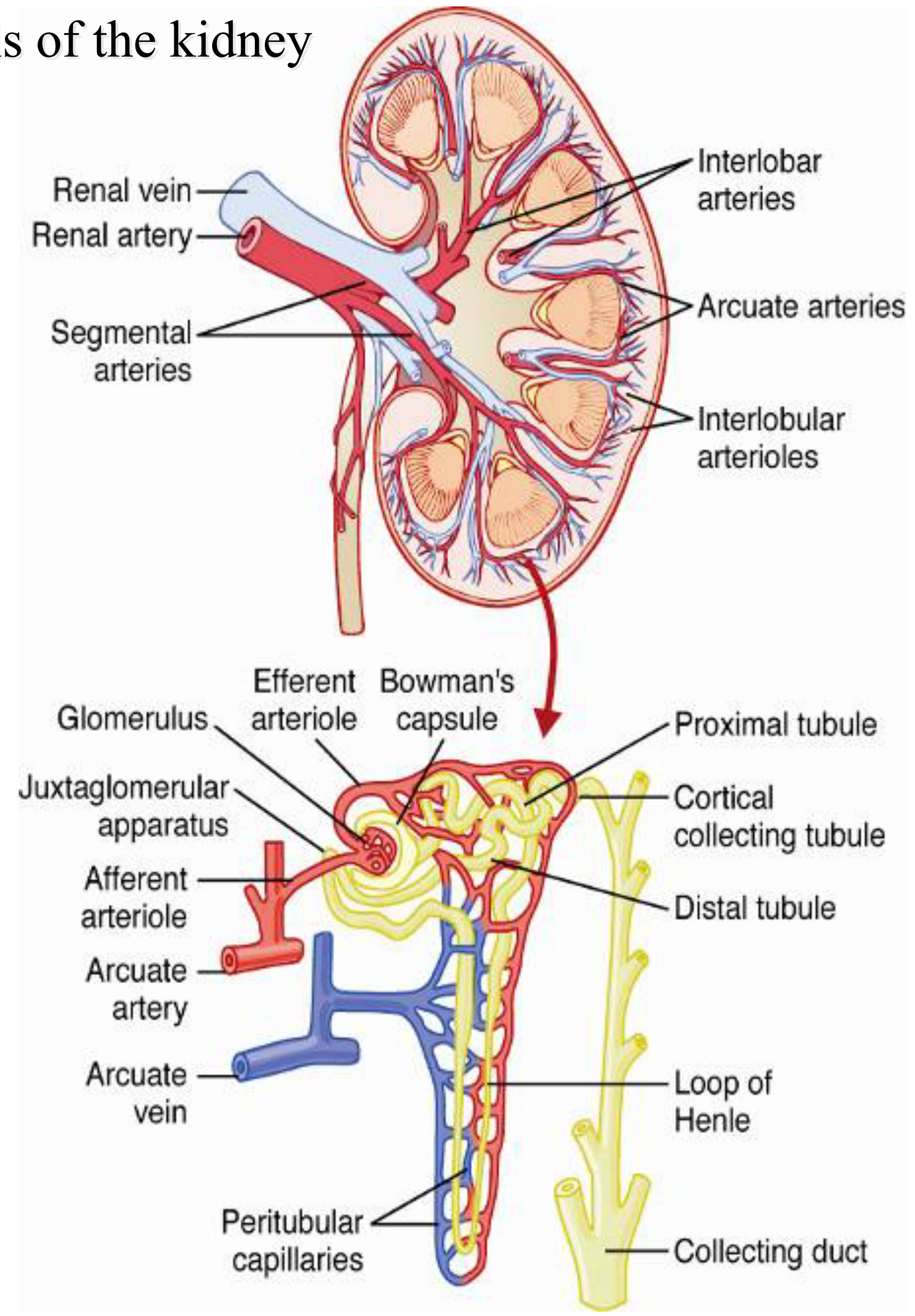
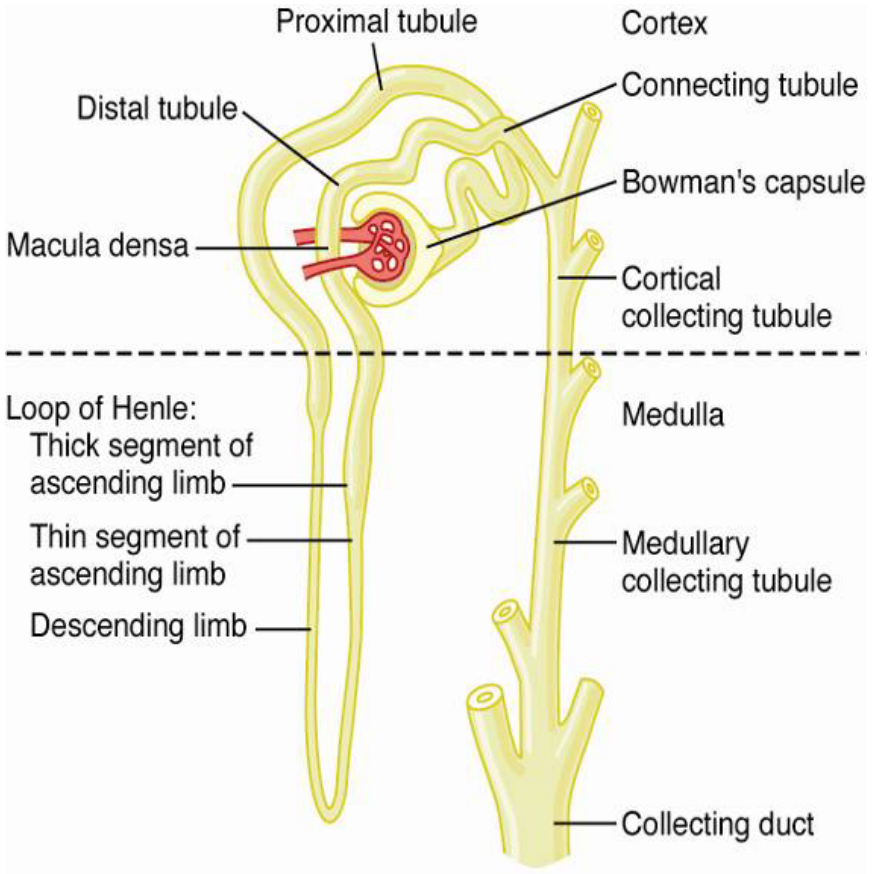


Figure 26-3



This is the structure of the nephron.
The blood supply of the nephron starts with the afferent arteriole, the glomerulus and the efferent arteriole. Around this system, a balloon-like structure forms and is called the renal capsule or Bowman's capsule.

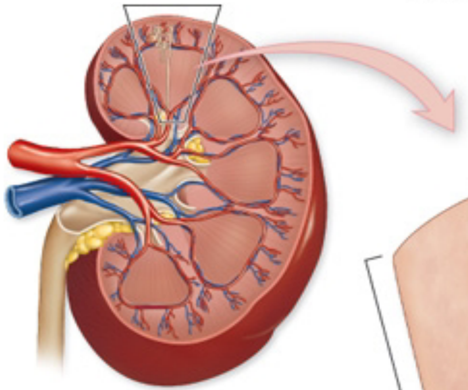
Figure 26-4

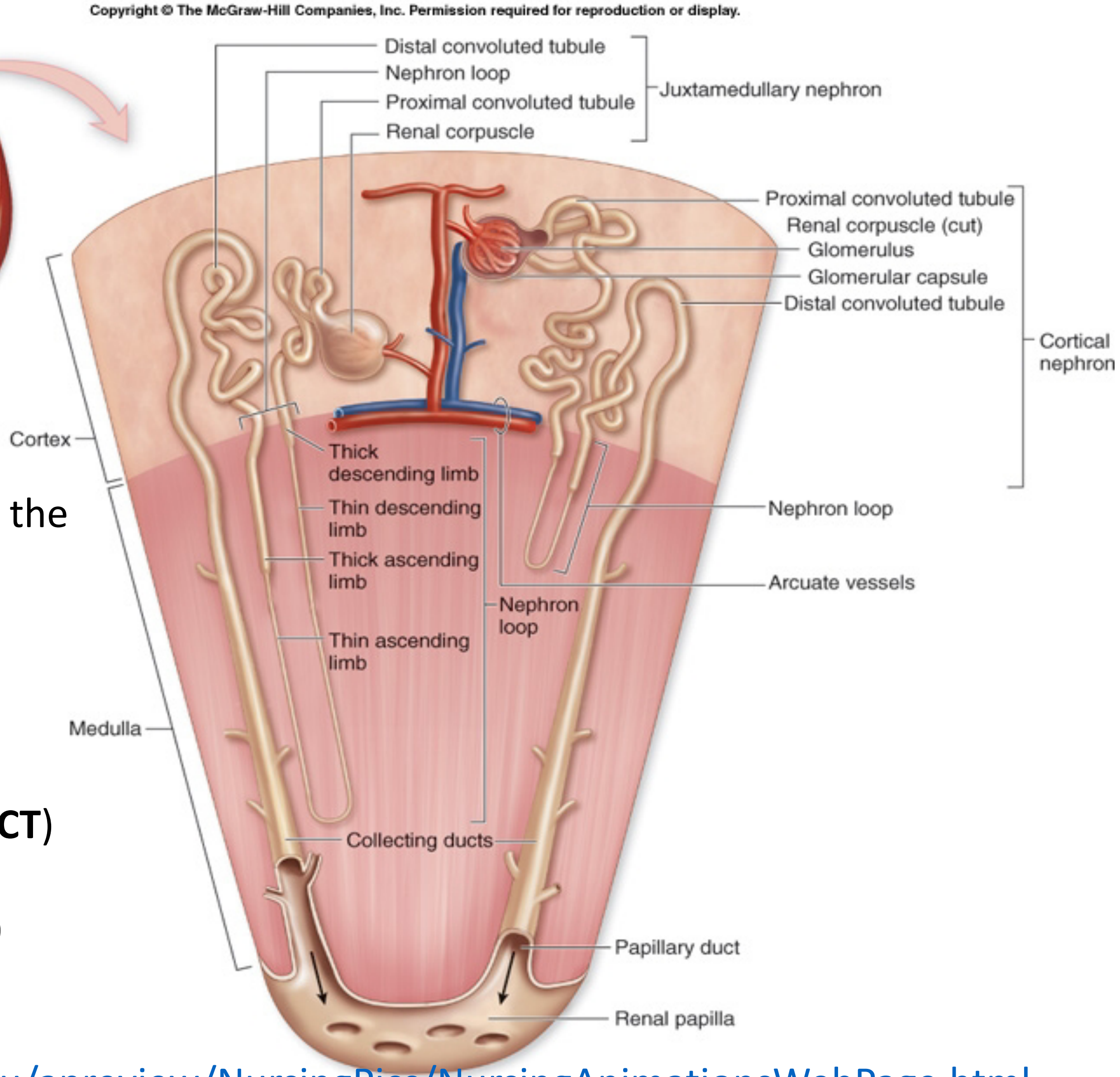
Bowman's capsule is like a balloon in structure, it is very close to a ball (the glomerulus) and the ball is pushing the outer surface of the balloon inward, so the glomerulus isn't actually inside the capsule it is only touching its outer surface and denting it.

Bowman's capsule is attached to a tubular system which is very convoluted, and we call it the proximal convoluted part of the tubular system, then there is a part that looks like a hair pin loop, and this is what we call the loop of Henle.
The loop of Henle is composed of a thin descending segment and then a thin ascending segment, then it gets thick, so we call it the thick ascending segment of the loop. We also call them limbs.

Then the tubule gets convoluted again, but this time we do not call it proximal, instead we say the distal convoluted tubule. This part is connected to the connecting duct which connects (ha) it to the collecting duct.
The collecting tubule connects many of the connecting tubules where urine will flow from all these tubular parts to the collecting tubule.
The collecting tubule terminates at the end in the renal papilla and will excrete all the filtered fluid into the renal calyces and renal pelvis.

The Functional Unit of The Kidney?





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

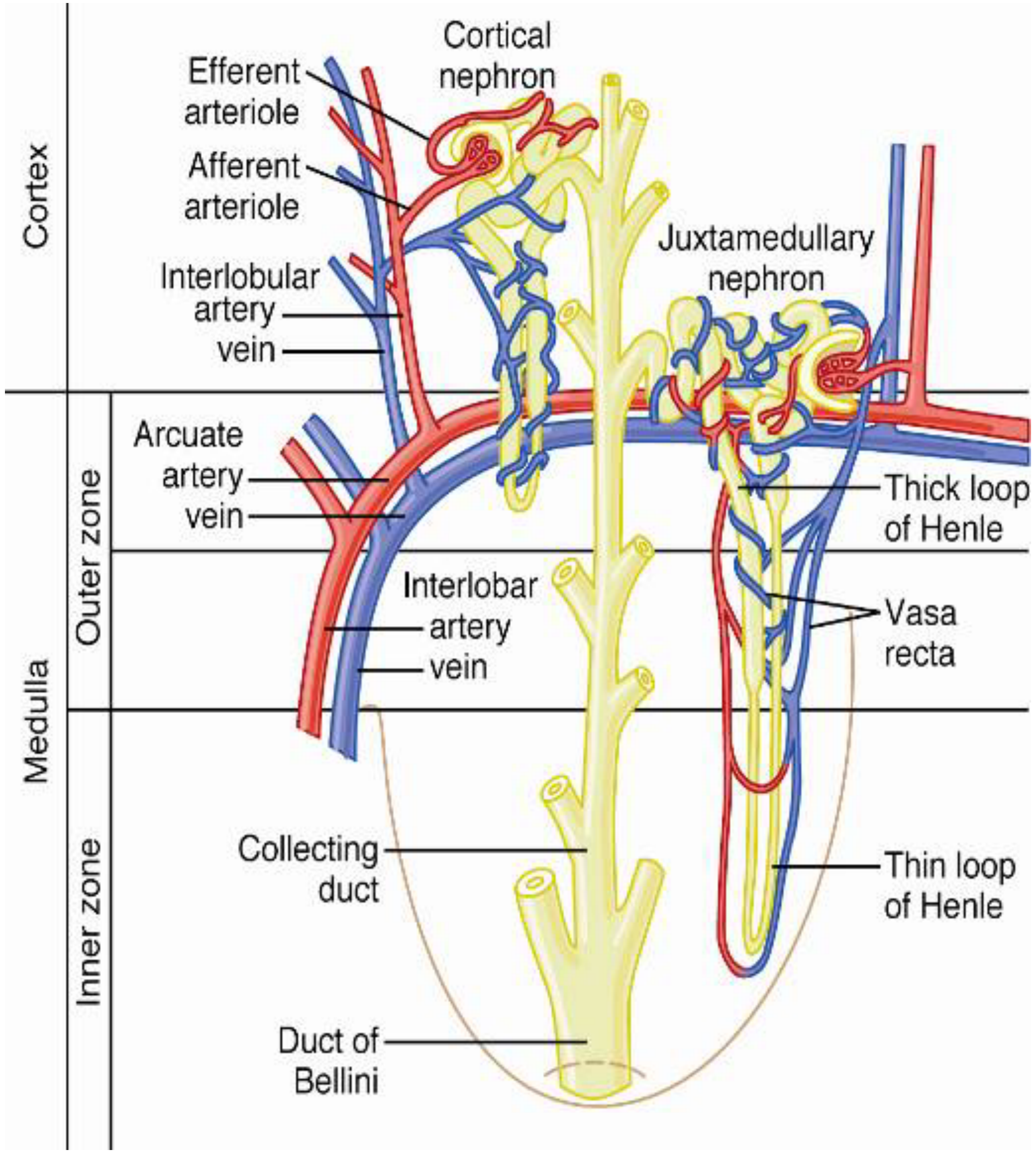
❑ Renal Tubules

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

http://www.austincc.edu/apreview/NursingPics/NursingAnimationsWebPage.html

Cortical and juxtamedullary nephrons

Here we can see that there are two types of nephrons. Depending on the **location** of the nephron, we have **cortical** nephrons (mainly lie in the cortex of the kidney and make up the majority of the nephrons) and **juxtamedullary** nephrons which are on the border between the cortex and the medulla: their system extends very deep into the medulla, they are very long, and they represent the minor percentage of the total number of nephrons.



This is a demonstration of their blood supply:
in the **juxtamedullary** nephrons we call the peritubular capillaries **vasa recta.** They have a very unique distribution between the venous and arterial capillaries. The veins and arteries lie **parallel** to each other. These vasa recta are very important in concentrating urine.
The **cortical** nephron is **short** and most of it lies in the cortex. Most of the loop of Henle and glomeruli and renal corpuscle lie in the cortex.

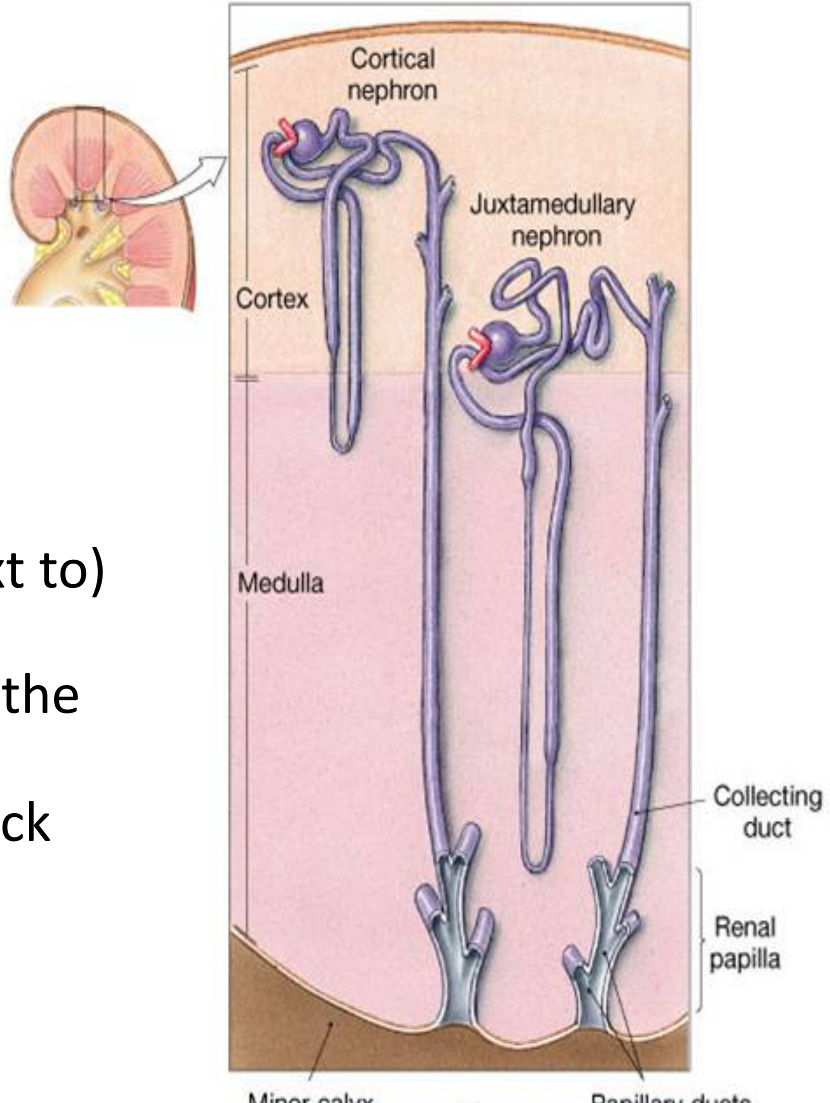
Figure 26-5

Types of Nephrons

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

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

Represents only 15% of the nephrons



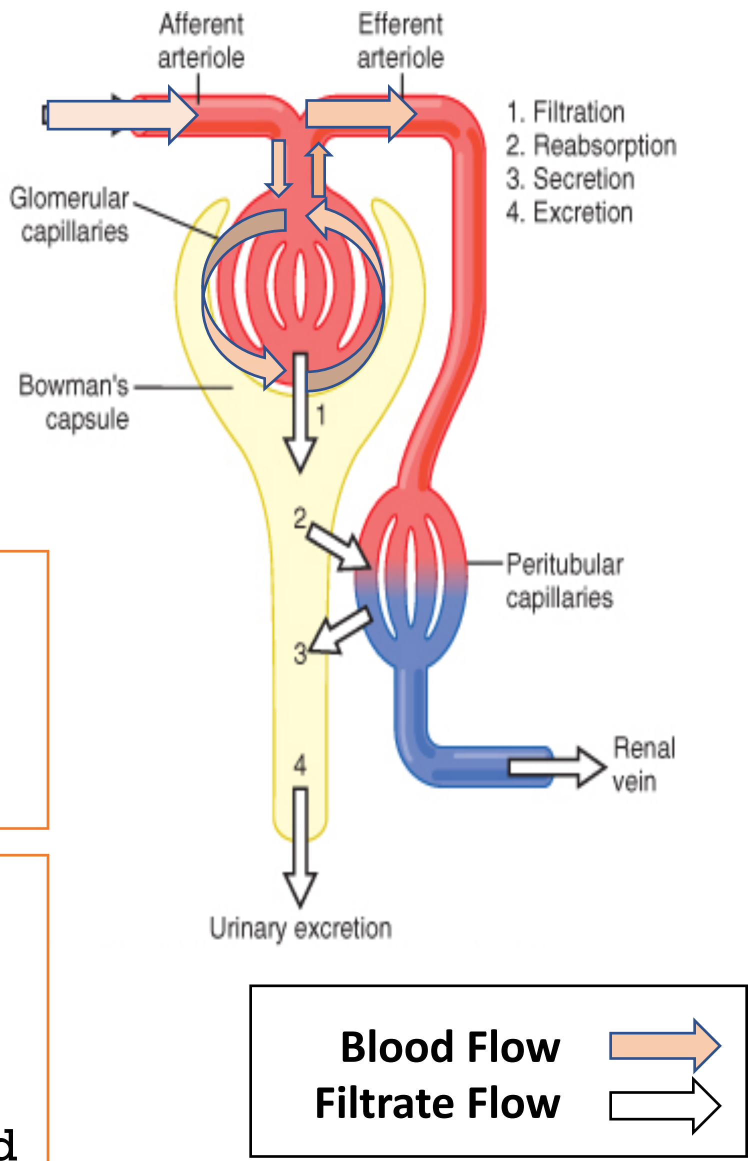
(a)

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**

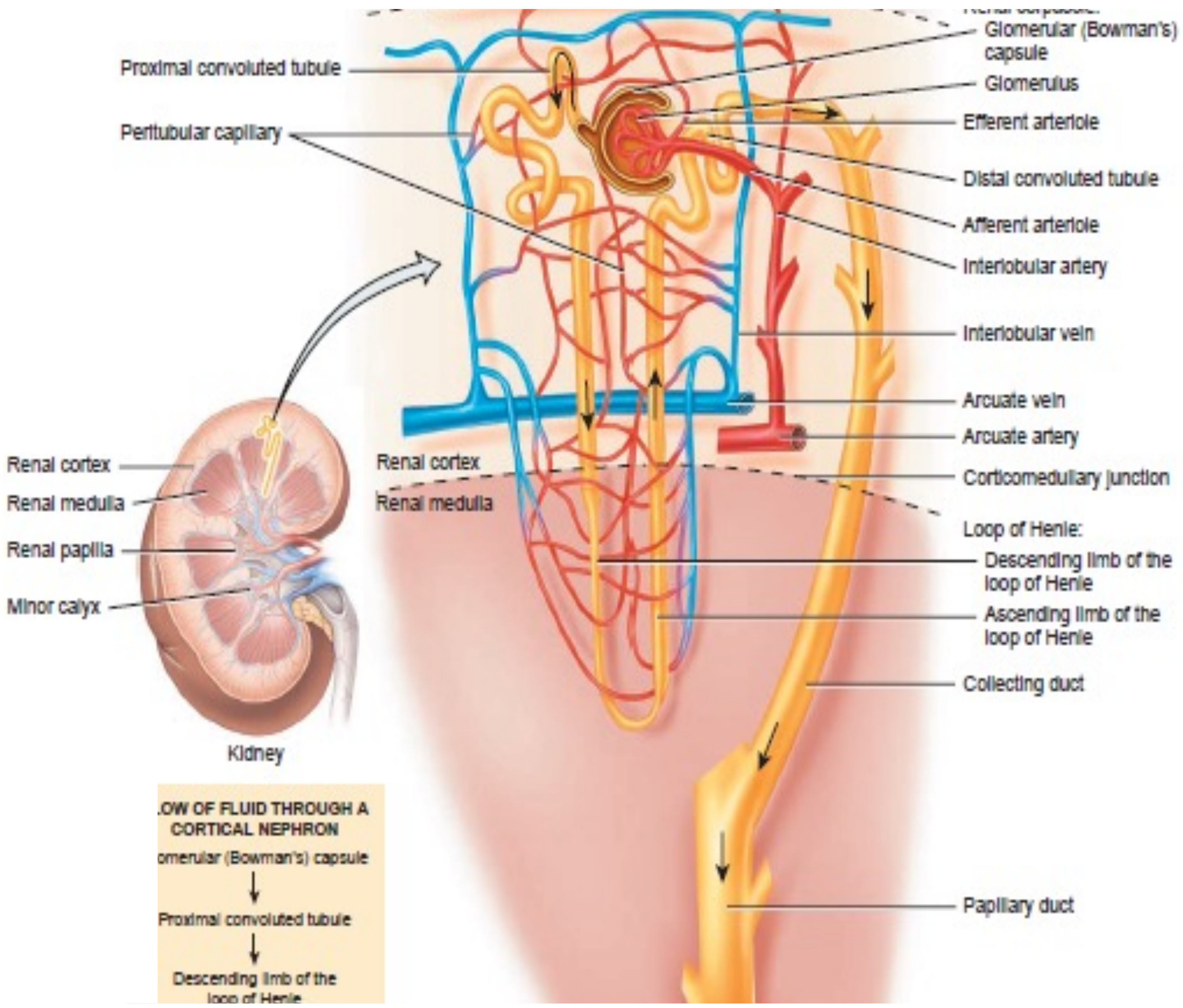
After that, blood will travel surrounding the tubular system and will give rise to another capillary system which we call the peritubular capillaries or vasa recta in the juxtamedullary nephrons. These capillaries will surround the tubular segment. Finally, the blood will end up in the renal vein.

1: **filtration**
2: **reabsorption:** some of the filtered fluid components will be reabsorbed back to the circulation
3: **secretion:** the direction is opposite to reabsorption; some of the unwanted waste products are eliminated from the blood directly from the peritubular capillaries to be excreted in the filtered fluid. This process adds up to the elimination done by filtration and it increases the efficiency of waste elimination



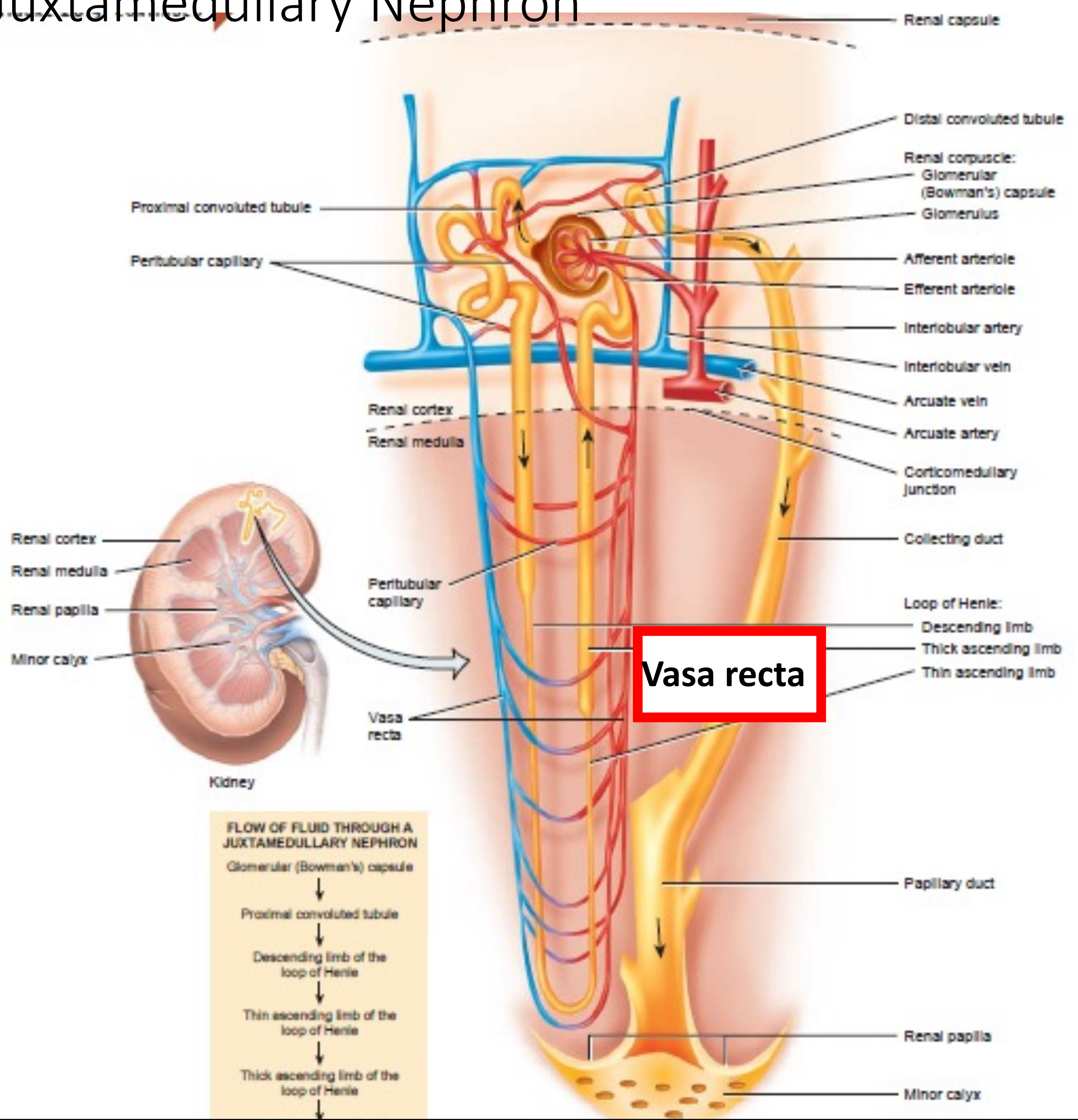
Blood Supply: Cortical Nephron

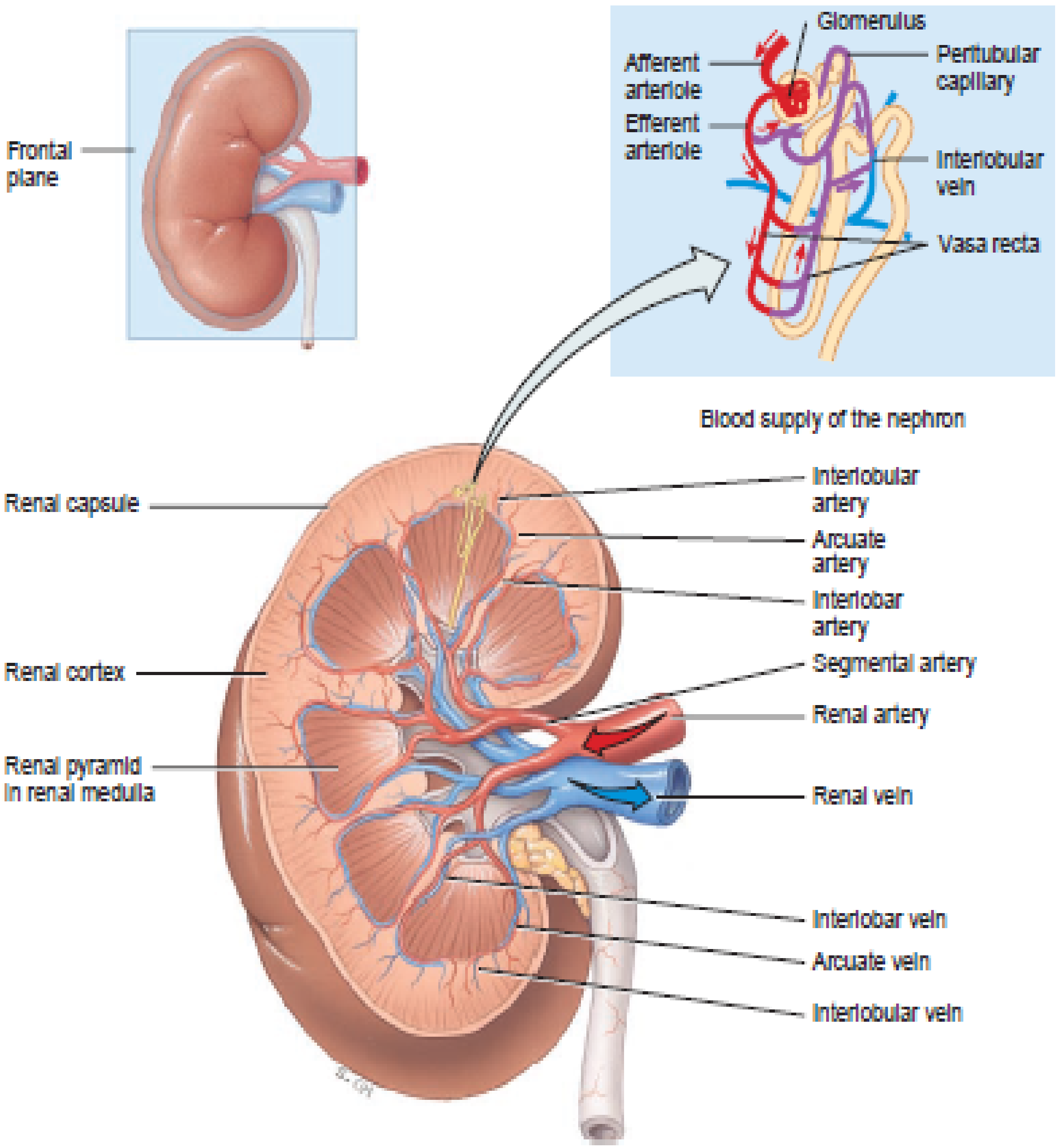
This is the blood supply of the **cortical** nephrons; we have the peritubular capillaries surrounding the tubules that start with an arterial side and end with a venous side.
Venules >> small veins >> larger veins >> renal vein
This is a complete circuit of blood that comes to supply the veins and then returns back to the venous stem of the body.



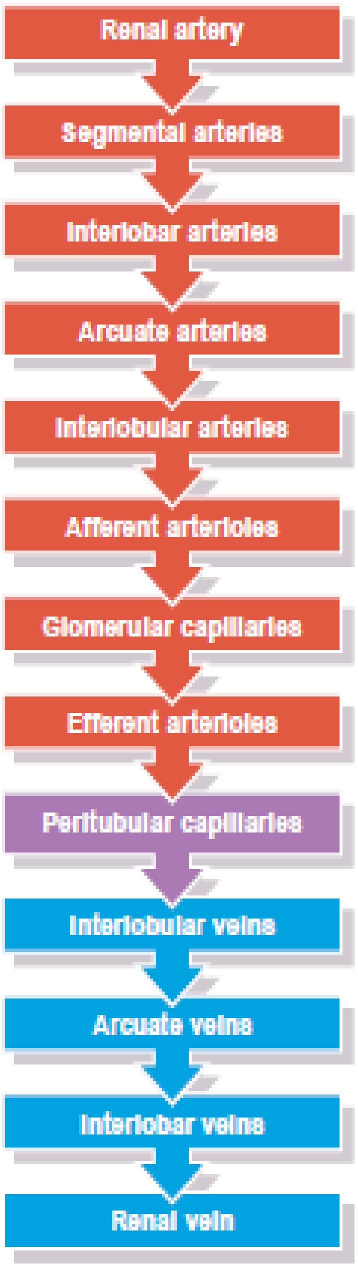
Blood Supply : Juxtamedullary Nephron

These are **juxtamedullary** nephrons. The peritubular capillaries are unique here, as we see the venous side is **parallel** to the arterial side and we call these **vasa recta**. We also have a very long loop of Henle. These capillaries are important for the function of the juxtamedullary nephron which is concentrating the urine.





(a) Frontal section of right kidney

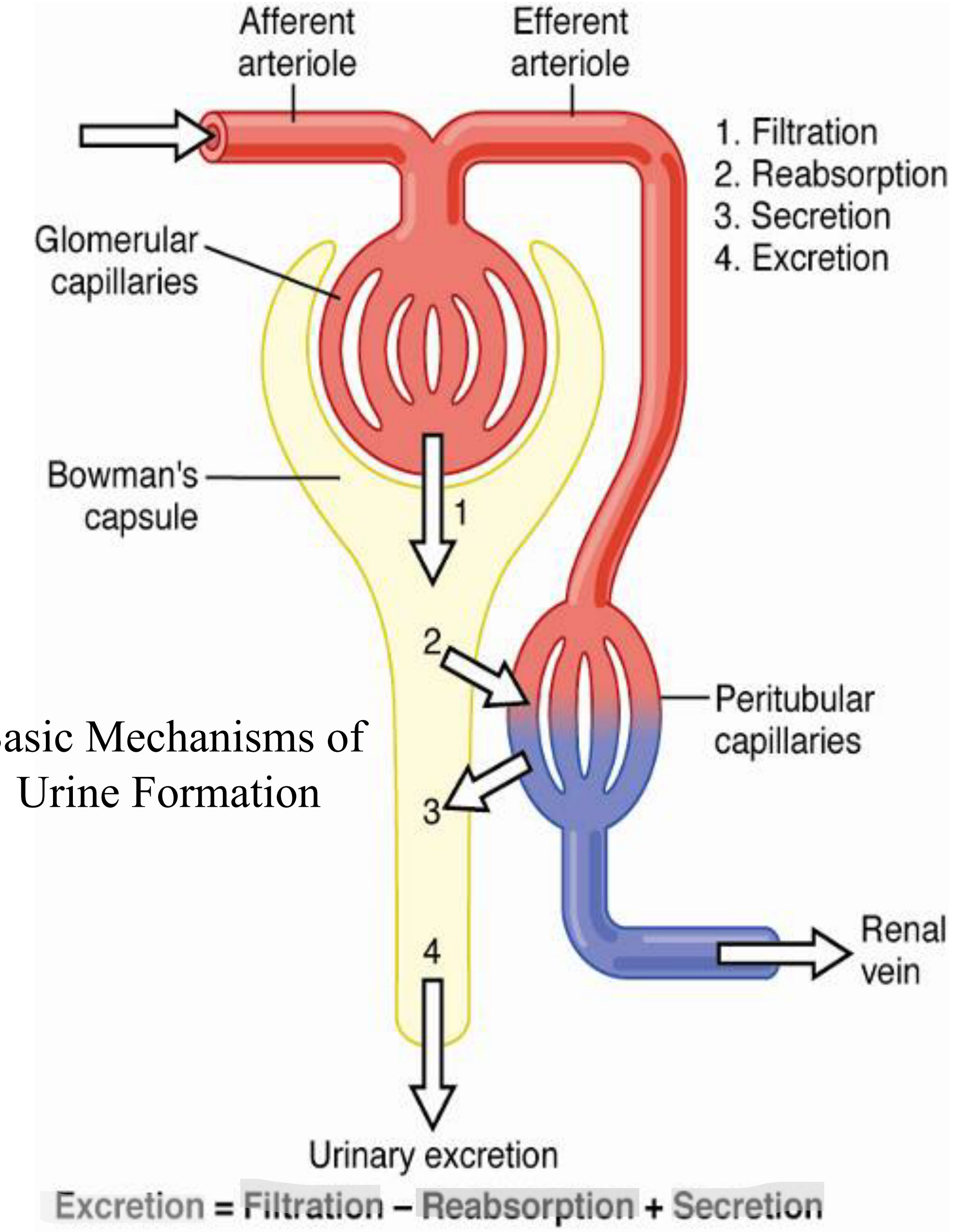


(b) Path of blood flow

Blood comes from the afferent arteriole and passes through the capillary system to get filtered. So, the first part of urine formation is the **filtration** process where fluid is filtered from the glomeruli and enters the Bowman's capsule.
Then blood will come out of the glomerulus via the efferent arterioles and then will give rise to peritubular capillaries that will surround the system.

In the peritubular capillaries we see another process which is important in urine formation, **reabsorption**. Some of the constituents of the filtered fluid will be reabsorbed back to the circulation because they are important to the body, and we cannot eliminate everything that has been filtered.

Then we have **secretion** from the venous side of the peritubular capillaries where some of the waste products or unwanted acids get eliminated from the peritubular capillaries directly into the filtered fluid. So, secretion adds up to the filtered fluid.
Finally, everything left that is **excreted** is called urinary excretion.



Basic Mechanisms of Urine Formation

Figure 26-9

Basic Mechanisms of Urine Formation

- Filtration :

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

It is exactly like putting fluid through a strainer (sieve) and whichever of the components inside this fluid fits within the pores will get out, and whatever stays, stays. (so that is why glucose is filtered out for example)

- Reabsorption:

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

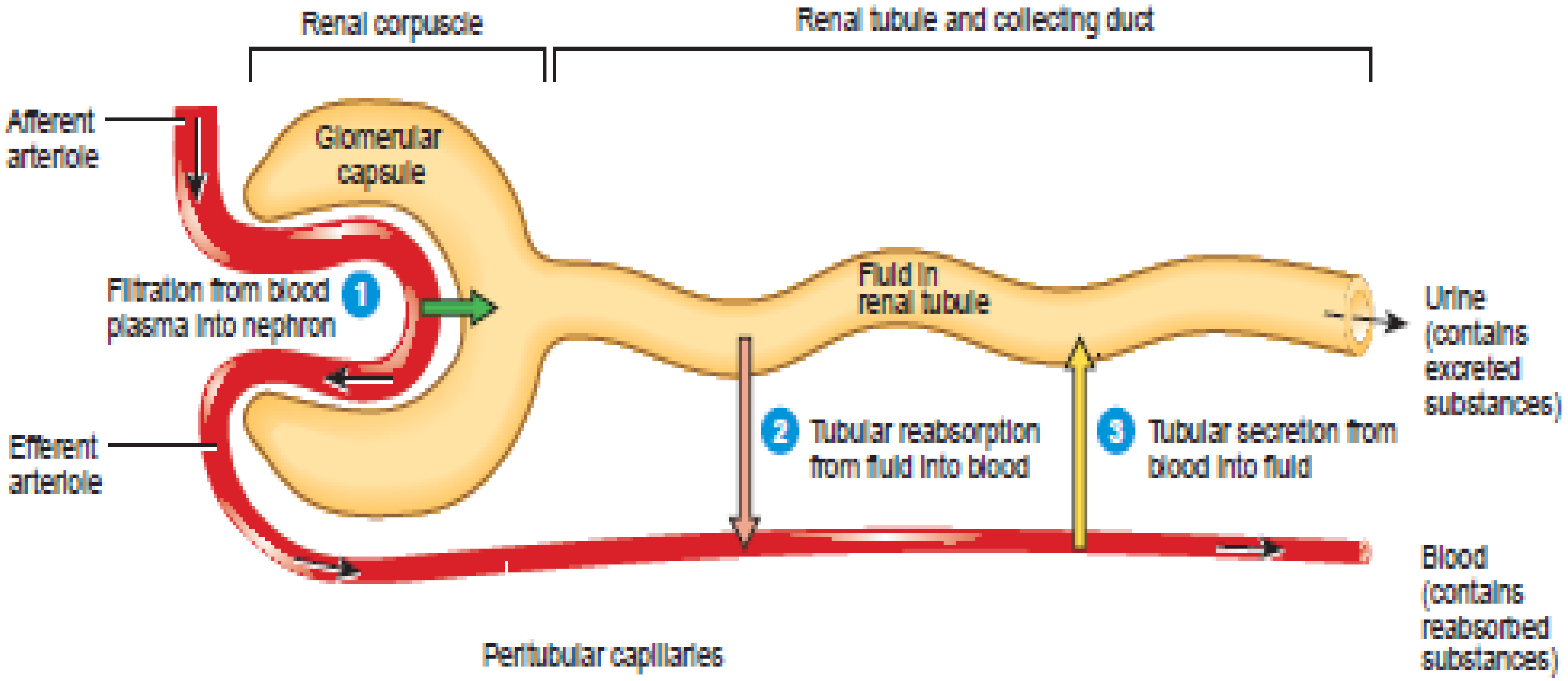
It is highly variable because it is mainly an active process, and it is highly selective because it takes place through highly selective transporters.
Electrolytes and nutritional substances cannot be transported by passive transport, and so there must be specific transporters to transport them.

Basic Mechanisms of Urine Formation

Secretion : highly variable; important for rapidly excreting some waste products (e.g. H^+), foreign substances (including drugs), and toxins

Secretion is highly variable because it depends on the availability of the amount of substances to be secreted.
This process increases the rate of elimination of waste products, so they don't stay for a long time in the body, adding to the filtration process.

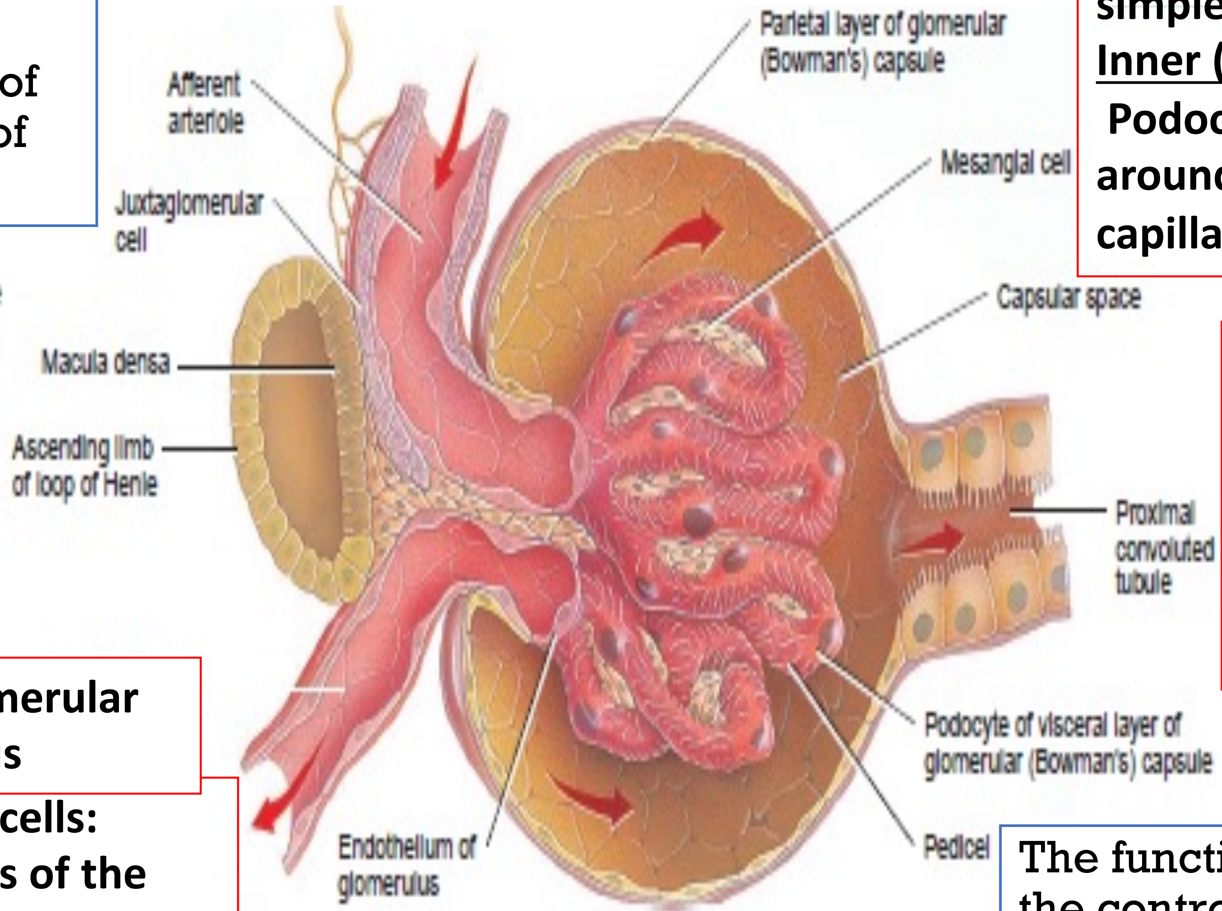
Nephron Structure and Function



Renal Corpuscle

The function of the **macula densa** cells is **renal autoregulation**. It is a kind of feedback mechanism between the blood flow that is coming from the afferent arterioles and the composition of filtered fluid that is in this part of the nephron.

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

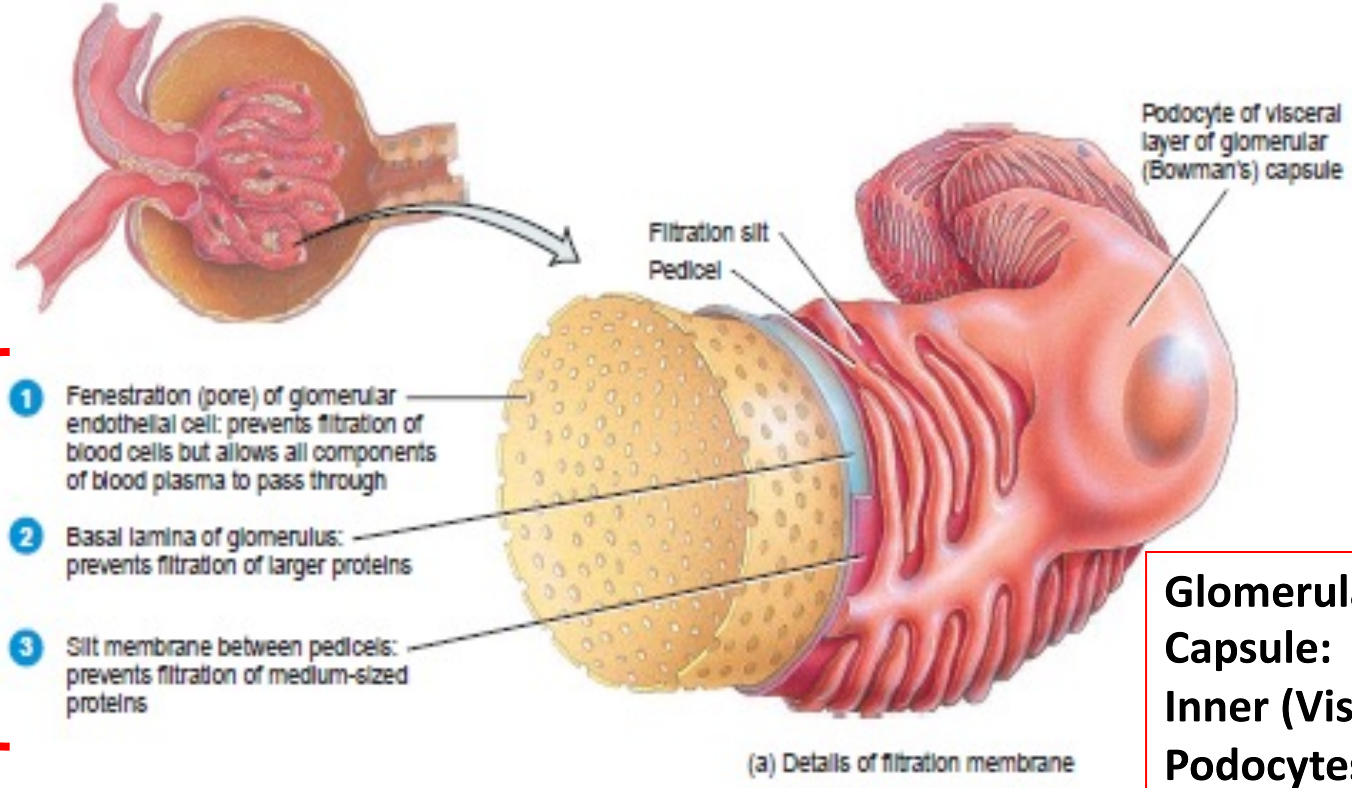
Juxtaglomerular cells: modified SM cells of the wall of afferent (or efferent) arterioles that are proximate to the Macula Densa (the thick ascending limb of Henle).

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

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

The function of mesangial cells is the control of the surface area; they increase or decrease it based on whether or not they are contracted, and they adjust the surface area for filtration.

Filtration Membrane



Glomerular Capillaries

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

The filtration membrane is composed of the wall of endothelial cells. These walls are composed of a **single layer of endothelial cells** that lies on a basement membrane. These endothelial cells are unique in that they have fenestrations and pores, and this facilitates the filtration function of the glomerulus. So, they are more permeable than the regular (continuous) capillaries.

The **basal lamina** is the second barrier. The fenestrations allow a certain size of substances to pass through, and any larger substance will not, so it prevents the filtration of blood cells but allows most of the components to pass through in terms of size. However, the basal lamina contains negatively charged fibers, so it won't allow negatively charged proteins from passing through, and that is why albumin can theoretically pass through the pores but cannot pass through the basal lamina. Therefore, very little amounts of albumin can be filtered due to this repulsion.

The last barrier is composed of the inner surface of Bowman's capsule which we call the **podocytes**. Podocytes are unique cells which have projections wrapping the glomeruli from the outside. Particles can only go through the spaces between these pedicles, and we call these spaces *slits*. Only medium-sized proteins will pass through them.

Glomerular capillary filtration barrier

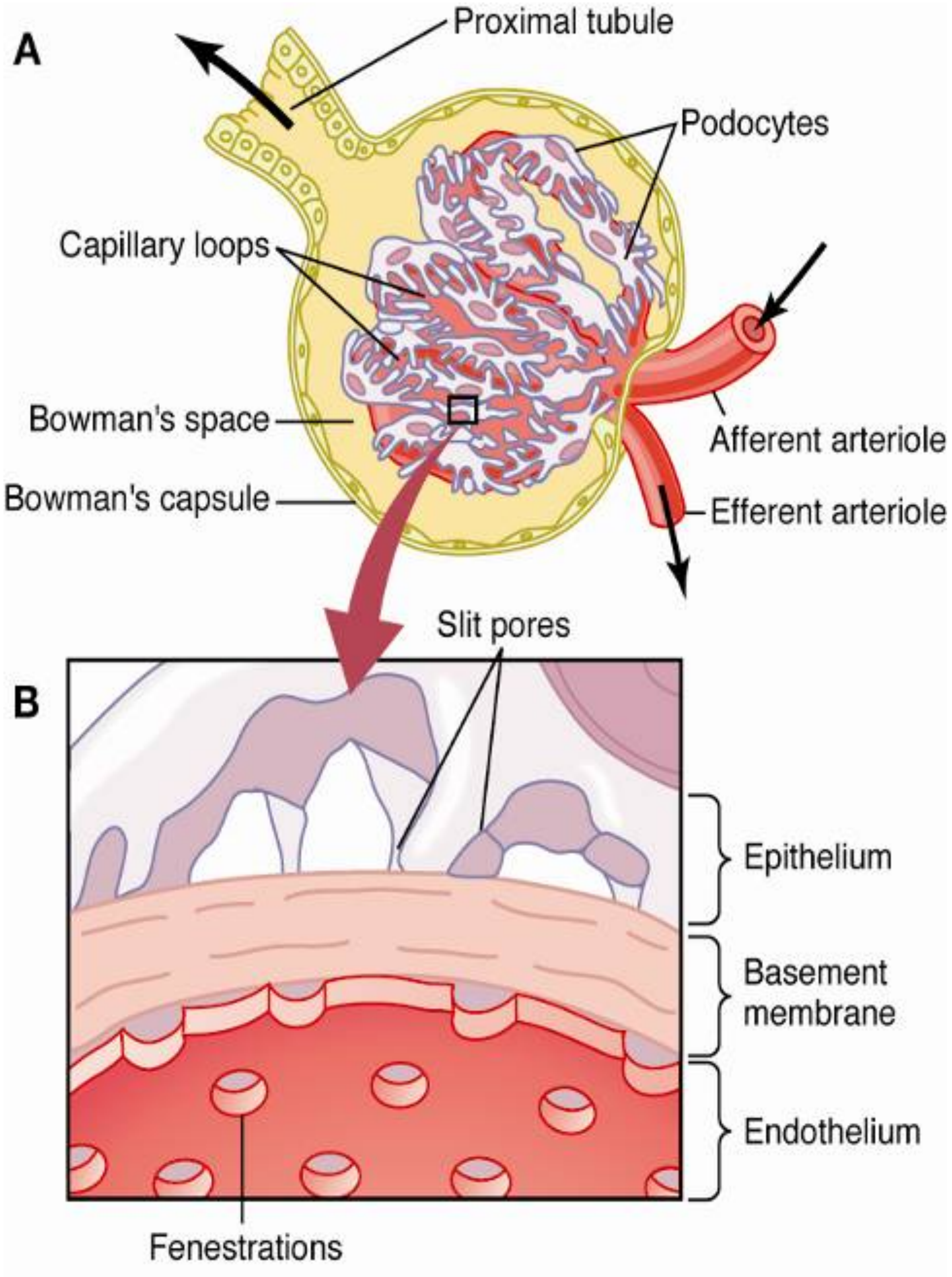


Figure 26-11

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**