URINARY SYSTEM

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Systematic physiology

Second Semester

Week 6

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Outline

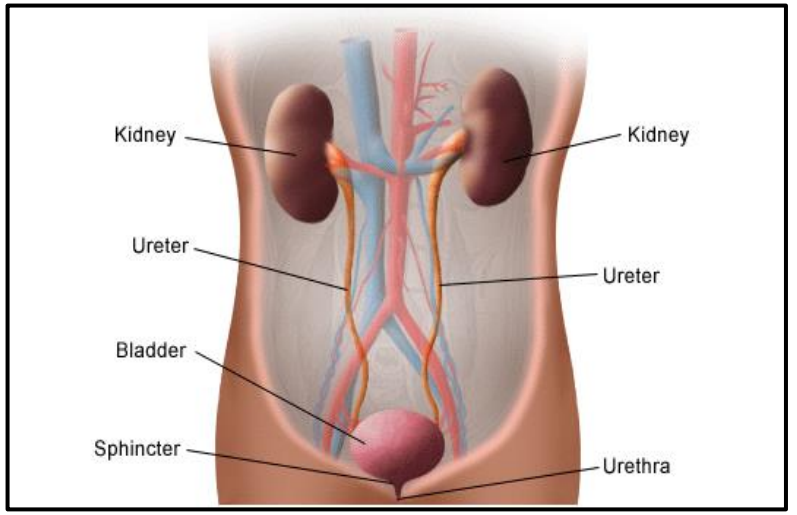
- Function of urinary system
- Structure of kidneys
- Structure of nephrons
- Basic stages of urine formation
- Ureter , Urinary bladder, Urethra

Objectives

- Familiarizing the students with functions of urinary system
- Understanding the structure of urinary system and nephrons
- Understanding the filtration process in nephrons
- Understanding the process of urin formation

Urinary system

- **Urinary system** rids the body of waste products
- Kidneys also play important roles in **blood volume**, **pressure**, and **composition**
- The urinary system is closely associated with the reproductive system
  - Shared embryonic development and adult anatomical relationship
  - Collectively called the urogenital (UG) system



Functions of the Kidneys

1. Filter blood plasma, excrete toxic wastes
2. Regulate blood volume, pressure, and osmolarity
3. Regulate electrolytes and acid-base balance
4. Secrete erythropoietin, which stimulates the production of red blood cells
5. Help regulate calcium levels by participating in calcitriol synthesis
6. They clear hormones and drugs from the blood and thereby limit their action.
7. Detoxify free radicals
8. In starvation, they synthesize glucose from amino acids

Nitrogenous Wastes(metabolic waste)

- **Waste**—any substance that is useless to the body or present in excess of the body's needs
- **Metabolic waste**—waste substance produced by the body. Feces is not metabolic waste
- Among the most toxic of our metabolic wastes are small nitrogen-containing compounds called **nitrogenous wastes**

Urea About 50% of the nitrogenous waste is urea

- Proteins→ amino acids → NH_2 removed → forms ammonia, Liver converts ammonia to urea

Uric acid

- Product of nucleic acid catabolism

Creatinine

- –Product of creatine phosphate catabolism
- **The level of nitrogenous waste in the blood is typically expressed as blood urea nitrogen (BUN).**

Excretion

Excretion—separating wastes from body fluids and eliminating them

Four body systems carry out excretion

1. **Respiratory system**

   CO_2, small amounts of other gases, and water

2. **Integumentary system**

   Water, inorganic salts, lactic acid, urea in sweat

3. **Digestive system**

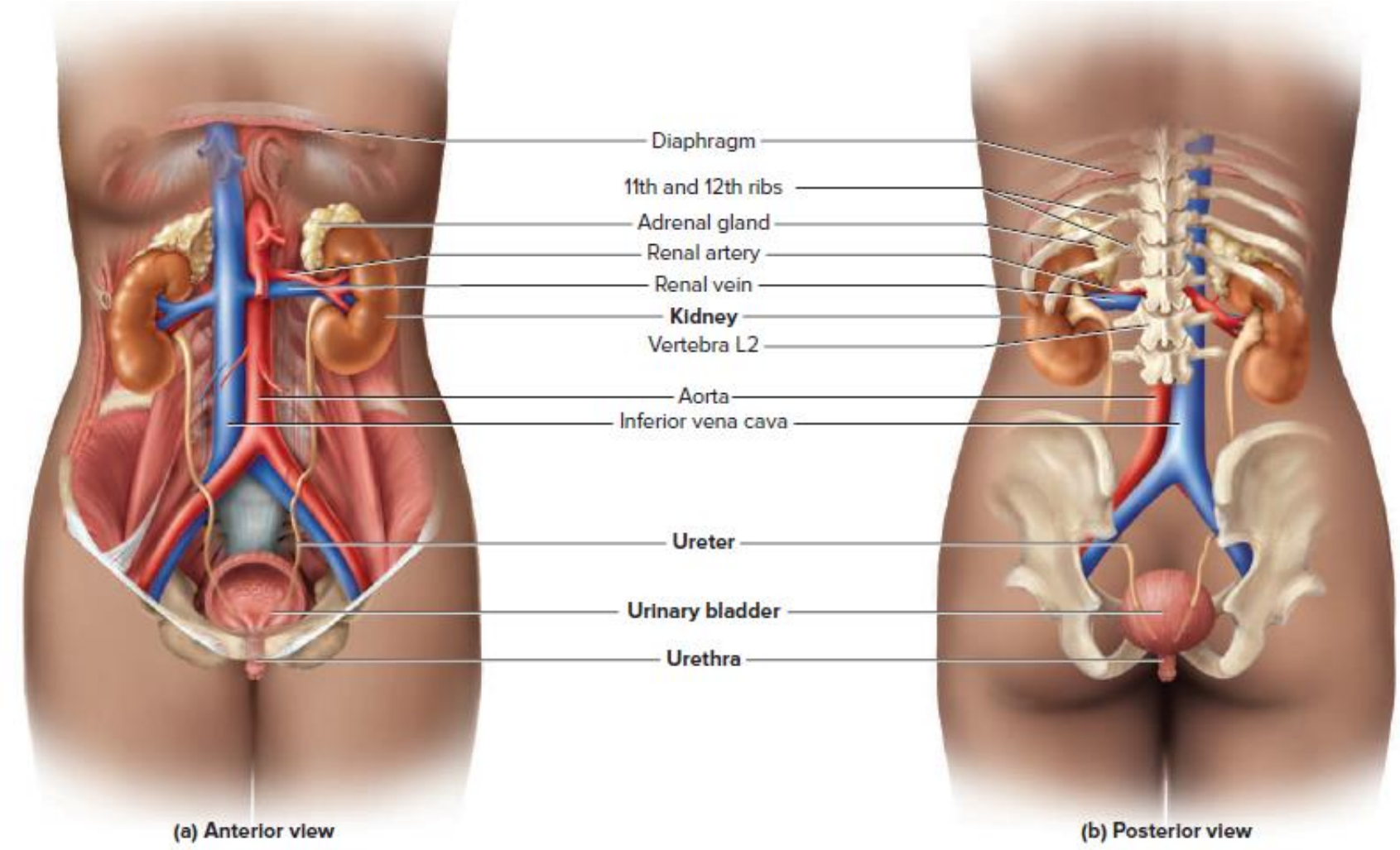
   Water, salts, CO_2, lipids, bile pigments, cholesterol, and other metabolic waste

4. **Urinary system**

   Many metabolic wastes, toxins, drugs, hormones, salts, H^+, and water

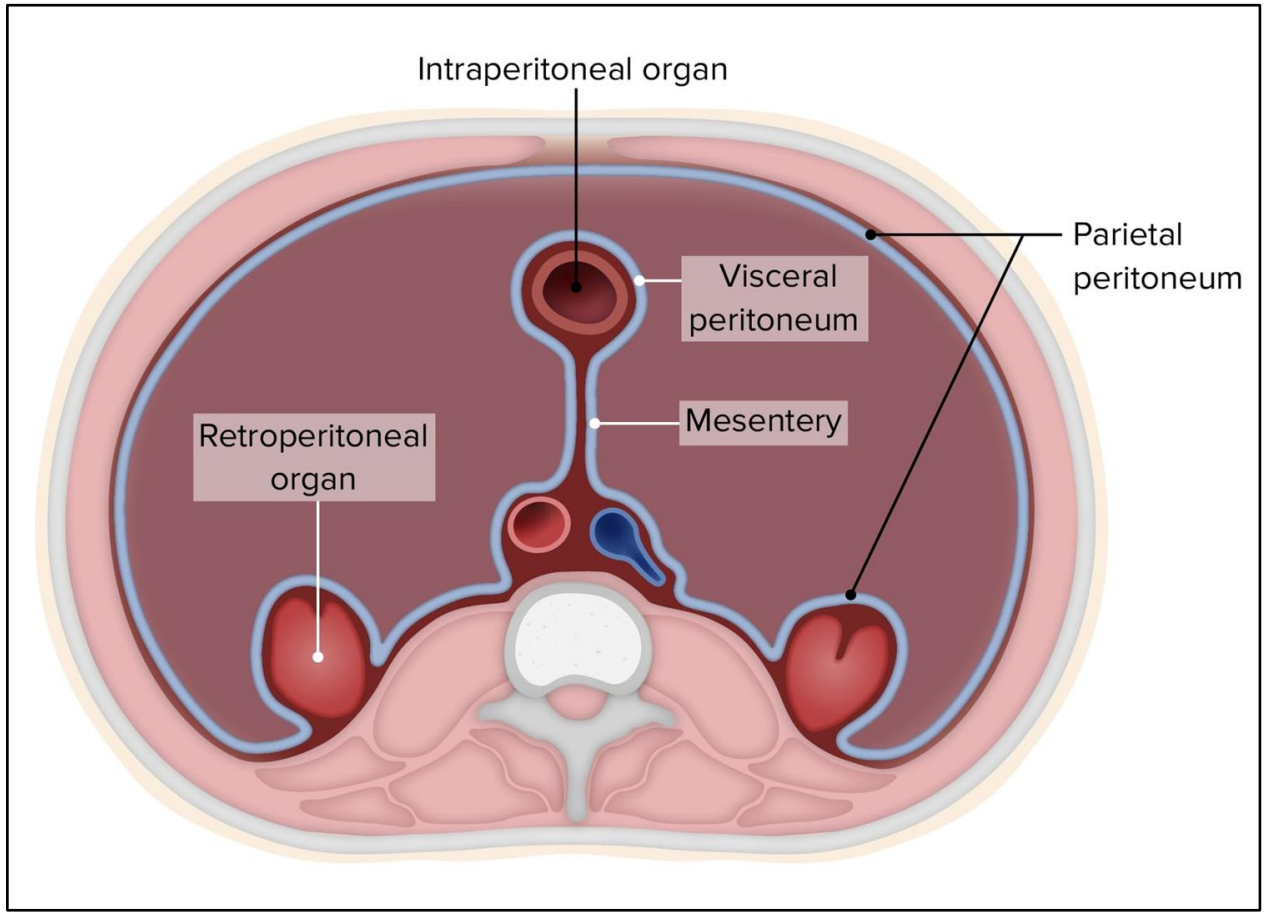
The urinary system

The **urinary system** consists of six principal organs: two **kidneys,** two **ureters,** the **urinary bladder,** and the **urethra**



The kidneys

- The kidneys lie against the posterior abdominal wall at the level of vertebrae T12 to L3. The right kidney is slightly lower than the left because of the space occupied by the large right lobe of the liver above it.
- The kidneys are retroperitoneal, along with the ureters, urinary bladder, renal artery and vein, and the adrenal glands

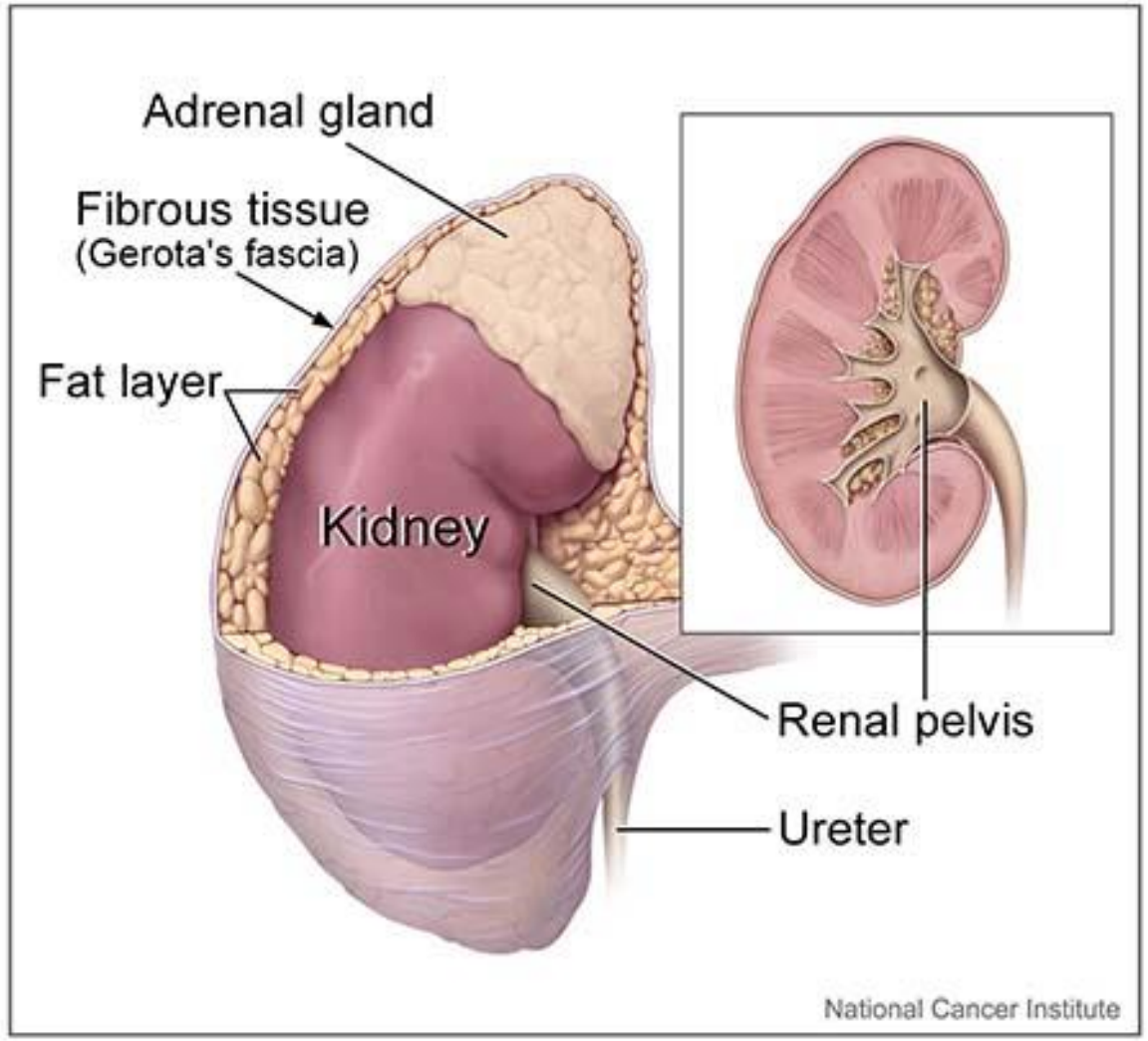


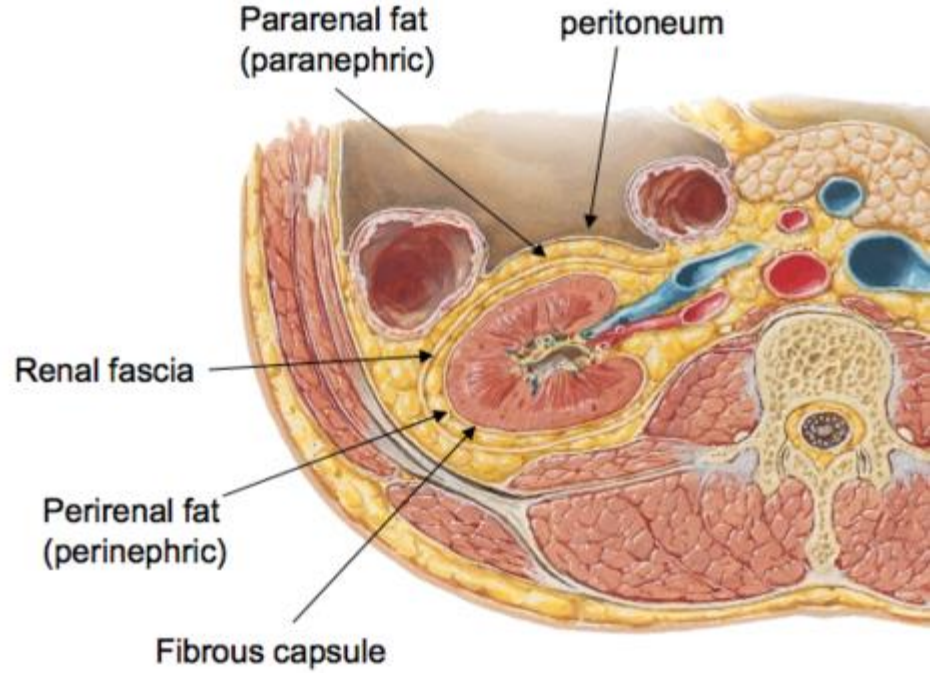
Gross Anatomy of the Kidney

Shape and size

- Each kidney weighs about 150 g and measures about 11 cm long, 6 cm wide, and 3 cm thick—
- Lateral surface is convex, and medial is concave with a slit, called the **hilum**, Receives renal nerves, blood vessels, lymphatics, and ureter

- **Three protective connective tissue coverings**
  1. **Renal fascia** immediately deep to parietal peritoneum
     - Binds it to abdominal wall
  2. **Perirenal fat capsule:** cushions kidney and holds it into place
  3. **Renal capsule (Fibrous capsule)** encloses kidney protecting it from trauma and infection
     - Collagen fibers extend from fibrous capsule to renal fascia
     - Still drop about 3 cm when going from lying down to standing up


Adrenal gland
Fibrous tissue
(Gerota's fascia)
Fat layer
Kidney
Renal pelvis
Ureter
National Cancer Institute


Pararenal fat
(paranephric)
peritoneum
Renal fascia
Perirenal fat
(perinephric)
Fibrous capsule

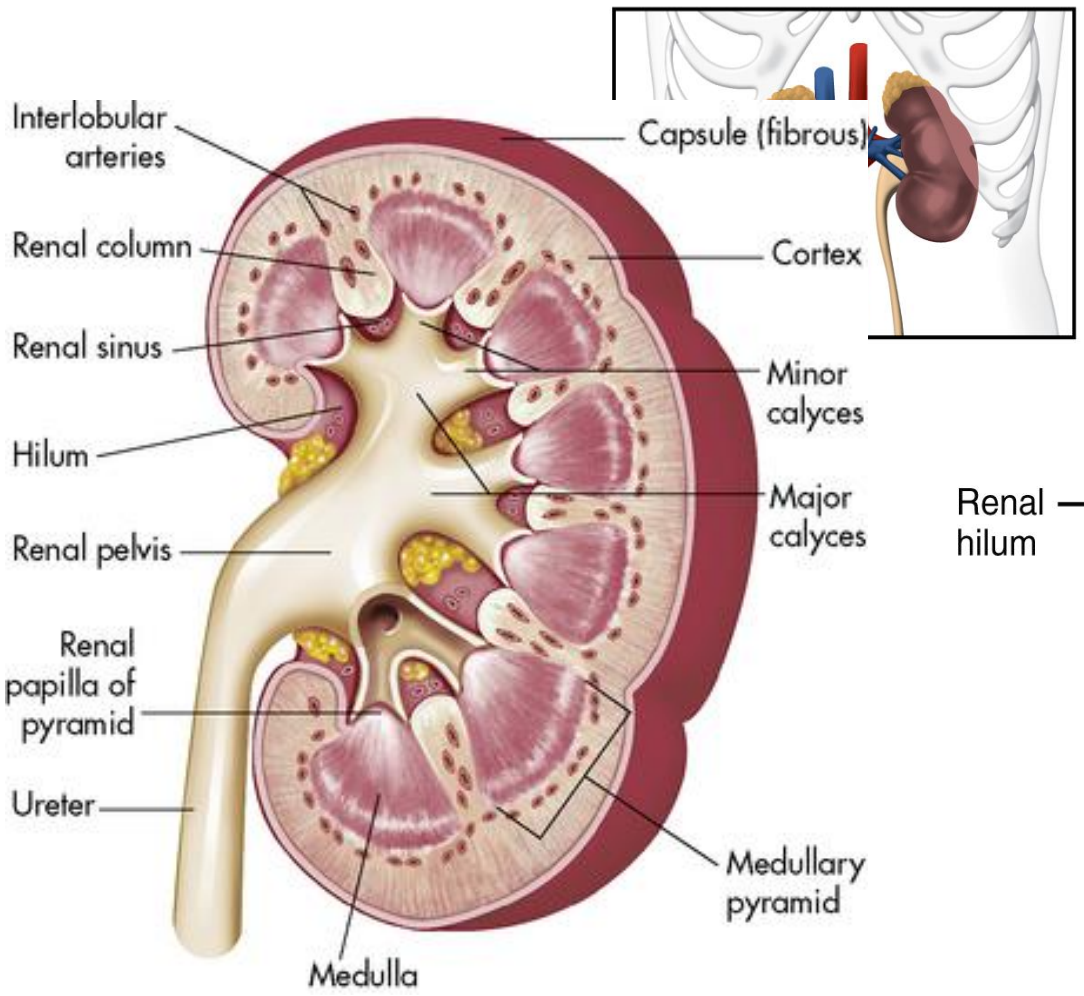
Gross Anatomy of the Kidney

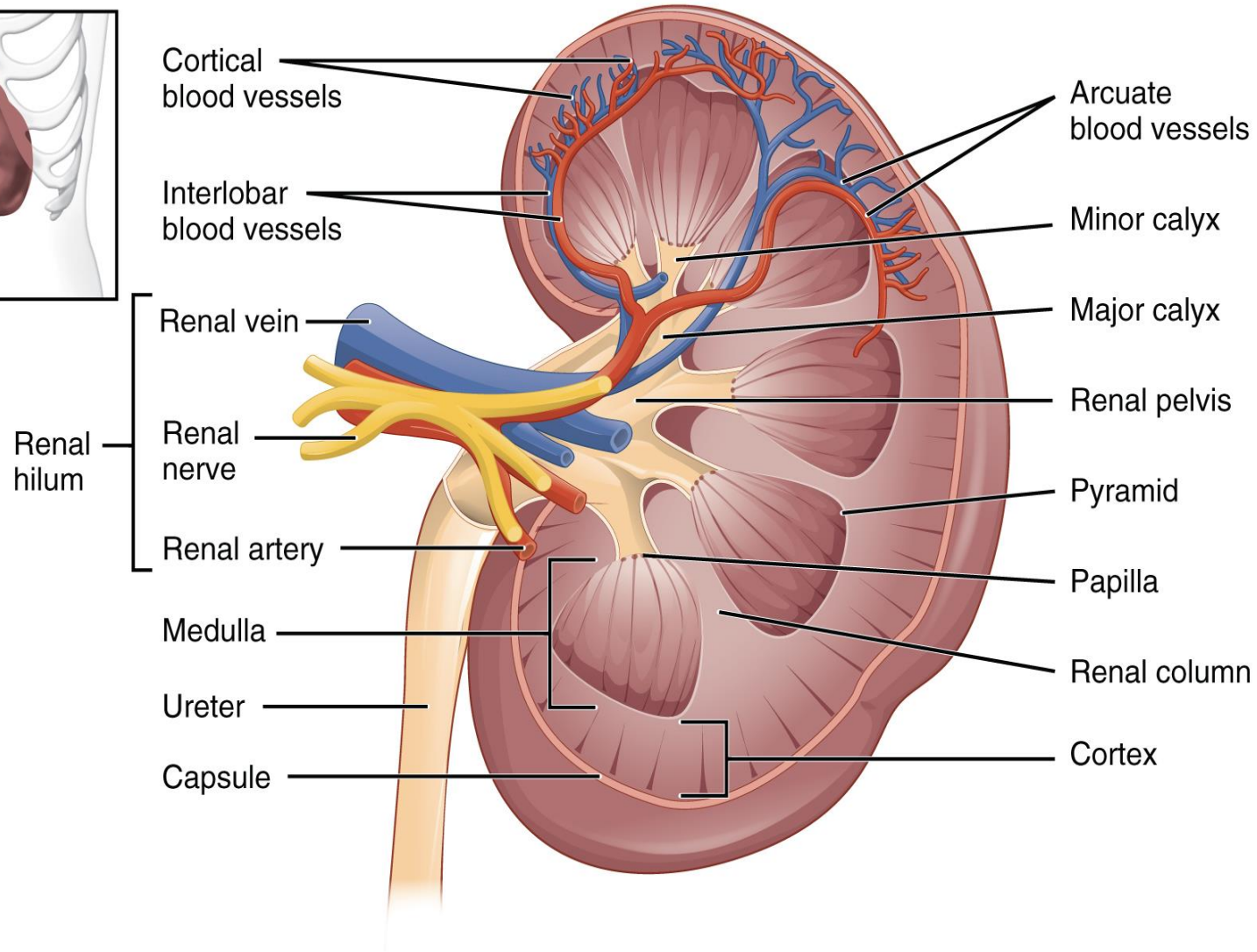
•Two zones of renal parenchyma

- **Outer renal cortex**
- Inner **renal medulla**

- Extensions of the cortex called **renal columns** project toward the sinus and divide the medulla into 6 to 10 **renal pyramids.** Each pyramid is conical, with a broad base facing the cortex and a blunt point called the **renal papilla** facing the sinus.
- One pyramid and the overlying cortex constitute one *lobe* of the kidney.
  - **Minor calyx:** cup that nestles the papilla of each pyramid; collects its urine
  - **Major calyces:** formed by convergence of 2 or 3 minor calyces
  - **Renal pelvis:** formed by convergence of 2 or 3 major calyces
  - **Ureter:** a tubular continuation of the pelvis that drains urine down to the urinary bladder

Gross Anatomy of the Kidney

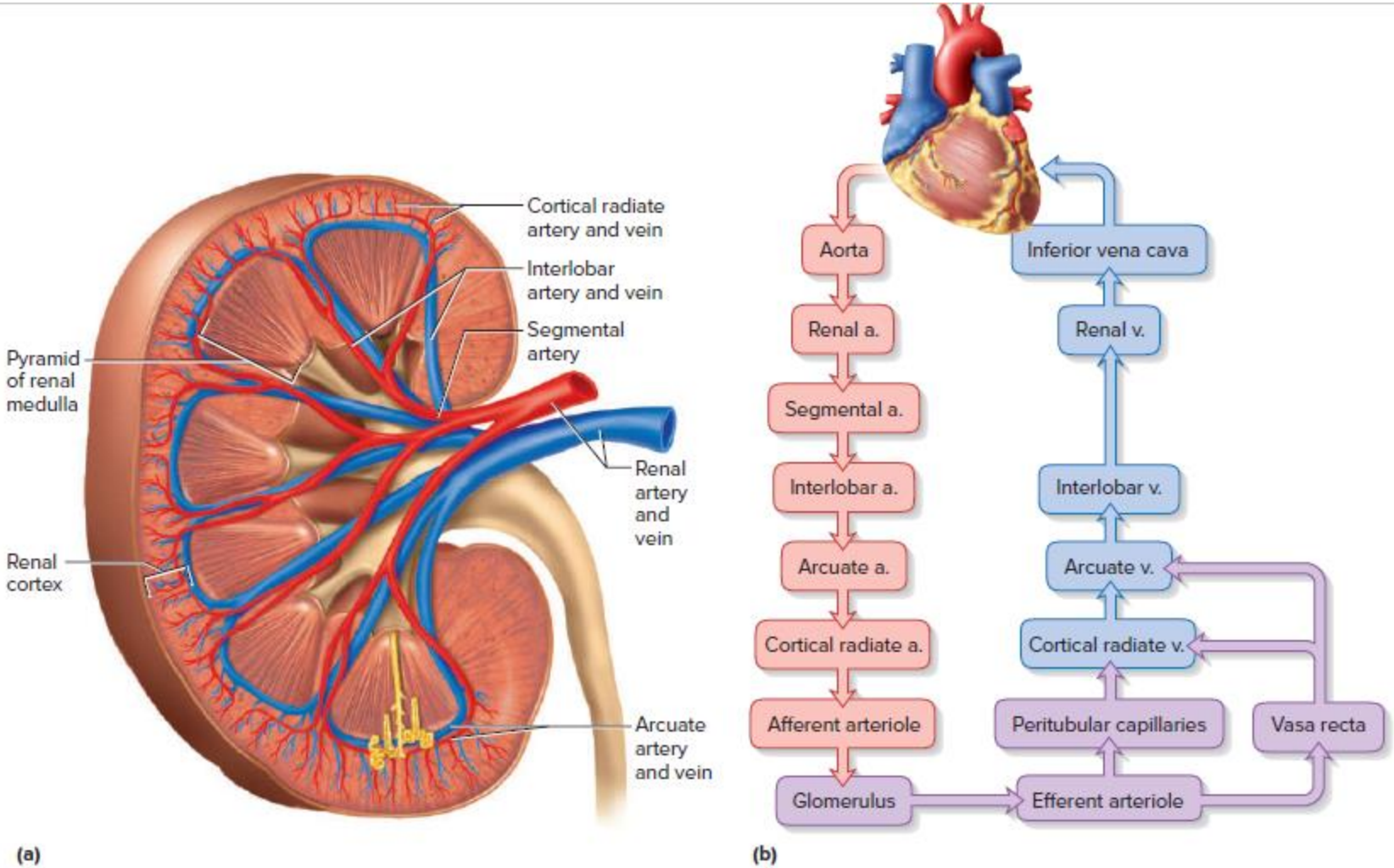




Renal Circulation

- Kidneys are only 0.4% of body weight, but receive about 21% of cardiac output **(renal fraction)**
- **Renal artery** divides into **segmental arteries** that give rise to:
- **Interlobar arteries:** up renal columns, between pyramids
- **Arcuate arteries:** over pyramids
- **Cortical radiate arteries:** up into cortex
- Branch into **afferent arterioles:** each supplying **one nephron**
- Leads to a ball of capillaries—**glomerulus**
- Blood is drained from the glomerulus by **efferent arterioles**
- Most efferent arterioles lead to **peritubular capillaries**
- Some efferents lead to **vasa recta**—a network of blood vessels within renal medulla
- Capillaries then lead to **cortical radiate veins** or directly into **arcuate veins**
- Arcuate veins lead to **interlobar veins** which lead to the renal vein
- **Renal vein** empties into **inferior vena cava**

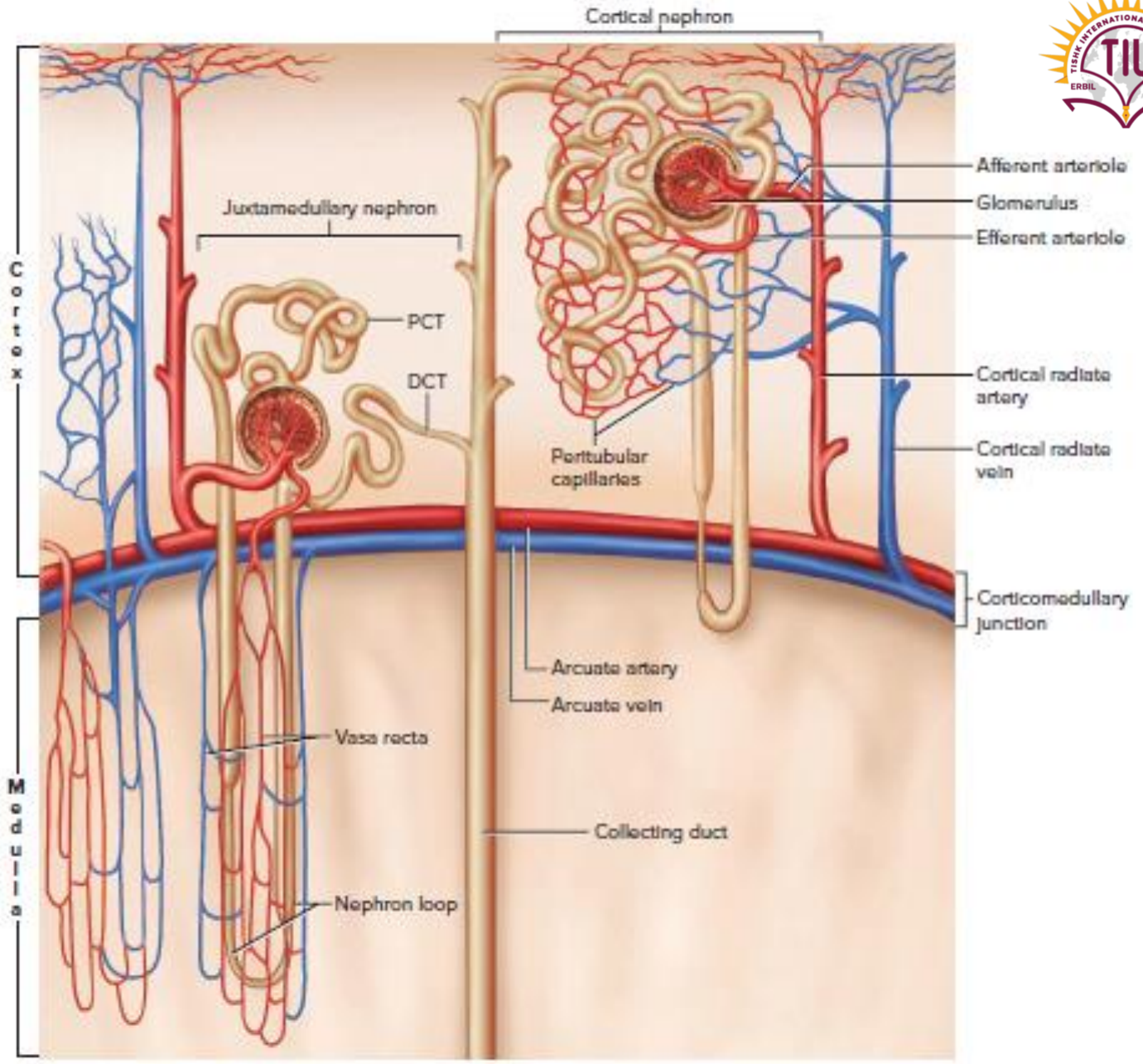
Renal Circulation



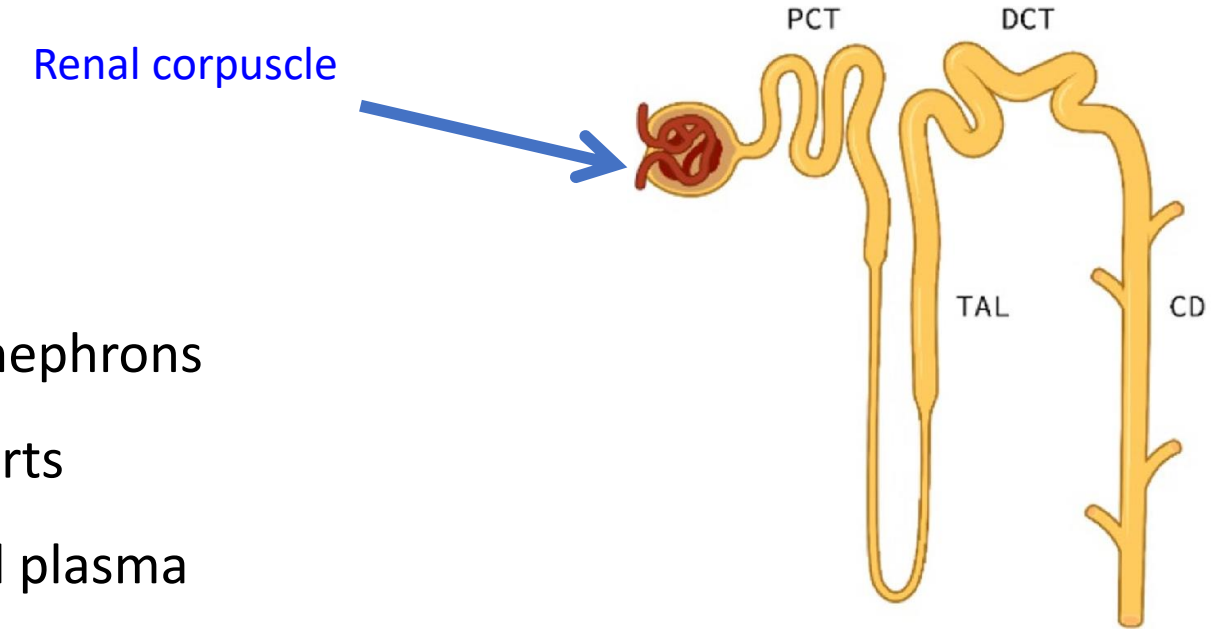
Kidneys receive 21% of cardiac output

Renal Circulation

- In the cortex, **peritubular capillaries** branch off of the efferent arterioles supplying the tissue near the glomerulus, the proximal and distal convoluted tubules
- In the medulla, the efferent arterioles give rise to the **vasa recta,** supplying the nephron loop portion of the nephron



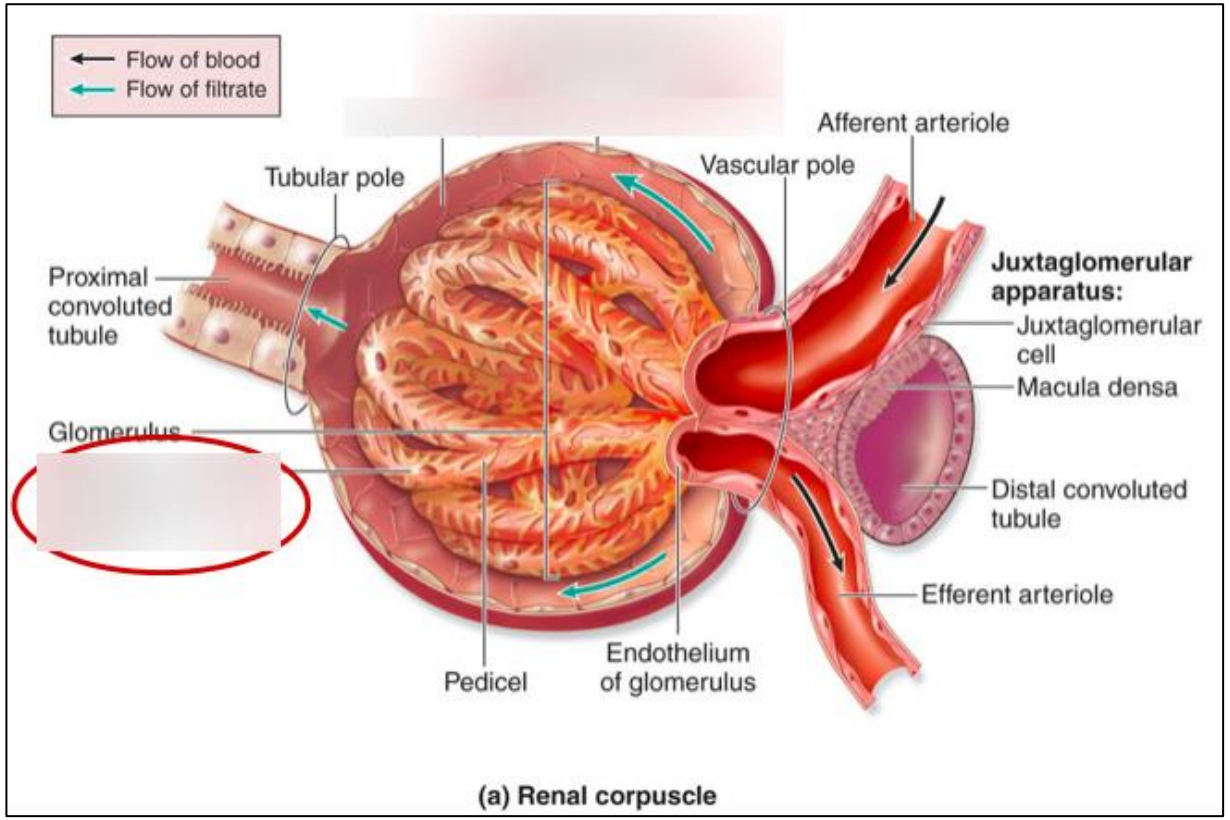
The Nephron



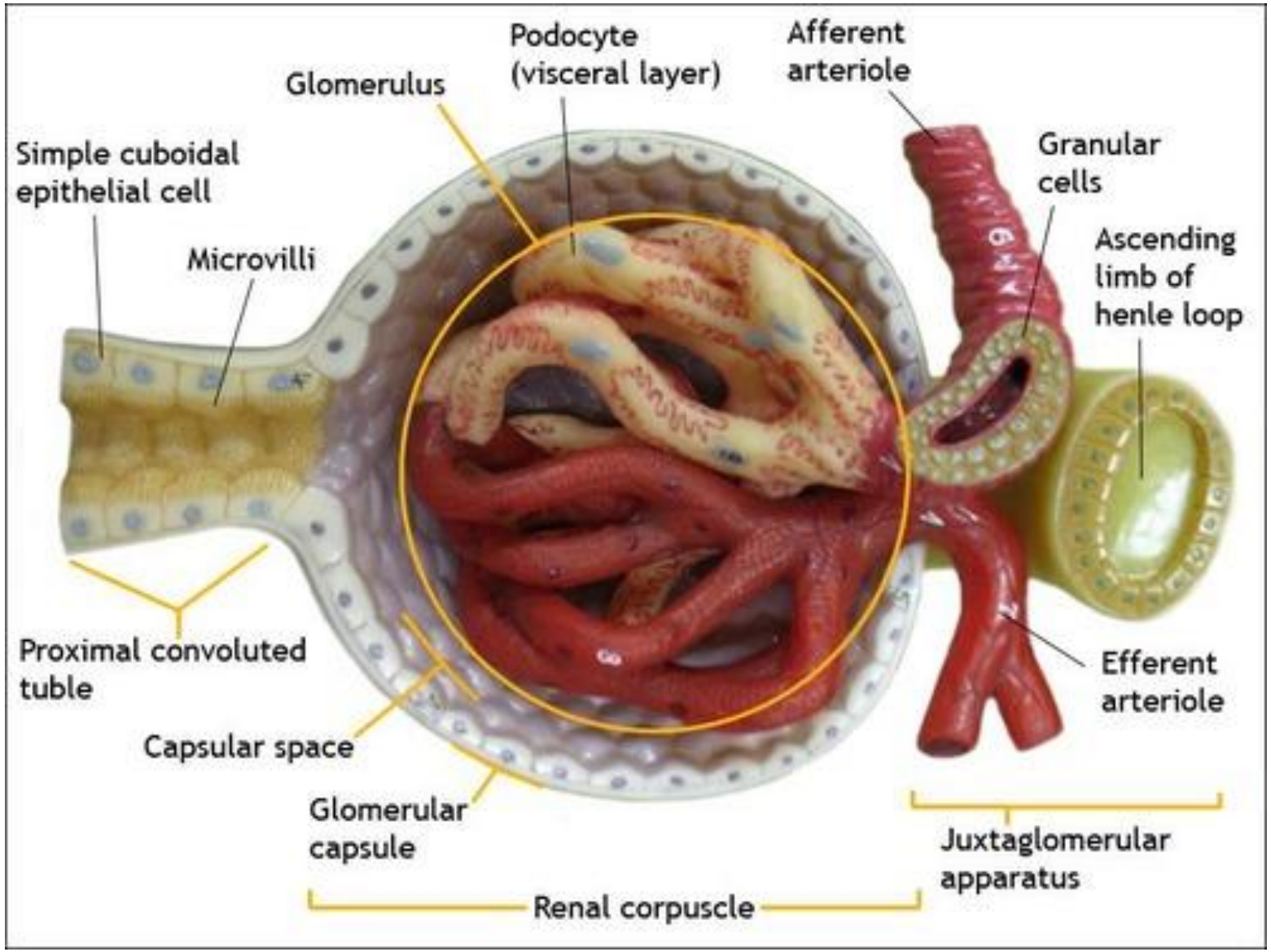
- Each kidney has about 1.2 million nephrons
- Each composed of two principal parts

1. –Renal corpuscle: filters the blood plasma
2. –Renal tubule: long, coiled tube that converts the filtrate into urine

- Renal corpuscle consists of the glomerulus and a two-layered glomerular capsule that encloses glomerulus
- –Parietal (outer) layer of glomerular capsule is simple squamous epithelium
- –Visceral (inner) layer of glomerular capsule consists of elaborate cells called podocytes that wrap around the capillaries of the glomerulus
- –Capsular space separates the two layers of glomerular capsule

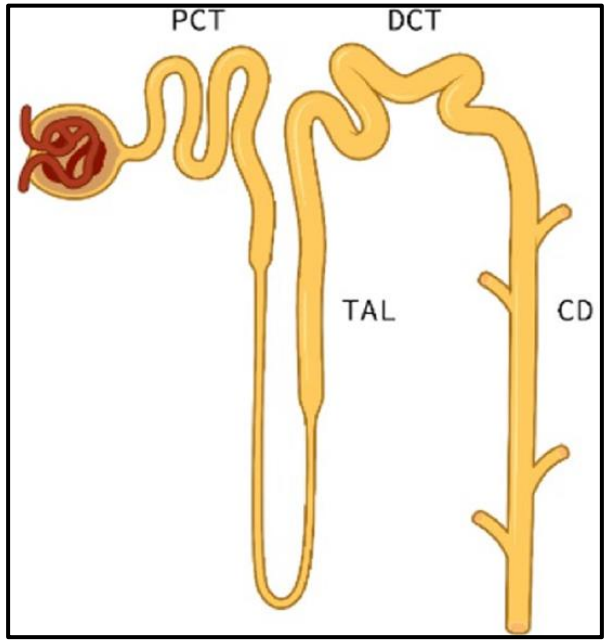


- **Vascular pole**—the side of the corpuscle where the afferent arterial enters the corpuscle and the efferent arteriole leaves
- **Urinary pole**—the opposite side of the corpuscle where the renal tubule begins
- **Glomerular filtrate collects in capsular space**, flows into proximal convoluted tubule. Note the vascular and urinary poles. Note the afferent arteriole is larger than the efferent arteriole.


Podocyte
(visceral layer)
Afferent
arteriole
Glomerulus
Simple cuboidal
epithelial cell
Granular
cells
Microvilli
Ascending
limb of
henle loop
Proximal convoluted
tuble
Efferent
arteriole
Capsular space
Glomerular
capsule
Juxtaglomerular
apparatus
Renal corpuscle

The Renal Tubule

- **Renal (uriniferous) tubule**—duct leading away from the glomerular capsule and ending at the tip of the medullary pyramid



Divided into four regions

1. **Proximal convoluted tubule,**
2. **Nephron loop,**
3. **Distal convoluted tubule:**
4. **Collecting duct receives fluid from many nephrons**

1- Proximal convoluted tubule(PCT)—arises from glomerular capsule

Longest and most coiled region, simple cuboidal epithelium with **prominent microvilli** for majority of absorption.

2- Nephron loop long U-shaped portion of renal tubule consisting of Descending limb and **ascending** limb

- **Thick segments** have simple cuboidal epithelium, Initial part of descending limb and part or all of ascending limb. Heavily engaged in the active transport of salts and have many mitochondria
- **Thin segment** has simple squamous epithelium. Forms lower part of descending limb. Cells very permeable to water

3- Distal convoluted tubule (DCT)—begins shortly after the ascending limb reenters the cortex

- Shorter and less coiled than PCT
- Cuboidal epithelium without microvilli
- DCT is the end of the nephron

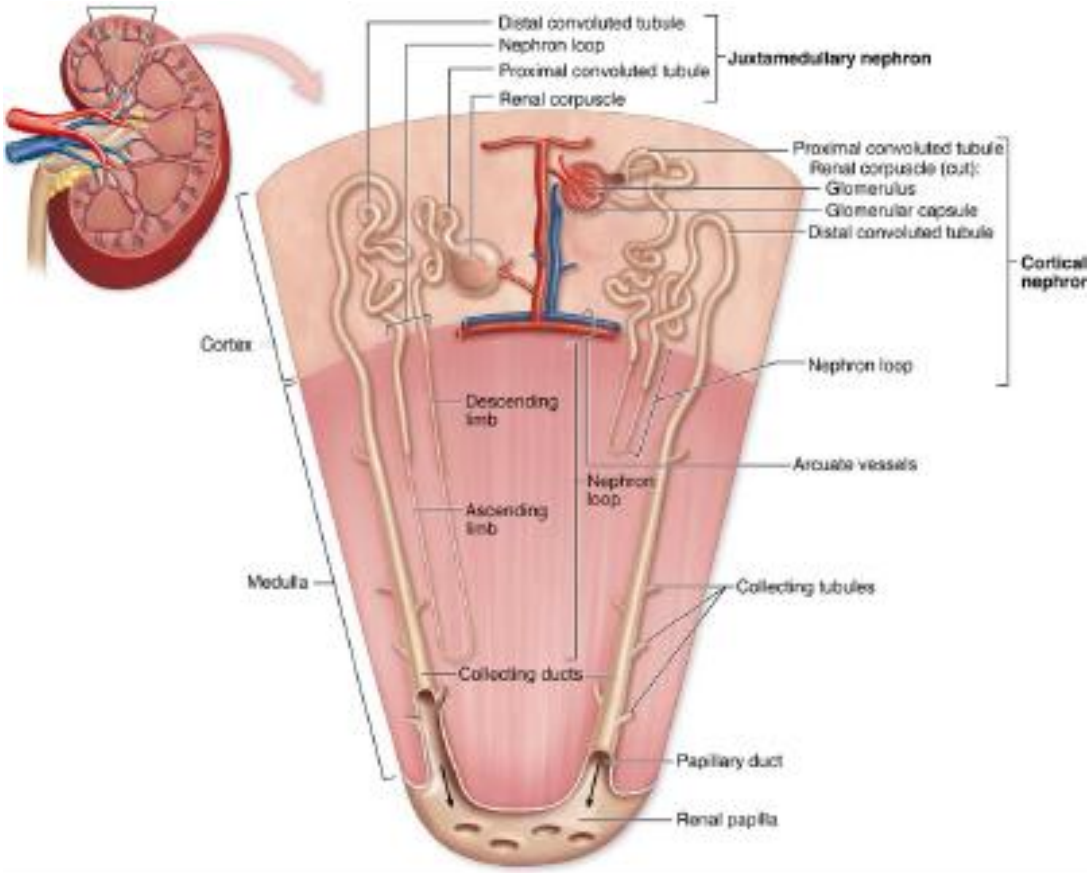
4 -Collecting duct—

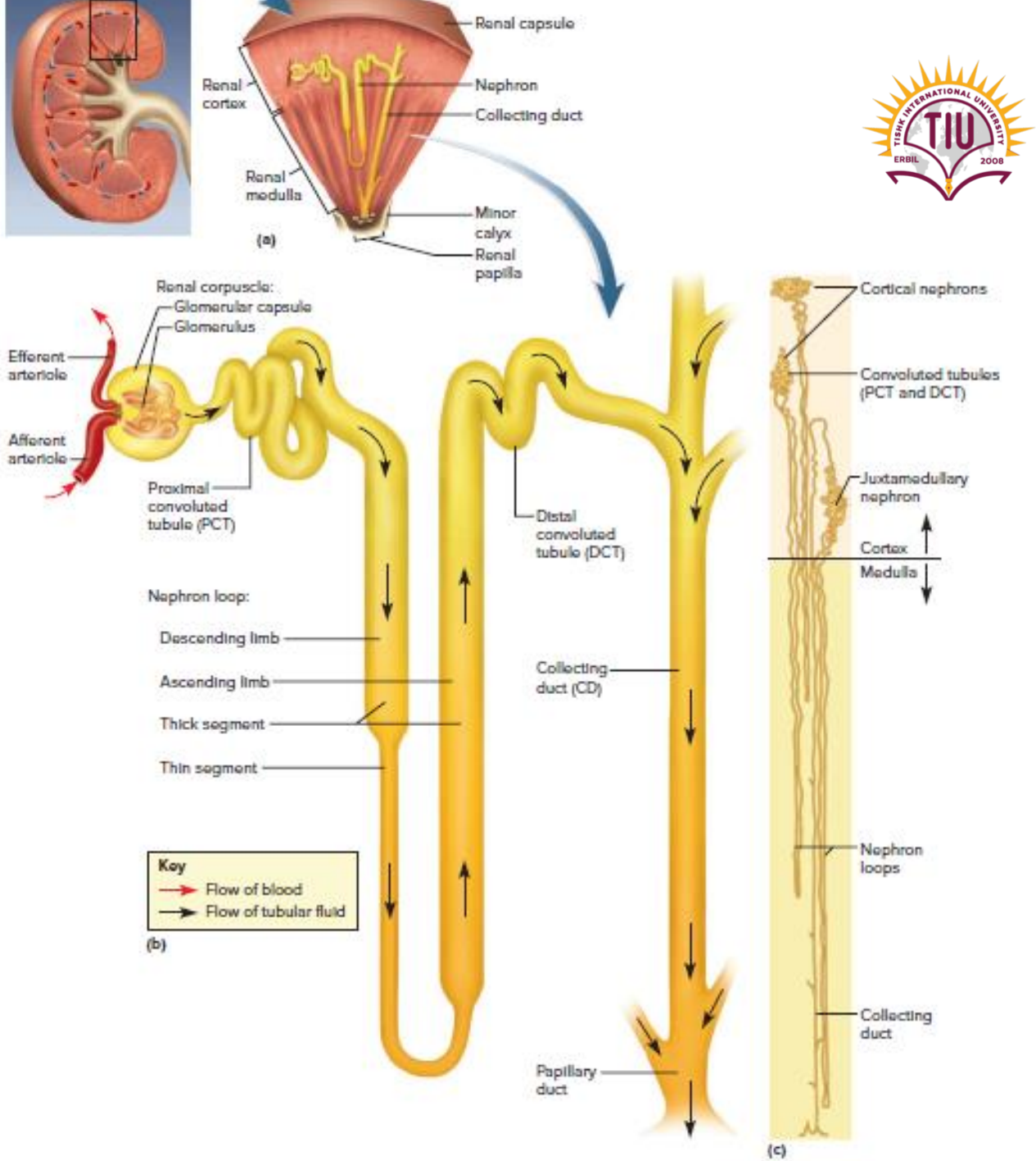
- The **collecting duct** receives fluid from the DCTs of several nephrons as it passes back into the medulla. Numerous collecting ducts converge toward the tip of a medullary pyramid, and near the papilla, they merge to form a larger **papillary duct.**
- About 30 papillary ducts end in pores at the conical tip of each papilla. Urine drains from these pores into the minor calyx that encloses the papilla. The collecting and papillary ducts are lined with simple cuboidal epithelium.

Flow of fluid from the point where the glomerular filtrate is formed to the point where urine leaves the body:

glomerular capsule → proximal convoluted tubule → nephron loop → distal convoluted tubule → collecting duct → papillary duct → minor calyx → major calyx → renal pelvis → ureter → urinary bladder → urethra

Microscopic Anatomy of the Nephron





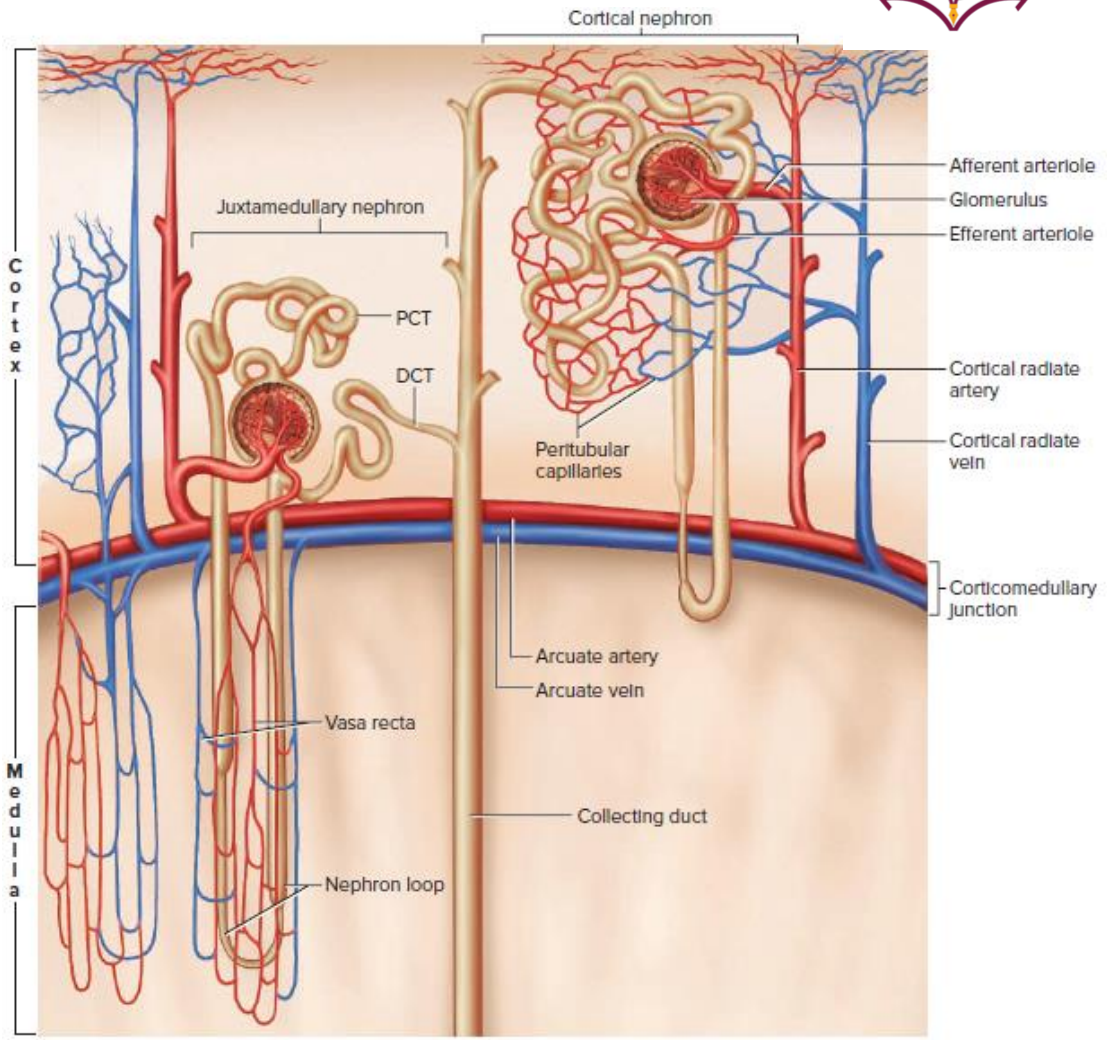
Cortical and Juxtamedullary Nephrons

Cortical nephrons

–85% of all nephrons, Short nephron loops, Efferent arterioles branch into peritubular capillaries around PCT and DCT

Juxtamedullary nephrons

–15% of all nephrons , Very long nephron loops, maintain salinity gradient in the medulla and help conserve water, Efferent arterioles branch into **vasa recta** around long nephron loop



Basic Stages of Urine Formation

Urine Formation :

Kidneys convert blood plasma to urine in four stages

1. Glomerular filtration
2. Tubular reabsorption
3. Tubular secretion
4. Water conservation

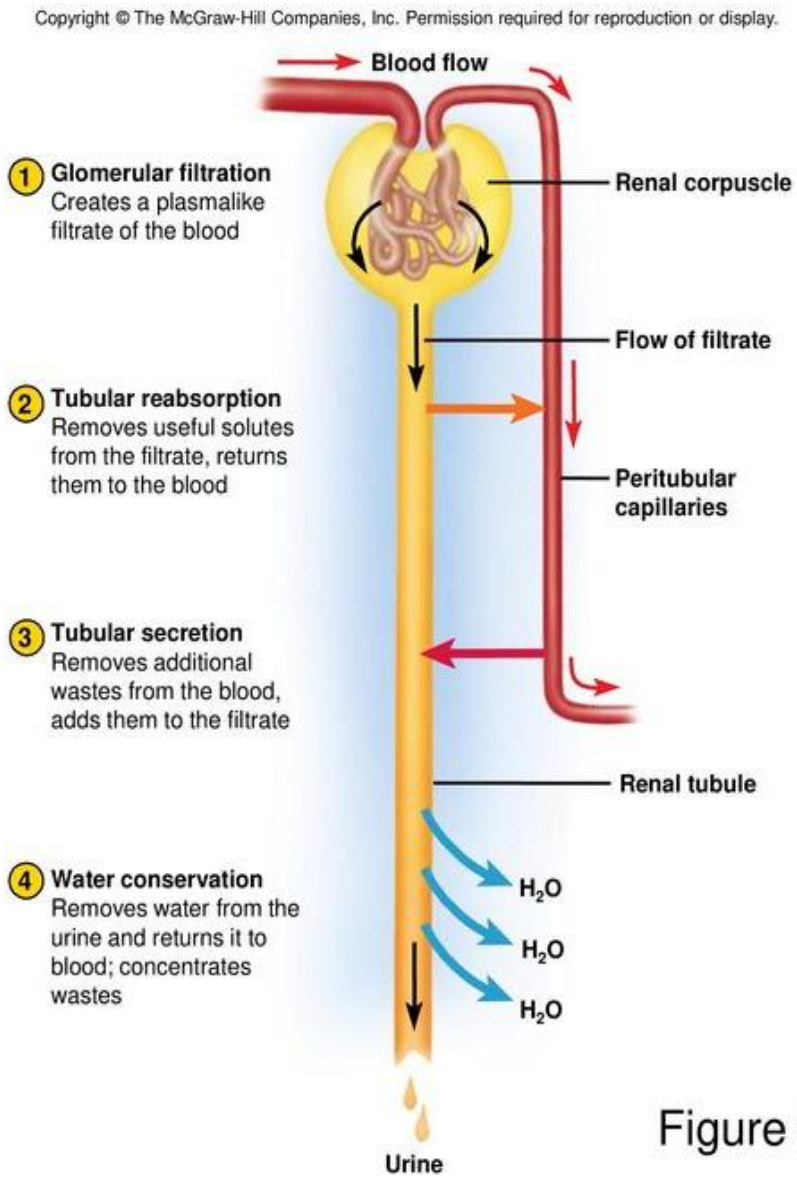


Figure 23.9

As we trace fluid through the nephron, we will refer to it by different names that reflect its changing composition:

Glomerular filtrate—the fluid in the capsular space

- Similar to blood plasma except that it has almost no protein

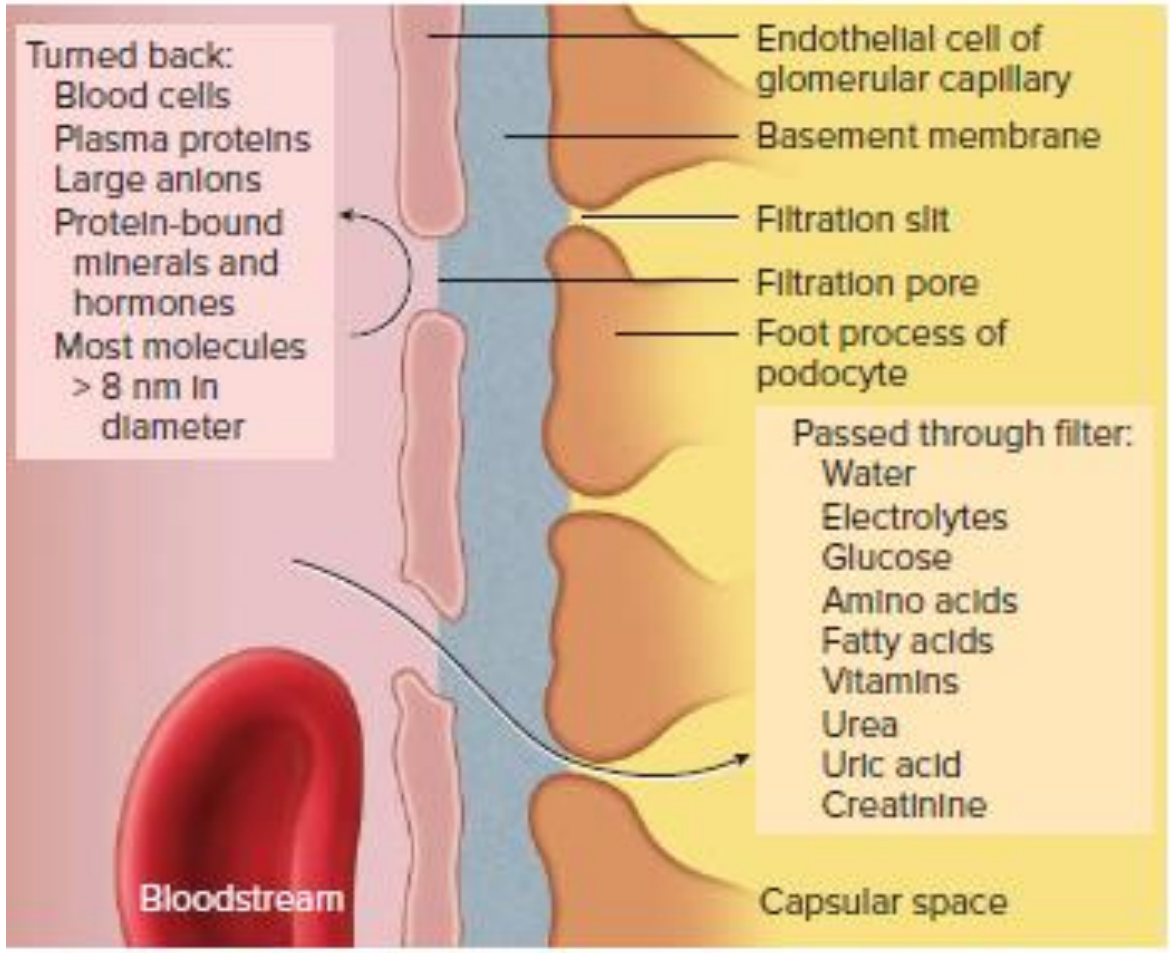
Tubular fluid—fluid from the proximal convoluted tubule through the distal convoluted tubule

- Substances have been removed or added by tubular cells

Urine

- fluid that enters the collecting duct. Undergoes little alteration beyond this point except for changes in water content

Glomerular filtration—a special case of capillary fluid exchange in which water and some solutes in the blood plasma pass from the capillaries of the glomerulus into the capsular space of the nephron



IGURE 23.11 The Glomerular Filtration Membrane.

Filtration membrane

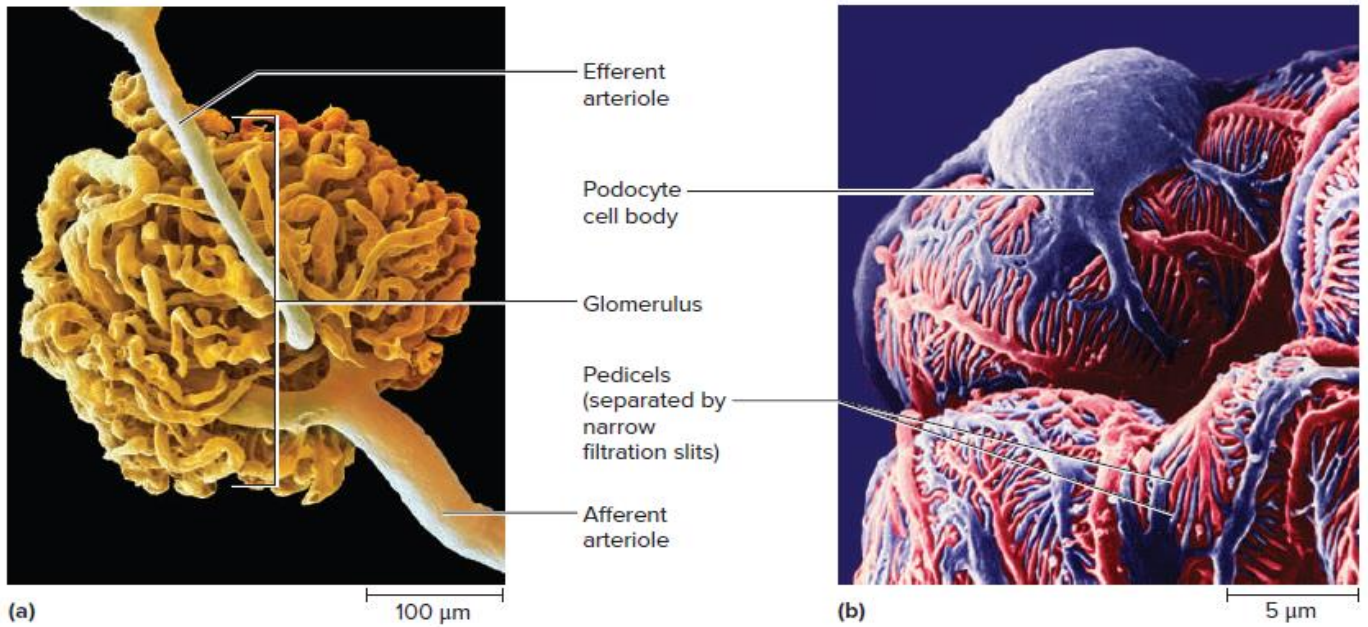
1. **The fenestrated endothelium of the capillary.** Endothelial cells of the glomerular capillaries are honeycombed with large filtration pores about 70 to 90 nm in diameter, these are highly permeable, although their pores are small enough to exclude blood cells from the filtrate.

2. **The basement membrane.** This consists of a proteoglycan gel. On the basis of size alone, the basement membrane excludes molecules larger than 8 nm.

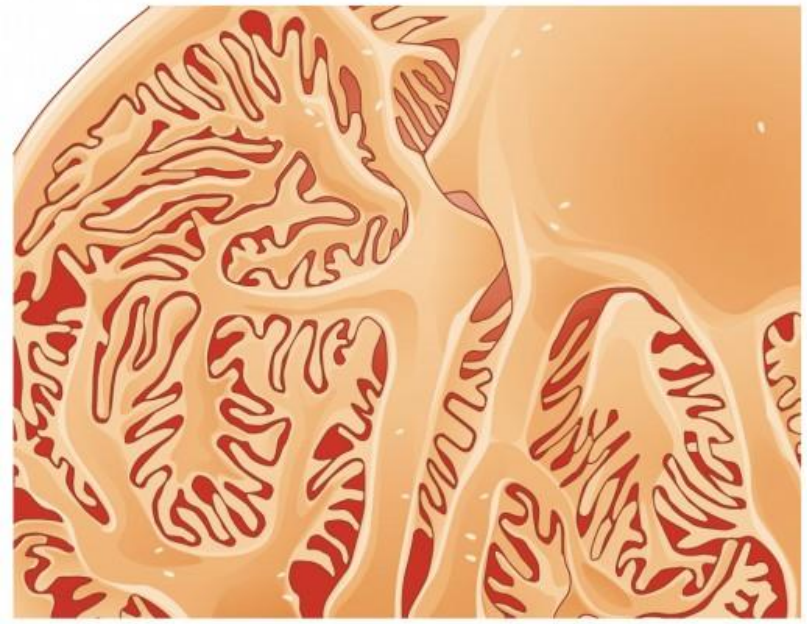
- Even some smaller molecules, however, are held back by negative tive charge on the proteoglycans. Blood albumin is slightly smaller than 7 nm, but it is also negatively charged and thus repelled by the basement membrane.
- Although the blood plasma is 7% protein, the glomerular filtrate is only 0.03% protein

3. **Filtration slits**. A podocyte of the glomerular capsule is shaped somewhat like an octopus, with a bulbous cell body and several thick arms.

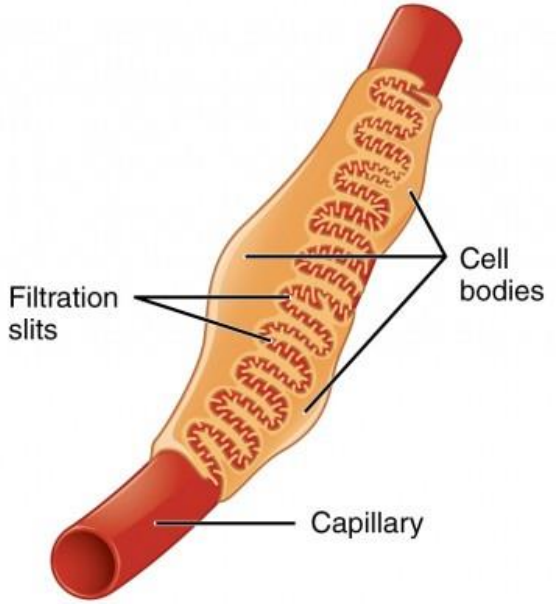
- Each arm has numerous extensions called foot processes (pedicels) that wrap around the capillaries and interdigitate with each other, like wrapping your hands around a pipe and lacing your fingers together.
- The foot processes have negatively charged filtration slits about 30 nm wide between them, which are an additional obstacle to large anion



- **Almost any molecule smaller than 3 nm can pass freely through the filtration membrane**
- Water, electrolytes, glucose, fatty acids, amino acids, nitrogenous wastes, and vitamins
- **Some substances of low molecular weight are bound to the plasma proteins and cannot get through the membrane**
- Most calcium, iron, and thyroid hormone
- Unbound fraction passes freely into the filtrate



(a)



(b)

Filtration Pressure

- **Filtration pressure depends on hydrostatic and osmotic pressures on each side of the filtration membrane**

Blood hydrostatic pressure (BHP)

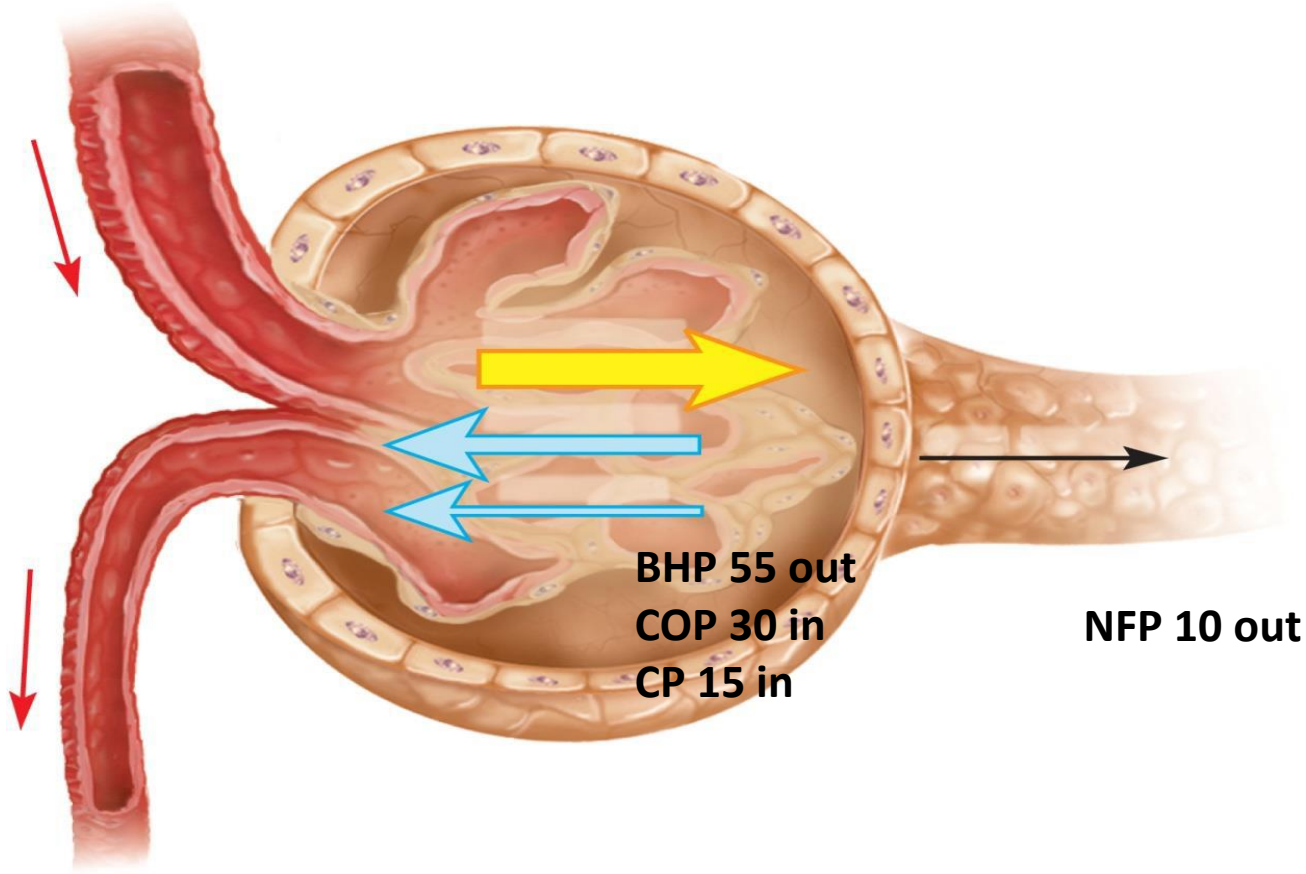
- –High in glomerular capillaries (55 mm Hg compared to 10 to 15 in most other capillaries), Because afferent arteriole is larger than efferent arteriole: a large inlet and small outlet

Hydrostatic pressure in capsular space

- –15 mm Hg due to high filtration rate and continual accumulation of fluid in the capsule

Colloid osmotic pressure (COP) of blood

- –About the same here as elsewhere: 30 mm Hg
- •**Glomerular filtrate** is almost protein-free and has no significant COP
- •**Higher outward pressure of 55 mm Hg,** opposed by two inward pressures of 15 mm Hg and 30 mm Hg
- •**Net filtration pressure:** 55 out–15in–30in= **10 mm Hg out**



Blood hydrostatic pressure (BHP)	**55 mm Hgout**
Colloid osmotic pressure (COP)	-30 mm Hgin
Capsular pressure (CP)	-15 mm Hgin
Net filtration pressure (NFP)	**10 mm Hgout**

- **The high blood pressure in the glomeruli makes the kidneys especially vulnerable to hypertension,** which can have devastating effects on renal function. Hypertension ruptures glomerular capillaries and leads to scarring of the kidneys *(nephrosclerosis).*
- It promotes atherosclerosis of the renal blood vessels just as it does elsewhere in the body and thus diminishes renal blood supply.
- Over time, hypertension often leads to renal failure and renal failure leads to worsening hypertension in an insidious positive feedback loop.

Glomerular Filtration Rate

Glomerular filtration rate (GFR)—amount of filtrate formed per minute by the two kidneys combined

–GFR = NFP x Kf = 125 mL/min. or 180 L/day (male)

–GFR = NFP x Kf= 105 mL/min. or 150 L/day (female)

Net filtration pressure (NFP)

Filtration coefficient (Kf) depends on permeability and surface area of filtration barrier

Total amount of filtrate produced per day equals 50 to 60 times the amount of blood in the body

–99% of filtrate is reabsorbed since only 1 to 2 L urine excreted per day

Tubular Reabsorption and Secretion

Conversion of the glomerular filtrate to urine involves the removal and addition of chemicals by tubular reabsorption and secretion

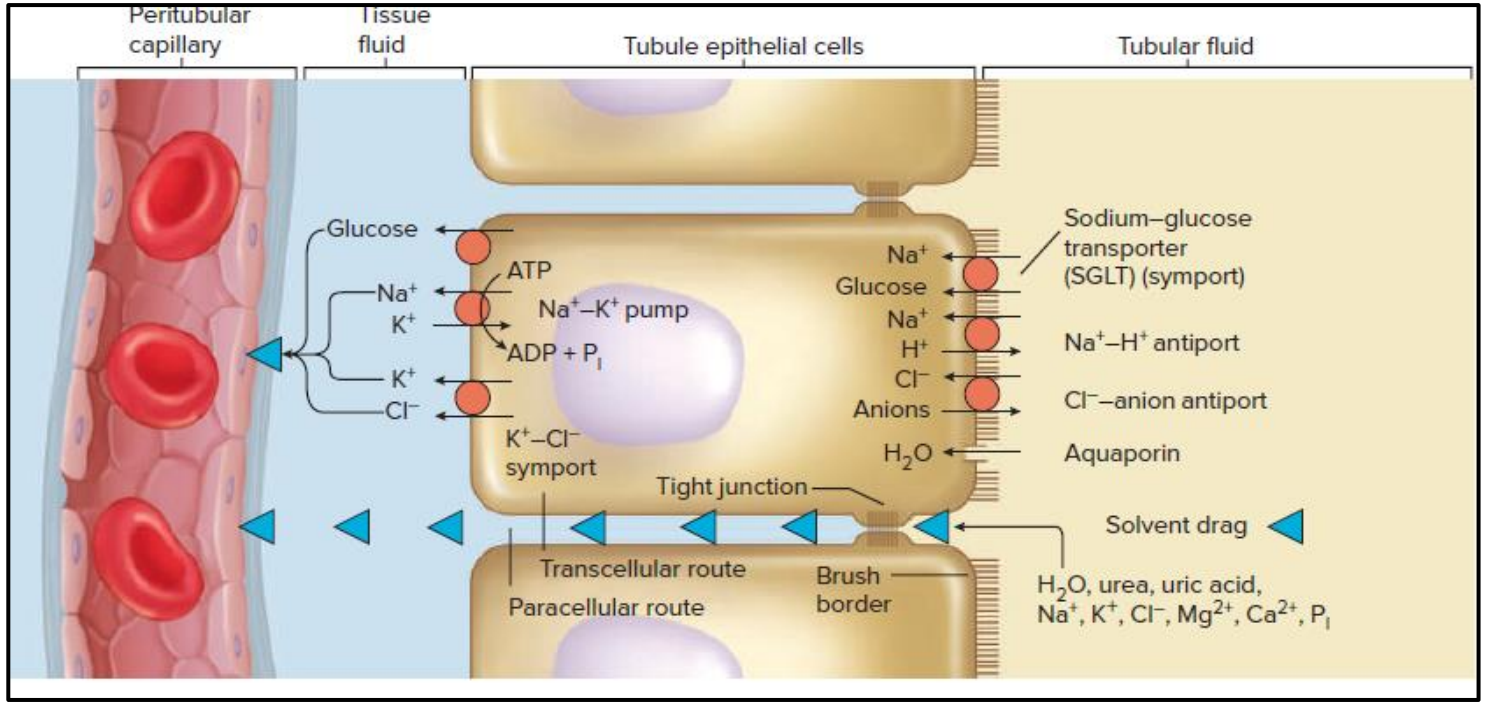
The Proximal Convoluted Tubule

- **PCT reabsorbs about 65% of glomerular filtrate,** removes some substances from blood, and **secretes** them into tubular fluid for disposal in urine
- **Prominent** microvilli and great length **which increase its absorptive surface area**
- **Abundant** mitochondria provide ATP for active transport
- **PCTs** alone account for about 6% of one's resting ATP and calorie consumption
- **Tubular reabsorption**—process of reclaiming water and solutes from tubular fluid and returning them to blood

Tubular reabsorption

There are two routes of reabsorption:

1. **The transcellular route**
2. **The paracellular route**



Sodium reabsorption is key

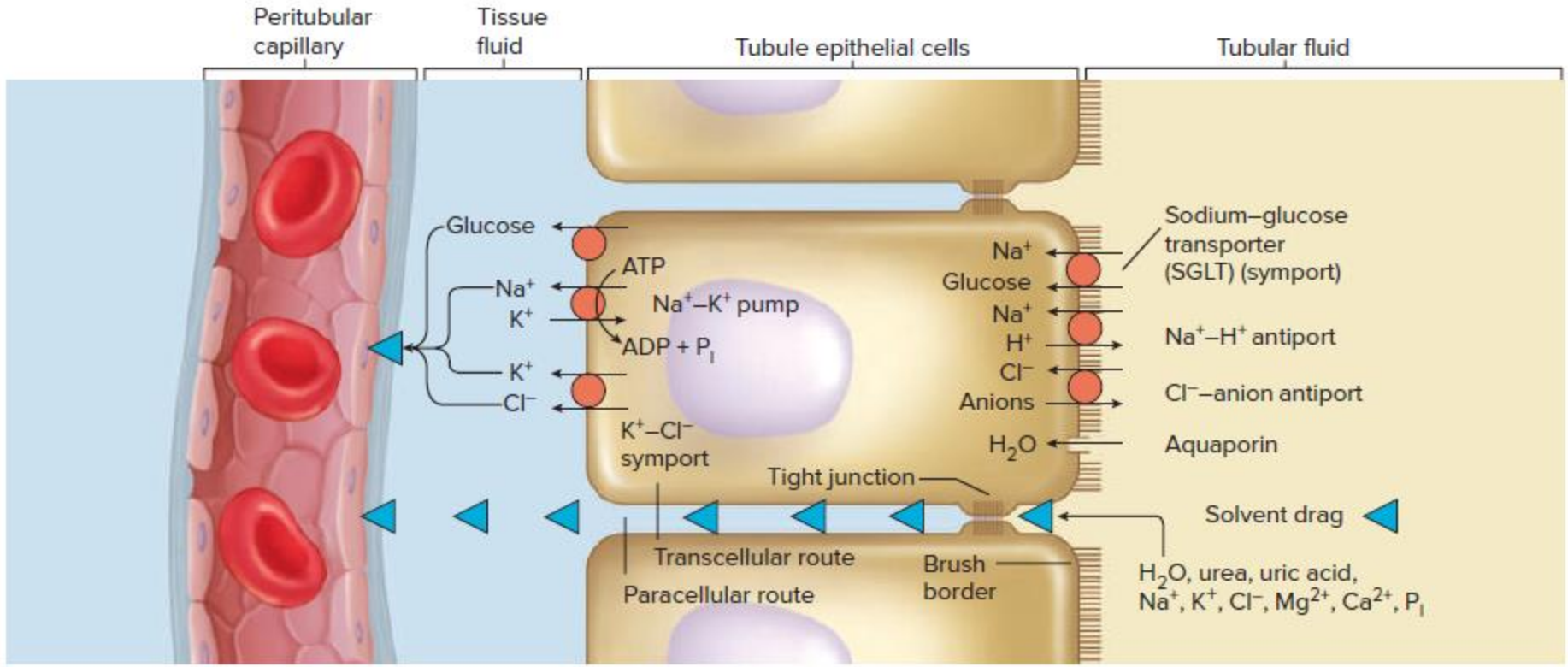
- Creates an osmotic and electrical gradient for everything else that drives the reabsorption of water and other solutes
- Na+is most abundant cation in filtrate (140 mEq/L) vs 2 mEq/L in the cytoplasm of the epithelial cells
- Creates steep concentration gradient that favors its diffusion into epithelial cells

Two types of transport proteins in the apical cell surface are responsible for sodium uptake

1. **Symports** that simultaneously bind Na+and another solute such as glucose, amino acids, or lactate
2. **Na+–H+antiport** that pulls Na+into the cell while pumping out H+into tubular fluid Sodium reabsorption

- –Sodium is prevented from accumulating in epithelial cells by **Na+–K+pumps** in the basal surface of the epithelium

- Pumps Na+out to extracellular fluid
- Na+is picked up by peritubular capillaries and returned to blood
- The Na+–K+ pumps (at the base) are examples of **primary active transport**–they use ATP
- The symports on the apical surface are examples of **secondary active transport** –they do not directly consume ATP, but are dependent on the primary transport Na+–K+pumps at the base of the cell to establish the sodium concentration gradient
- **Negative chloride ions follow the positive sodium ions by electrical attraction**
- **Various antiports in the apical cell membrane that absorb Cl–in exchange for other anions they eject into the tubular fluid**
- **Chloride and potassium ions are driven out through the basal cell surface by a K+–Cl– symport**


Peritubular capillary
Tissue fluid
Tubule epithelial cells
Tubular fluid
Glucose
ATP
Na+
K+
Na+–K+ pump
ADP + PI
K+
Cl–
K+–Cl– symport
Tight junction
Transcellular route
Paracellular route
Brush border
Na+
Glucose
Na+
H+
Cl–
Anions
H2O
Sodium–glucose transporter (SGLT) (symport)
Na+–H+ antiport
Cl––anion antiport
Aquaporin
Solvent drag
H2O, urea, uric acid, Na+, K+, Cl–, Mg2+, Ca2+, PI

Other Electrolytes

- Potassium, magnesium, and phosphate ions pass through the paracellular route with water. Phosphate is also cotransported into the epithelial cells with Na+.
- Roughly 52% of the filtered calcium is reabsorbed by the paracellular route and
- 4% by the transcellular route in the PCT, but another 33% of the calcium is reabsorbed later in the nephron
- ***Glucose*** Glucose is cotransported with Na+ by symports called **sodium–glucose transporters (SGLTs).** It is then removed from the basolateral surface of the cell by facilitated diffusion.,
- Normally, all glucose in the tubular fluid is reabsorbed and there is none in the urine.
- **Urea passes through the epithelium with water. The nephron as a whole reabsorbs 40% to 60% of the urea in the tubular fluid, Thus, the kidney removes about half of the urea**
- Creatinine isn't reabsorbed at all

- The kidneys reduce about 180 L of glomerular filtrate to 1 or 2 L of urine each day, so water reabsorption is a significant function. About two-thirds of the water is reabsorbed by the PCT
- Transcellular absorption occurs by way of water channels called **aquaporins**

Tubular Secretion

Tubular secretion—renal tubule extracts chemicals from capillary blood and secretes them into tubular fluid

Purposes of secretion in PCT and nephron loop include:

1. **Acid–base balance:Secretion of varying proportions of hydrogen and bicarbonate ions helps regulate pH of body fluids**
2. **Waste removal: Urea, uric acid, bile acids, ammonia, and a little creatinine are secreted into the tubule**
3. **Clearance of drugs and contaminants Examples include morphine, penicillin, and aspirin. Some drugs must be taken multiple times per day to keep up with renal clearance**

The Nephron Loop

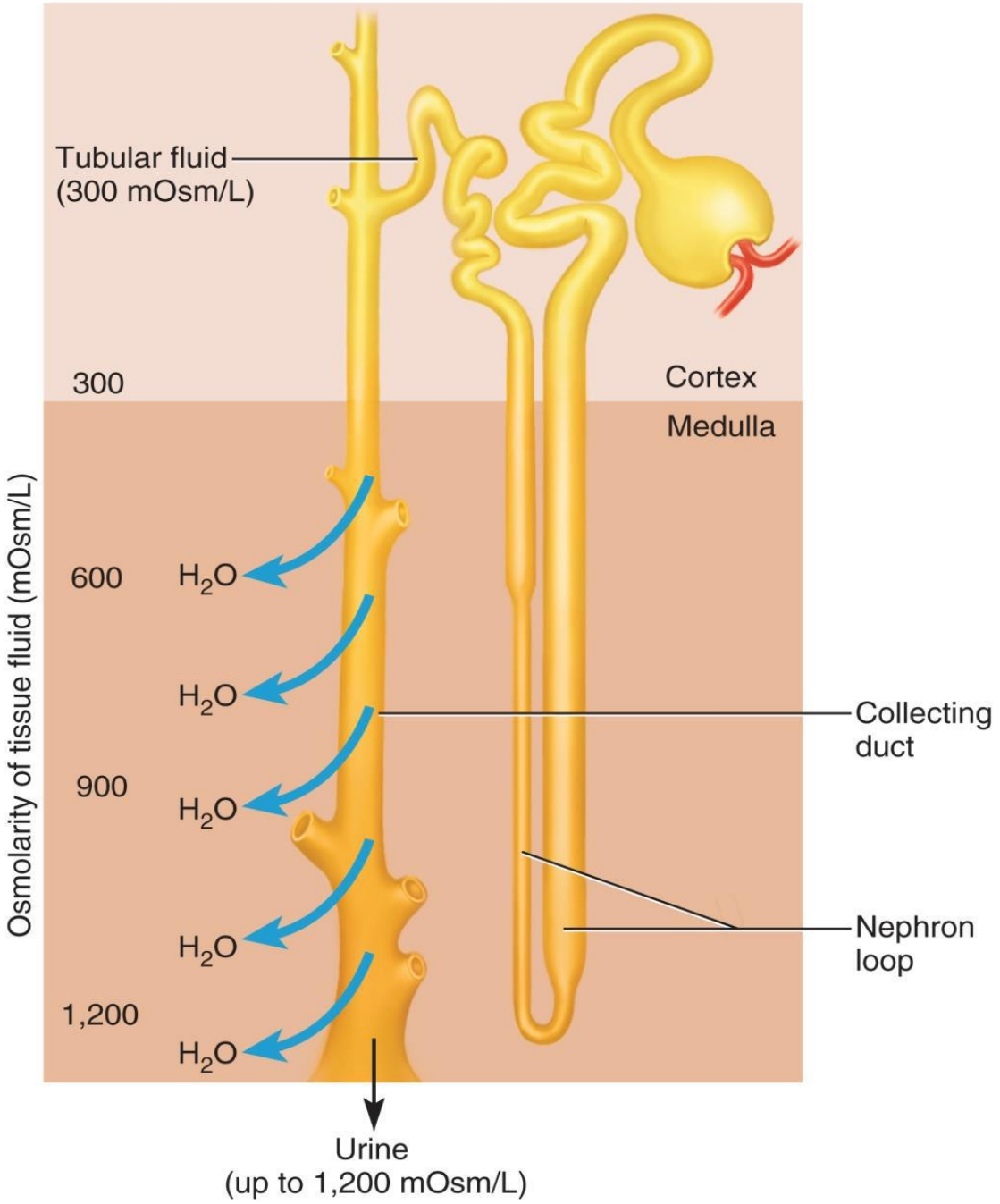
- Primary function of nephron loop is to generate salinity gradient that enables collecting duct to concentrate the urine and conserve water
- Electrolyte reabsorption from filtrate
- Thick segment reabsorbs 25% of Na+, K+, and Cl− in filtrate
- Ions leave cells by active transport and diffusion
- NaCl remains in the tissue fluid of renal medulla
- Water cannot follow since thick segment is impermeable
- Tubular fluid very dilute as it enters distal convoluted tubule

The Distal Convoluted Tubule and Collecting Duct

- **Fluid arriving in the DCT still contains about 20% of the water and 7% of the salts from glomerular filtrate**
- If this were all passed as urine, it would amount to 36 L/day
- **DCT and collecting duct reabsorb variable amounts of water and salt and are regulated by several hormones**
- **–Aldosterone, atrial natriuretic peptide, ADH,** and **parathyroid hormone**

• Collecting Duct

- Collecting duct (CD) begins in the cortex where it receives tubular fluid from several nephrons
- CD runs through medulla, and reabsorbs water, making urine up to four times more concentrated
- Medullary portion of CD is more permeable to water than to NaCl
- As urine passes through the increasingly salty medulla, water leaves by osmosis, concentrating urine



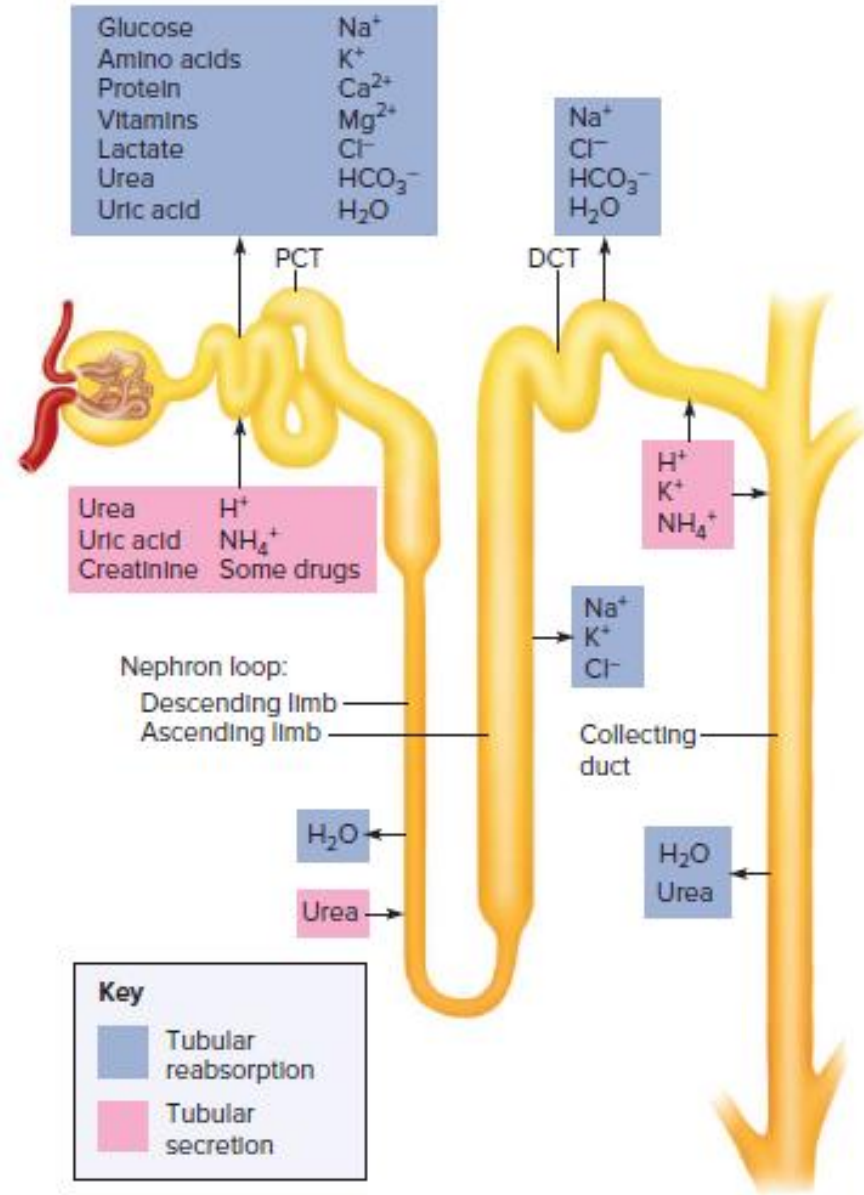


FIGURE 23.22 **Solutes Reabsorbed and Secreted in Each Portion of the Renal Tubule.**

TABLE 23.1 Hormones Affecting Renal Function

Hormone	Renal Targets	Effects
Aldosterone	Nephron loop, DCT, CD	Promotes Na^+ reabsorption and K^+ secretion; indirectly promotes Cl^- and H_2O reabsorption; maintains blood volume and reduces urine volume
Angiotensin II	Afferent and efferent arterioles, PCT	Reduces water loss, stimulates thirst and encourages water intake, and constricts blood vessels, thus raising blood pressure. Reduces GFR; stimulates PCT to reabsorb NaCl and H_2O; stimulates aldosterone and ADH secretion
Antidiuretic hormone	Collecting duct	Promotes H_2O reabsorption; reduces urine volume, increases concentration
Natriuretic peptides	Afferent and efferent arterioles, collecting duct	Dilate afferent arteriole, constrict efferent arteriole, increase GFR; inhibit secretion of renin, ADH, and aldosterone; inhibit NaCl reabsorption by collecting duct; increase urine volume and lower blood pressure
Calcitonin	DCT	Weak effects similar to those of parathyroid hormone
Calcitriol	DCT	Weak effects similar to those of parathyroid hormone
Epinephrine and norepinephrine	Juxtaglomerular apparatus, afferent arteriole	Induce renin secretion; constrict afferent arteriole; reduce GFR and urine volume
Parathyroid hormone	PCT, DCT, nephron loop	Promotes Ca^{2+} reabsorption by loop and DCT; increases phosphate excretion by PCT; promotes calcitriol synthesis

The Ureters

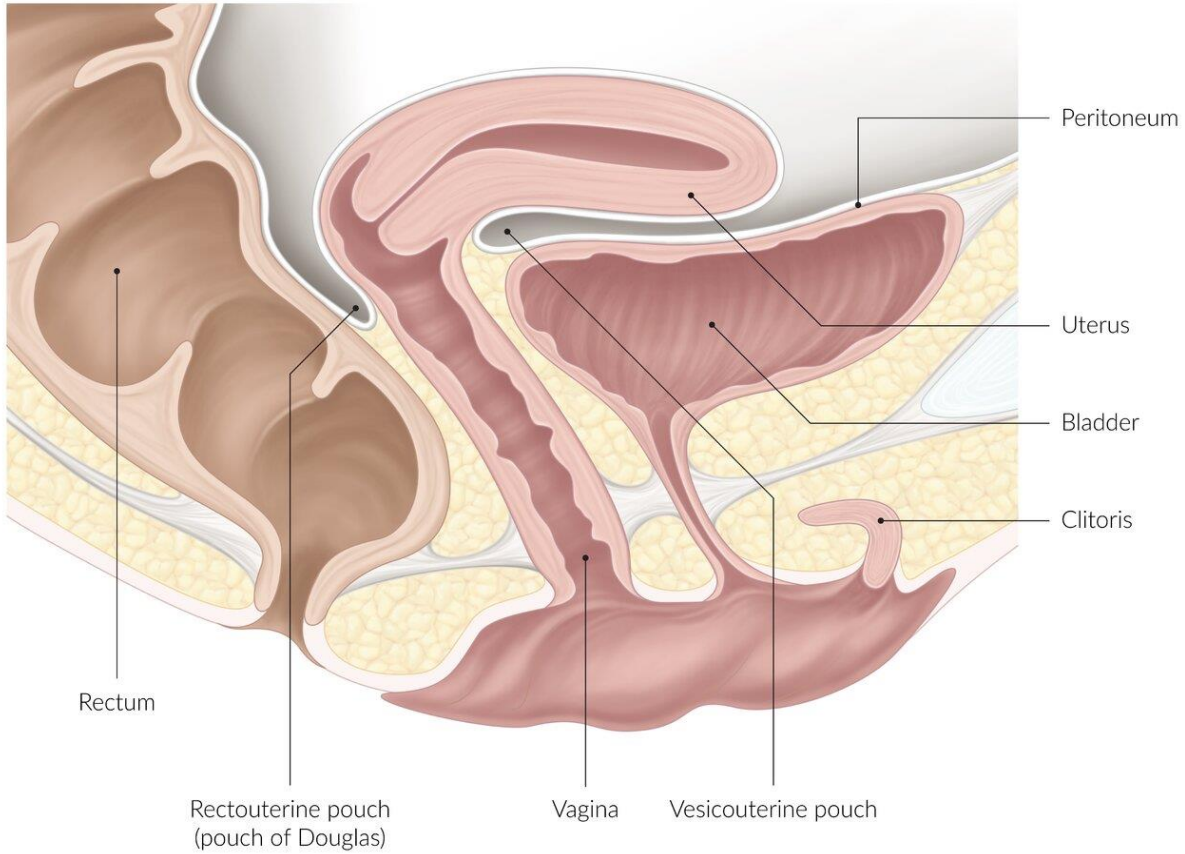
Ureters—retroperitoneal, muscular tubes that extend from each **kidney to the urinary bladder**

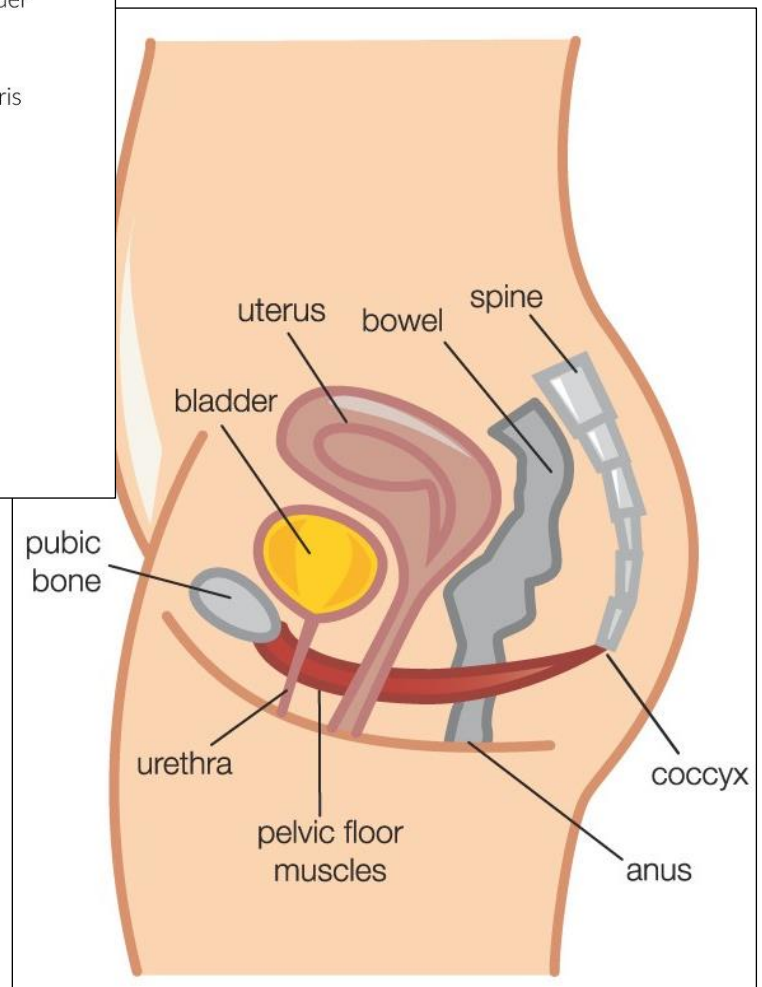
- About 25 cm long
- Pass posterior to bladder and enter it from below
- Flap of mucosa at entrance of each ureter acts as a valve into bladder
- Keeps urine from backing up into ureter when bladder contracts

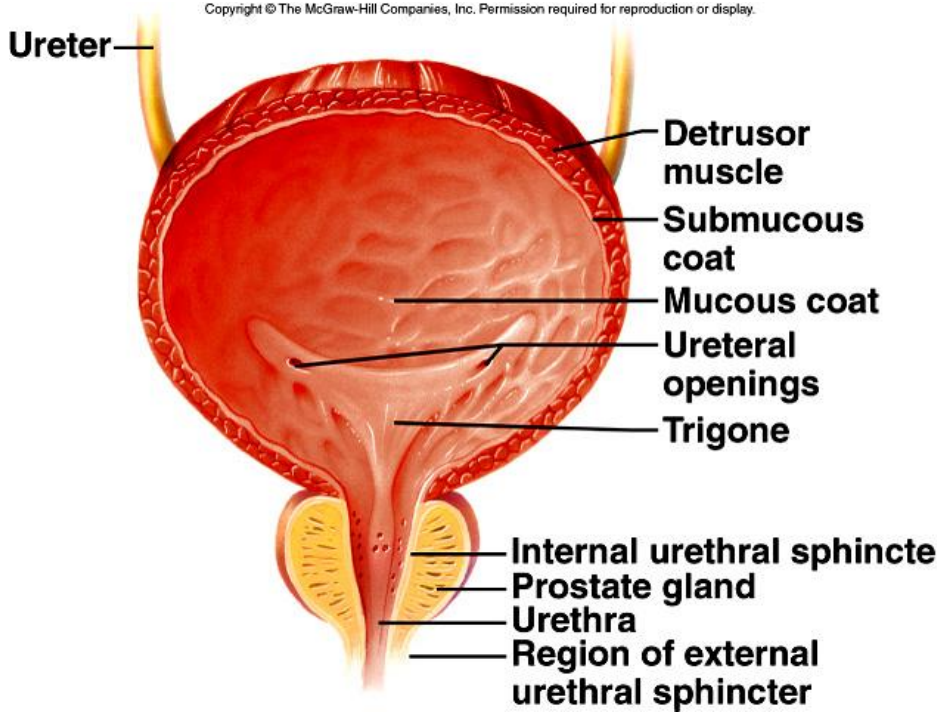
- Three layers of ureter
- **Adventitia**—connective tissue layer that connects ureter to surrounding structures
- **Muscularis**—two layers of smooth muscle with third layer in lower ureter
- Urine enters, it stretches and contracts in peristaltic wave
- **Mucosa**—transitional epithelium
- –Begins at minor calyces and extends through the bladder
- –Lumen very narrow, easily obstructed by kidney stones

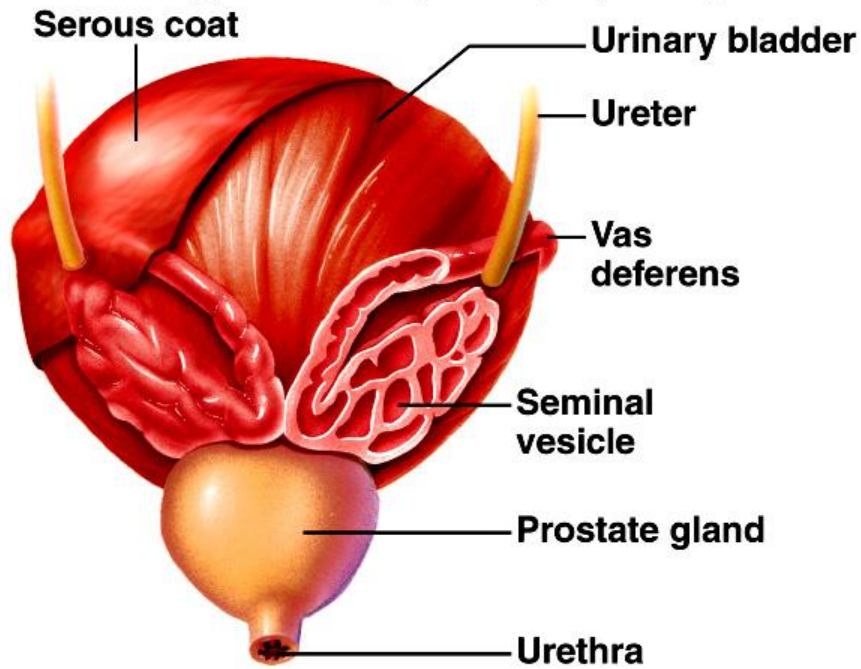
The Urinary Bladder

- **Urinary bladder—**muscular sac located on floor of the pelvic cavity
- Inferior to peritoneum and posterior to pubic symphysis
- Three layers
- **Covered by parietal peritoneum, superiorly, and by fibrous adventitia elsewhere**
- Muscularis: detrusor: three layers of smooth muscle
- Mucosa: transitional epithelium
- Umbrella cells on surface of epithelium protect it from the hypertonic, acidic urine
- Rugae—conspicuous wrinkles in empty bladder


Peritoneum
Uterus
Bladder
Clitoris
Rectum
Rectouterine pouch
(pouch of Douglas)
Vagina
Vesicouterine pouch

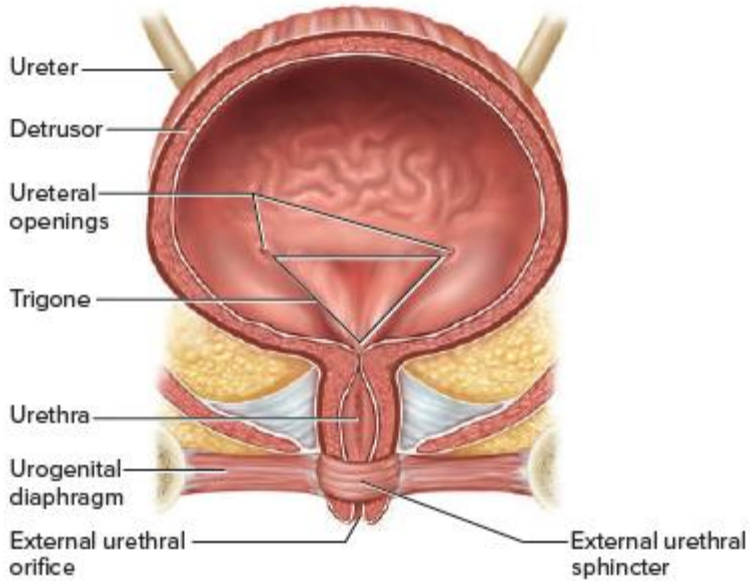

uterus
bowel
spine
bladder
pubic
bone
urethra
pelvic floor
muscles
coccyx
anus



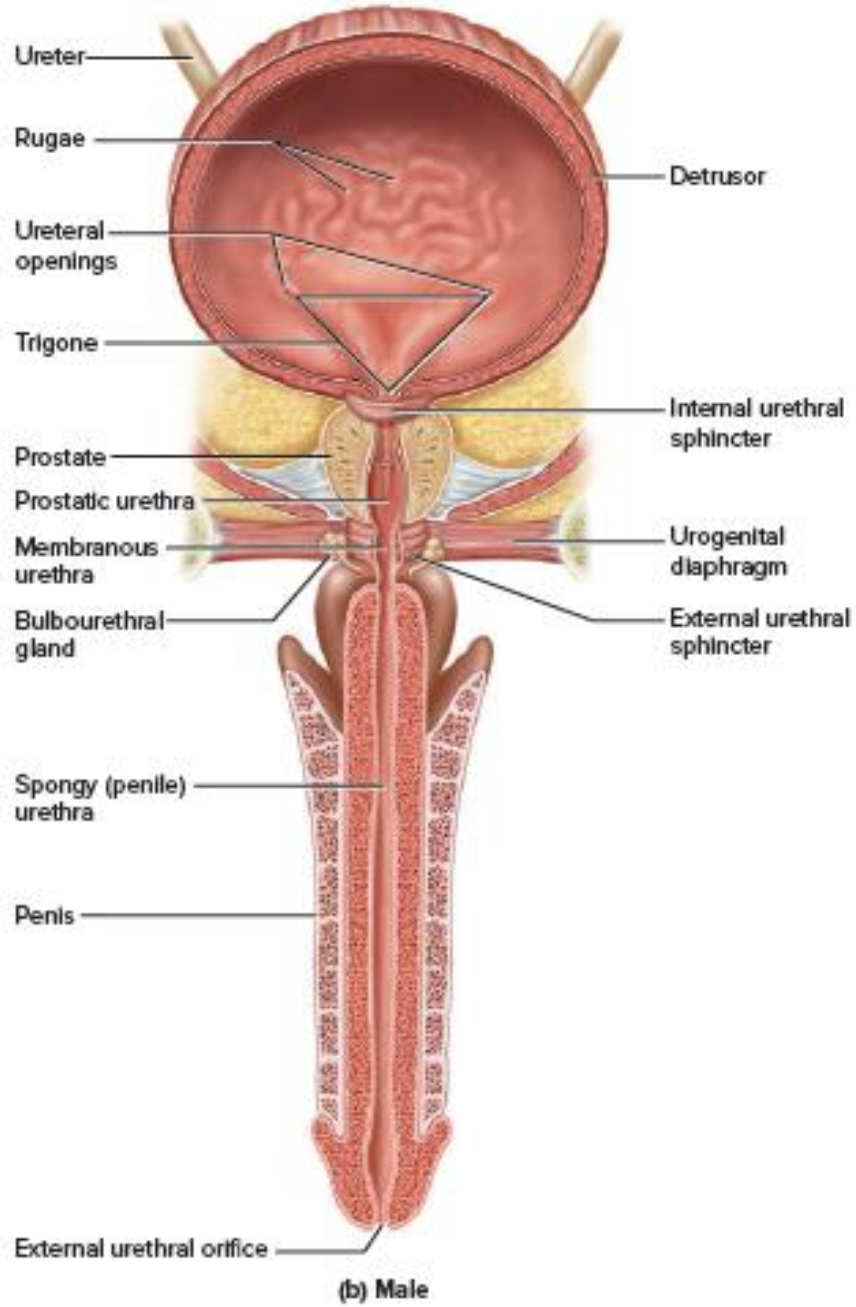


Urethra

- The urethra is a tube that conveys urine from the urinary bladder to the outside.
- It is a muscular tube with urethral glands that secrete mucus into the urethral canal.
- In the female, it is a tube 3 to 4 cm long bound to the anterior wall of the vagina by fibrous connective tissue. Its opening, the **external urethral orifice,**
- The male urethra opens in penis



(a) Female



(b) Male

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- Saladin, K. (2020). Anatomy & Physiology: The Unity of Form and Function. McGraw-Hill Education.