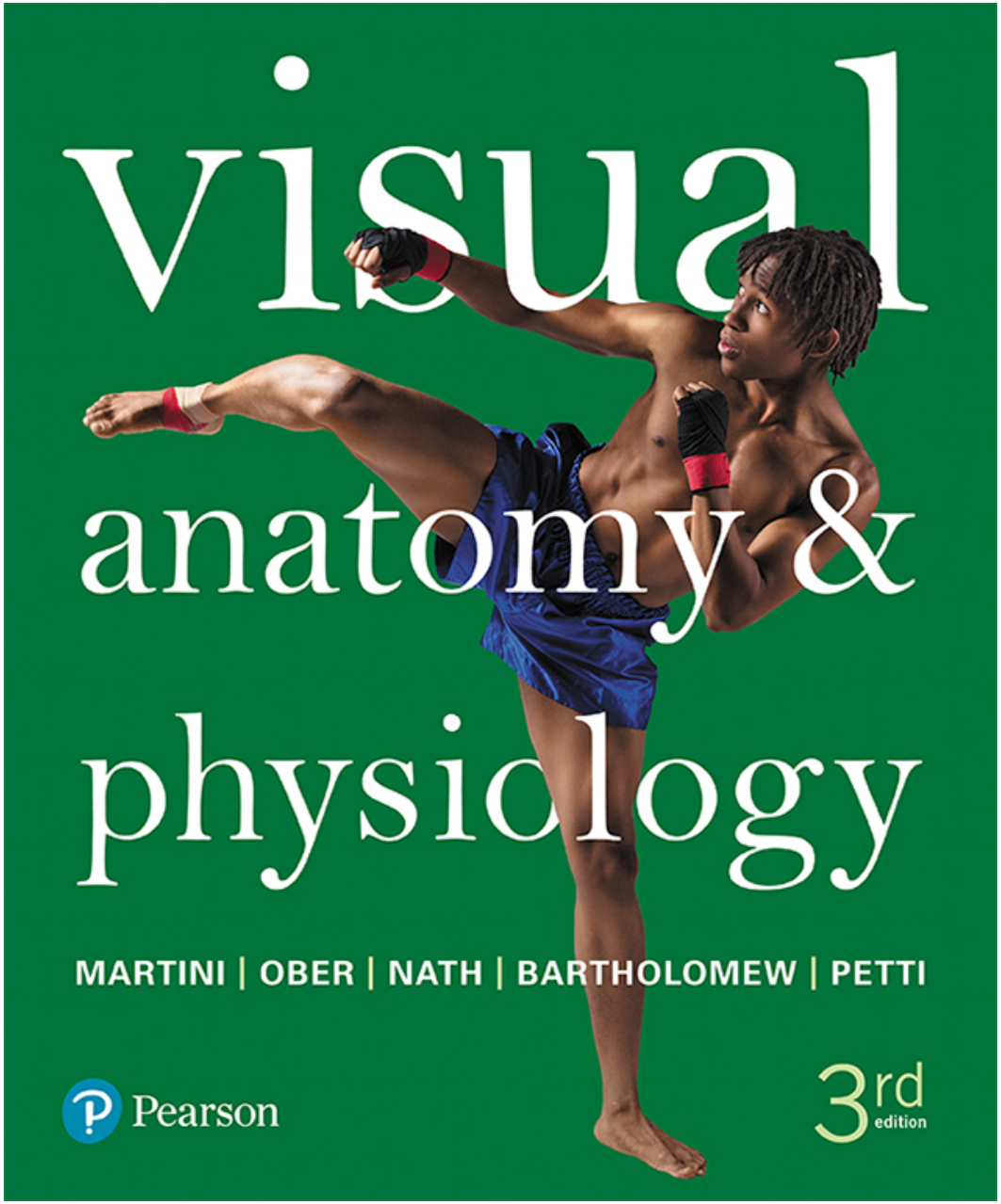

24

The Urinary System

Lecture Presentation by
Lori Garrett

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Section 1: Anatomy of the Urinary System

Learning Outcomes

24.1 Identify the organs of the urinary system, and cite a primary function of each.

24.2 Describe the location and structural features of the kidneys.

24.3 Describe the gross structural features of the kidney, and distinguish between cortical and juxtamedullary nephrons.

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Section 1: Anatomy of the Urinary System

Learning Outcomes (continued)

24.4 Describe the segments of the nephron and collecting system, including their general functions and histological appearance.

24.5 Trace the pathway of blood flow through a kidney, and compare the pattern of blood flow in cortical and juxtamedullary nephrons.

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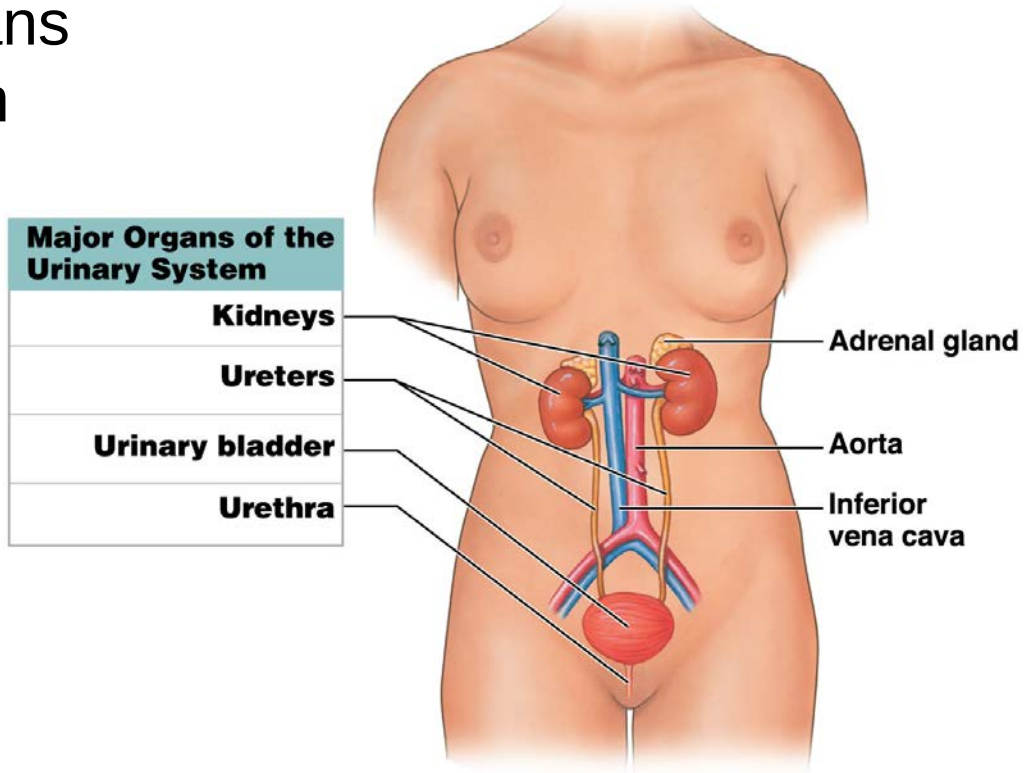
Module 24.1: The urinary system organs are the kidneys, ureters, urinary bladder, and urethra

Urinary system

- Two **kidneys**
  - Receive 25 percent of the cardiac output
  - Major excretory organs of the urinary system
  - Produce **urine** (fluid containing water, ions, and small soluble substances)



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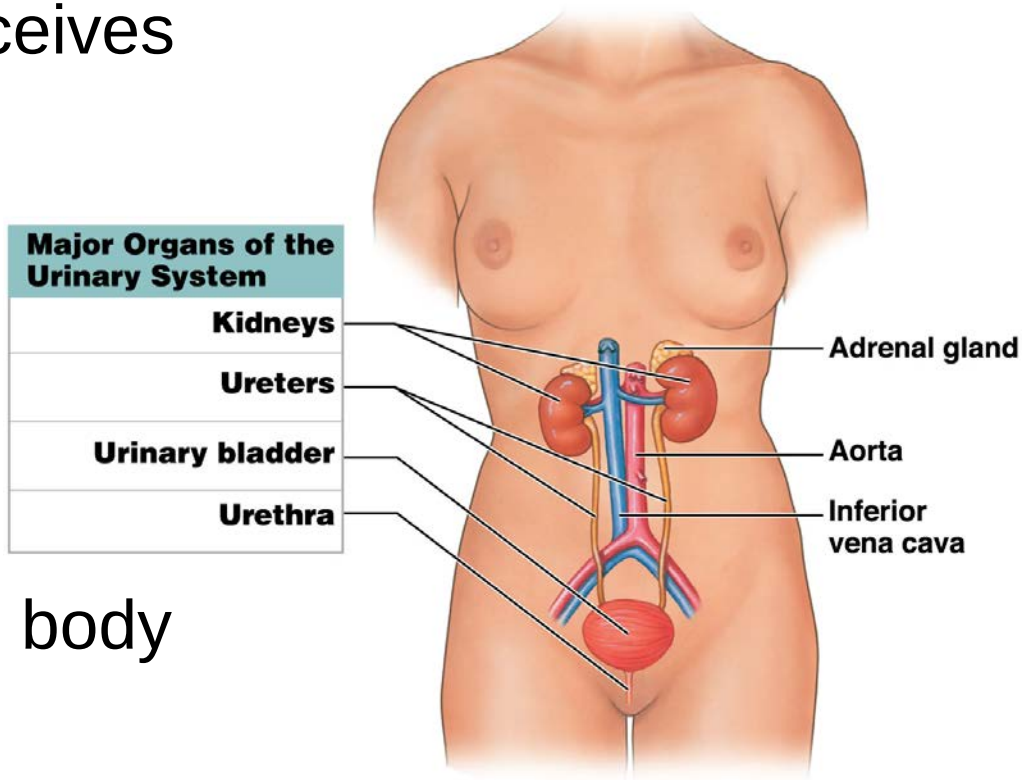
Module 24.1: Urinary system organs

Urinary tract

- **Ureters**—receive urine from the kidneys
  - Conduct urine to the urinary bladder by gravity and peristalsis
- **Urinary bladder**—receives and stores urine
  - Contraction of muscle in walls drives **urination**
- **Urethra**—conducts urine from the bladder to outside the body



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Functions of the Urinary System

- Adjusting blood volume and blood pressure
- Regulating blood plasma concentrations of sodium, potassium, chloride, and other ions
- Stabilizing blood pH
- Conserving valuable nutrients by preventing their loss in urine
- Removing drugs and toxins from the bloodstream

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Module 24.1: Review

A. Name the major excretory organs of the urinary system.
B. Describe the functions of the urinary system.

Learning Outcome: Identify the organs of the urinary system, and cite a primary function of each.

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Module 24.2: The kidneys are paired retroperitoneal organs

Kidney structure

- Reddish brown
- Dimensions
  - ~10 cm (4 in.) long; ~5.5 cm (2.2 in.) wide; ~3 cm (1.2 in.) thick Weight: ~150 g (5.25 oz)
- **Hilum**
  - Medial indentation
  - Point of entry/exit for the renal artery, renal nerves, renal vein, and the ureter

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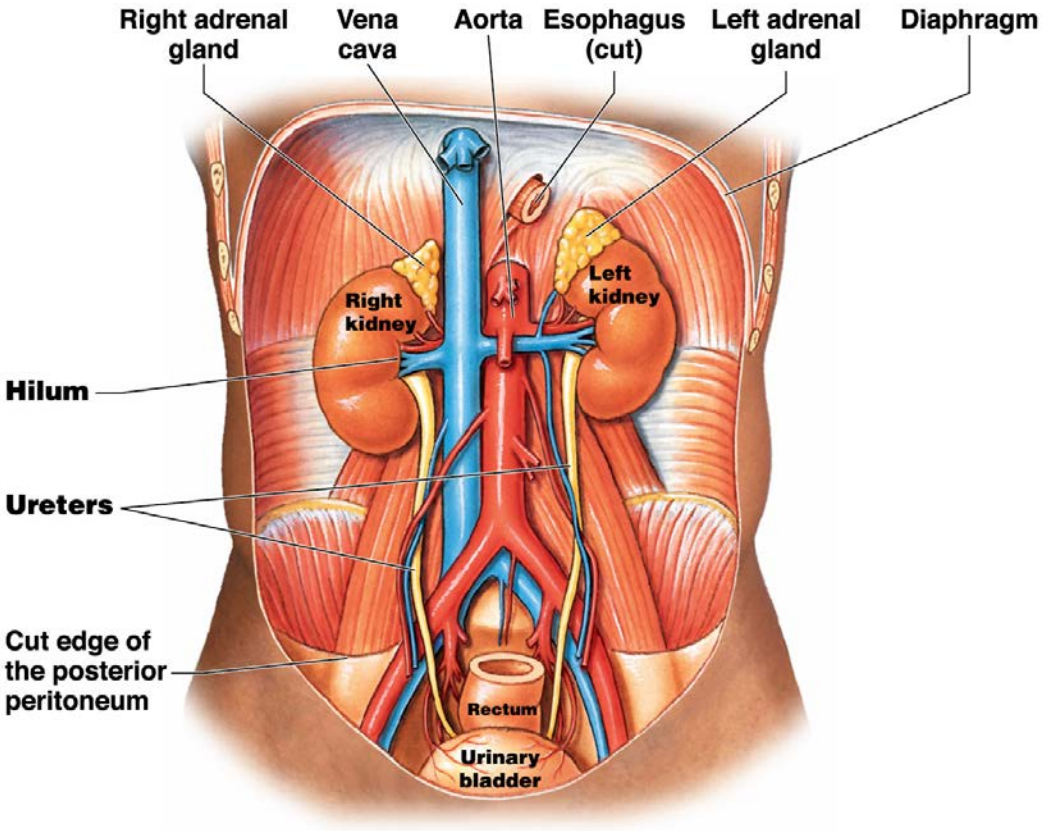
Module 24.2: Kidney location and structure

- Located in a **retroperitoneal** position
  - Between the muscles of the posterior body wall and the parietal peritoneum
- Connected to the urinary bladder by the **ureters**
  - Empty into the posterior, inferior surface of the urinary bladder



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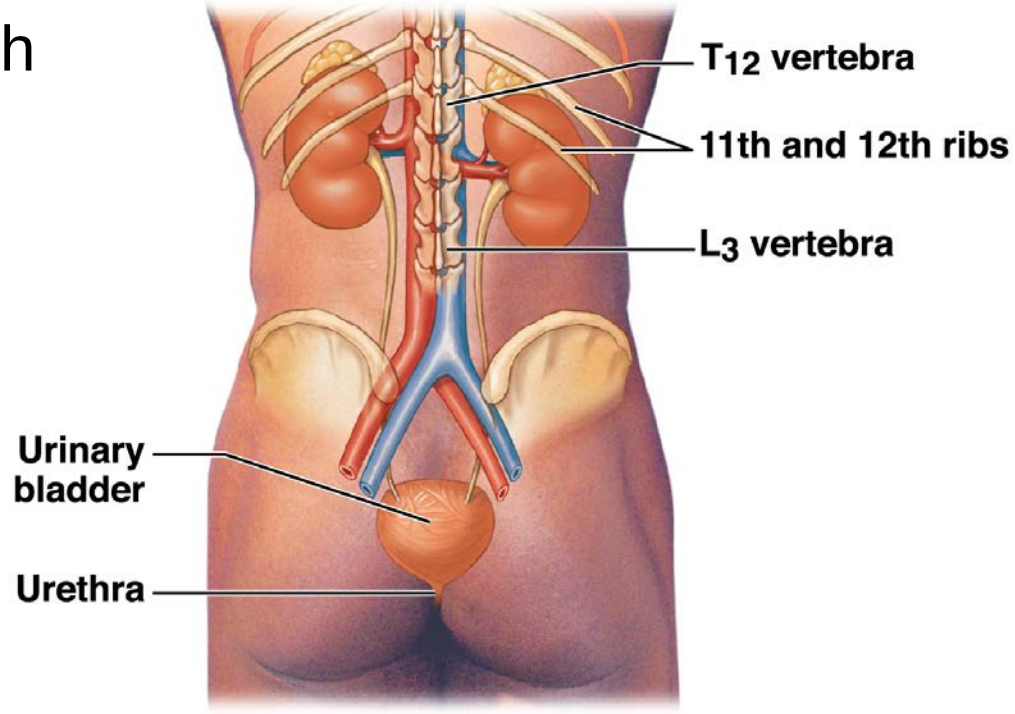
Module 24.2: Kidney location and structure

Kidney location

- Either side of vertebral column
- Protected by:
  - Visceral organs (anteriorly)
  - Body wall musculature and the 11th and 12th ribs (posteriorly and laterally)
- Left kidney slightly superior to the right



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Module 24.2: Kidney location and structure

Kidney location (continued)

- Position maintained by:
  1. Overlying peritoneum
  2. Adjacent visceral organs
  3. Supporting connective tissues

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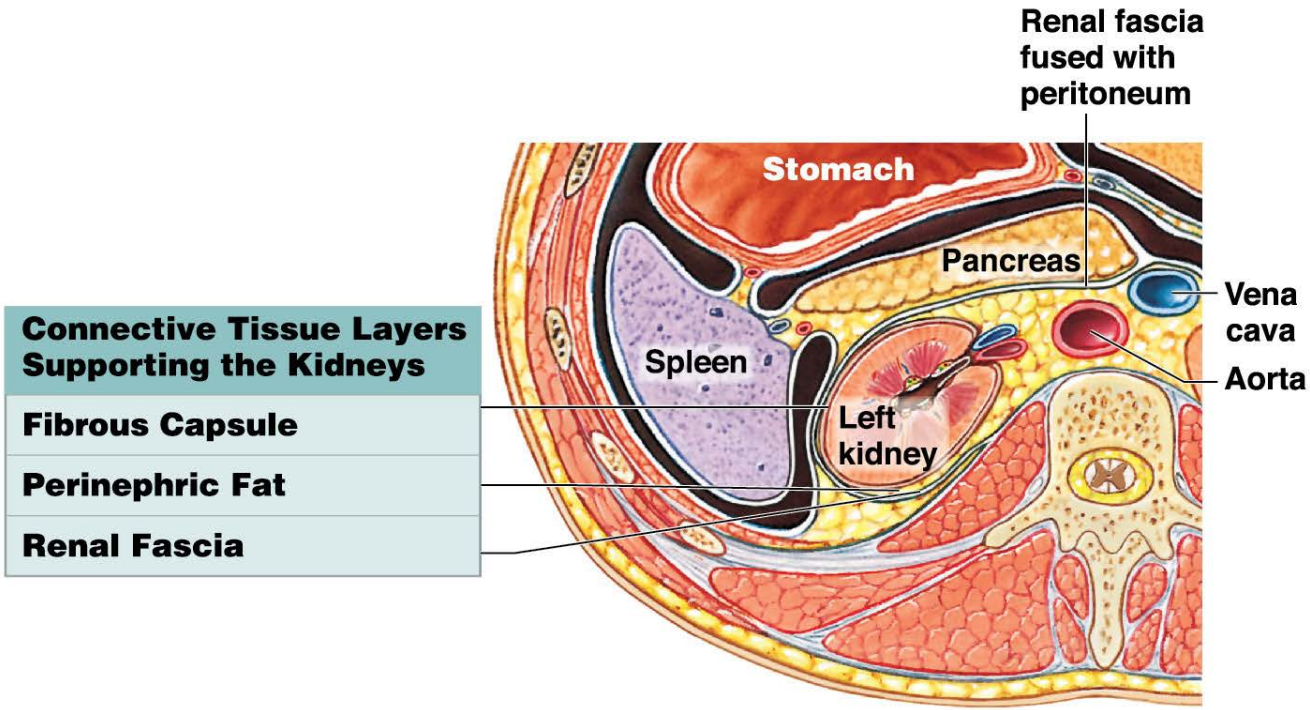
Module 24.2: Kidney location and structure

Connective tissues supporting kidney

- **Fibrous capsule** (layer of collagen fibers)
  - Covers the outer surface of the kidney
  - Projects collagen fibers through the perinephric fat to the renal fascia



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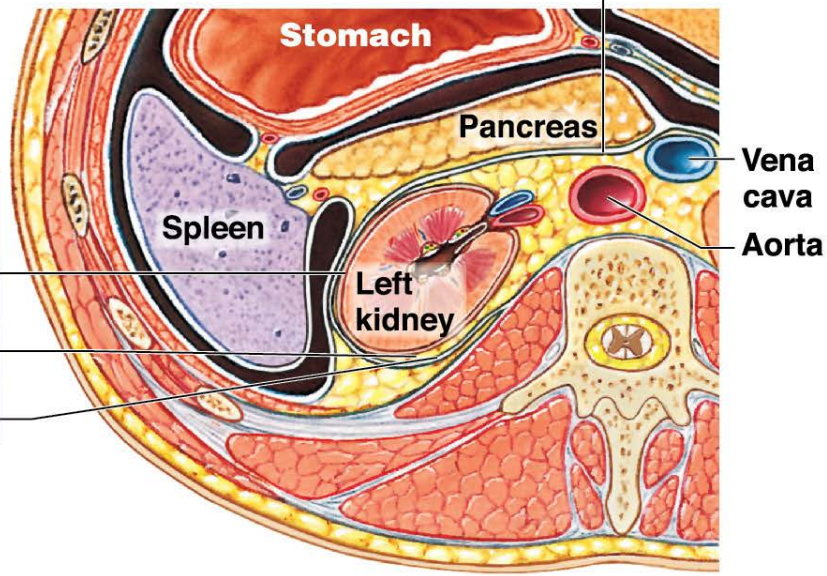
Module 24.2: Kidney location and structure

Connective tissues supporting kidney (continued)

- **Perinephric fat** (perinephric fat capsule)
  - Thick layer of adipose tissue
- **Renal fascia** (dense, fibrous outer layer)
  - Anchors the kidney to surrounding structures

Connective Tissue Layers Supporting the Kidneys
Fibrous Capsule
Perinephric Fat
Renal Fascia



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Module 24.2: Review

A. What structures enter and exit the kidney at the hilum?
B. Describe the concentric layers of connective tissue that protect and anchor the kidney.
C. What would happen to a kidney's position if the perinephric fat layer were depleted and the collagen fibers of the fibrous capsule were to become detached?

Learning Outcome: Describe the location and structural features of the kidneys.

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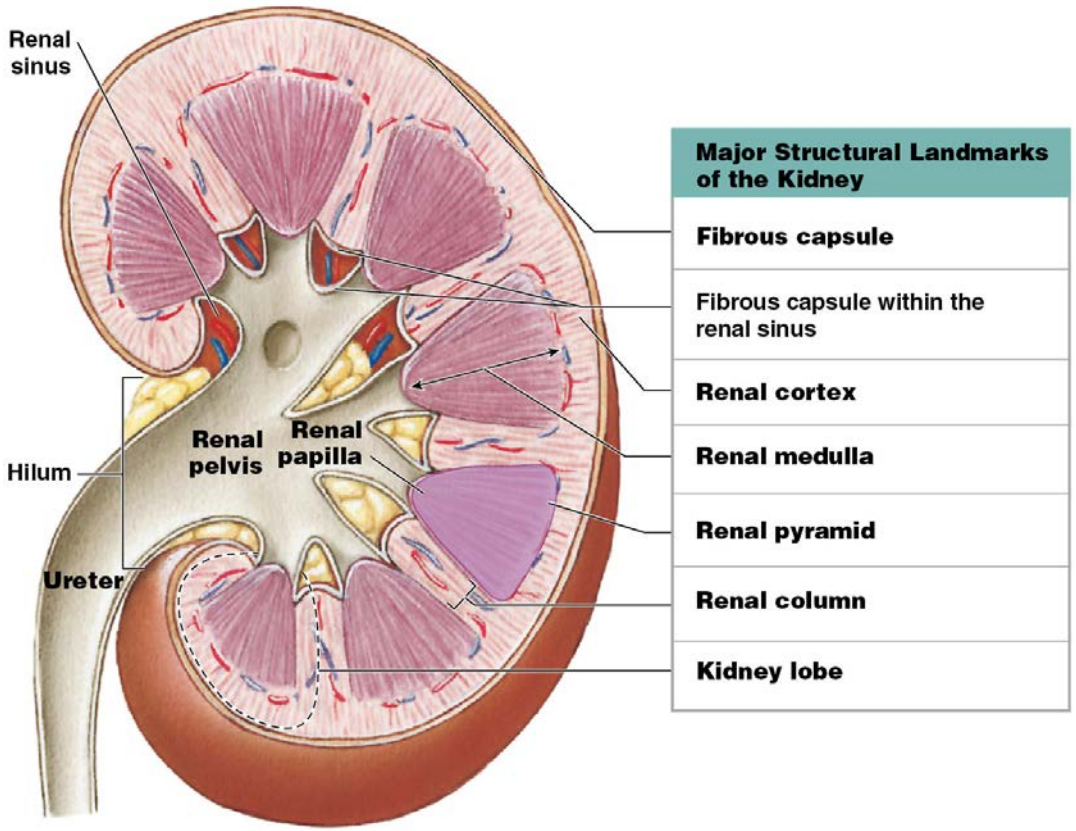
Module 24.3: The kidneys are complex at the gross and microscopic levels

Major structural landmarks

- **Fibrous capsule**
  - Lines the **renal sinus** (internal cavity within the kidney)
- **Renal cortex** (superficial region of the kidney)



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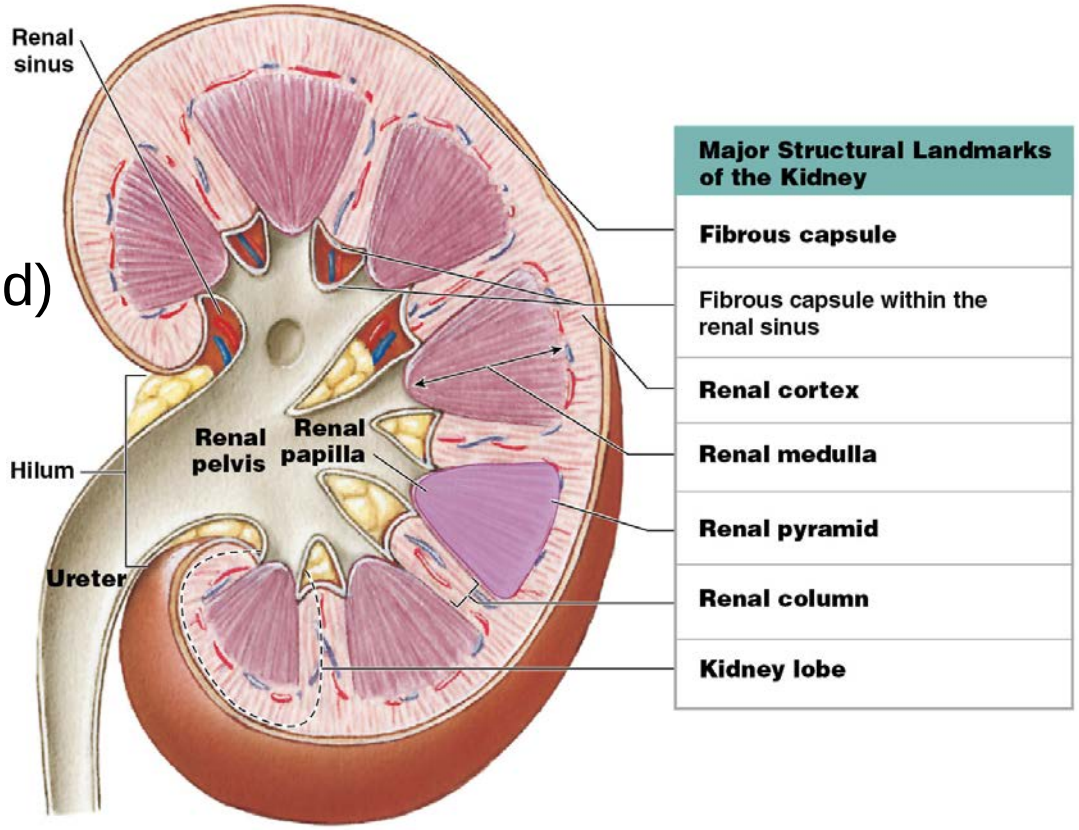
Module 24.3: Gross and microscopic anatomy of the kidney

Major structural landmarks (continued)

- **Renal medulla** (inner region of the kidney)
  - **Renal pyramid** (conical structure in the medulla)
    - **Renal papilla** (tip of the pyramid)
  - **Renal column** (separates adjacent pyramids)



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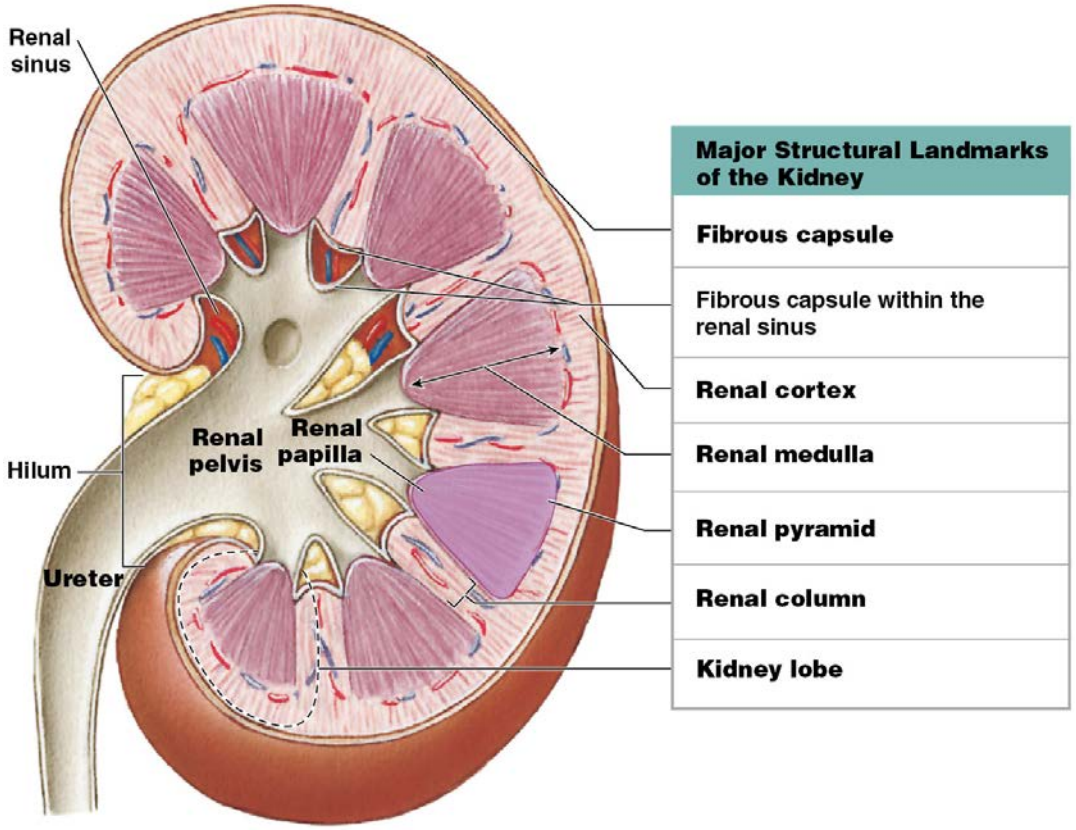
Module 24.3: Gross and microscopic anatomy of the kidney

Major structural landmarks (continued)

- **Kidney lobe** (pyramid, the overlying cortex, and adjacent renal columns)
  - Each kidney contains 6–18 lobes



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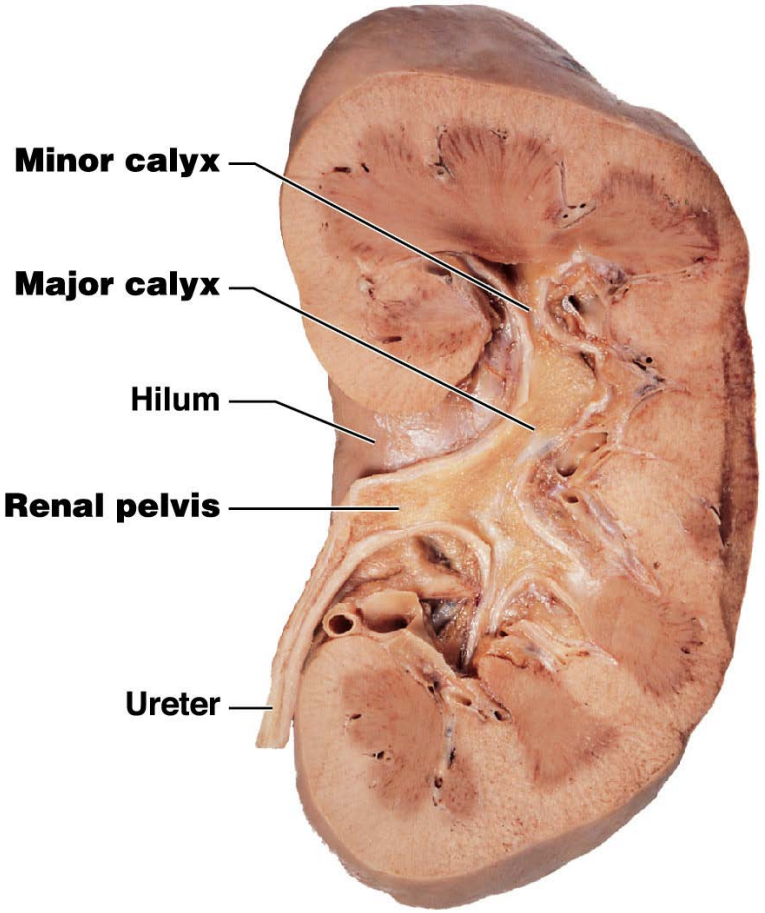
Module 24.3: Gross and microscopic anatomy of the kidney

Other features of the kidney

- **Hilum**
  - Medial indentation in the kidney
- **Minor calyx**
  - Collects urine from a single kidney lobe
- **Major calyx**
  - Forms from the fusion of 4–5 minor calyces



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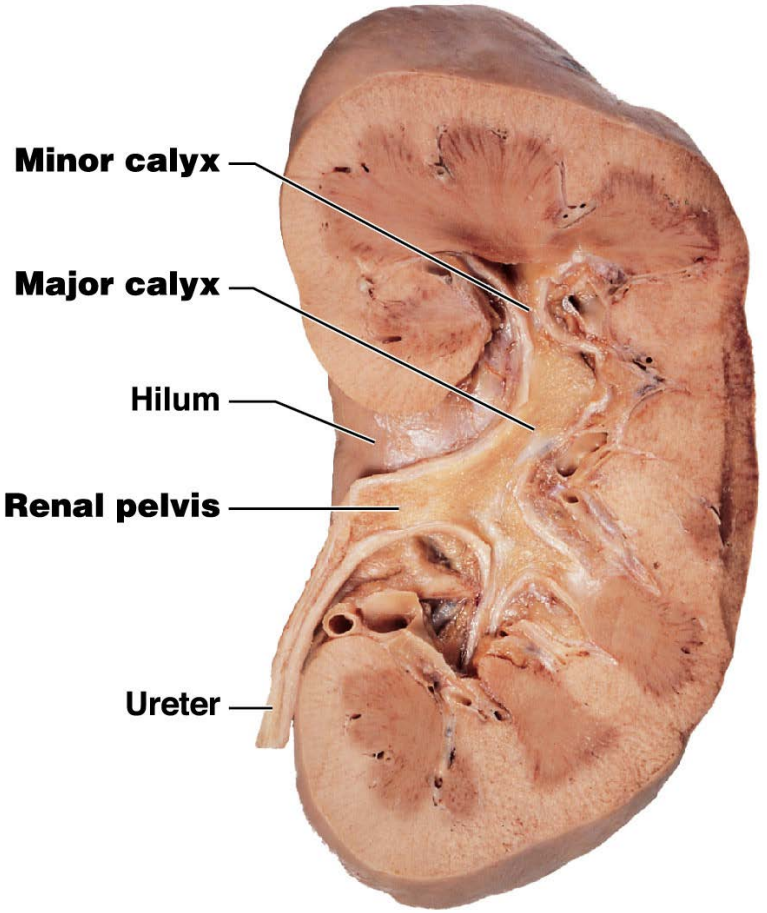
Module 24.3: Gross and microscopic anatomy of the kidney

Other features of the kidney (continued)

- **Renal pelvis**
  - Funnel-shaped structure that collects urine from major calyces
  - Continuous with the ureter



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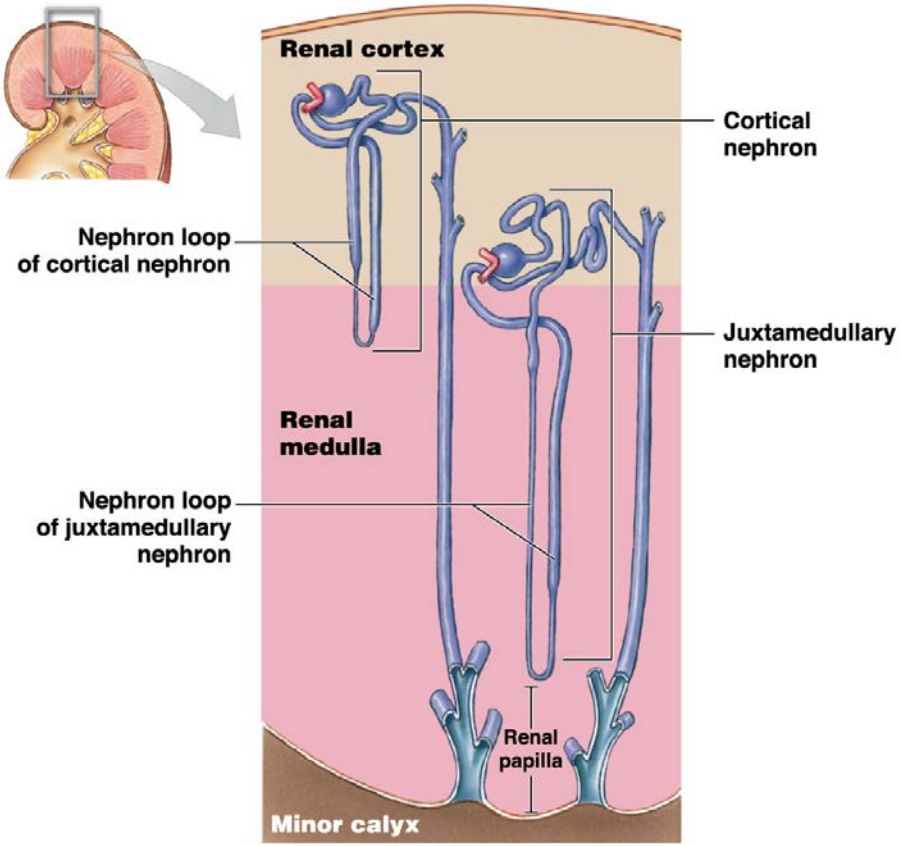
Module 24.3: Gross and microscopic anatomy of the kidney

Two types of nephrons

- Microscopic functional units of the kidney
  1. **Cortical nephrons**
     - 85 percent of all nephrons
     - Located primarily in the cortex
     - Responsible for most regulatory functions



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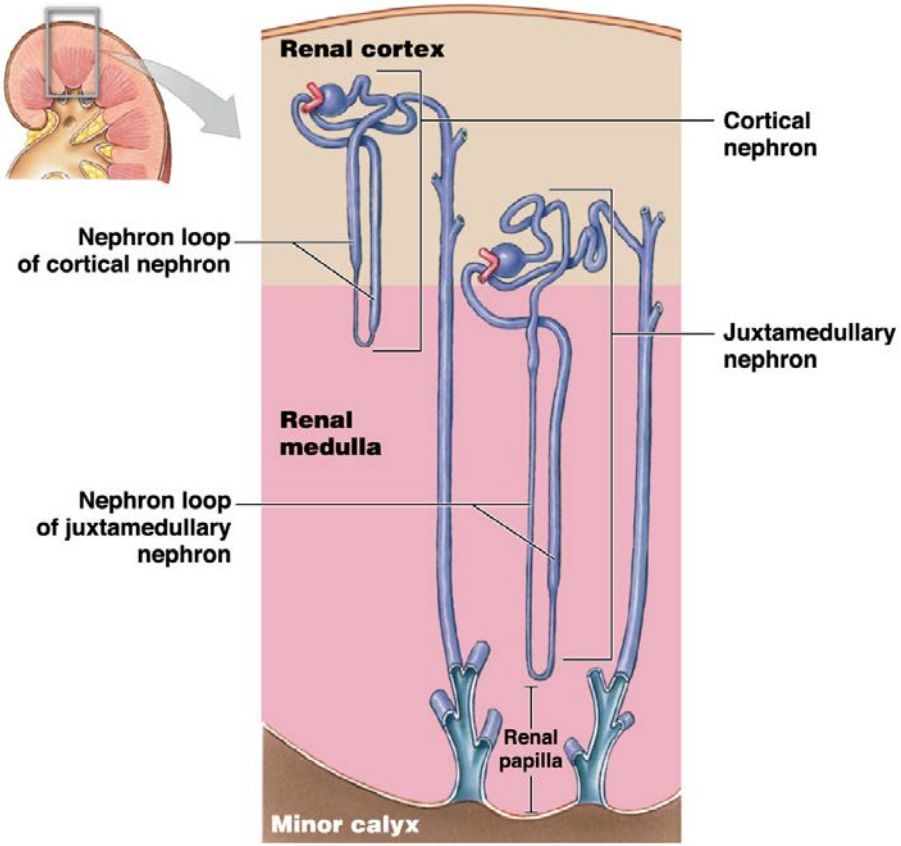
Module 24.3: Gross and microscopic anatomy of the kidney

Two types of nephrons (continued)

2. **Juxtamedullary nephrons**
   - 15 percent of all nephrons
   - Long **nephron loop** extending deep into medulla
   - Essential to producing concentrated urine



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Module 24.3: Review

A. Which structure is a conical mass within the renal medulla that ends at the papilla?
B. Compare the minor and major calyces.
C. Which type of nephron is essential for water conservation and concentrated urine production?

Learning Outcome: Describe the gross structural features of the kidney, and distinguish between cortical and juxtamedullary nephrons.

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Module 24.4: A nephron is divided into segments; each segment has specific functions

Two components

1. **Renal corpuscle**
   - Blood pressure forces water and solutes out of the glomerular capillaries in a process called filtration
     - Produces **filtrate** (protein-free solution, similar to blood plasma)
   - Collected in the surrounding **capsular space**
2. **Renal tubule**
   - Tubular passageway up to 50 mm long
   - Receives filtrate and modifies it to create urine

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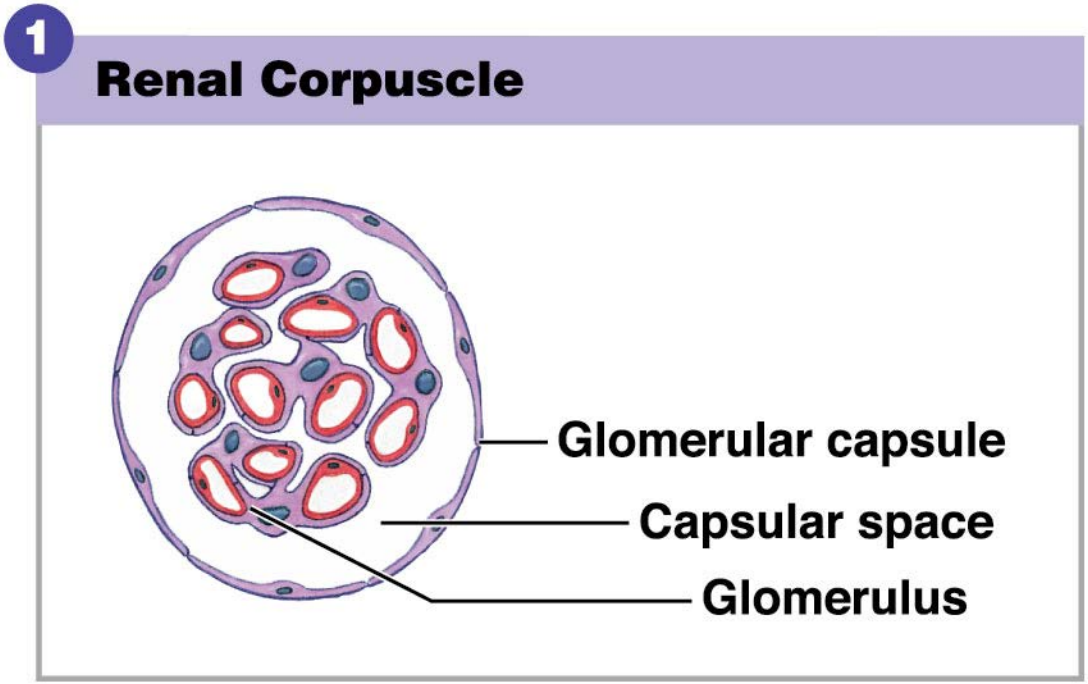
Module 24.4: Segments of a nephron

- **Renal corpuscle**
  - **Glomerular capsule** (*Bowman's capsule*)
    - Cup-shaped chamber
  - Capillary network (**glomerulus**)



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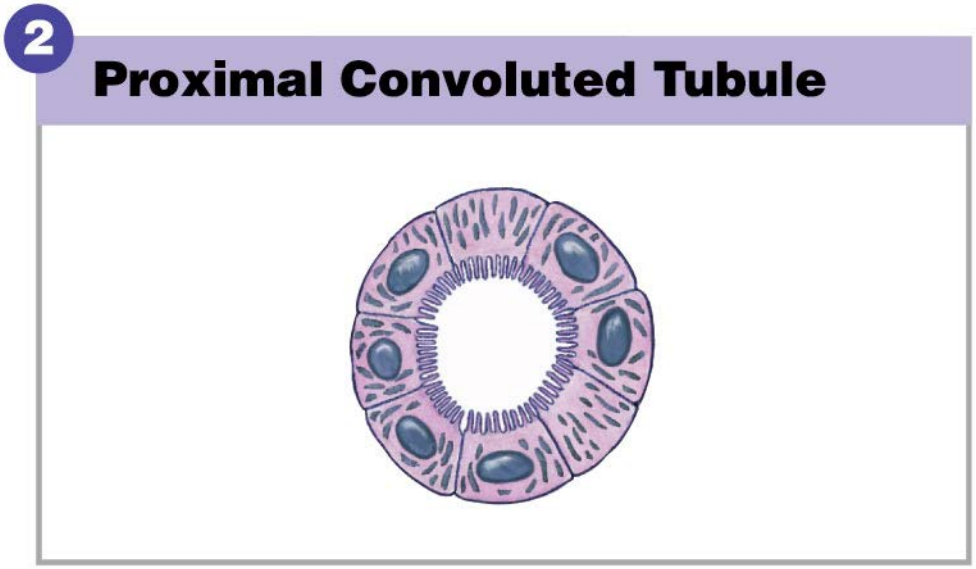
Module 24.4: Segments of a nephron

- **Proximal convoluted tubule** (**PCT**)
  - Reabsorbs nutrients from the filtrate (now called **tubular fluid**)



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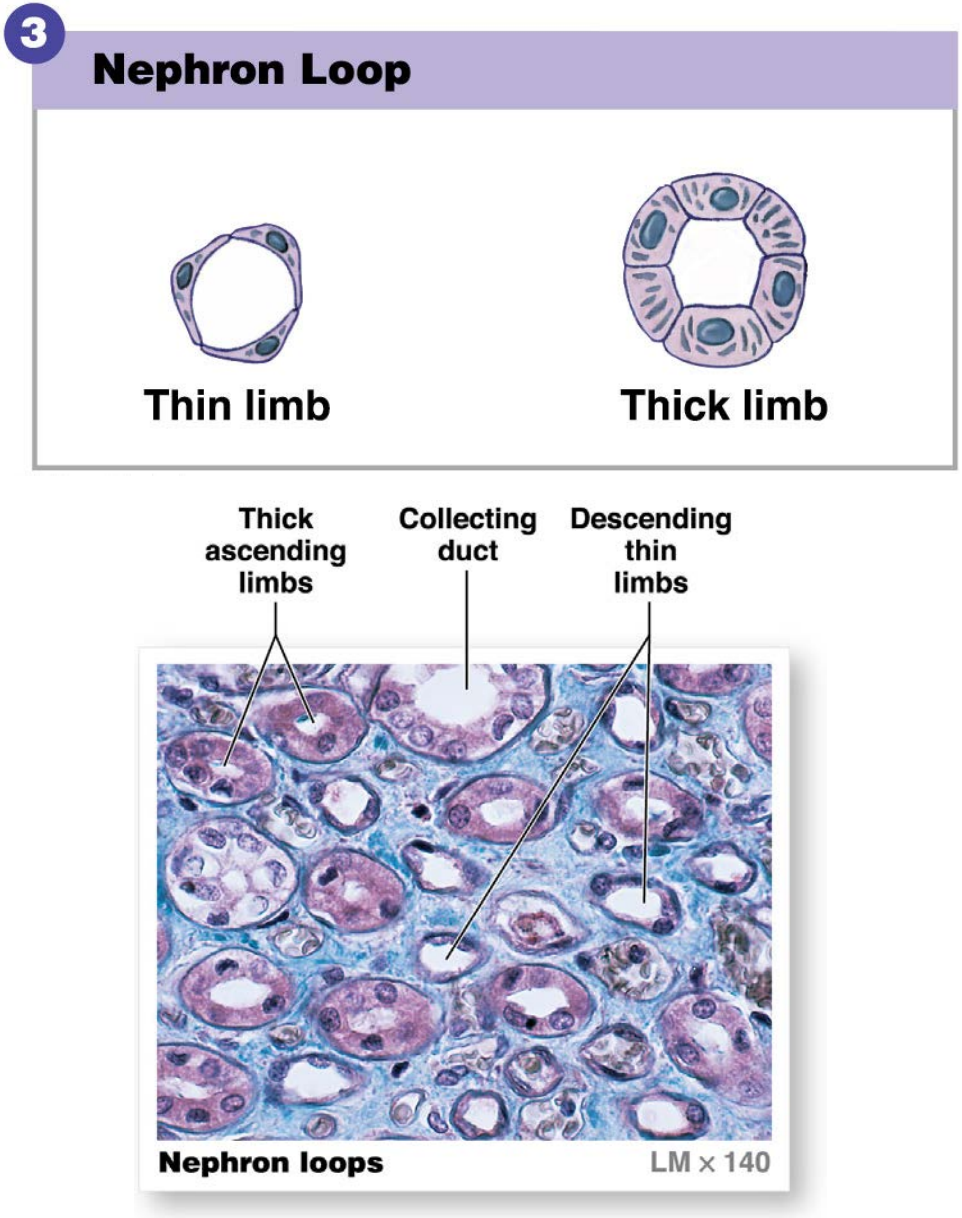
Module 24.4: Segments of a nephron

- **Nephron loop**
  - Establishes osmotic gradient for water reabsorption
  - Each limb contains a *thin segment* and a *thick segment*



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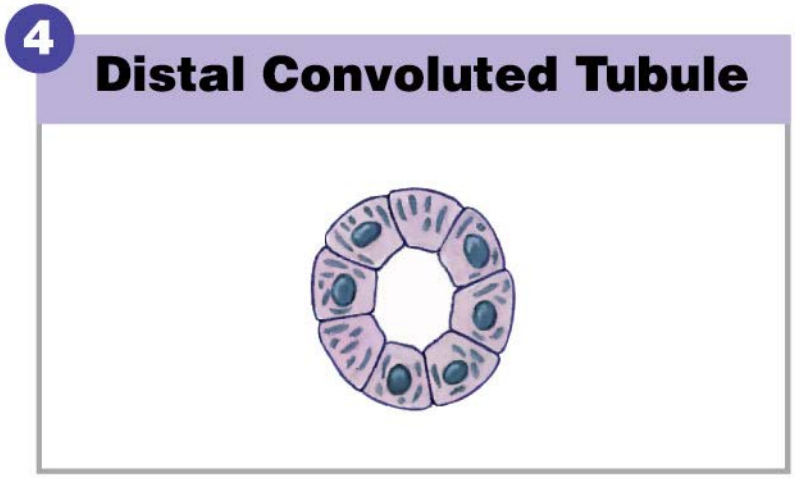
Module 24.4: Segments of a nephron

- **Distal convoluted tubule** (**DCT**)
  - Adjusts tubular fluid composition by reabsorption and secretion



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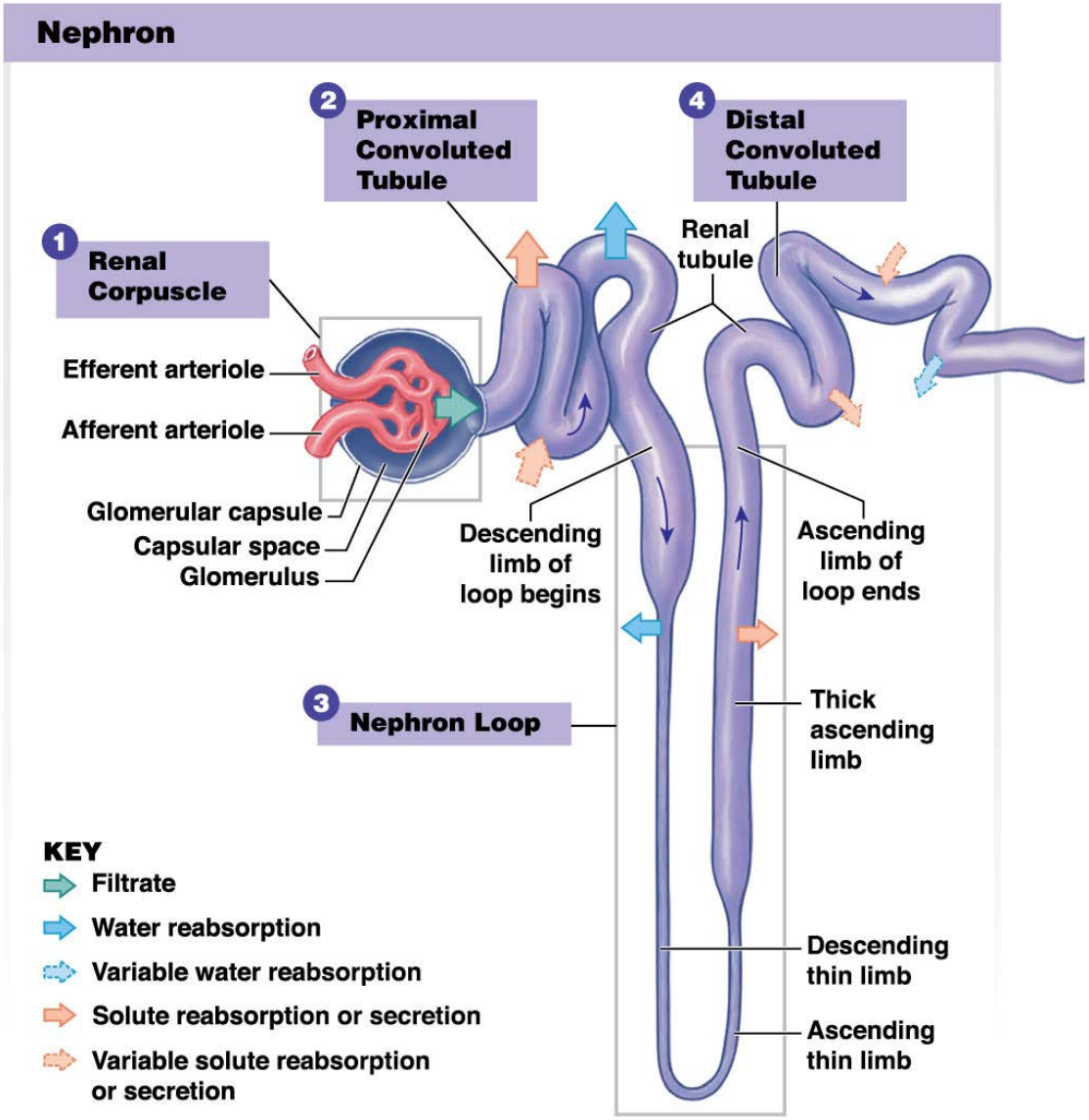
Segments of a nephron



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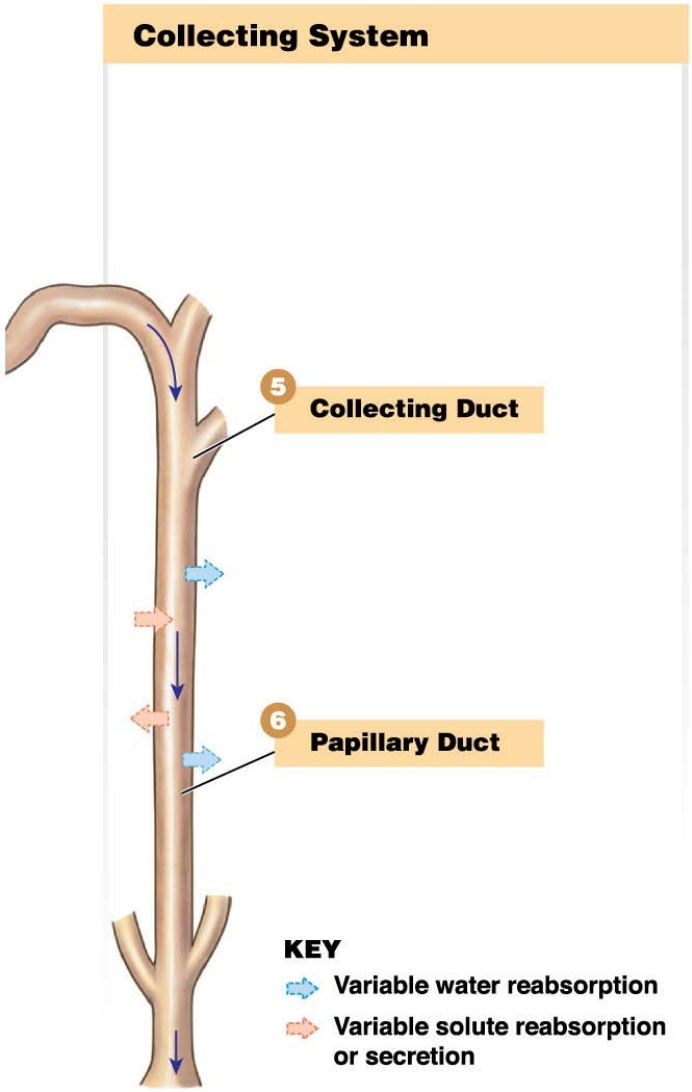
Module 24.4: Segments of a nephron

Collecting system

- Series of tubes carrying tubular fluid away from the nephron



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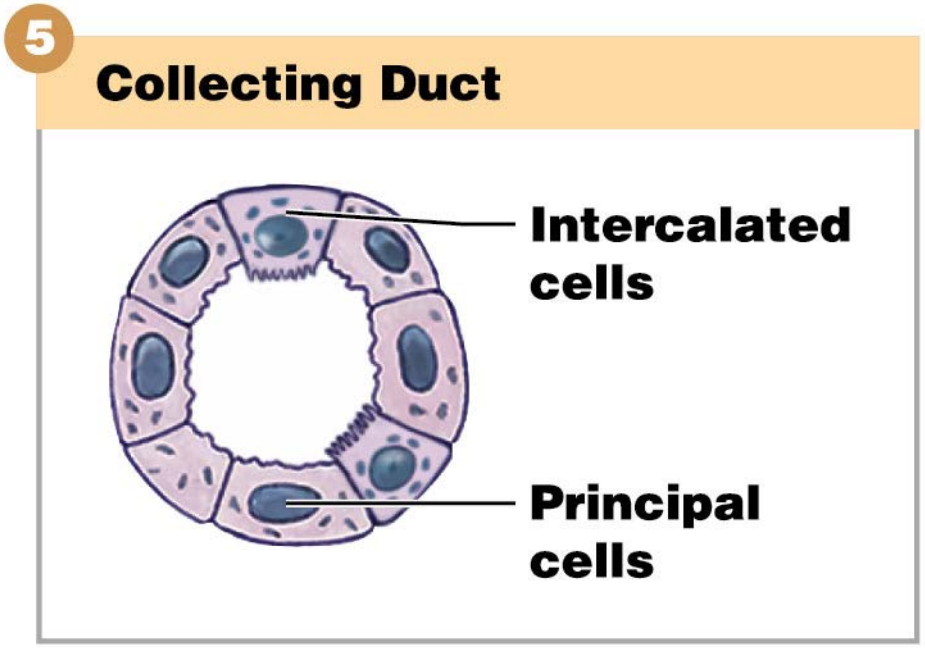
Module 24.4: Segments of a nephron

Collecting system (continued)

- **Collecting duct**
  - Collects fluid from many nephrons
  - Carries fluid through the renal medulla



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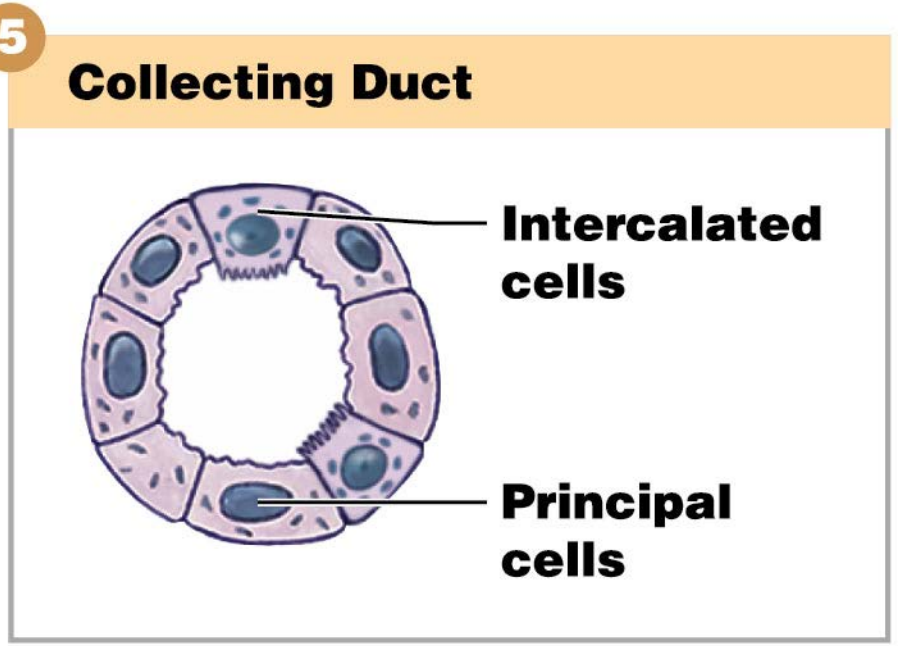
Module 24.4: Segments of a nephron

Collecting system (continued)

- **Collecting duct** (continued)
  - Lined with two main types of cells:
    - **Intercalated cells** (play a role in secreting and reabsorbing hydrogen and bicarbonate ions)
    - **Principal cells** (reabsorb water and secrete potassium)



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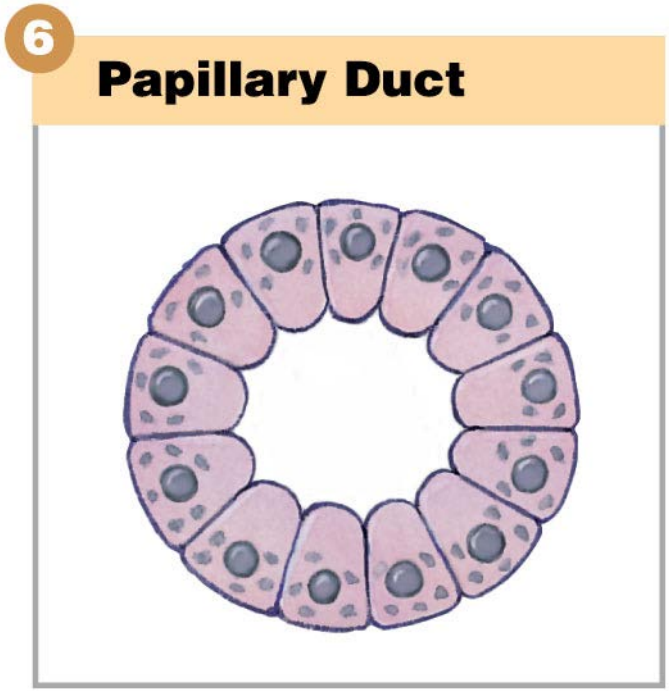
Module 24.4: Segments of a nephron

Collecting system (continued)

- **Papillary duct**
  - Collects fluid from multiple collecting ducts
  - Delivers fluid to minor calyx



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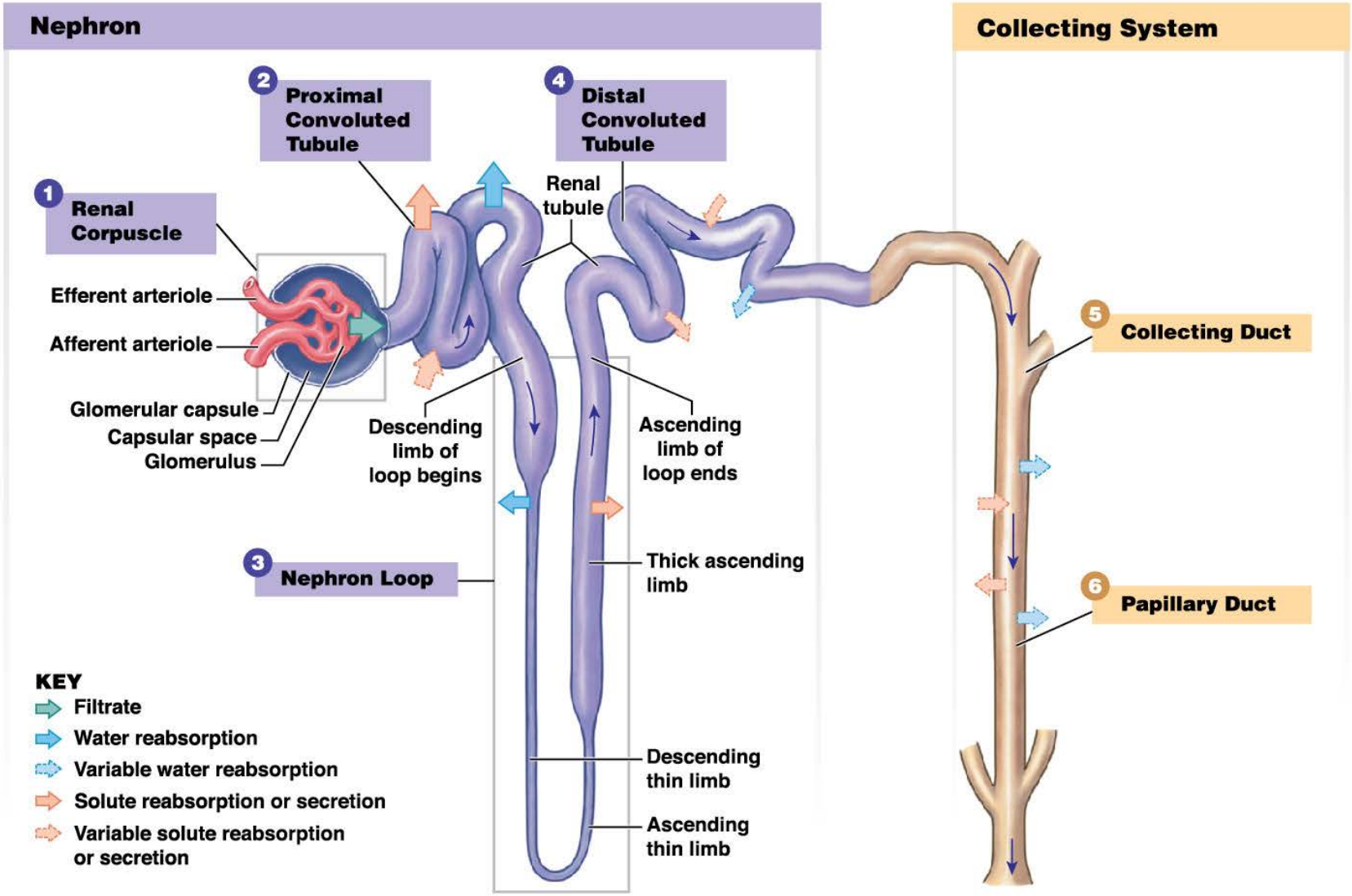
The Nephron and collecting system



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Module 24.4: Review

A. Describe filtrate.
B. Identify the structures of the renal corpuscle.
C. Describe the structures of the collecting system.

Learning Outcome: Describe the segments of the nephron and collecting system, including their general functions and histological appearance.

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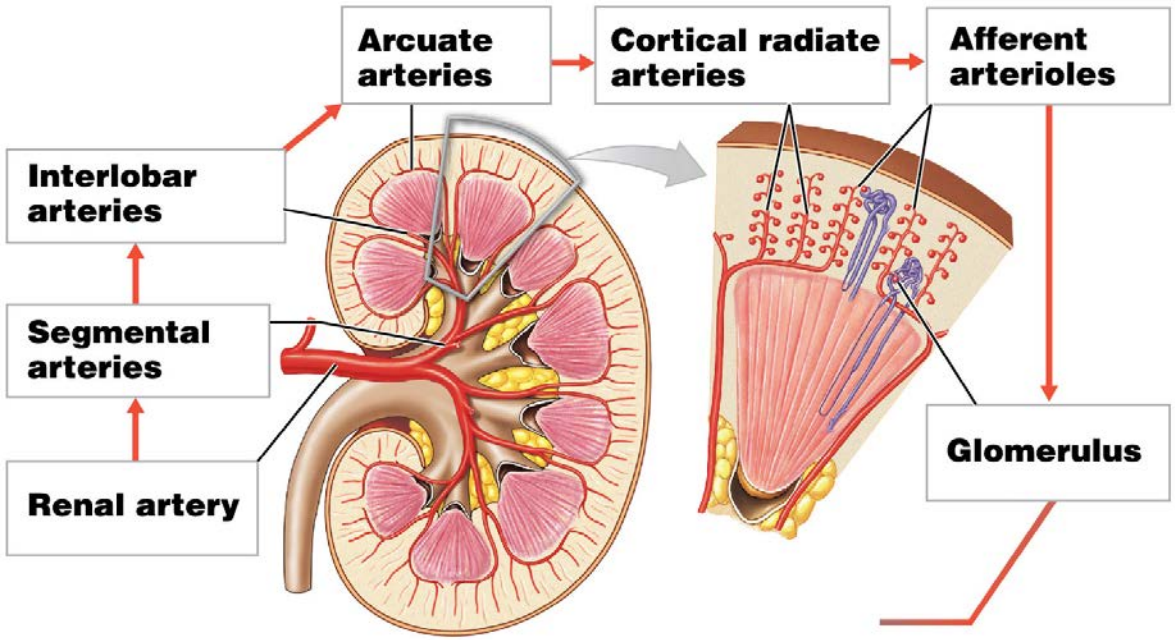
Module 24.5: The kidneys are highly vascular, and the circulation patterns are complex

Arterial system

- **Renal artery** delivers blood to kidney, branching into:
  - **Segmental arteries** in the renal sinus



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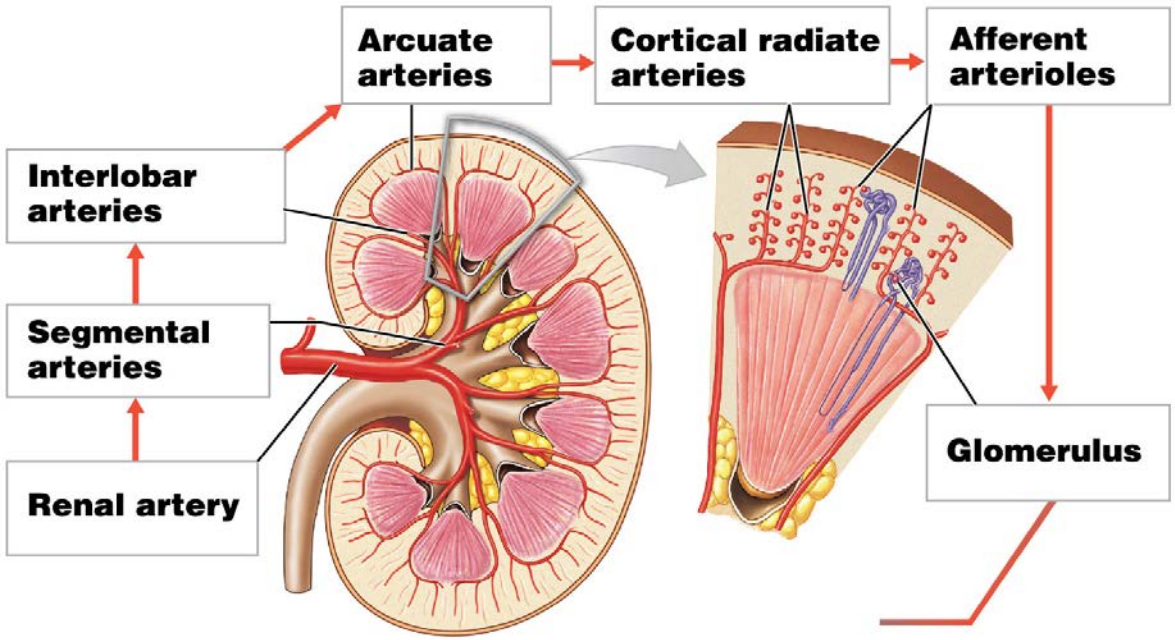
Module 24.5: Circulation patterns in the kidney

Arterial system (continued)

- **Renal artery** → **Segmental arteries**, which branch into:
  - **Interlobar arteries** running within renal columns



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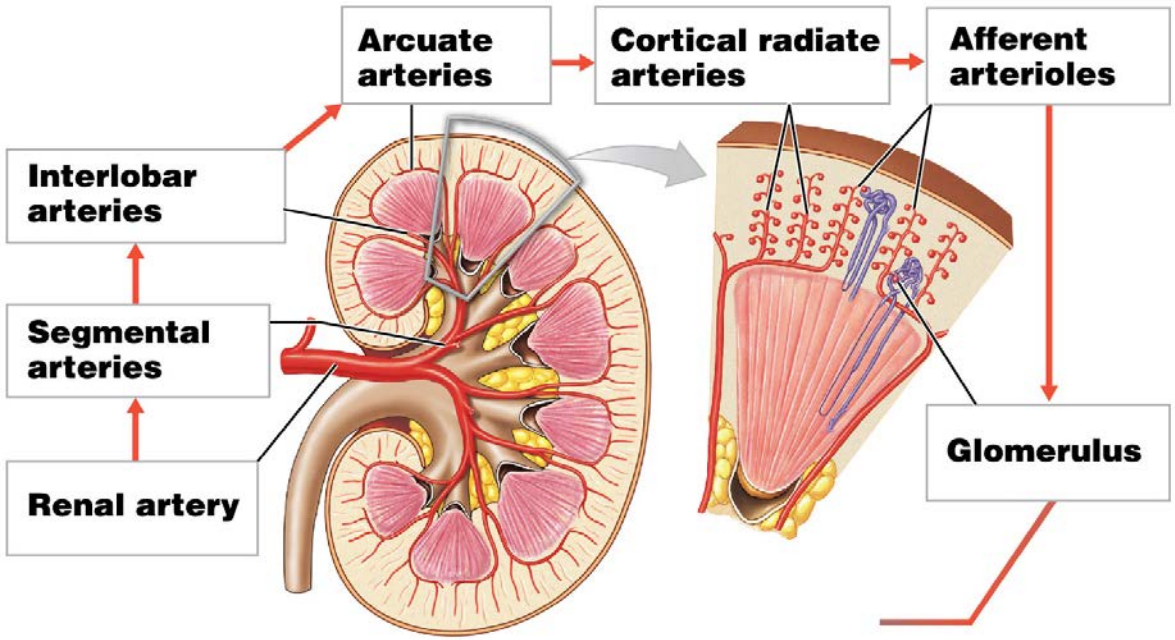
Module 24.5: Circulation patterns in the kidney

Arterial system (continued)

- **Renal artery → Segmental arteries → Interlobar arteries,** which branch into:
  - **Arcuate arteries**, which arch along the boundary between the renal cortex and renal medulla



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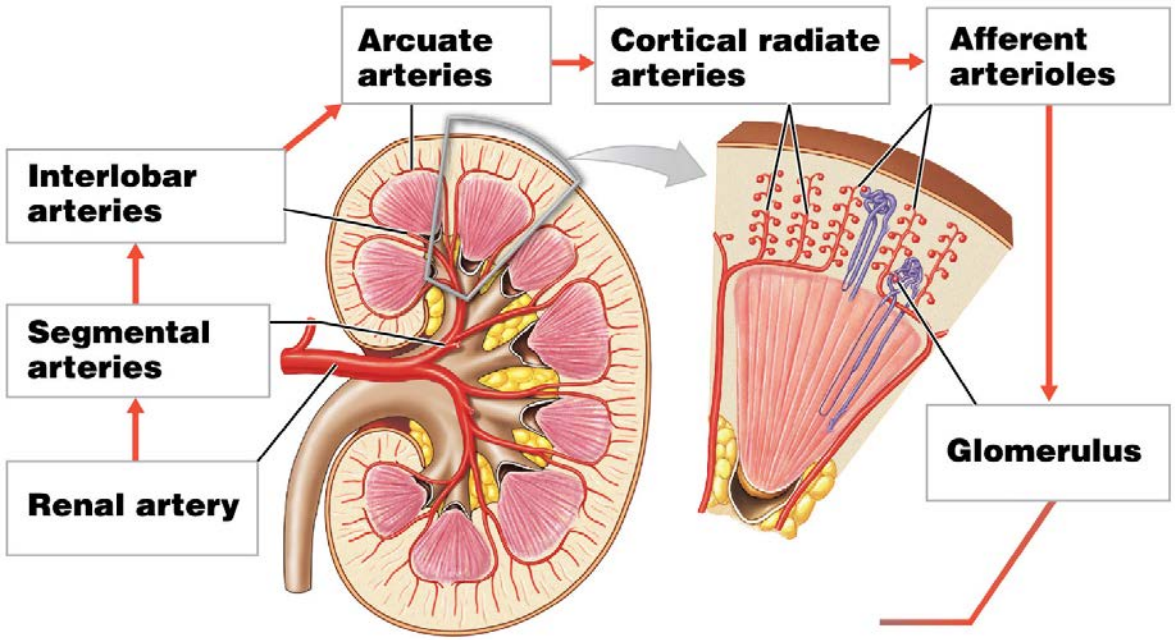
Module 24.5: Circulation patterns in the kidney

Arterial system (continued)

- **Renal artery → Segmental arteries → Interlobar arteries → Arcuate arteries**, which branch into:
  - **Cortical radiate arteries**, which branch into:



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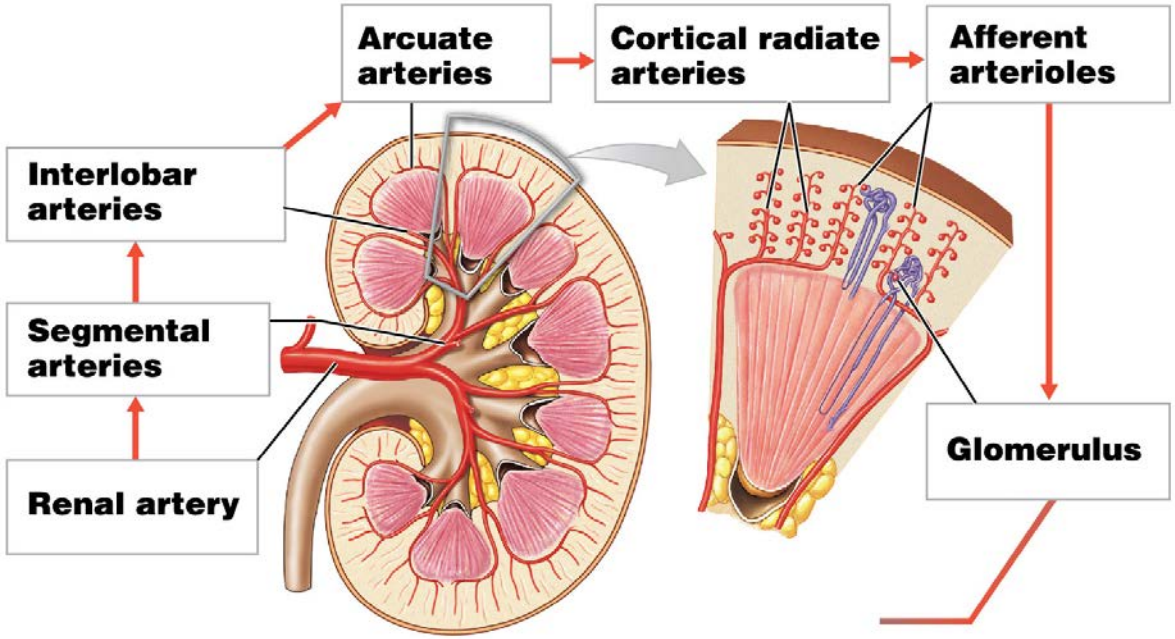
Module 24.5: Circulation patterns in the kidney

Arterial system (continued)

- **Renal artery → Segmental arteries → Interlobar arteries → Arcuate arteries → Cortical radiate arteries**, which branch into:
  - **Afferent arterioles**, which supply each nephron, specifically a capillary knot known as a **glomerulus**



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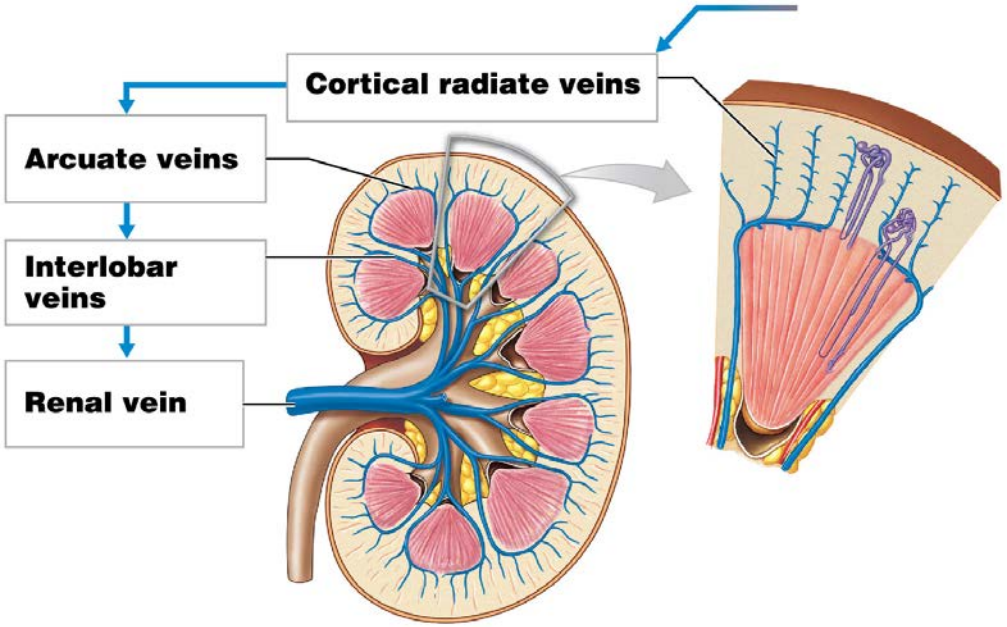
Module 24.5: Circulation patterns in the kidney

Venous system

- **Cortical radiate veins** collect blood from the capillaries of the nephron and drain into:
  - **Arcuate veins**, then to:
    - **Interlobar veins**, which drain into the:
      - **Renal vein**, which drains into the inferior vena cava



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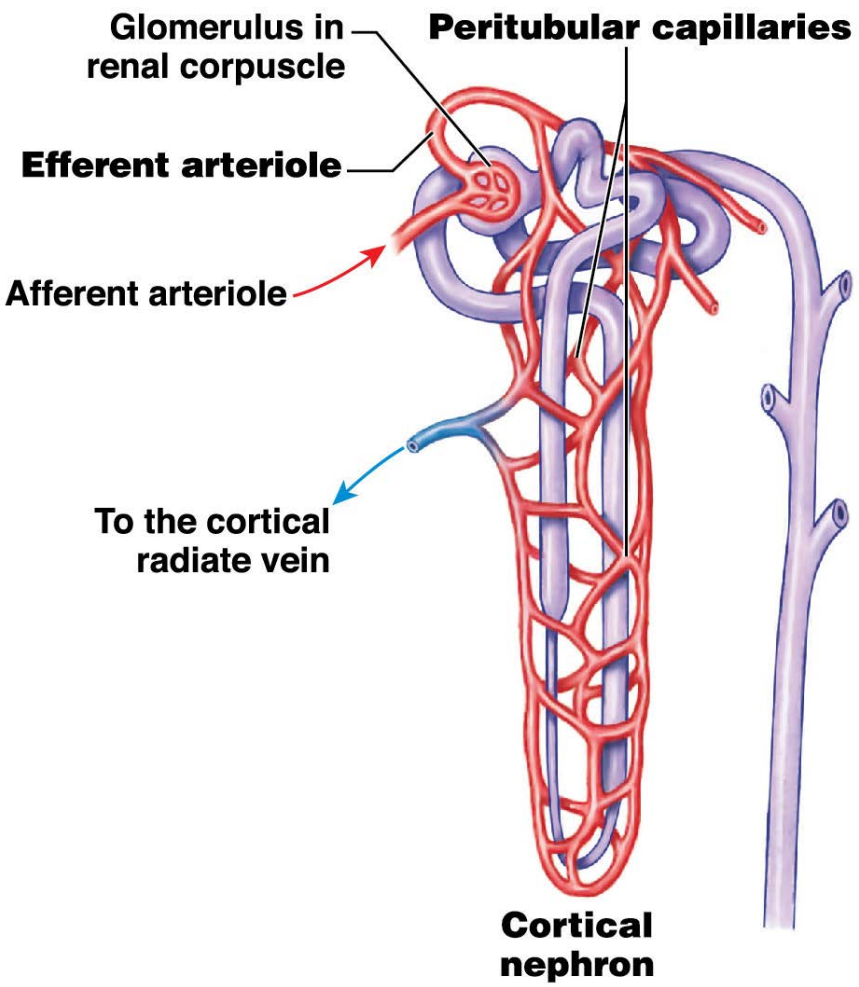
Module 24.5: Circulation patterns in the kidney

Blood flow around a cortical nephron

- **Afferent arteriole**
  - Supplies blood to each individual nephron
- **Glomerulus**
- **Efferent arteriole**
  - Carries blood from the glomerulus to the peritubular capillaries



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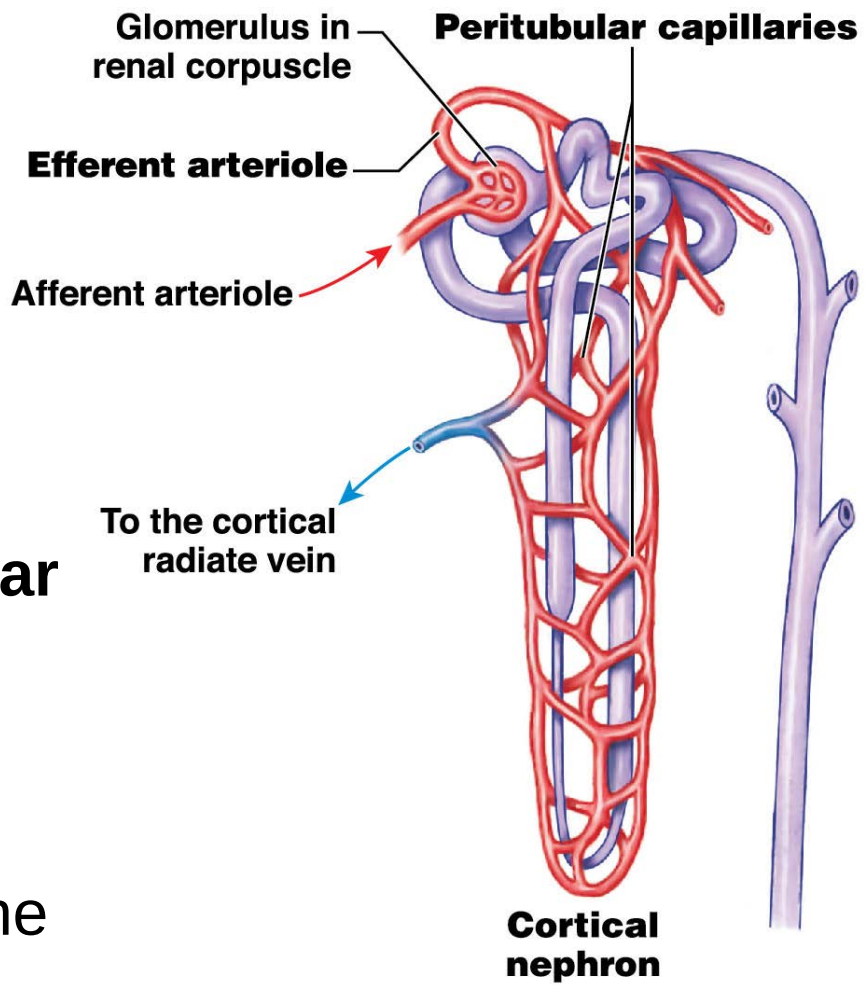
Module 24.5: Circulation patterns in the kidney

Blood flow around a cortical nephron (continued)

- **Peritubular capillaries**
  - Surround the entire renal tubule
  - Surrounded by **peritubular fluid**
  - Collect water and solutes absorbed by the nephron
  - Deliver other solutes to the nephron for secretion
  - Drain into cortical radiate veins



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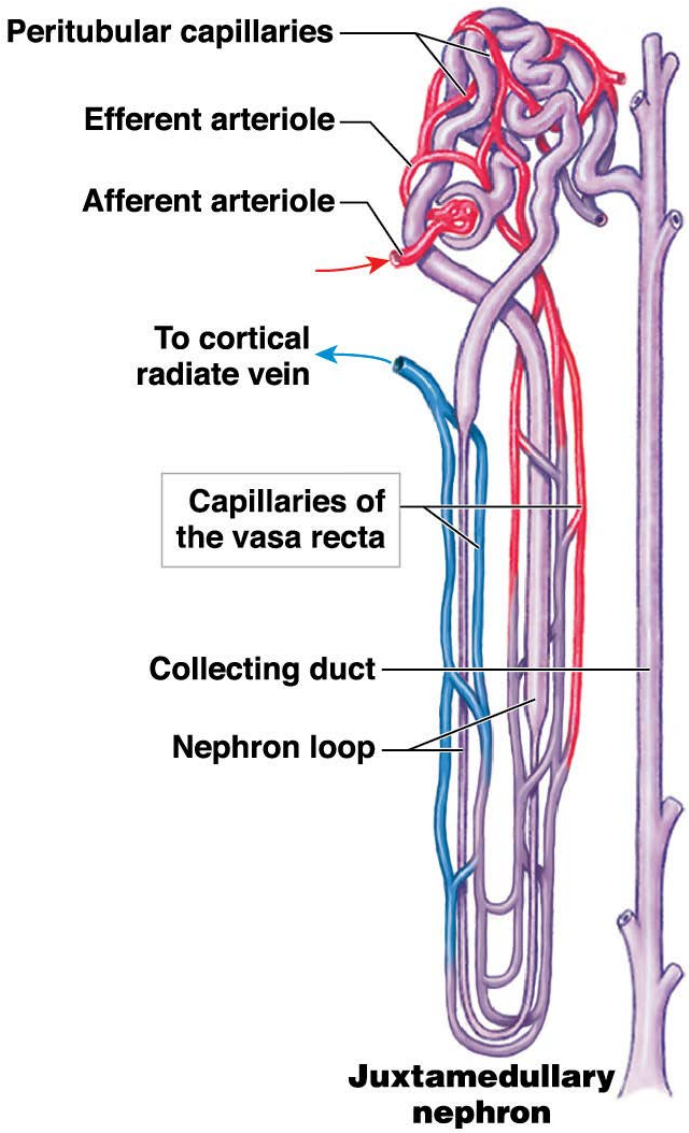
Module 24.5: Circulation patterns in the kidney

Blood flow around a juxtamedullary nephron

- Same blood flow until after the peritubular capillaries
- **Vasa recta** (*vasa*, vessels + *recta*, straight)
  - Connected to the distal end of the peritubular capillaries
  - Long, straight capillaries that parallel the nephron loop
  - Transport water and solutes within the renal medulla
  - Drain into cortical radiate veins



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Module 24.5: Circulation patterns in the kidney

Nephron innervation

- Each kidney has ~1.25 million nephrons
- Both cortical and juxtamedullary nephrons are innervated by renal nerves
  - Enter at the hilum and follow the branches of the renal artery
- Most of the nerve fibers are sympathetic postganglionic fibers from the celiac plexus and inferior splanchnic nerves
  - Sympathetic stimuli adjust blood flow and blood pressure at the glomeruli
  - Also stimulate the release of renin

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Module 24.5: Review

A. Trace the pathway of blood from the renal artery to the renal vein.
B. Describe how blood enters and leaves the glomerulus.
C. Define the *vasa recta*.

Learning Outcome: Trace the pathway of blood flow through a kidney, and compare the pattern of blood flow in cortical and juxtamedullary nephrons.

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Section 2: Overview of Renal Physiology

Learning Outcomes

24.6 Briefly describe how the kidneys maintain homeostasis and produce urine.

24.7 Describe filtration, reabsorption, and secretion along each segment of the nephron and collecting system.

24.8 Describe the structural features of a renal corpuscle, and explain the functions of the filtration membrane components.

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Section 2: Overview of Renal Physiology

Learning Outcomes (continued)

24.9 Describe the factors that influence filtration pressure and the glomerular filtration rate.

24.10 Identify the types of transport mechanisms along the proximal and distal convoluted tubules of the nephron.

24.11 Explain the role of countercurrent multiplication in the formation of a concentration gradient in the renal medulla.

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Section 2: Overview of Renal Physiology

Learning Outcomes (continued)

24.12 Describe how antidiuretic hormone influences the volume and concentration of urine.

24.13 Summarize the major steps involved in \water reabsorption and urine production.

24.14 **Clinical Module:** Compare and contrast chronic and acute renal failure, and explain the process of hemodialysis.

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Module 24.6: The kidneys maintain homeostasis by removing wastes and producing urine

Renal physiology

- Urinary system maintains homeostasis by regulating the volume and composition of blood
- Concentrates urine to 855–1355 mOsm/L
- Excretes solutes, especially metabolic wastes

Normal Laboratory Values for Solutes in Plasma and Urine

Solute	Blood Plasma	Urine
Ions (mEq/L)		
Sodium (Na^+)	135–145	40–220
Potassium (K^+)	3.5–5.0	25–100
Bicarbonate (HCO_3^-)	20–28	1.9
Metabolites and Nutrients (mg/dL)		
Glucose	70–110	0.009
Lipids	450–1000	0.002
Proteins	6.0–8.0 g/dL	0.000
Nitrogenous Wastes (mg/dL)		
Urea	8–25	1800
Creatinine	0.6–1.5	150
Uric acid	2–6	40
Ammonia	<0.1	60

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Module 24.6: Renal physiology

Examples of metabolic wastes

- **Urea**
  - Most abundant organic waste
  - By-product of amino acid breakdown
- **Creatinine**
  - By-product of creatine phosphate breakdown in muscles
- **Uric acid**
  - Formed during recycling of nitrogenous bases of RNA

Normal Laboratory Values for Solutes in Plasma and Urine

Solute	Blood Plasma	Urine
Ions (mEq/L)		
Sodium (Na^+)	135–145	40–220
Potassium (K^+)	3.5–5.0	25–100
Bicarbonate (HCO_3^-)	20–28	1.9
Metabolites and Nutrients (mg/dL)		
Glucose	70–110	0.009
Lipids	450–1000	0.002
Proteins	6.0–8.0 g/dL	0.000
Nitrogenous Wastes (mg/dL)		
Urea	8–25	1800
Creatinine	0.6–1.5	150
Uric acid	2–6	40
Ammonia	<0.1	60

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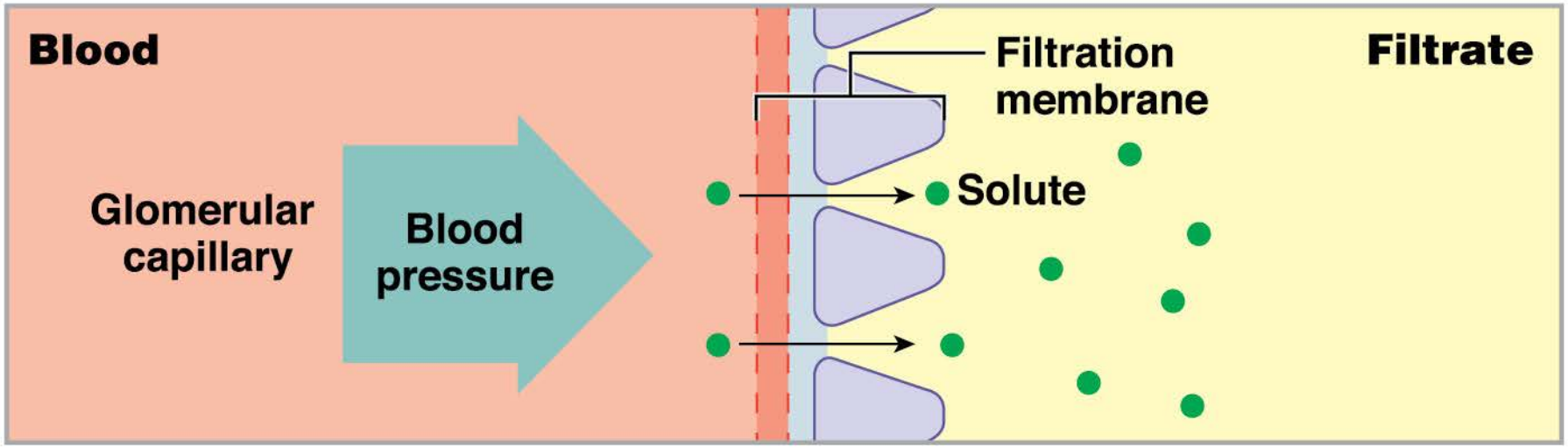
Module 24.6: Renal physiology

Three processes in urine formation

1. **Filtration**
   - Blood pressure forces water and solutes across the membranes of the glomerular capillaries into the capsular space



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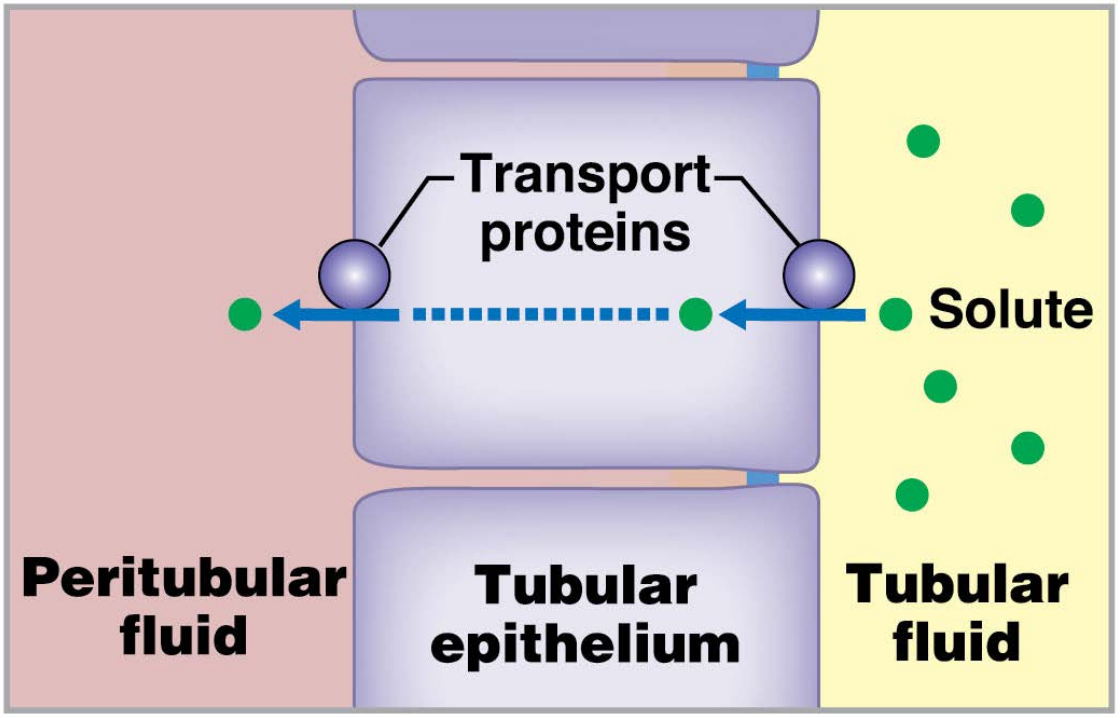
Module 24.6: Renal physiology

Three processes in urine formation (continued)

2. **Reabsorption**

- Transport of water and solutes from the tubular fluid across tubular epithelium into the peritubular fluid



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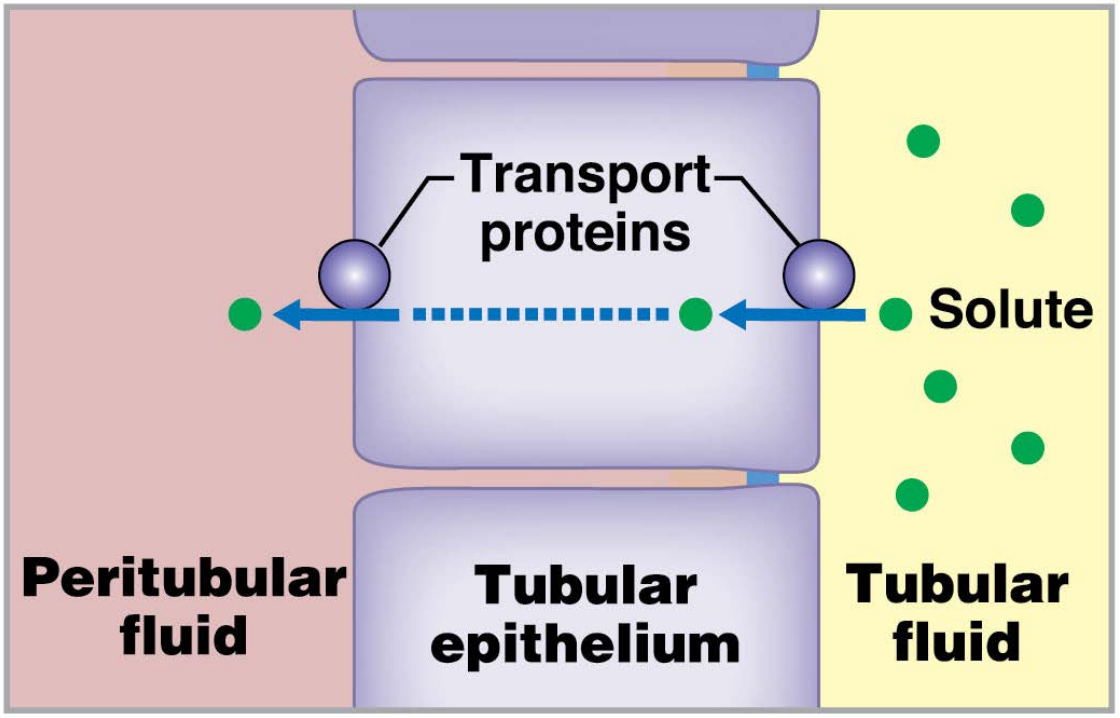
Module 24.6: Renal physiology

Three processes in urine formation (continued)

3. **Secretion**

- Transport of solutes from the peritubular fluid across tubular epithelium into the tubular fluid



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Module 24.6: Review

A. In which direction do fluids and solutes move in each of the three kidney processes?

Learning Outcome: Briefly describe how the kidneys maintain homeostasis and produce urine.

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Module 24.7: Filtration, reabsorption, and secretion occur in specific segments of the nephron and collecting system

Functions of each nephron segment

- Three processes in urine formation: filtration, reabsorption, and secretion
- Filtration occurs only in the renal corpuscle
- Balance between reabsorption and secretion varies in remaining nephron segments
- Regulation of final volume and solute concentration is from the interaction between the collecting system and the nephron loops

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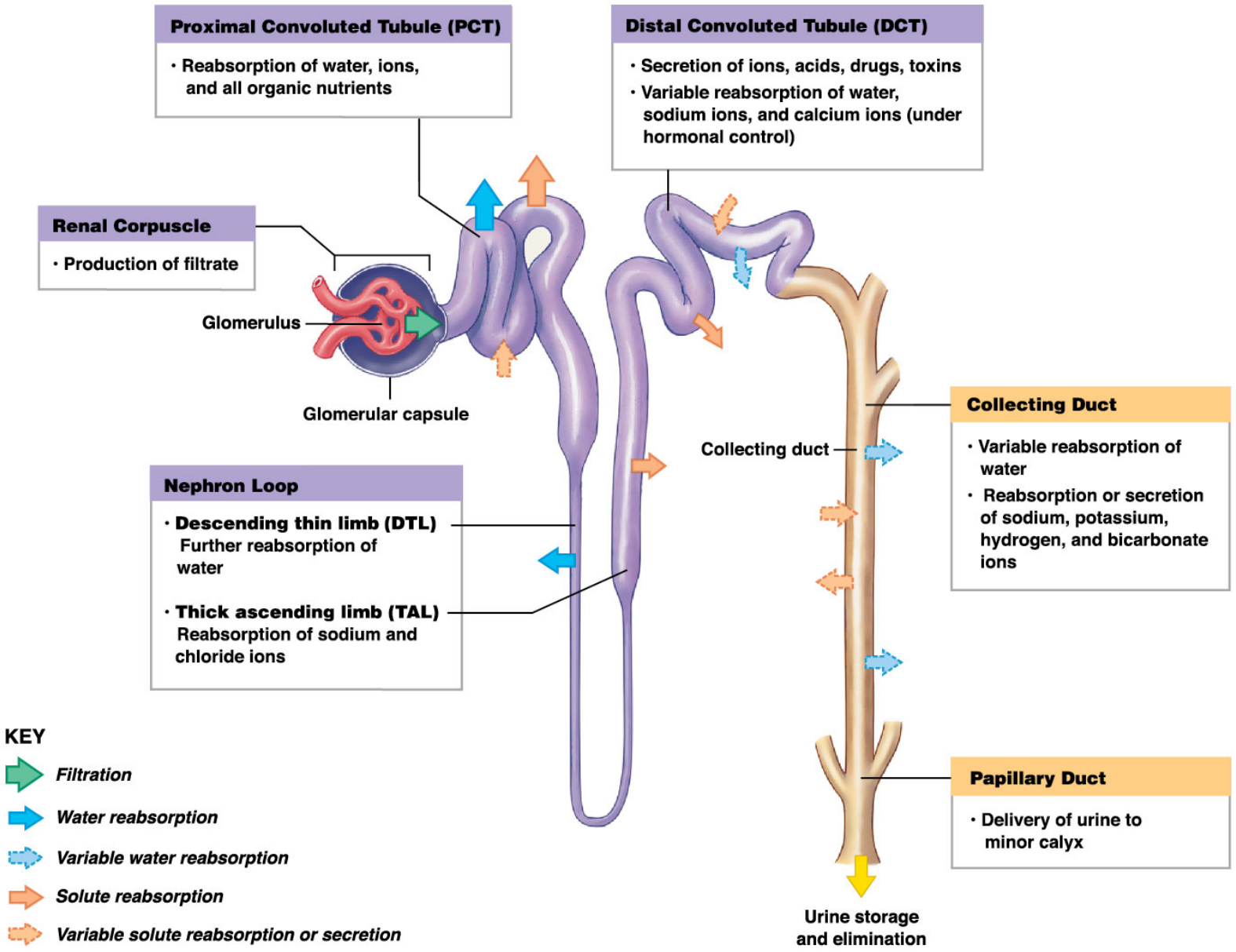
Filtration, reabsorption, and secretion



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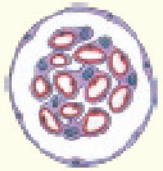
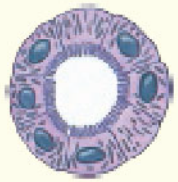
Renal Structures and Their Functions

Segment	General Functions	Specific Functions
Renal corpuscle 	*Filtration* of blood; generates approximately 180 L/day of filtrate similar in composition to blood plasma but without plasma proteins	*Filtration* Water and inorganic and organic solutes from plasma *Retention* Plasma proteins and blood cells
Proximal convoluted tubule (PCT) 	*Reabsorption* of 60–70% of the water (108–116 L/day), 99–100% of the organic substrates, and 60–70% of the sodium and chloride ions in the original filtrate	*Active reabsorption* Glucose, other simple sugars, amino acids, vitamins, ions (including sodium, potassium, calcium, magnesium, phosphate, and bicarbonate) *Passive reabsorption* Urea, chloride ions, lipid-soluble materials, water *Secretion* Hydrogen ions, ammonium ions, creatinine, drugs, and toxins

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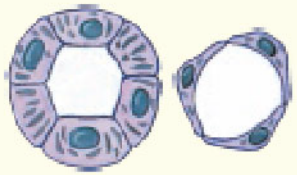
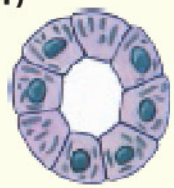
Renal Structures and Their Functions

Segment	General Functions	Specific Functions
Nephron loop 	*Reabsorption* of 25% of the water (45 L/day) and 20–25% of the sodium and chloride ions in the original filtrate; creation of the concentration gradient in the renal medulla	*Reabsorption* Sodium and chloride ions, water
Distal convoluted tubule (DCT) 	*Reabsorption* of a variable amount of water (usually 5%, or 9 L/day) under antidiuretic hormone (ADH) stimulation, and a variable amount of sodium ions under aldosterone stimulation	*Reabsorption* Sodium and chloride ions, sodium ions (variable), calcium ions (variable), water (variable) *Secretion* Hydrogen ions, ammonium ions, creatinine, drugs, and toxins
Collecting system	*Reabsorption* of a variable amount of water (usually 9.3%, or 16.8 L/day) under antidiuretic hormone stimulation, and a variable amount of sodium ions under aldosterone stimulation	*Reabsorption* Sodium ions (variable), bicarbonate ions (variable), water (variable) *Secretion* Potassium and hydrogen ions (variable)

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Renal Structures and Their Functions		
Segment	**General Functions**	**Specific Functions**
Blood Vessels		
Peritubular capillaries	*Redistribution* of water and solutes reabsorbed in the renal cortex	Return of water and solutes from the peritubular fluid to the general circulation
Vasa recta	*Redistribution* of water and solutes reabsorbed in the renal medulla, and stabilization of the concentration gradient of the renal medulla	Return of water and solutes from the peritubular fluid to the general circulation

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Module 24.7: Review

A. Identify the three distinct processes of urine formation in the kidney.
B. Where does filtration exclusively occur in the kidney?
C. Which segment of the nephron is solely involved in the reabsorption of water and sodium and chloride ions?

Learning Outcome: Describe filtration, reabsorption, and secretion along each segment of the nephron and collecting system.

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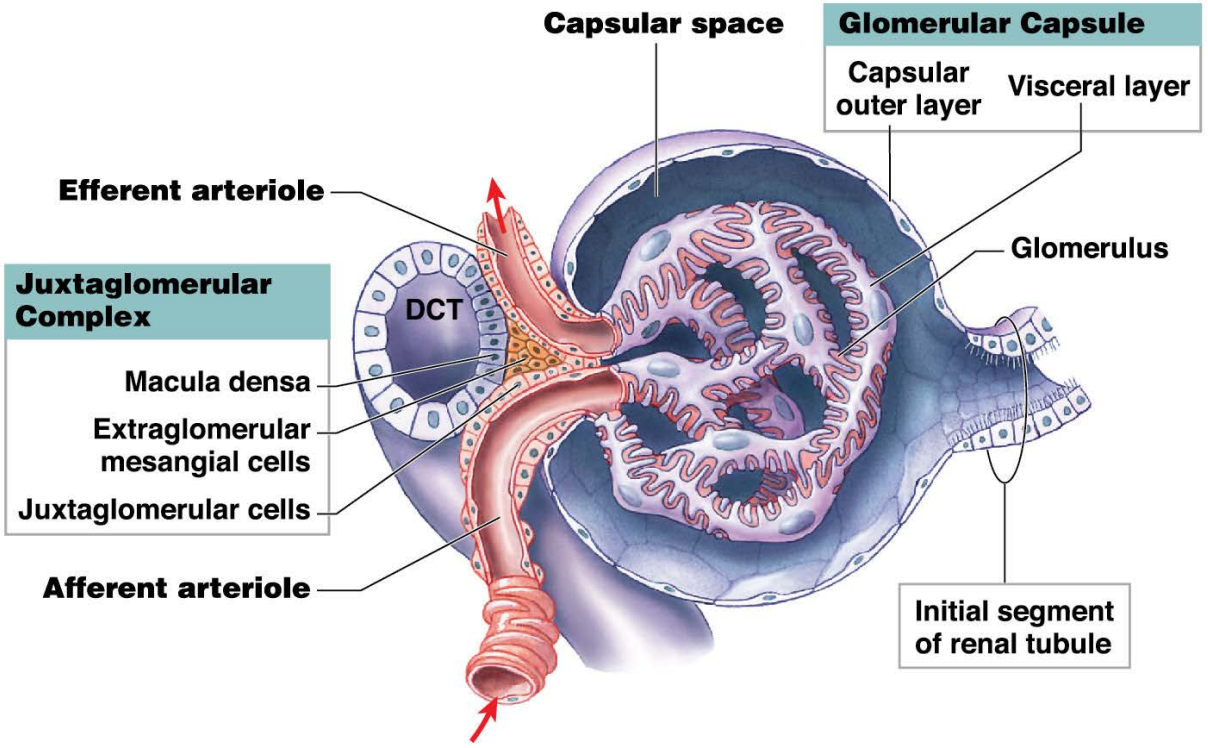
Module 24.8: Filtration occurs at the renal corpuscle

- **Afferent arteriole** (delivers blood to the corpuscle)
- **Glomerulus** (capillary knot)
  - Filtration occurs here



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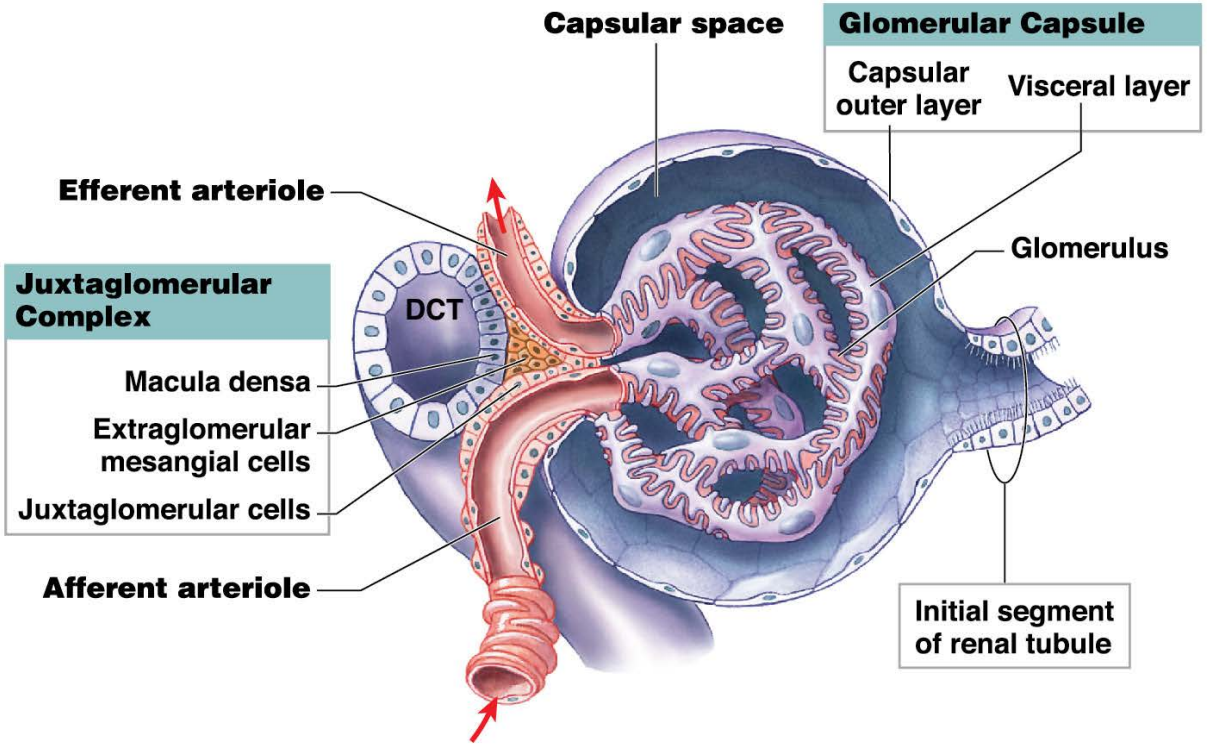
Module 24.8: Filtration

- **Efferent arteriole** (delivers blood to peritubular capillaries)
  - Smaller diameter than the afferent arteriole
  - Increases the blood pressure in the glomerulus, aiding filtration



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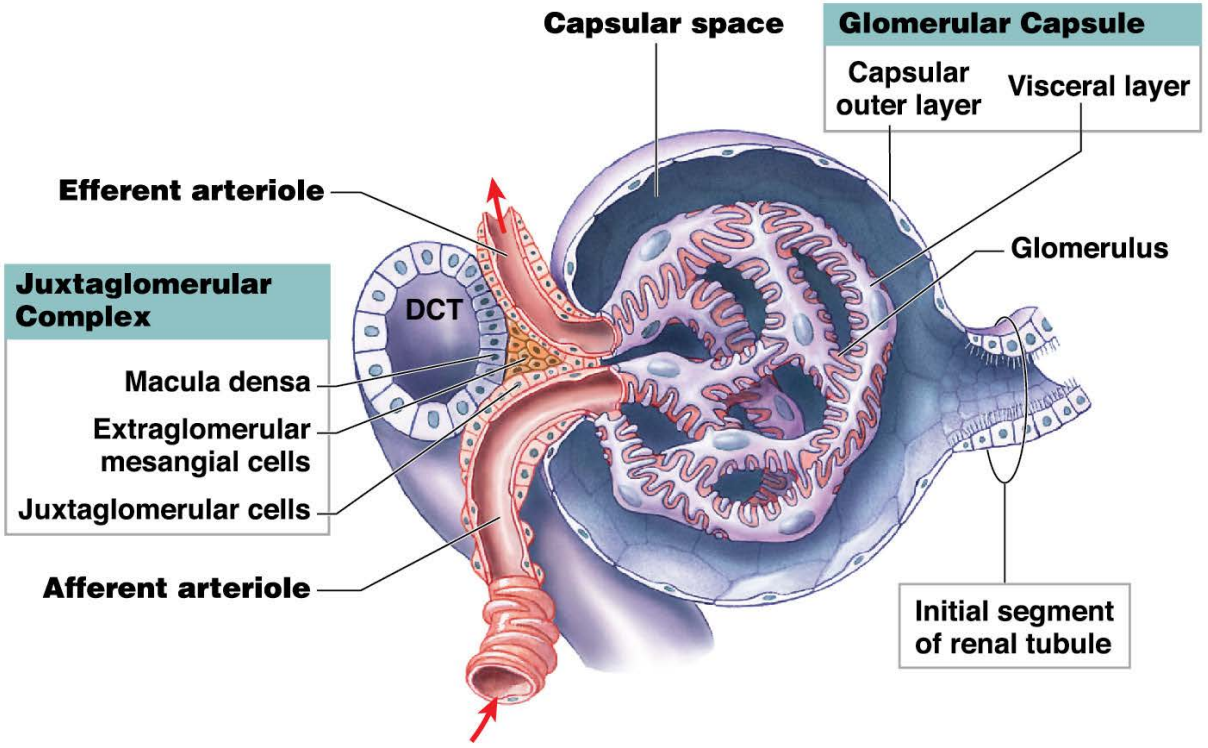
Module 24.8: Filtration

- **Capsular space**
  - Between layers of the glomerular capsule
- **Juxtaglomerular complex**
  - Secretes renin when glomerular blood pressure decreases



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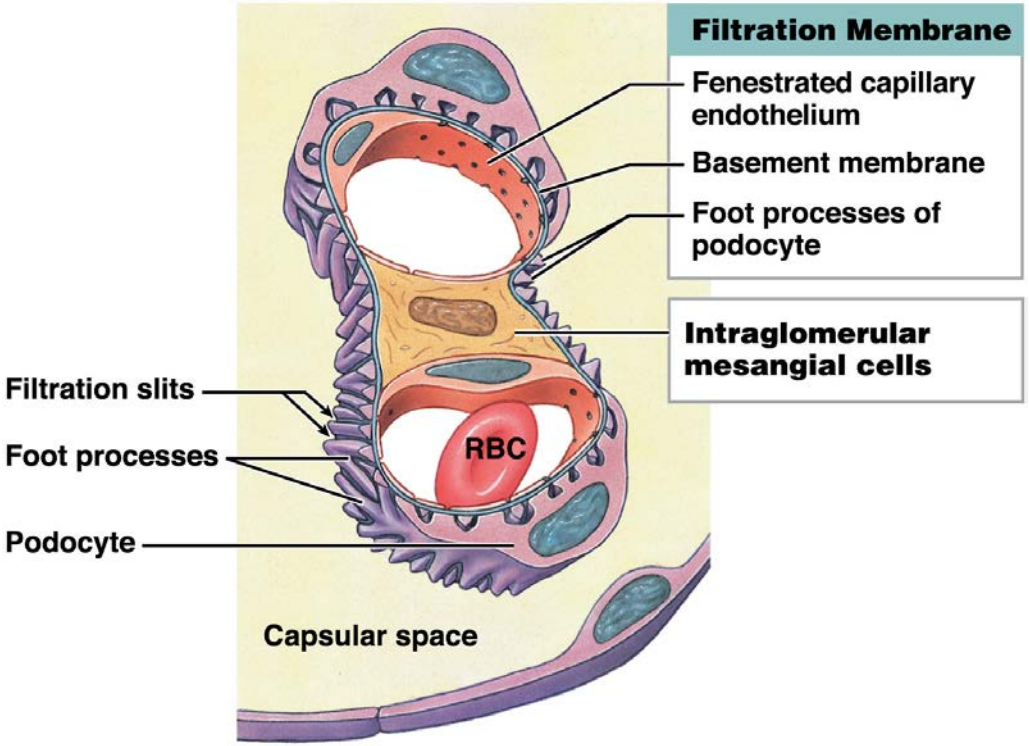
Module 24.8: Filtration

- **Intraglomerular mesangial cells**
  - Supporting cells
  - Lie between adjacent glomerular capillaries
  - Control capillary diameter and rate of blood flow



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Module 24.8: Filtration

Glomerular capsule

- Forms the outer wall of the renal corpuscle and covers the glomerular capillaries
- Parietal layer (forms outer capsule)

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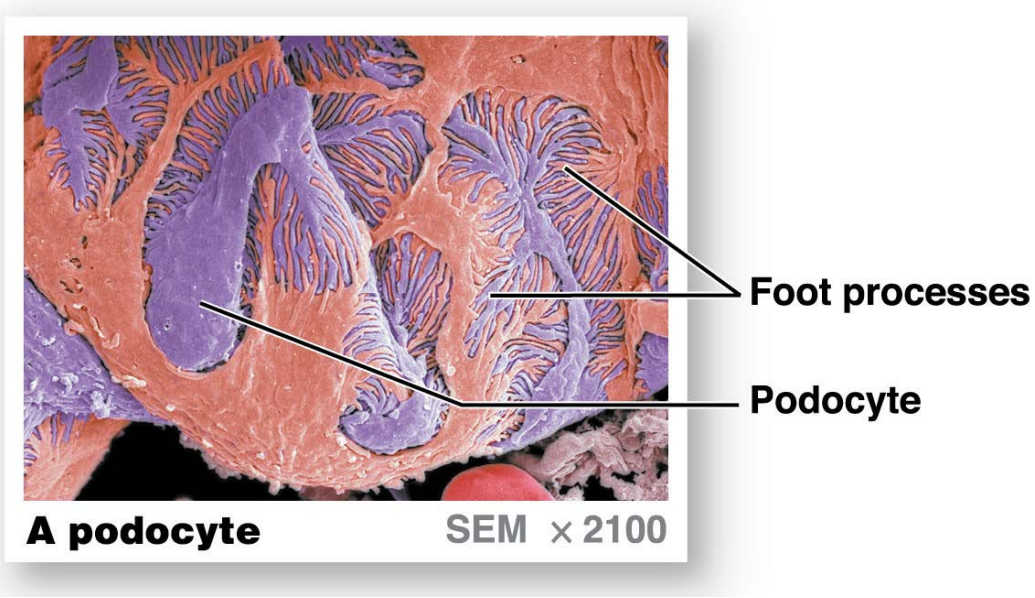
Module 24.8: Filtration

Glomerular capsule (continued)

- Visceral layer (covers the capillaries)
  - Composed of **podocytes** (*podos*, foot + -*cyte*, cell)
    - Large cells with **foot processes** (pedicels) that wrap around the glomerular capillaries
    - Gaps between adjacent pedicels are **filtration slits**



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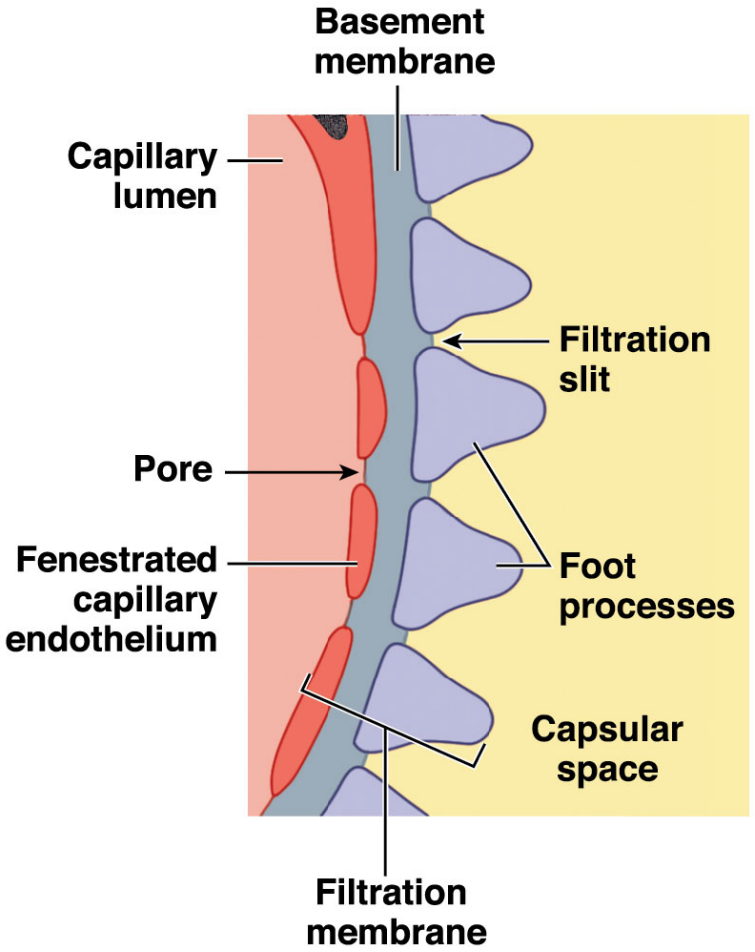
Module 24.8: Filtration

Filtration membrane

1. Fenestrated glomerular capillaries
   - Contain large diameter pores
2. *Dense layer*
   - Specialized **basement membrane**
3. Filtration slits from podocytes

- Combination of these layers prevents most plasma proteins from entering the capsular space



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Module 24.8: Filtration

Factors controlling glomerular filtration

- **Glomerular hydrostatic pressure** (**GHP**)
  - Blood pressure in the glomerular capillaries
  - Tends to push water and solutes out of plasma and into the filtrate
- **Capsular colloid osmotic pressure**
  - Few, if any, plasma proteins enter the capsular space
- **Blood colloid osmotic pressure** (**BCOP**)
  - Pressure due to materials in solution
  - Tends to draw water out of the filtrate and into the plasma (opposes filtration)

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Module 24.8: Filtration

Factors controlling glomerular filtration (continued)

- **Capsular hydrostatic pressure** (**CsHP**)
  - Opposes GHP
  - Tends to push water and solutes out of the filtrate and into the plasma
  - Results from resistance of filtrate already in the nephron

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Module 24.8: Filtration

Factors controlling glomerular filtration (continued)

- **Net filtration pressure** (**NFP**)
  - Pressure acting across the glomerular capillaries
  - Represents the sum of the hydrostatic pressures and colloid osmotic pressures
    - Average pressure forcing water and dissolved substances out of the glomerular capillaries and into the capsular space

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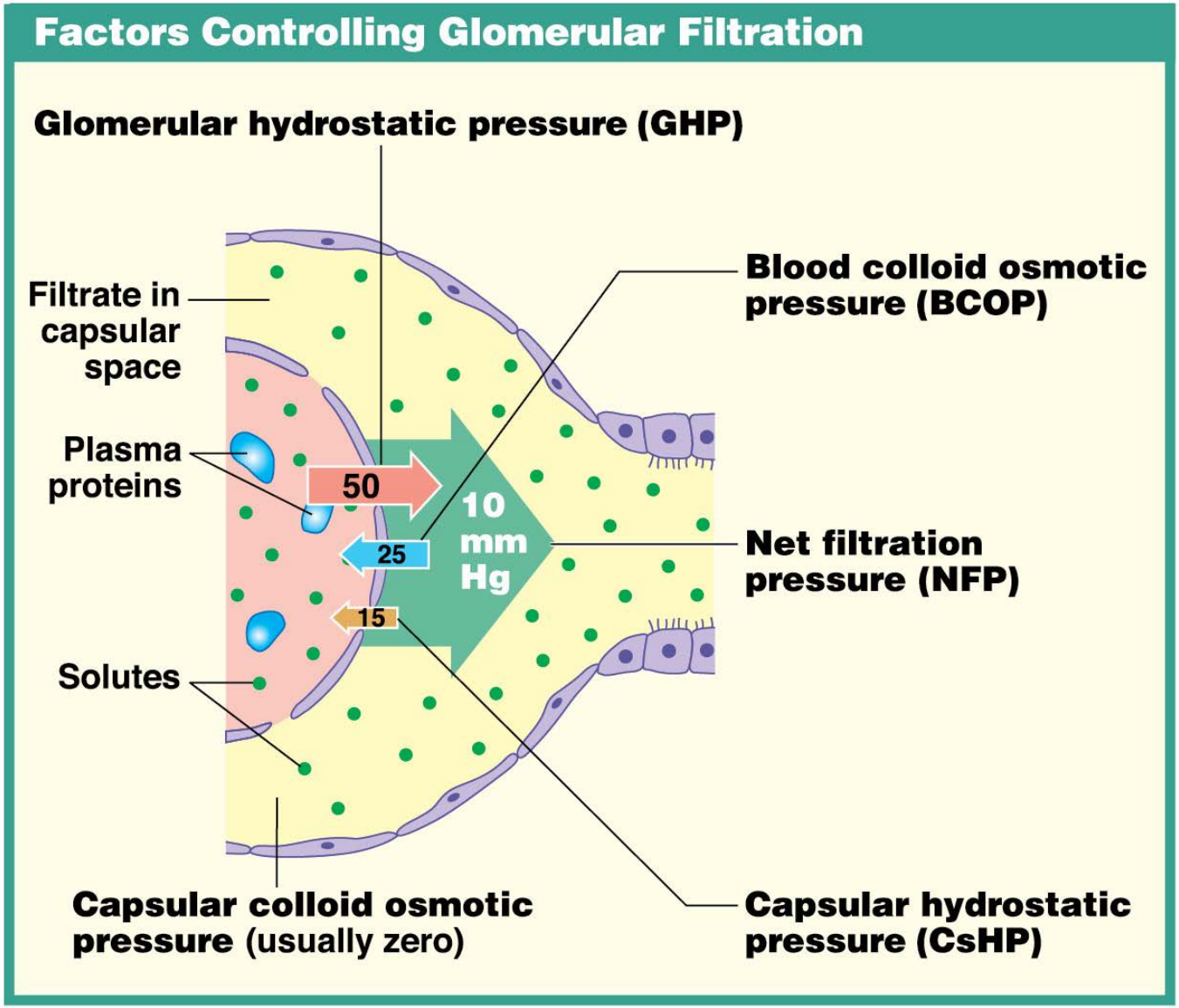
Filtration



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Module 24.8: Review

A. What three elements form the filtration membrane?
B. Explain why blood pressure is higher in glomerular capillaries than in other systemic capillaries.
C. Blood colloid osmotic pressure tends to draw water out of the filtrate and into the plasma. Why does this occur?

Learning Outcome: Describe the structural features of a renal corpuscle, and explain the functions of the filtration membrane components.

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Module 24.9: The glomerular filtration rate is the amount of filtrate produced each minute

- Two interacting levels of control help stabilize **Glomerular filtration rate** (**GFR**)
  1. **Autoregulation** at the local level
  2. **Central regulation**
     - Endocrine component
       - Initiated by the kidneys
     - Neural component
       - Involves the sympathetic division of the ANS

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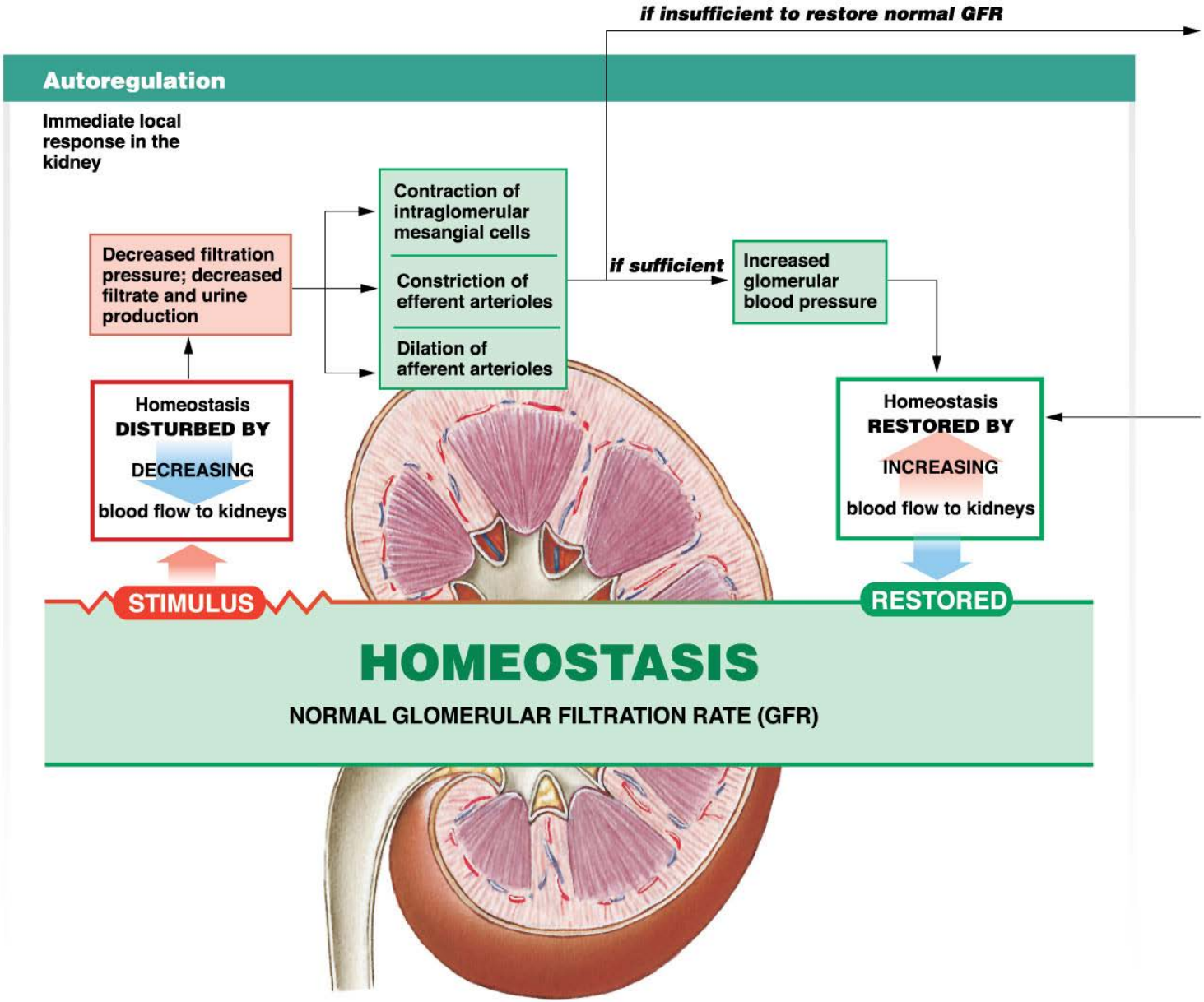
Autoregulation maintains adequate GFR



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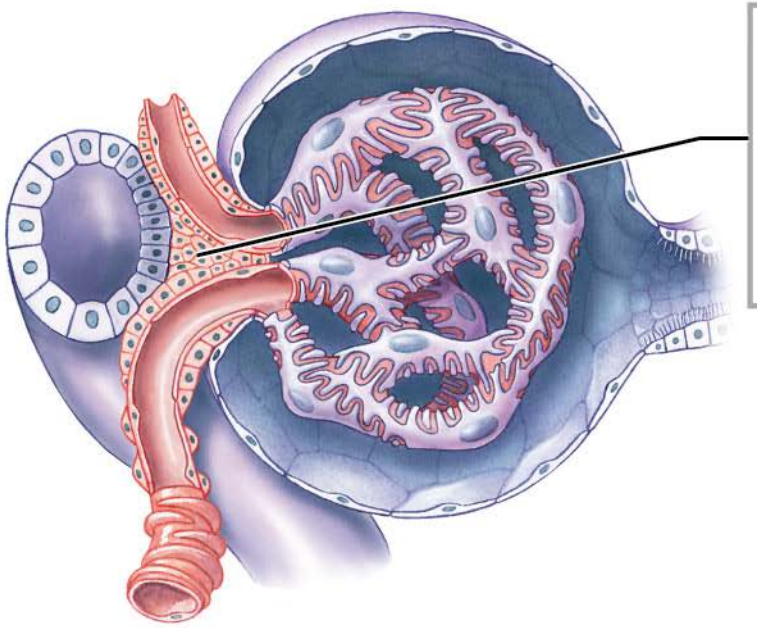
Module 24.9: Glomerular filtration

If autoregulation is ineffective, central regulation is involved

- Juxtaglomerular complex



The juxtaglomerular complex plays a key role in coordinating responses to decreased GFR by initiating the renin-angiotensin-aldosterone system (RAAS).

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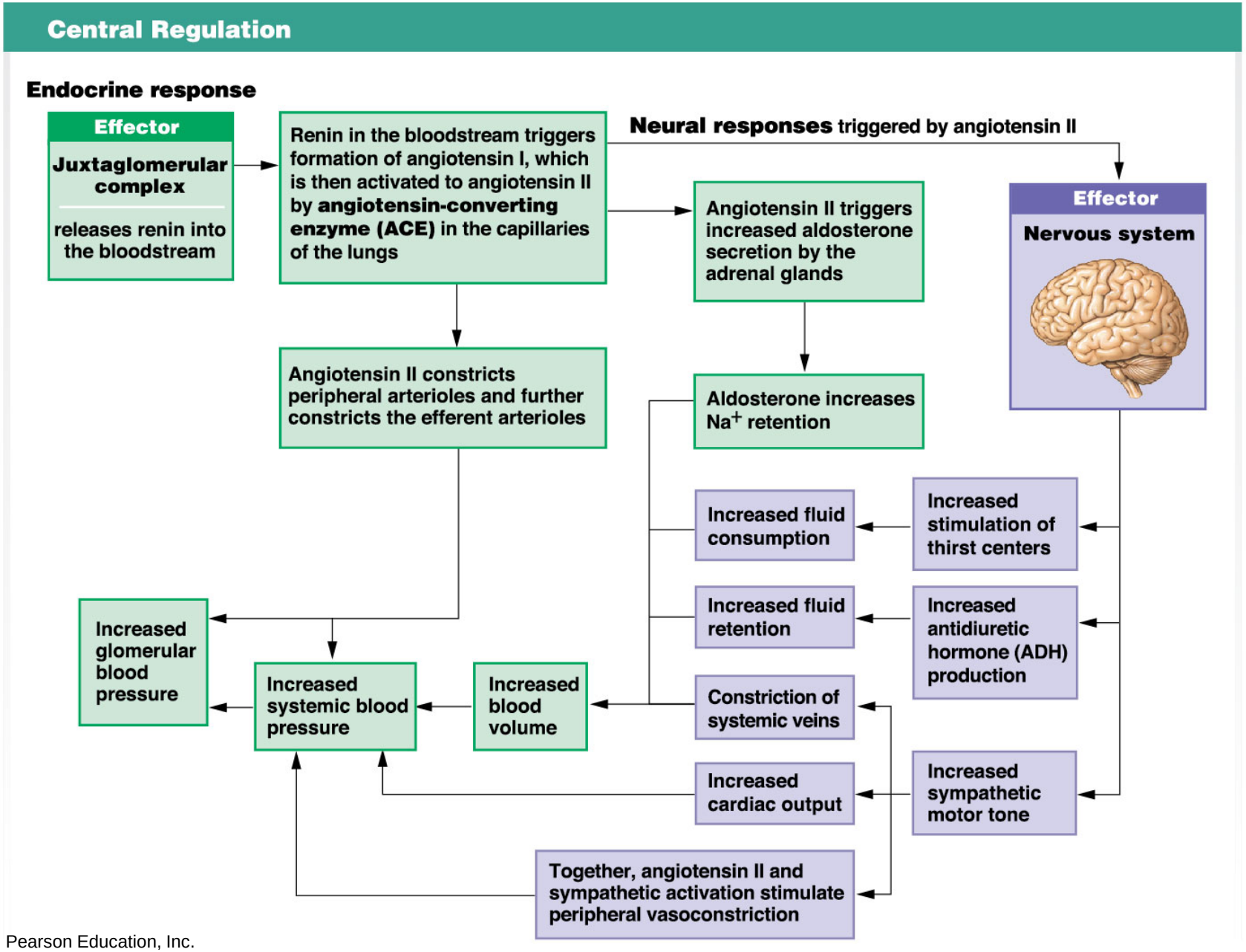
Central regulation



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Module 24.9: Review

A. Describe autoregulation at the kidneys.
B. What does the juxtaglomerular complex do in response to decreased filtration pressure?
C. Angiotensin II has what effect on the CNS?

Learning Outcome: Describe the factors that influence filtration pressure and the glomerular filtration rate.

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Module 24.10: Reabsorption predominates along the proximal convoluted tubule…

- Reabsorption in the PCT includes:
  - >99 percent of glucose, amino acids, and other organic nutrients
  - Sodium, potassium, bicarbonate, magnesium, phosphate, sulfate ions
  - Water (about 108 liters each day)
    - Solute concentration of tubular fluid decreases
    - Water moves into the peritubular fluid

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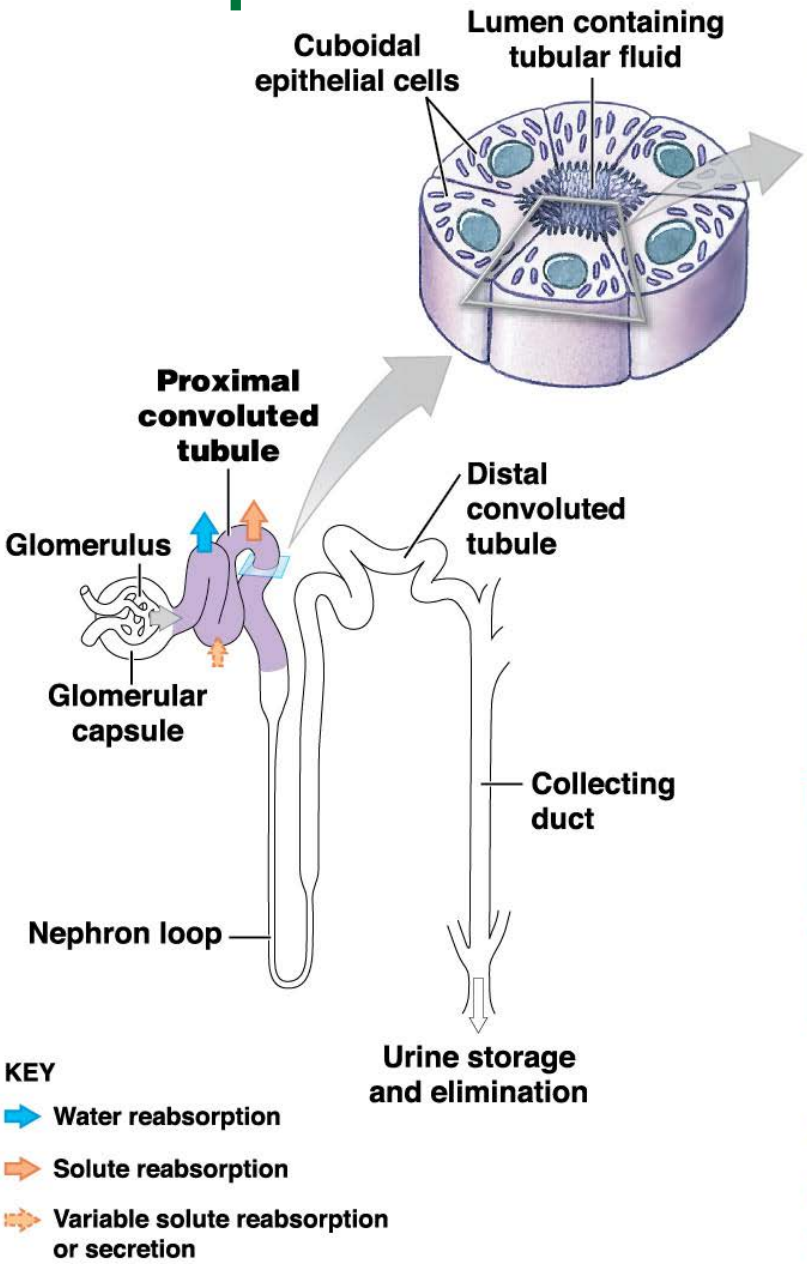
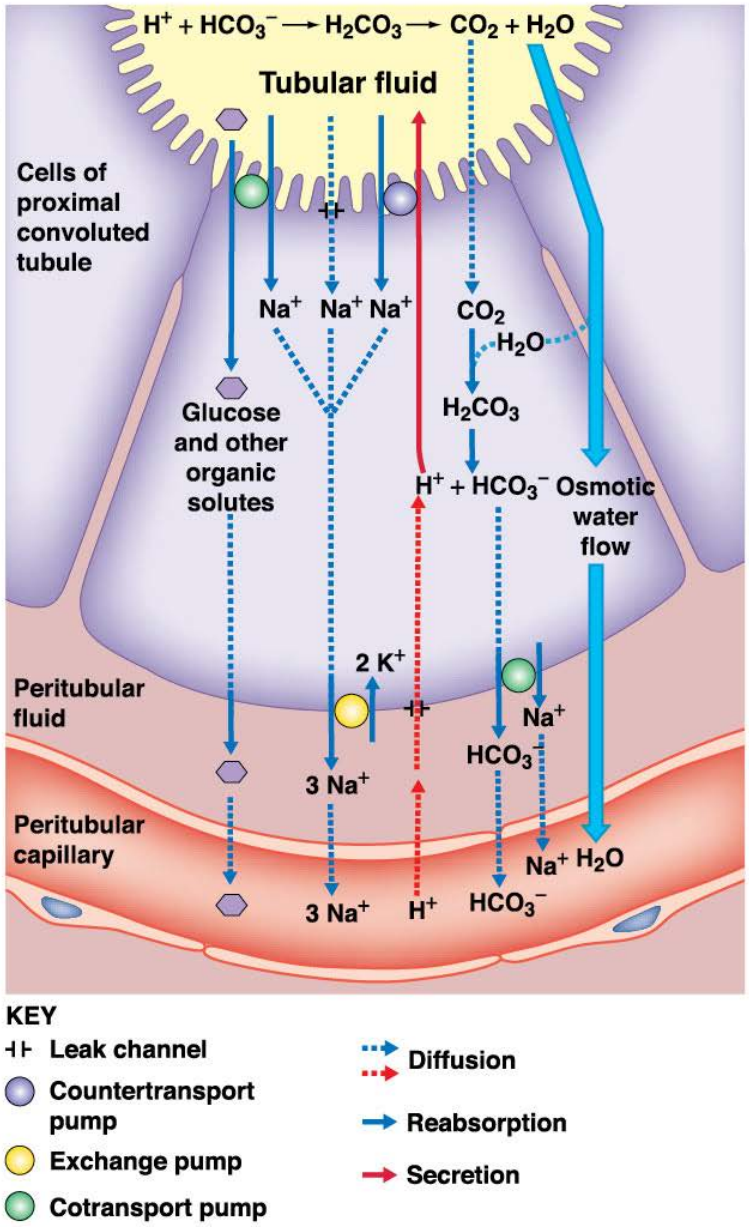
Reabsorption





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Module 24.10: …whereas reabsorption and secretion are often linked along the distal convoluted tubule

- Movement of water and solutes out of peritubular fluid into the tubular fluid
- Only 15–20 percent of the initial filtrate volume reaches the distal convoluted tubule (DCT)
- Combination of reabsorption and secretion in the DCT alters solute composition in the tubular fluid
  - Sodium ions are reabsorbed in exchange for potassium ions (pumps are stimulated by aldosterone)
  - Hydrogen ions are secreted in exchange for sodium ions (to increase pH of body fluids)
  - Carrier proteins also secrete toxins or drugs

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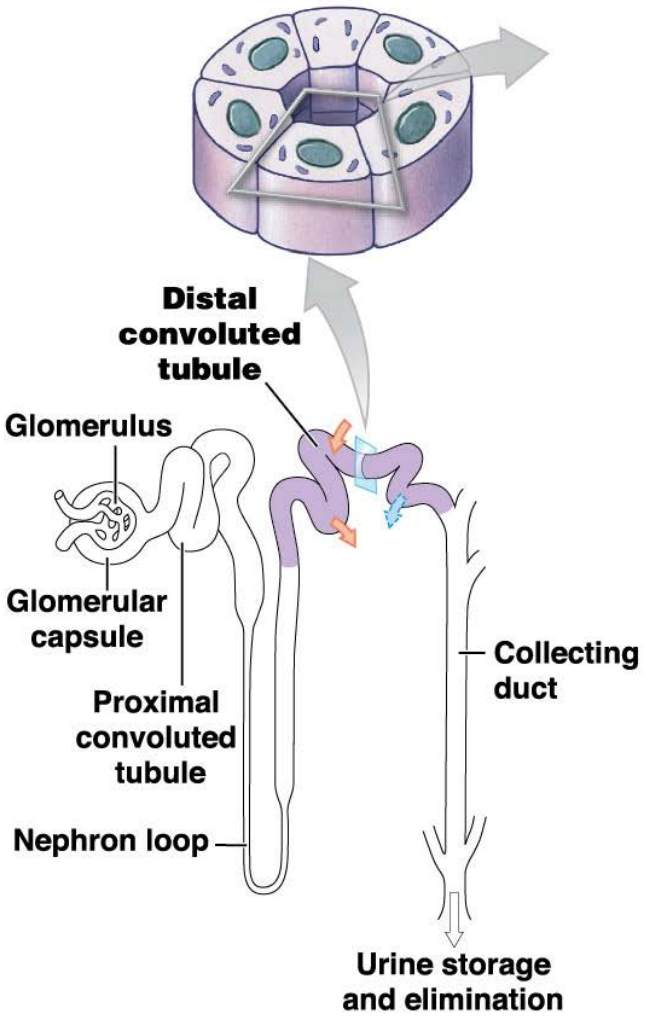
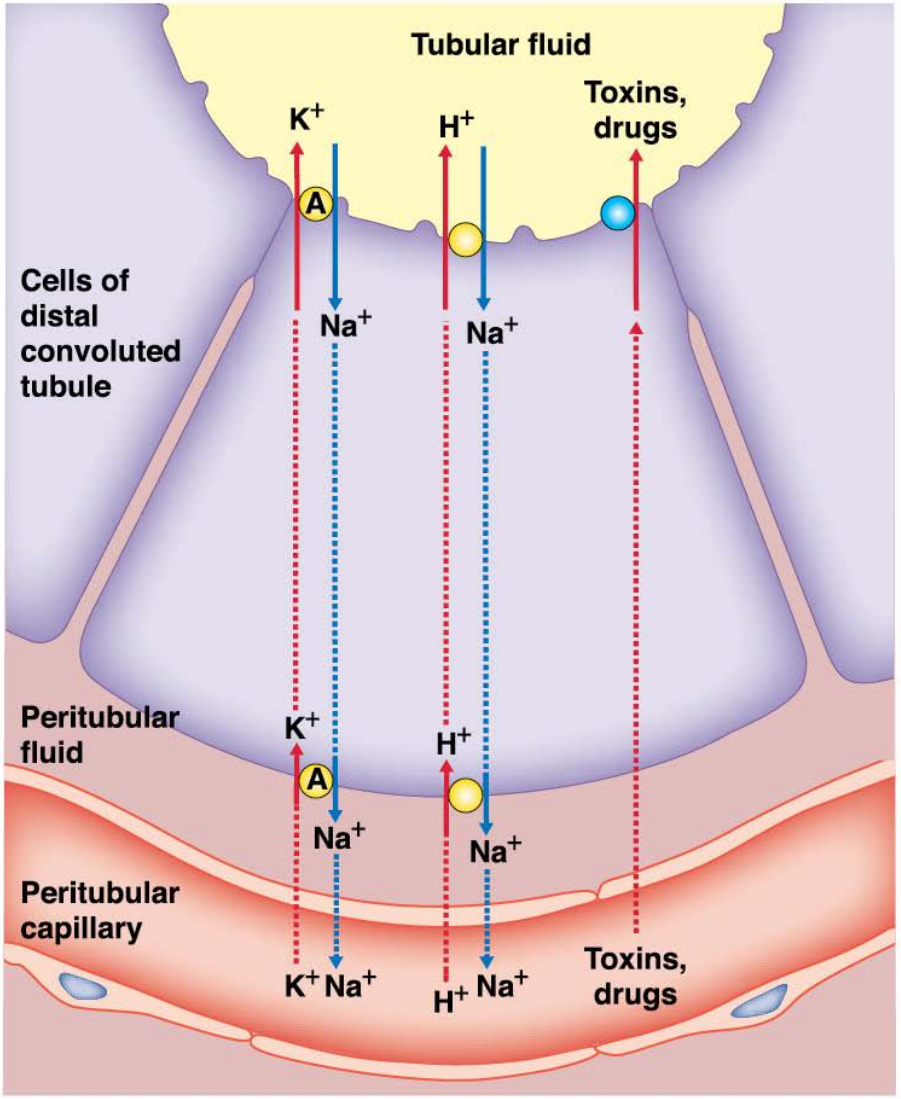
Secretion and reabsorption





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Module 24.10: Review

A. Identify the segment of the nephron that makes final adjustments to the composition of tubular fluid.
B. What effect would increased amounts of aldosterone have on the K^+ concentration in urine?
C. What effect would a decrease in the Na^+ concentration of filtrate have on the pH of tubular fluid?

Learning Outcome: Identify the types of transport mechanisms along the proximal and distal convoluted tubules of the nephron.

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Module 24.11: Exchange between the limbs of the nephron create an osmotic concentration gradient in the renal medulla

Countercurrent multiplication

- Thin descending limb and thick ascending limb
  - Located very close to each other
  - Separated by peritubular fluid
  - Exchange between these adjacent limbs is called **countercurrent multiplication**
    - *Countercurrent*—fluids moving in opposite directions
    - *Multiplication*—effect increases with fluid movement
  - Responsible for creating concentration gradient in the renal medulla
  - Enables production of highly concentrated urine

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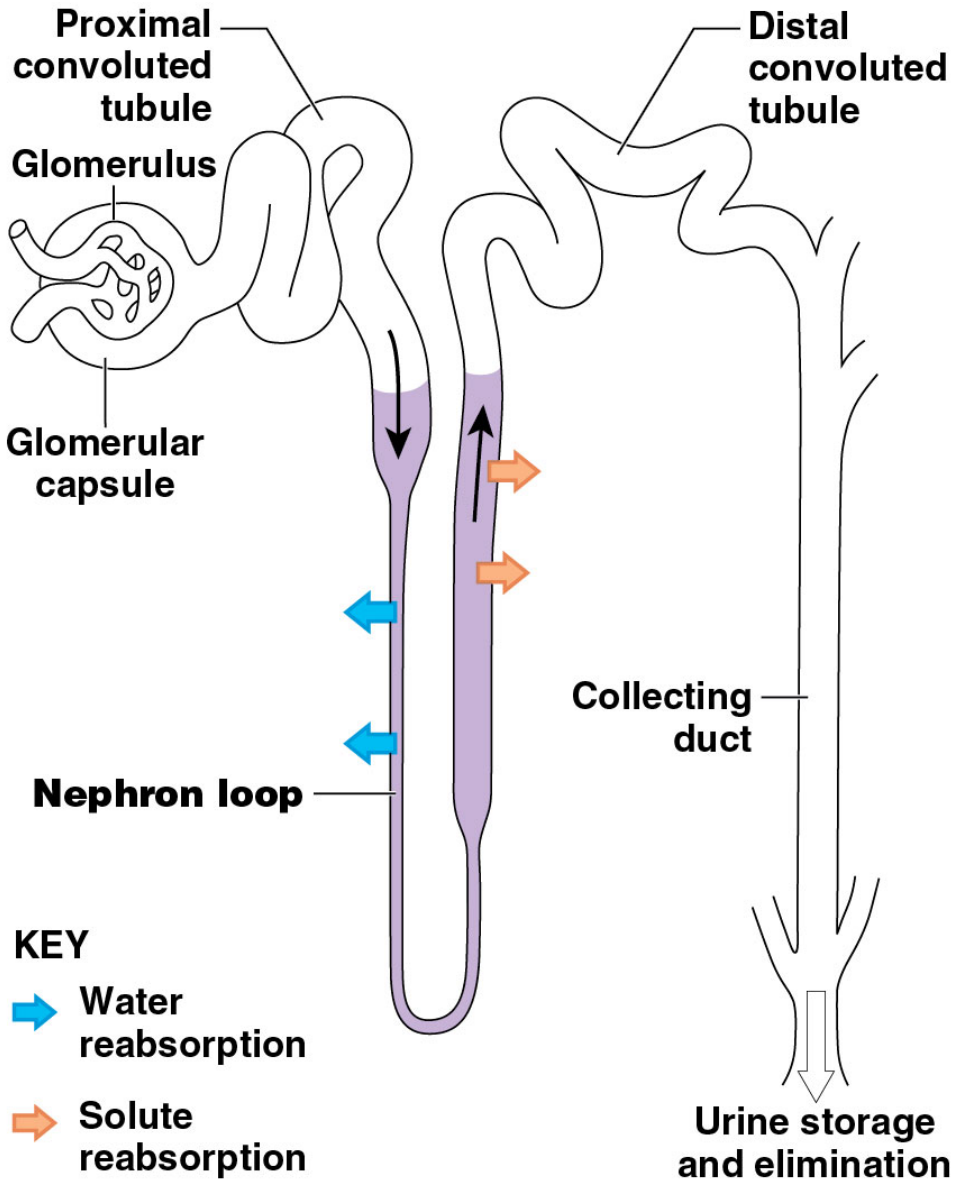
Nephron loop



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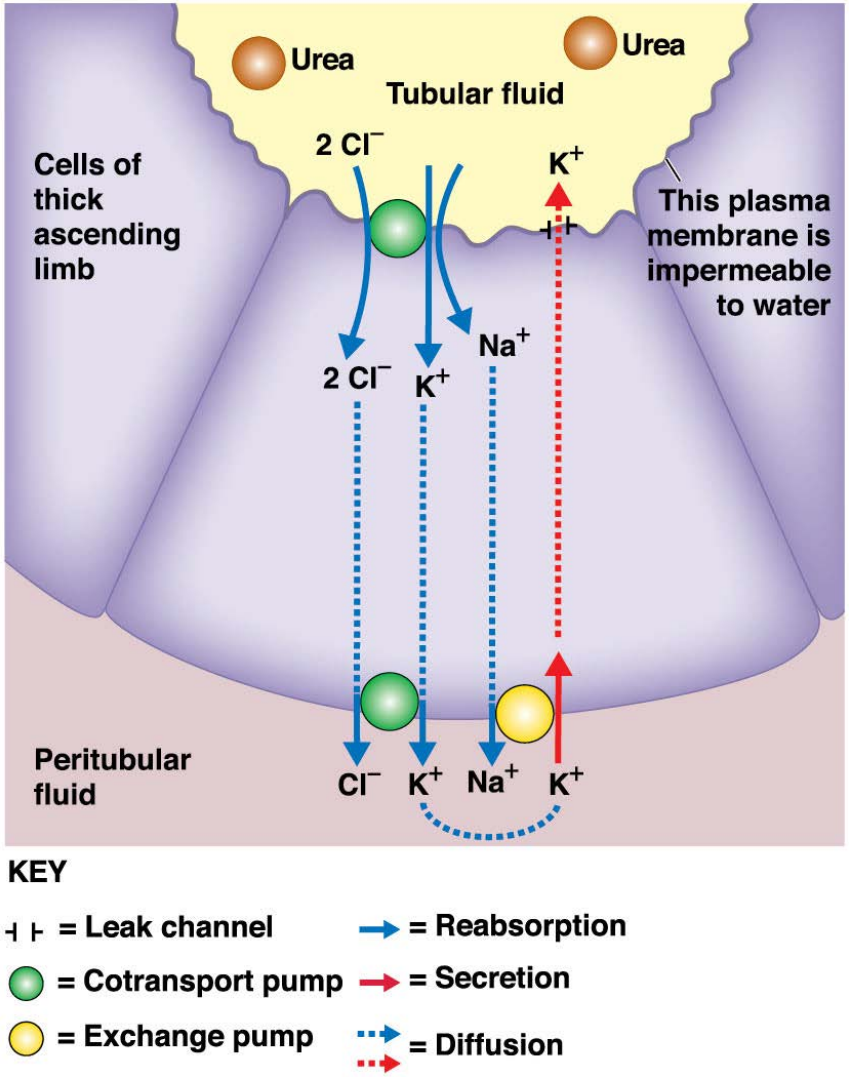
Module 24.11: Nephron loop

Thick ascending limb

- Actively transports Na^+ and Cl^- out of the tubular fluid
- Impermeable to water
- Tubular fluid solute concentration decreases
- Peritubular fluid solute concentration increases



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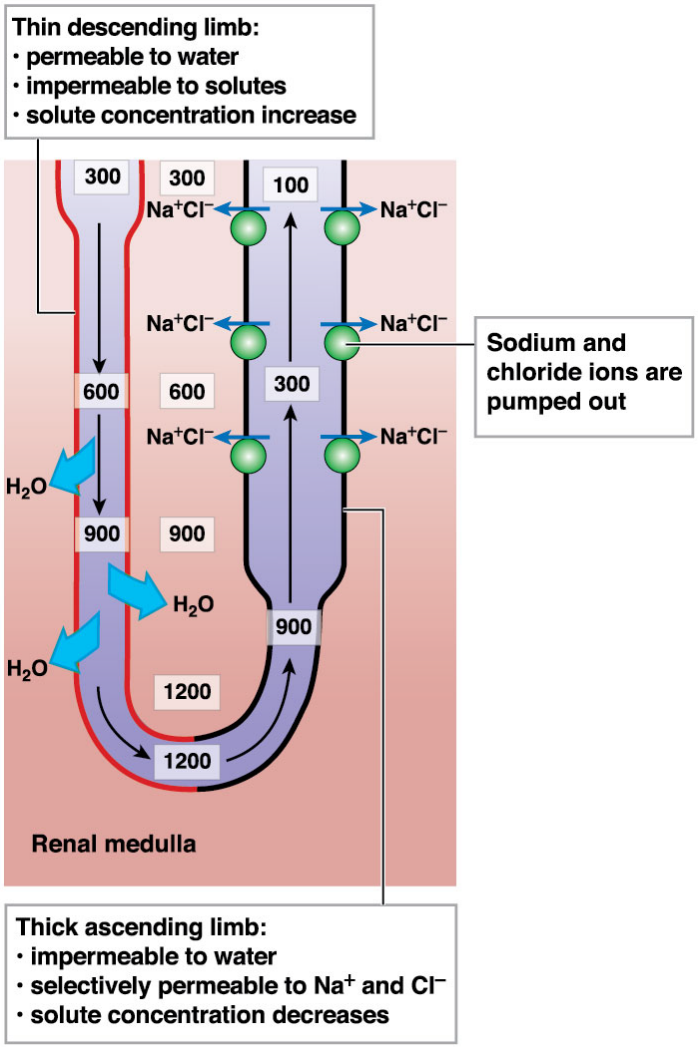
Module 24.11: Nephron loop

Osmotic concentration of peritubular fluid is increased from activity of the thick ascending limb

Thin descending limb

- Permeable to water
- Impermeable to solutes
- Water moves from tubular fluid into the peritubular fluid by osmosis
- Tubular fluid solute concentration increases



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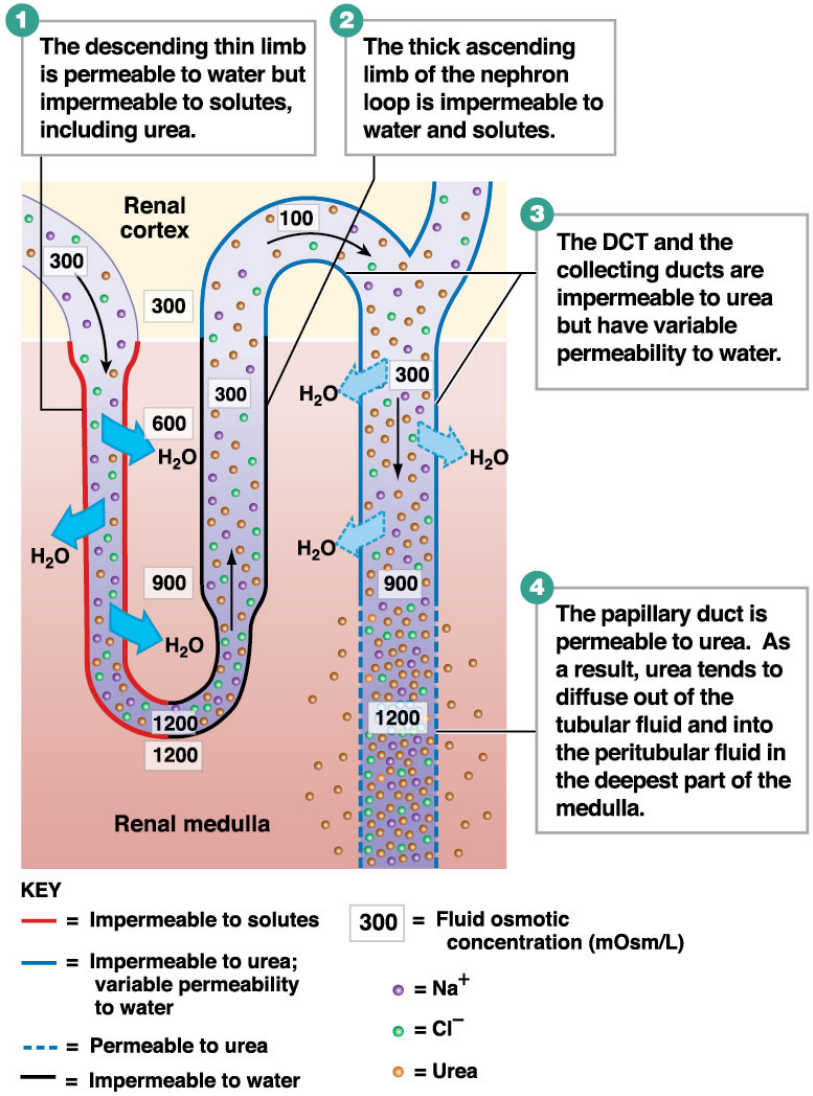
Module 24.11: Nephron loop

Concentration of urine

- Water is reabsorbed along the DCT and collecting duct
  - Increases concentration of solutes within the tubular fluid, particularly urea
- Tubular fluid reaching the papillary duct has a typical urea concentration of ~450 mOsm/L



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Module 24.11: Review

A. Define *countercurrent multiplication* as it occurs in the kidneys.
B. The thick ascending limb of the nephron loop actively pumps what substances into the peritubular fluid?
C. An increase in sodium and chloride ions in the peritubular fluid affects the descending thin limb in what way?

Learning Outcome: Explain the role of countercurrent multiplication in the formation of a concentration gradient in the renal medulla.

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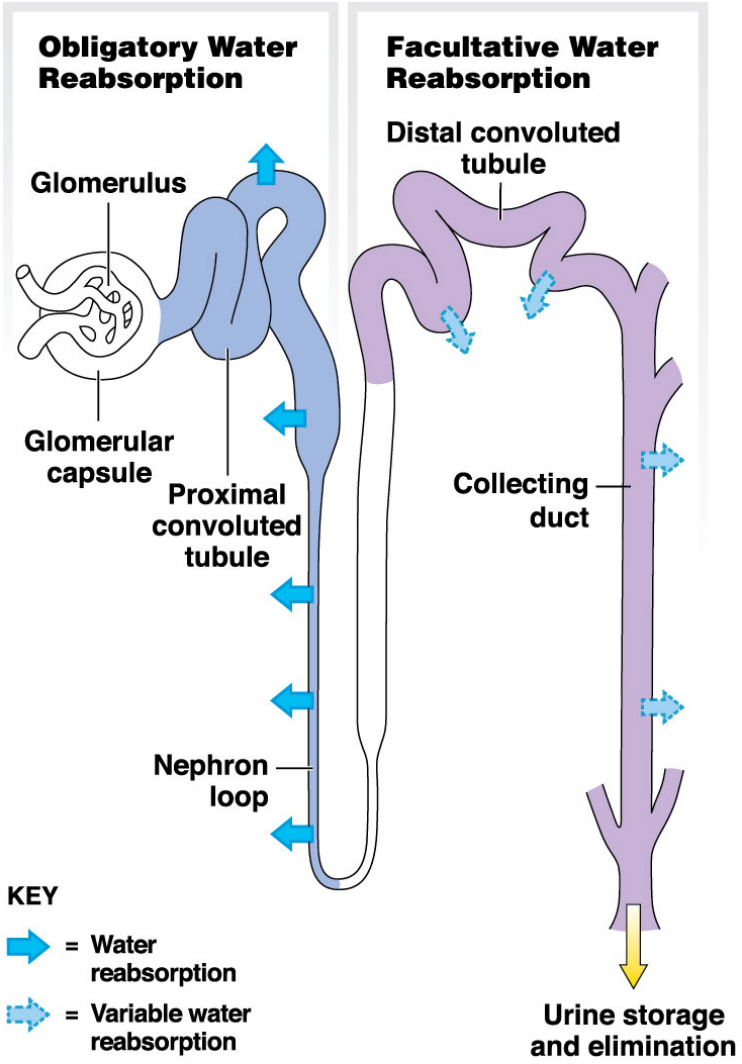
Module 24.12: Urine volume and concentration are hormonally regulated

Obligatory water reabsorption

- Occurs in locations where water movements cannot be prevented
  - PCT and descending limb of nephron loop
- Rate cannot be adjusted
- Recovers 85 percent of filtrate



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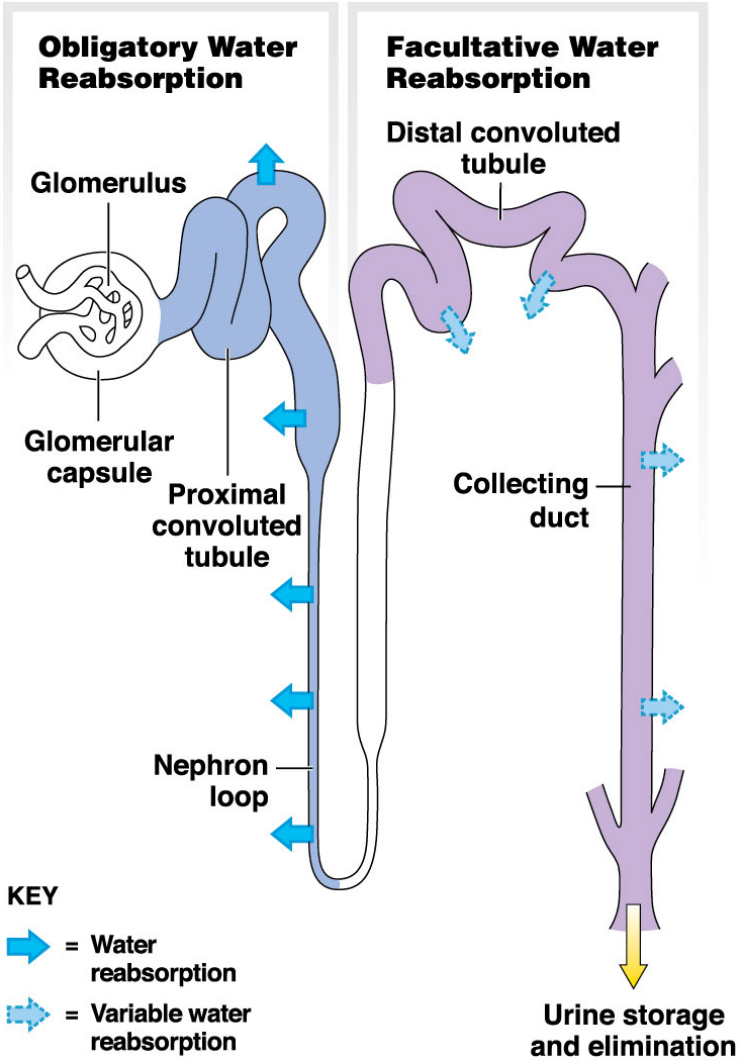
Module 24.12: Urine volume and concentration

Facultative water reabsorption

- Occurs in the DCT and collecting tubule
- Allows precise control of water reabsorption
- Adjusts urine volume by reabsorbing a portion (or all) of the remaining 15 percent of filtrate volume



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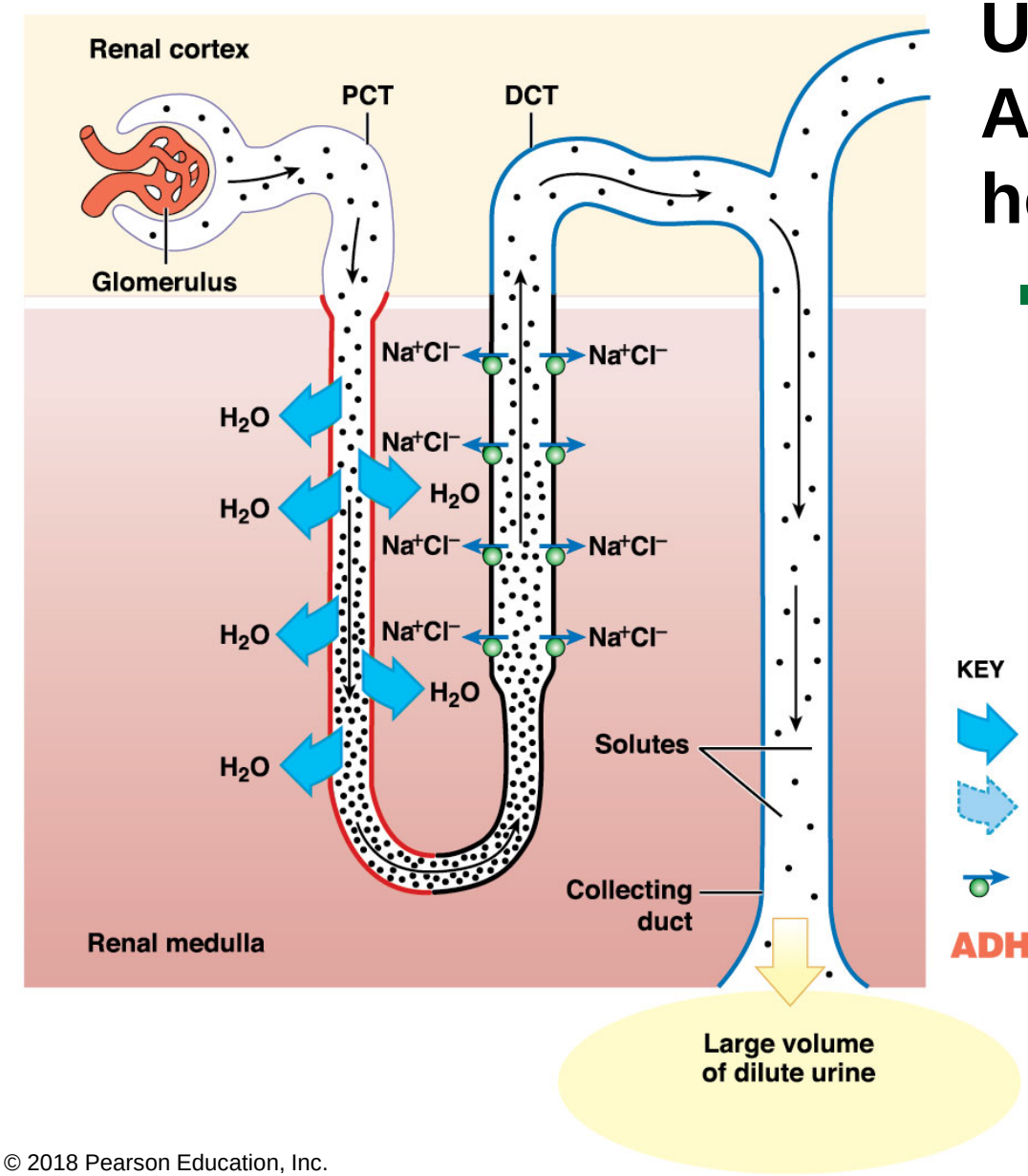
Module 24.12: Urine volume and concentration



Urine volume without ADH (antidiuretic hormone)

- No water is reabsorbed in DCT and collecting tubule
  - No facultative water reabsorption

KEY

- = Water reabsorption
- = Variable water reabsorption
- = Na^+/Cl^- transport
- ADH = Antidiuretic hormone
- = Solutes
- = Impermeable to solutes
- = Impermeable to water
- = Variable permeability to water

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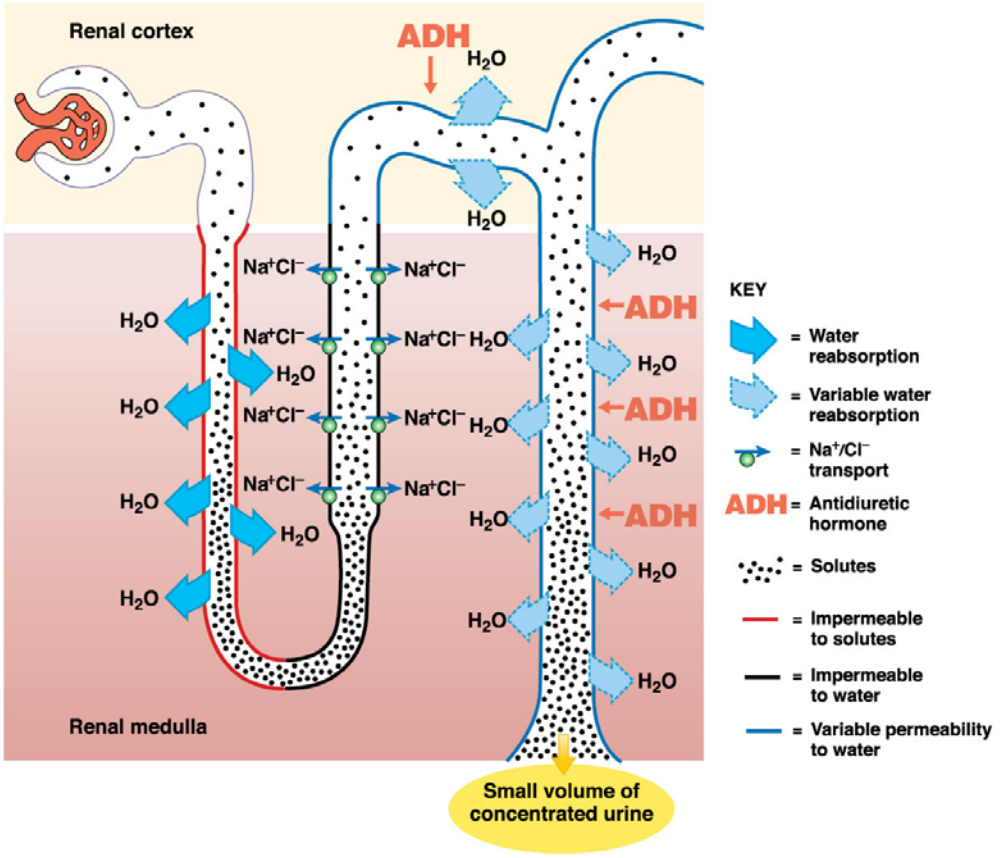
Module 24.12: Urine volume and concentration

Urine volume with ADH

- ADH allows water channels to form
  - **Aquaporins** appear in the apical plasma membranes of the DCT and collecting tubule cells
- Water permeability of the last tubular segments increases, increasing water reabsorption



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Module 24.12: Urine volume and concentration

Normal urine

- Normal volume is about 1200 mL/day with an osmotic concentration of 1000 mOsm/L
- Values differ from person to person and from day to day
  - Kidneys alter their function to maintain homeostasis

General Characteristics of Normal Urine

Characteristic	Normal Range
pH	4.5–8 (average: 6.0)
Specific gravity	1.003–1.030
Osmotic concentration (osmolarity)	855–1335 mOsm/L
Water content	93–97%
Volume	700–2000 mL/day
Color	Pale yellow
Odor	Varies with composition
Bacterial content	None (sterile)

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Module 24.12: Review

A. Can the water permeability of the PCT or DCT ever change? Explain.
B. Compare obligatory water reabsorption with facultative water reabsorption.
C. What effect does an increase in ADH levels have on the DCT?
D. When ADH levels in the DCT decrease, what happens to the urine osmotic concentration?
E. What effect does ADH have on the apical plasma membranes lining the DCT and collecting ducts?

Learning Outcome: Describe how antidiuretic hormone influences the volume and concentration of urine.

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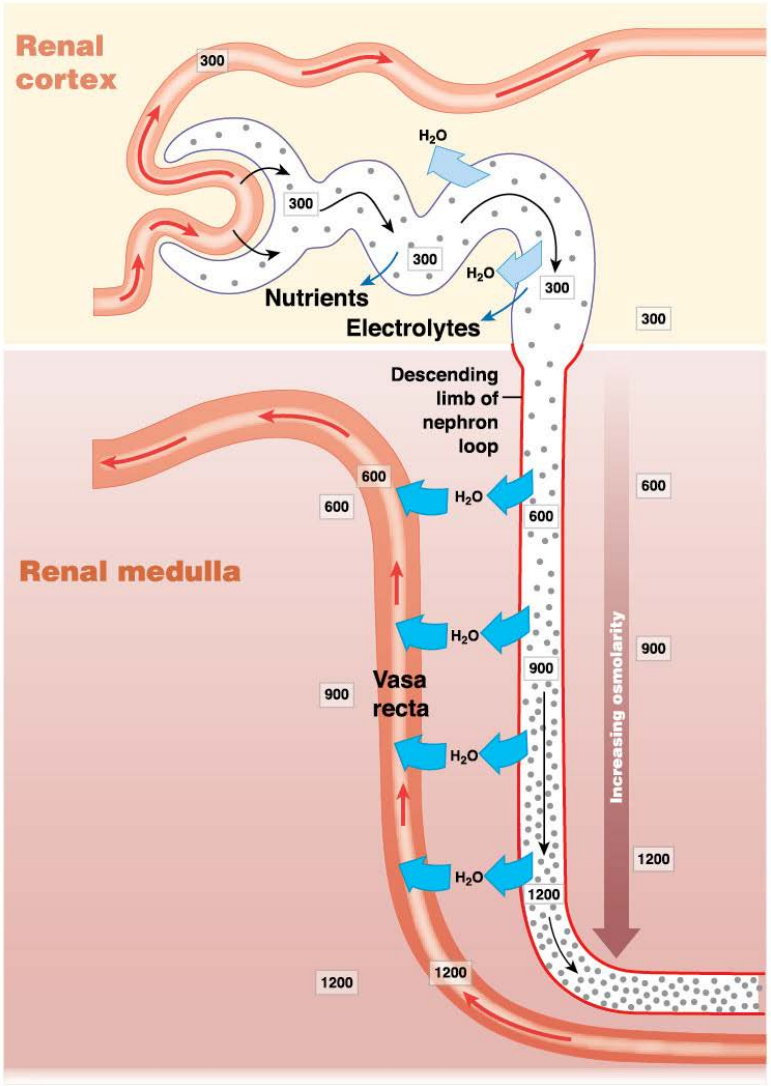
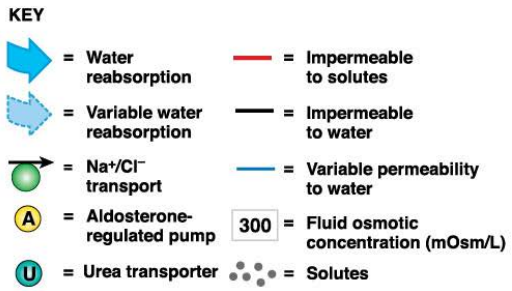
Module 24.13: Renal function is an integrative process involving filtration, reabsorption, and secretion



Renal corpuscle

- Filtrate has the same osmotic composition as plasma (~300 mOsm/L)
- Same composition as plasma except for plasma proteins



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Module 24.13: Renal function as an integrative process

Proximal convoluted tubules

- Ions and organic nutrients removed from tubular fluid
- Water follows by osmosis
- Reduces tubular fluid volume but keeps tubular fluid and peritubular fluid isotonic

PCT and descending limb of nephron loop

- Obligatory water reabsorption concentrates the tubular fluid

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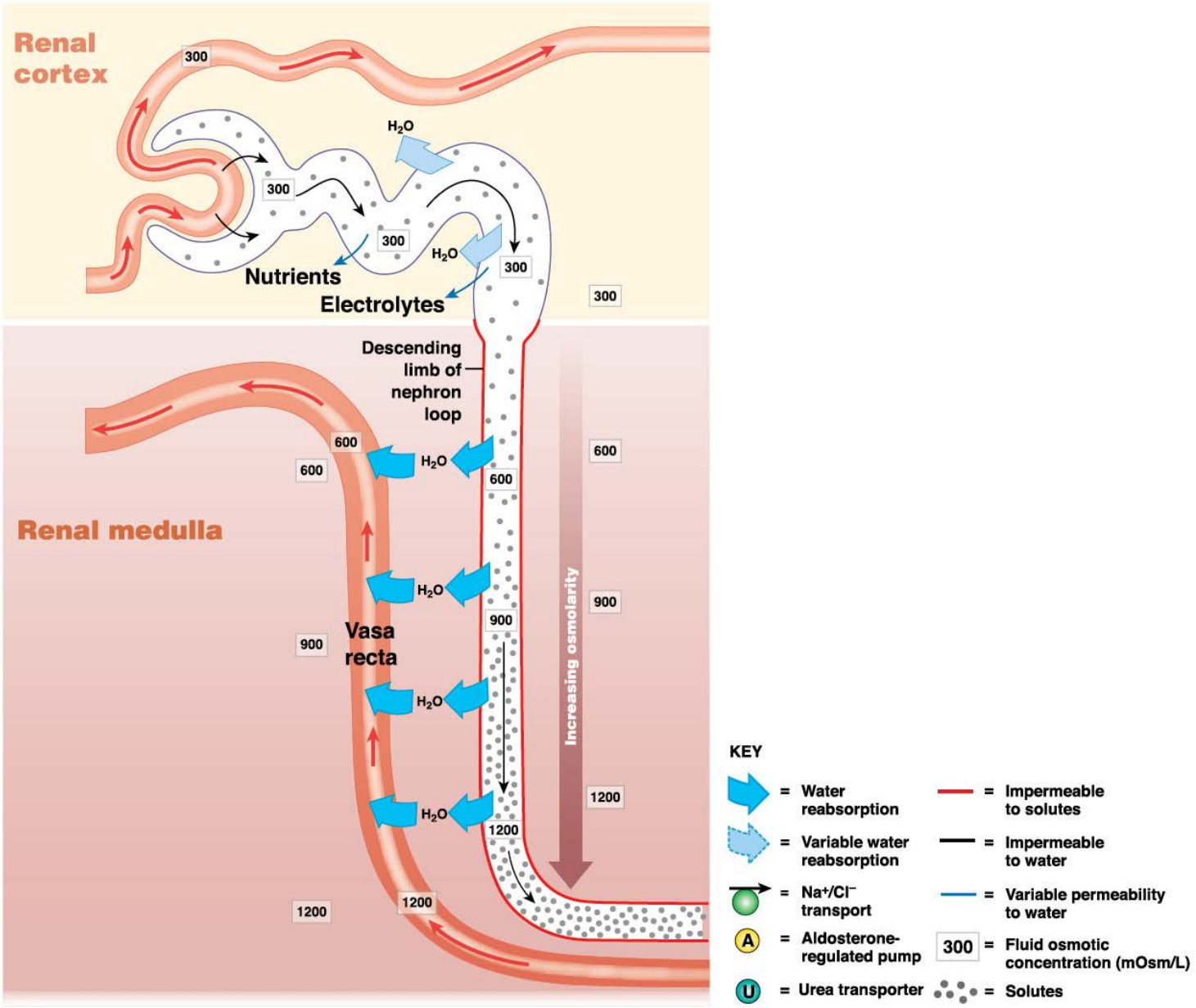
Filtration, reabsorption, and secretion



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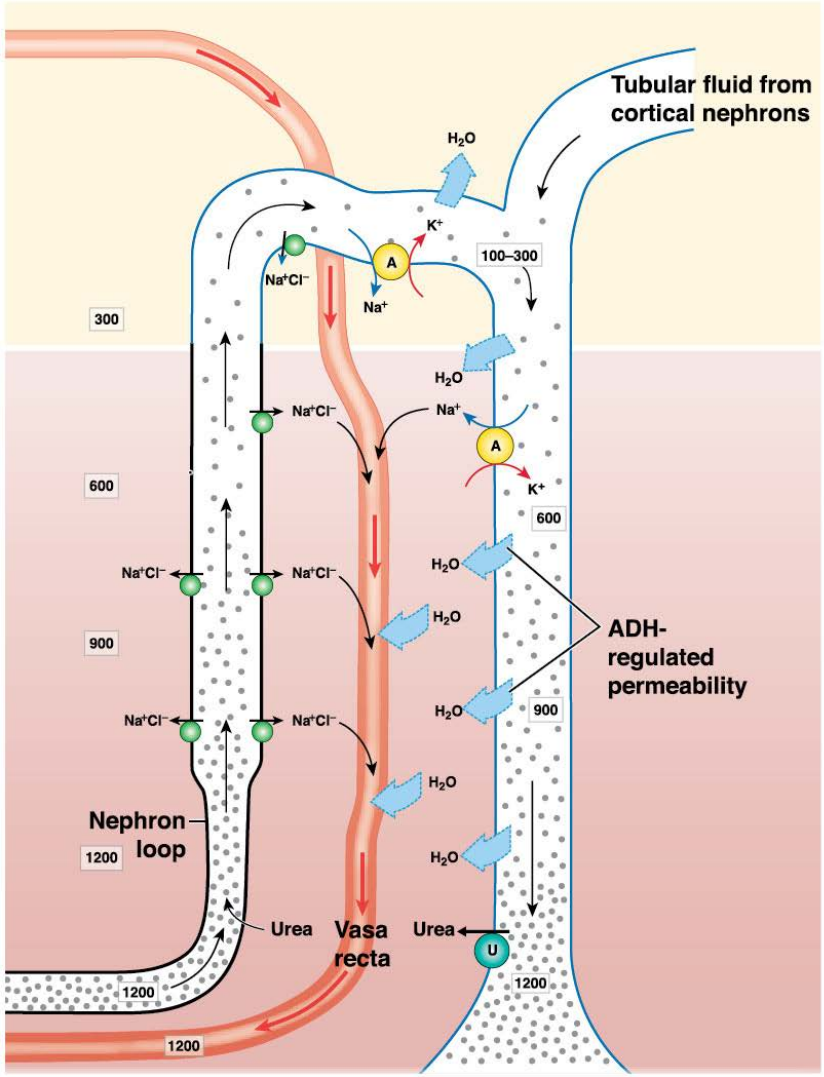
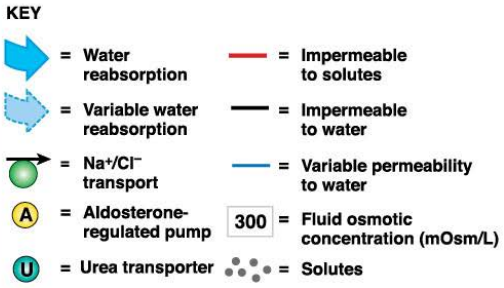
Module 24.13: Renal function as an integrative process



Ascending limb of nephron loop

- Actively transports Na^+ and Cl^- out of the tubule (impermeable to water)
- Lowers the osmotic concentration of tubular fluid



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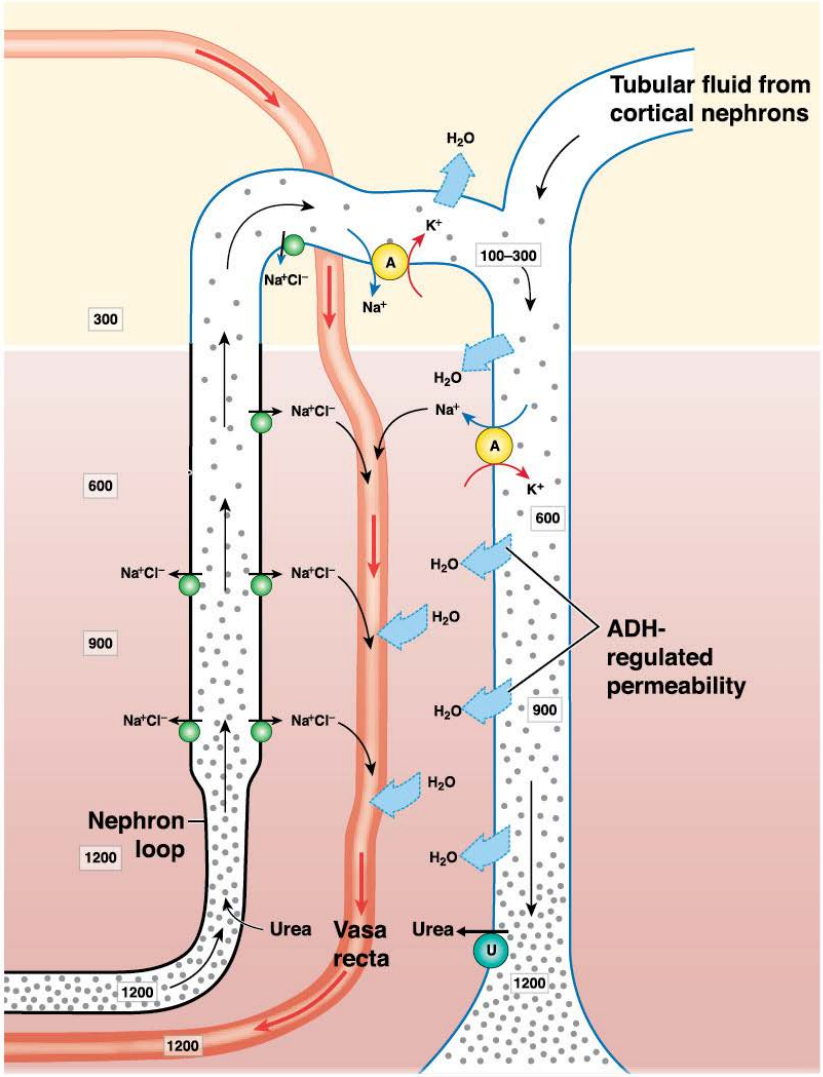
Module 24.13: Renal function as an integrative process



DCT and collecting system make adjustments

- Reabsorption and secretion of solutes
- Hormonally controlled water reabsorption

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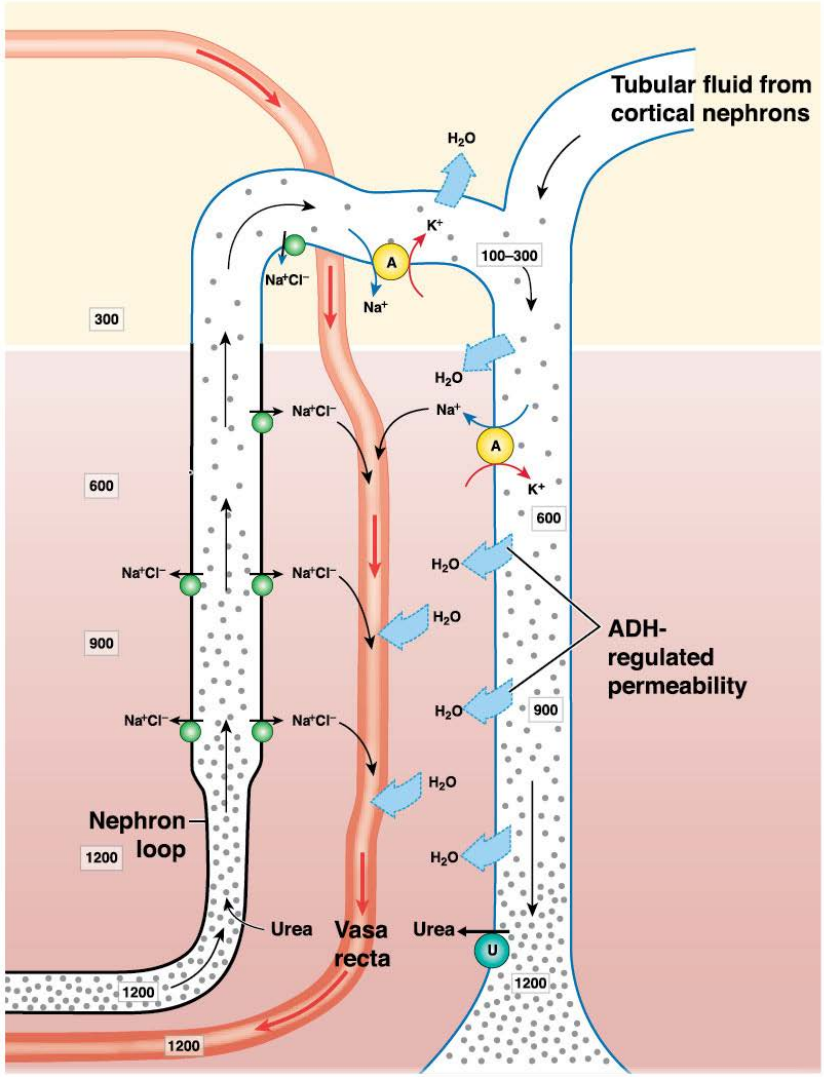
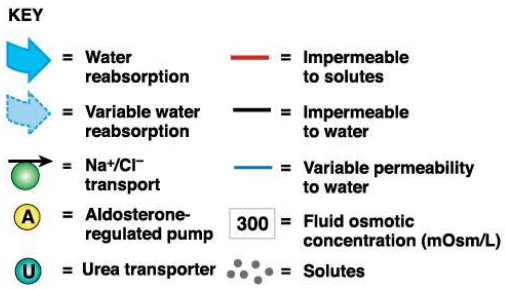
Module 24.13: Renal function as an integrative process





Vasa recta

- Absorbs solutes and water from the tubules into the systemic circuit
- Maintains concentration gradient of medulla

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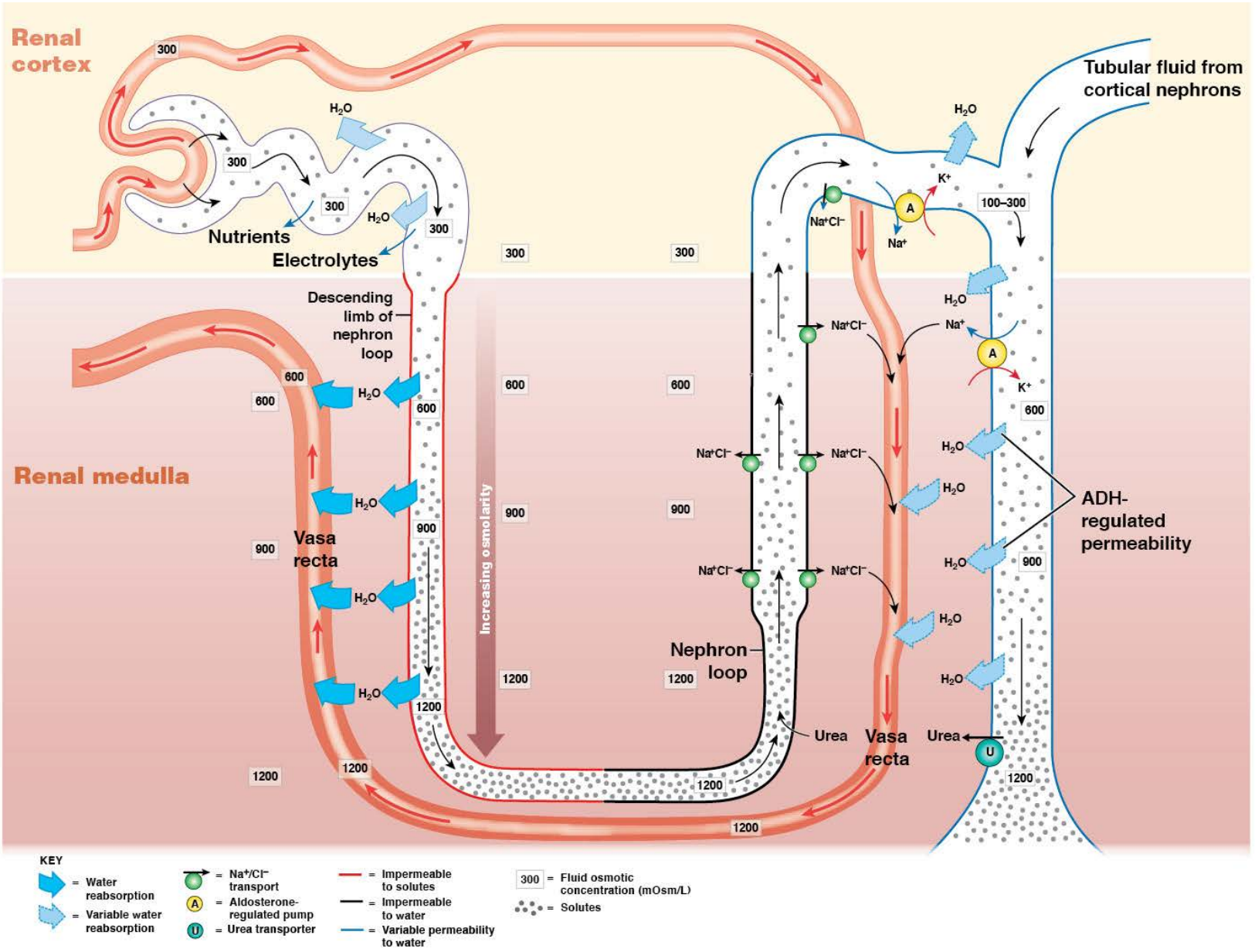
Production of urine



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Module 24.13: Review

A. In the PCT, ions and organic substrates are actively removed, thus causing what to occur?

Learning Outcome: Summarize the major steps involved in water reabsorption and urine production.

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Module 24.14: Clinical Module: Renal failure is a life-threatening condition

Occurs when the kidneys cannot filter wastes from blood and can no longer maintain homeostasis

Impairs all systems in the body, resulting in:

- Decrease in urine production
- Rise in blood pressure
- Anemia from decline in erythropoietin production
- Central nervous system problems (sleeplessness, seizures, delirium, and coma)

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Module 24.14: Renal failure

Chronic renal failure

- Kidney function deteriorates gradually
  - Associated problems accumulate over time
- Progression can be slowed, but the condition is not reversible
- Management involves restricted water, salt, and protein intake
  - Reduces strain on urinary system by minimizing:
    - Volume of urine produced
    - Amount of nitrogenous waste generated
- Acidosis (a common problem with renal failure) can be countered by ingesting bicarbonate ions

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Module 24.14: Renal failure

Acute renal failure

- Kidney function deteriorates rapidly in just a few days
  - May be impaired for weeks
- Sudden slowing or stopping of filtration caused by:
  - Exposure to toxic drugs, renal ischemia, urinary obstruction, or trauma
  - Allergic response to antibiotics or anesthetics in sensitized individuals
- Recovery of partial or complete function is possible if patients survive the initial incident
  - Survival rate ~50 percent with supportive treatment

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Module 24.14: Renal failure

Dialysis

- Process of passive diffusion across a selectively permeable membrane
- **Hemodialysis**
  - Uses an artificial membrane as an alternative to the kidney's normal membrane around the glomerulus
  - Regulates the composition of blood using a dialysis machine
  - Membrane pores allow diffusion of ions, nutrients, and organic wastes, but not plasma proteins

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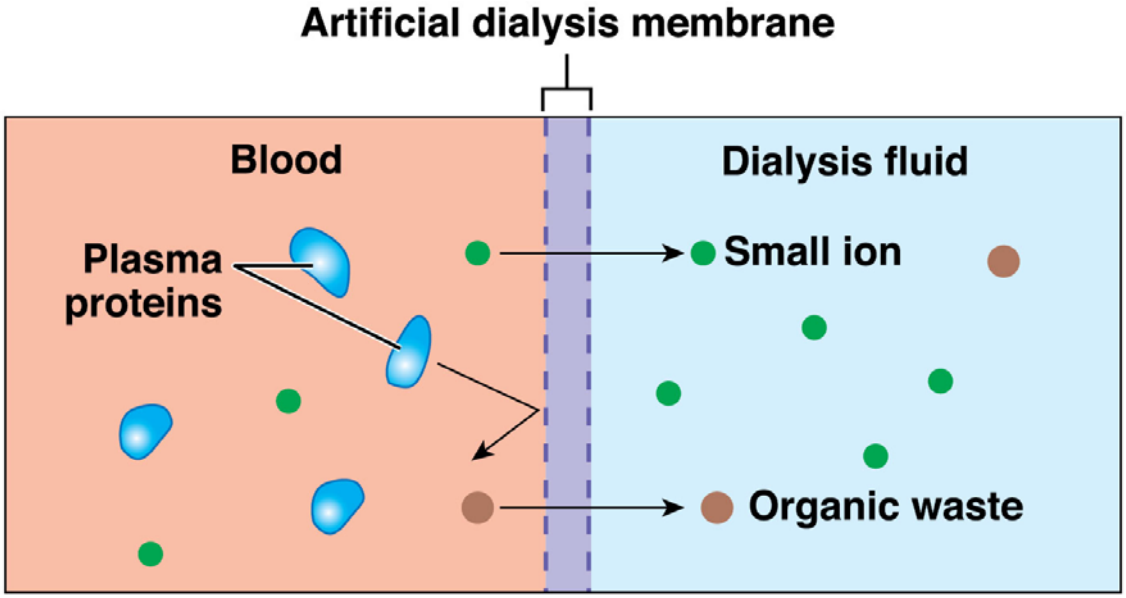
Module 24.14: Renal failure

Dialysis (continued)

- **Hemodialysis** (continued)
  - Dialysis fluid containing specific concentrations of solutes is run on the other side of the membrane
  - **Shunts** (silicone rubber tubes) connect blood vessels with the dialysis machine



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Comparative Composition of Plasma and Dialysis Fluid

Component	Plasma	Dialysis Fluid
Electrolytes (mEq/L)		
Sodium (Na^+)	135–145	136–140
Potassium (K^+)	3.5–5.0	0–3.0
Calcium (Ca^{2+})	4.3–5.3	1.5
Magnesium (Mg^{2+})	1.4–2.0	0.5–1.0
Chloride (Cl^-)	100–108	99–110
Bicarbonate (HCO_3^-)	21–28	27–39
Phosphate (PO_4^{2-})	3	0
Sulfate (SO_4^{2-})	1	0
Nutrients (mg/dL)		
Glucose	70–110	100

Note: Although these values are representative, the precise dialysis fluid composition can be tailored to meet specific clinical needs. For example, if plasma potassium levels are too low, the dialysis fluid potassium ion concentration can be elevated to remedy the situation.

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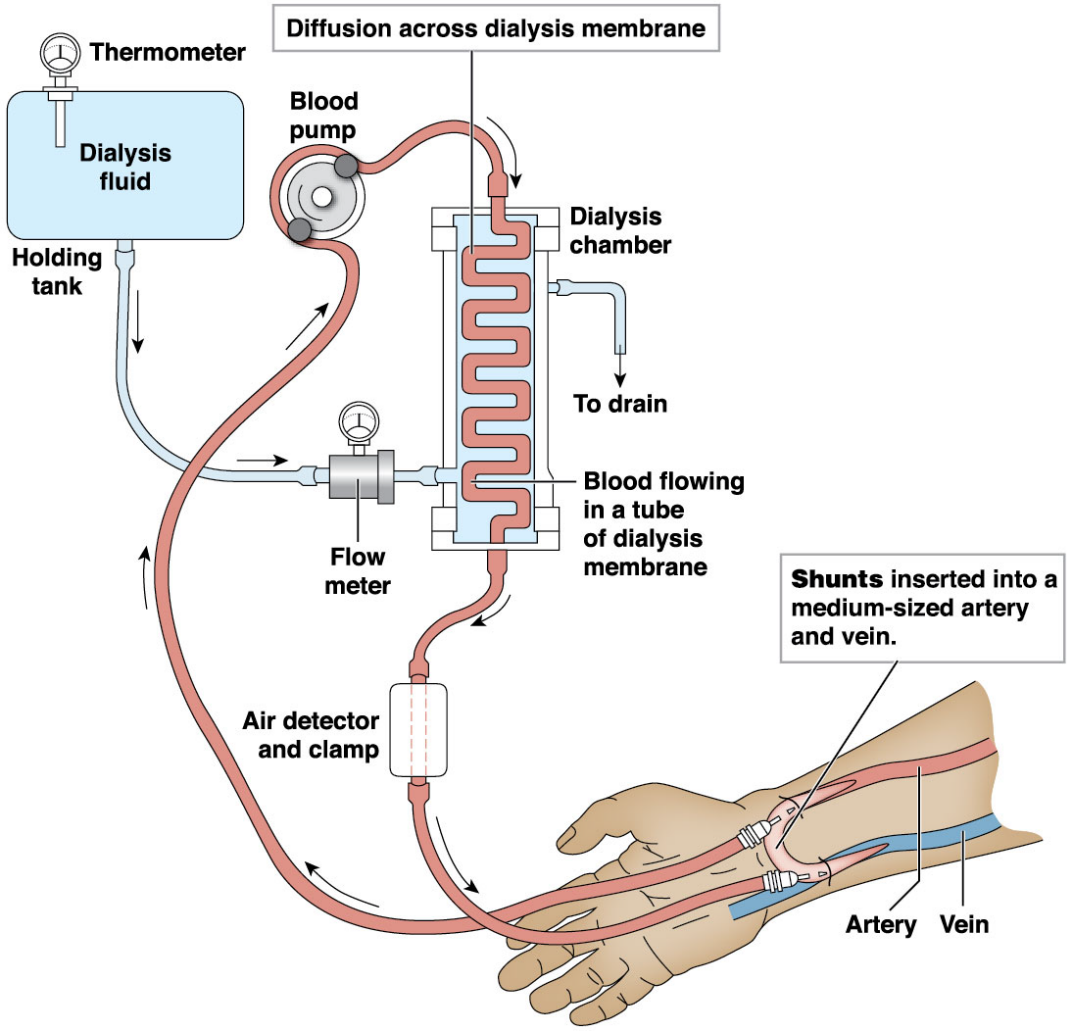
Renal failure



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Module 24.14: Renal failure

Renal failure treatment

- Dialysis relieves renal failure symptoms, but is not a cure
- Kidney transplant is the only real cure for severe renal failure
  - Patient survival is more than 90 percent at 2 years after the transplant
  - Close relative donor increases success rate
  - Immunosuppressive drugs are necessary to reduce rejection of transplant

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Module 24.14: Review

A. Briefly explain the difference between chronic and acute renal failure.
B. Define *dialysis*.
C. Explain why patients on dialysis often receive Epogen or Procrit, synthetic forms of erythropoietin.

Learning Outcome: Compare and contrast chronic and acute renal failure, and explain the process of hemodialysis.

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Section 3: Urine Storage and Elimination

Learning Outcomes

24.15 Name the organs responsible for the transport, storage, and elimination of urine.

24.16 Describe the structures and functions of the ureters, urinary bladder, and urethra.

24.17 Describe the urine storage and urine voiding reflexes.

24.18 **Clinical Module:** Describe common urinary disorders related to output and frequency.

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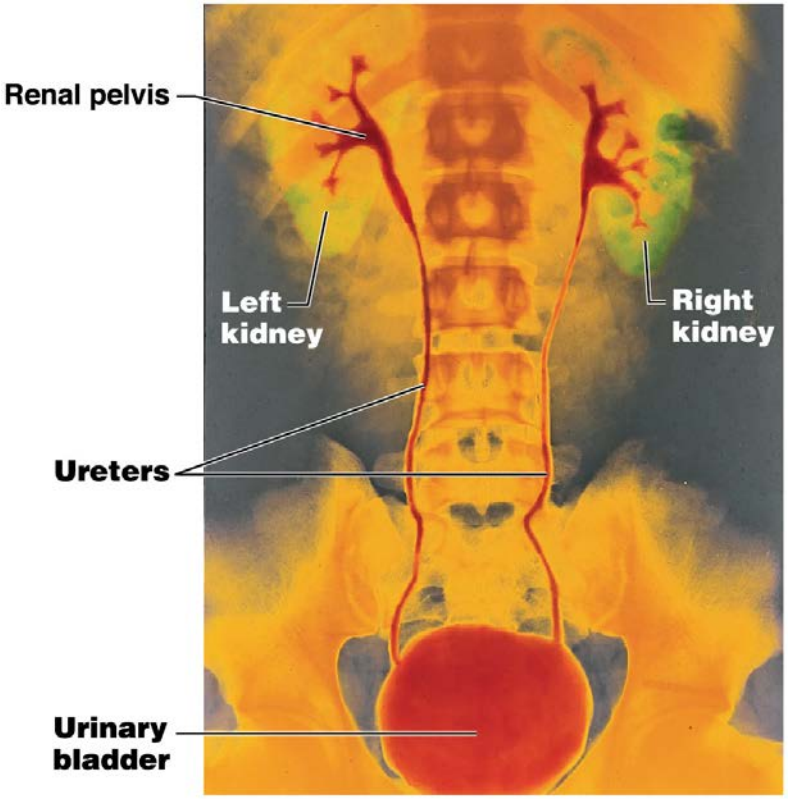
Module 24.15: The urinary tract transports, stores, and eliminates urine

Urinary tract

- Transports, stores, and eliminates urine
- Includes the ureters, urinary bladder, and urethra
- Can be visualized using a **pyelogram**
  - X-ray image of the urinary tract taken after a radiopaque dye is administered intravenously



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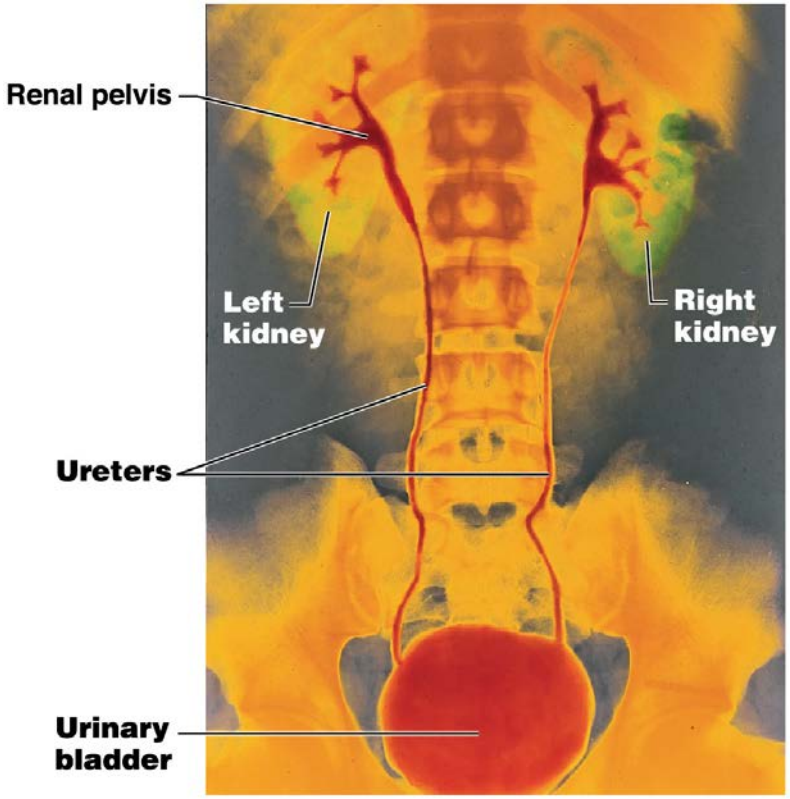
Module 24.15: The urinary tract

- **Ureters**
  - Paired muscular tubes extending from the kidney to the urinary bladder (about 30 cm)
  - Retroperitoneal and attached to the posterior abdominal wall
- **Urinary bladder**
  - Hollow, muscular organ holding up to a liter of urine
- **Urethra**



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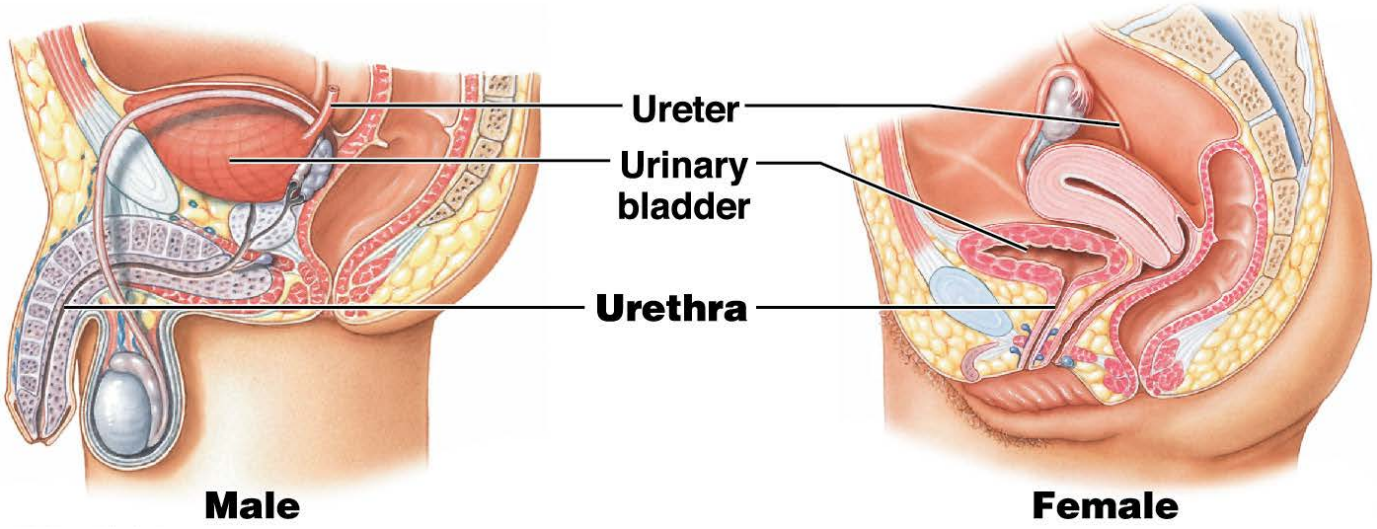
Module 24.15: The urinary tract

Urethra

- Extends from the neck of the urinary bladder to the exterior of the body
- Different lengths and functions in males versus females
  - Male urethra is longer and transports semen as well as urine



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Module 24.15: Review

A. When does urine production end?
B. What is a pyelogram?
C. How does the urethra differ between males and females?

Learning Outcome: Name the organs responsible for the transport, storage, and elimination of urine

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Module 24.16: The ureters, urinary bladder, and urethra are specialized to conduct urine

Urinary bladder

- Filled by the ureters and drained by the urethra
- Dimensions vary with state of distension
- Posterior, inferior, and anterior surfaces outside the peritoneal cavity
  - Anchored to the pelvic and pubic bones by supporting ligaments
  - **Lateral umbilical ligaments**
    - Vestiges of the umbilical arteries
  - **Middle umbilical ligament**

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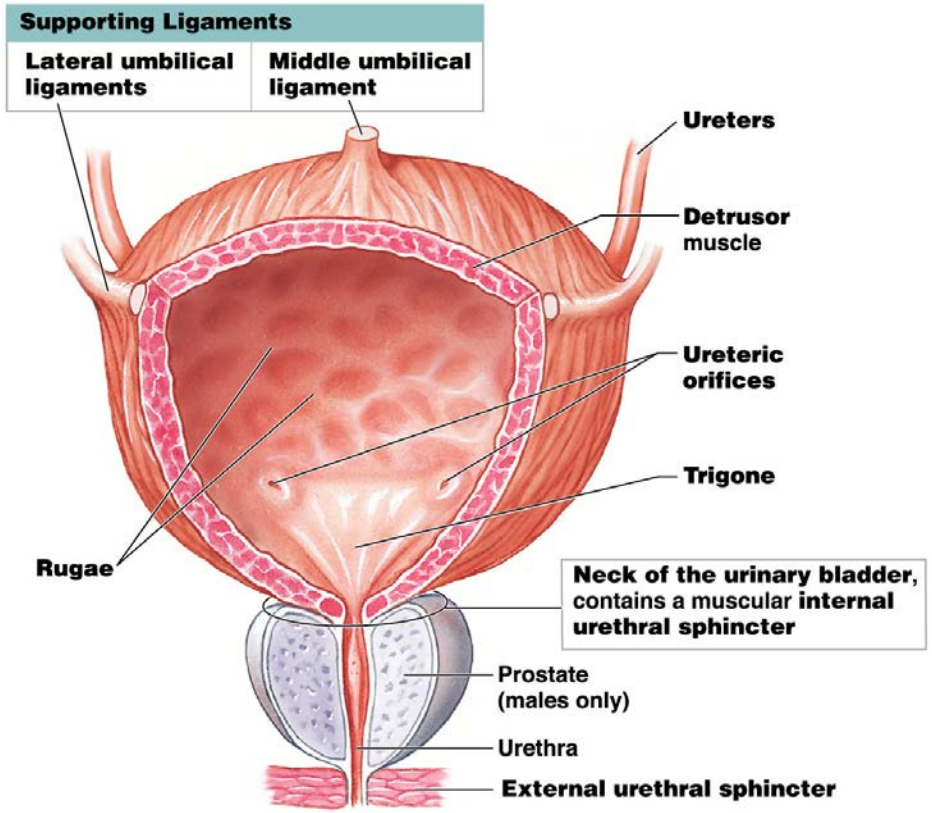
Module 24.16: Conduction and storage of urine

Urinary bladder (continued)

- **Rugae**
  - Folds in the bladder lining that disappear with expansion as the bladder fills
- **Ureteric orifices**
  - Slitlike shape helps prevent backflow of urine into ureters with bladder contraction



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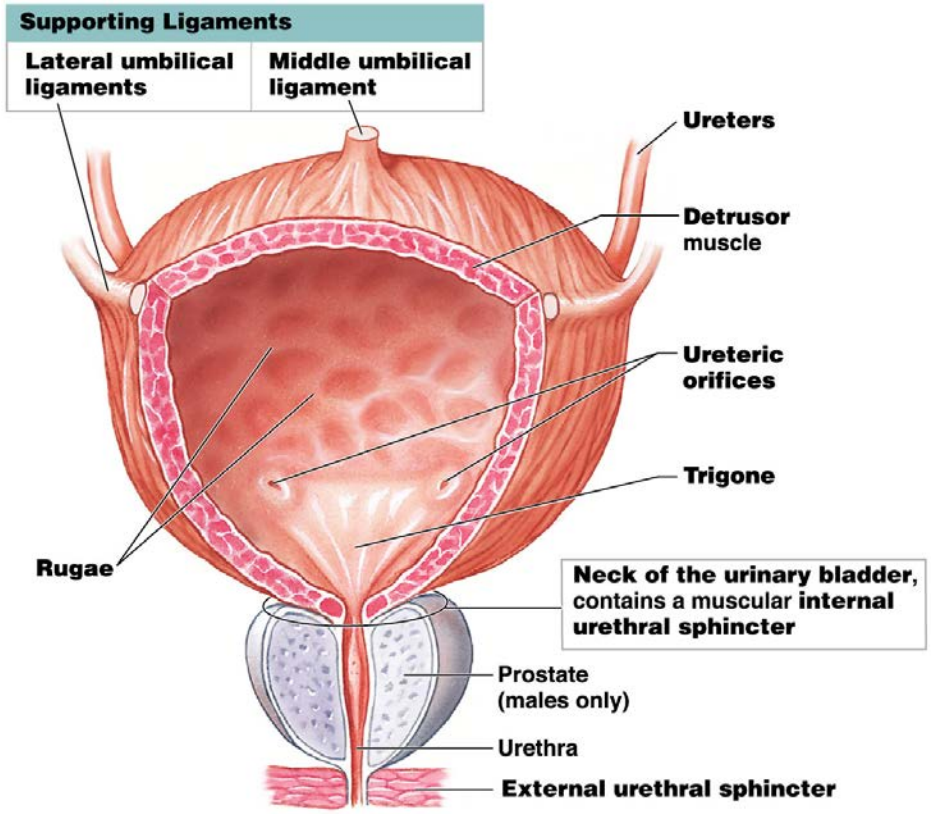
Module 24.16: Conduction and storage of urine

Urinary bladder (continued)

- **Ureters** penetrate posterior bladder wall at an oblique angle
- **Trigone**
  - Triangular area bounded by the ureteral openings and the entrance to the urethra



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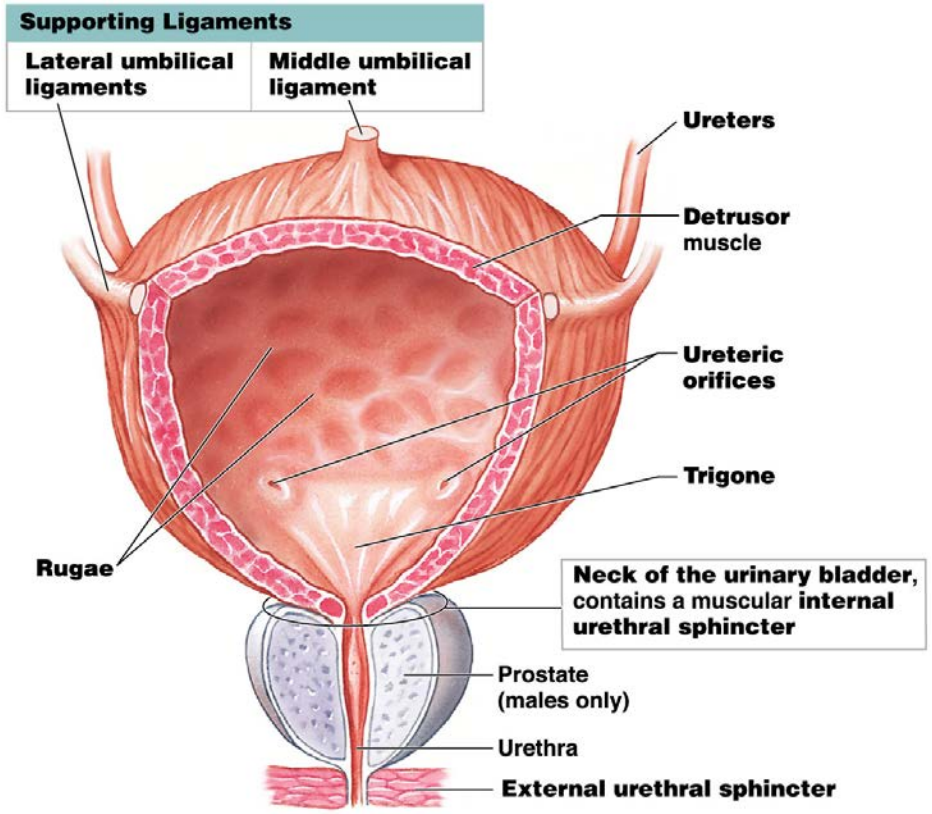
Module 24.16: Conduction and storage of urine

Urinary bladder (continued)

- **Neck of the urinary bladder**
  - Surrounds the urethral opening
  - Contains a muscular **internal urethral sphincter** (involuntary smooth muscle)



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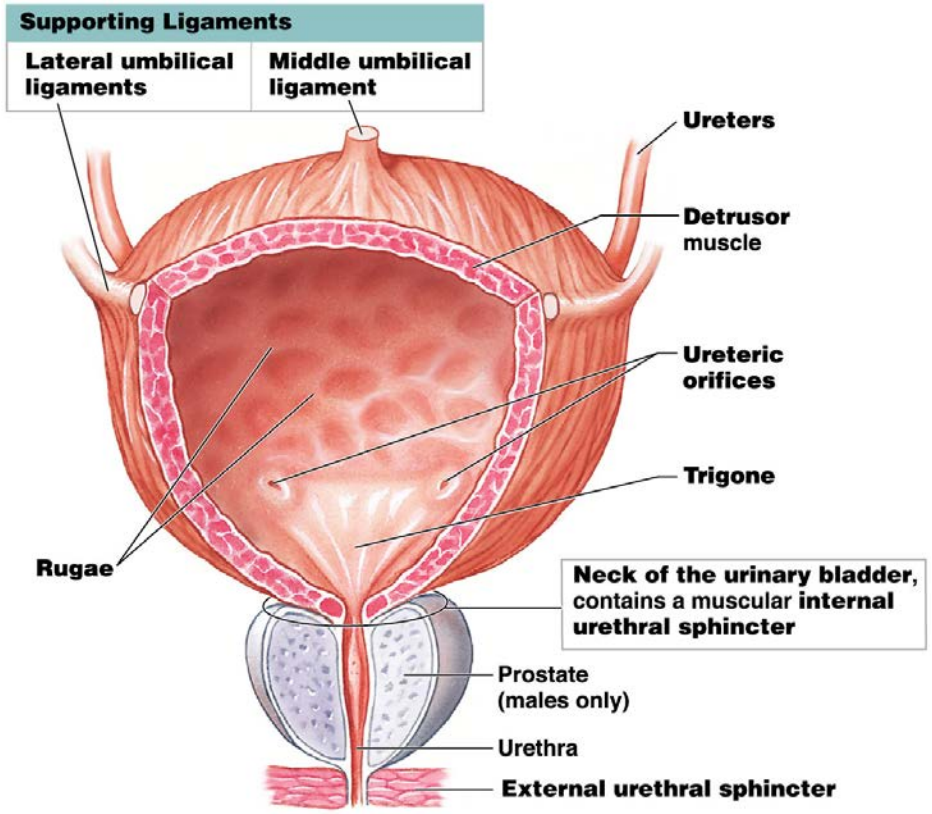
Module 24.16: Conduction and storage of urine

Urinary bladder (continued)

- **External urethral sphincter**
  - Located where the urethra passes through the urogenital diaphragm
  - Under voluntary control
  - Must be voluntarily relaxed to permit urination



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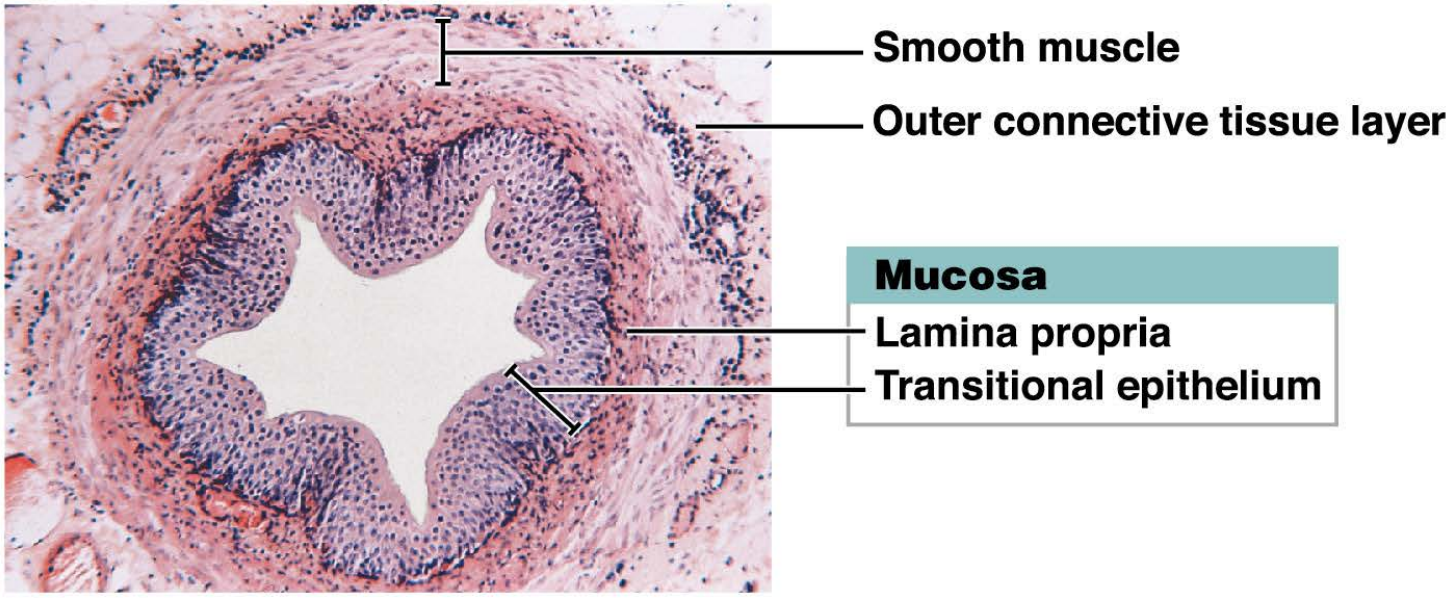
Module 24.16: Conduction and storage of urine

Ureters conduct urine to the bladder

1. Inner mucosa
   - Transitional epithelium and surrounding lamina propria



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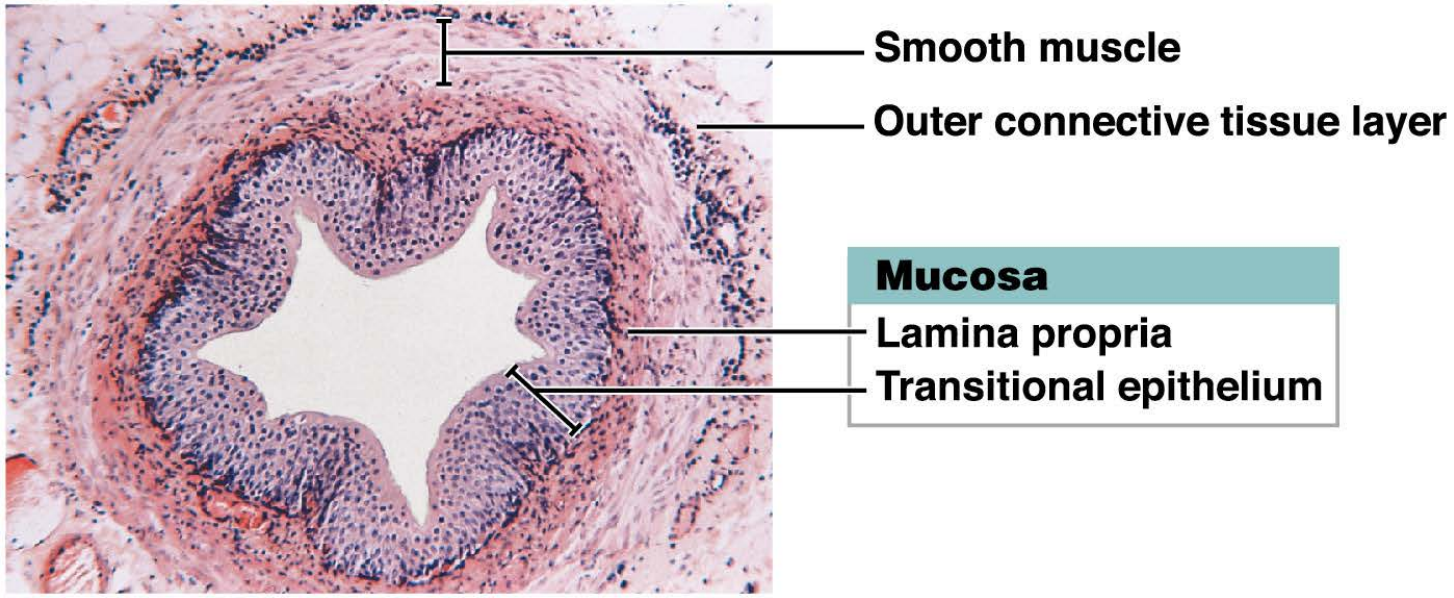
Module 24.16: Conduction and storage of urine

Ureters (continued)

2. Middle muscular layer
   - Bands of smooth muscle that create peristaltic waves to move urine to the bladder
3. Outer connective tissue layer
   - Continuous with the fibrous capsule and peritoneum



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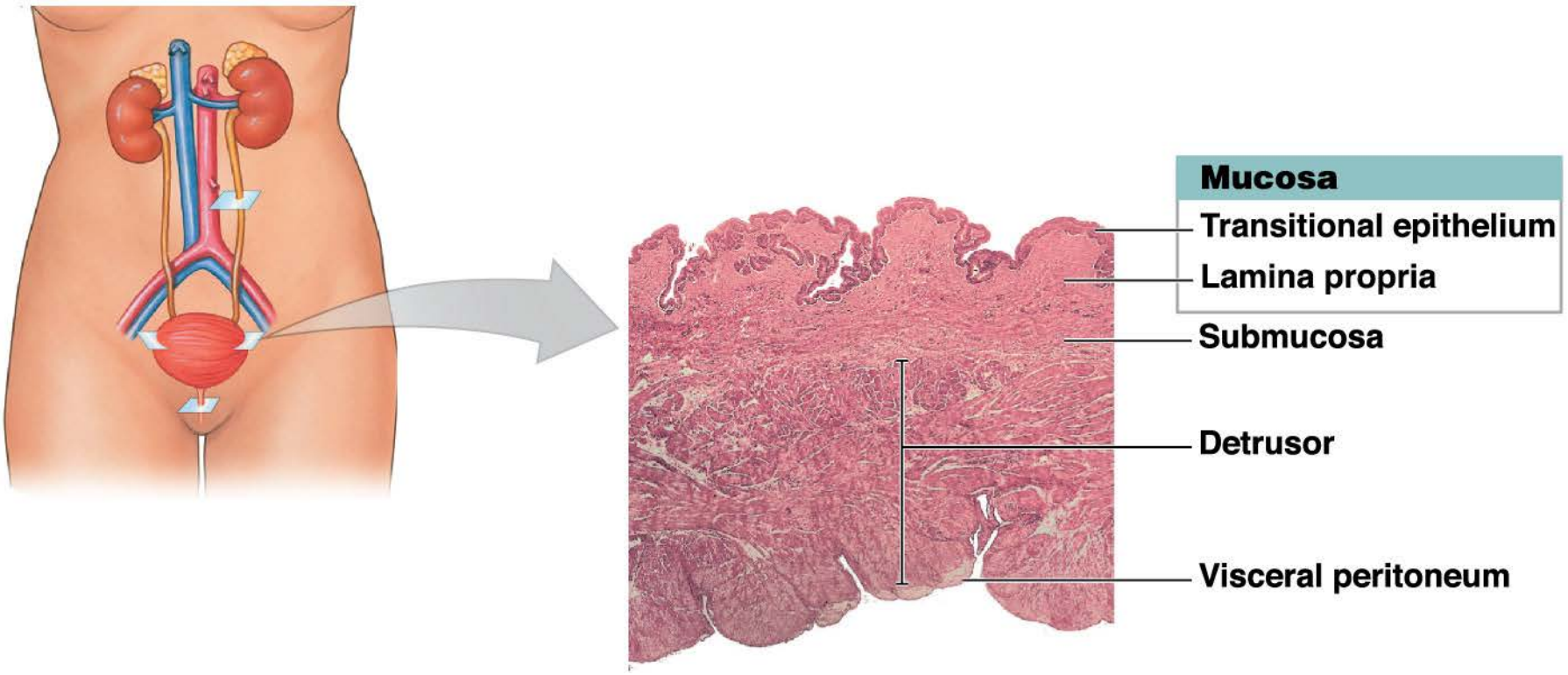
Module 24.16: Conduction and storage of urine

Wall of the urinary bladder

- Contains mucosa, submucosa, and muscularis layers



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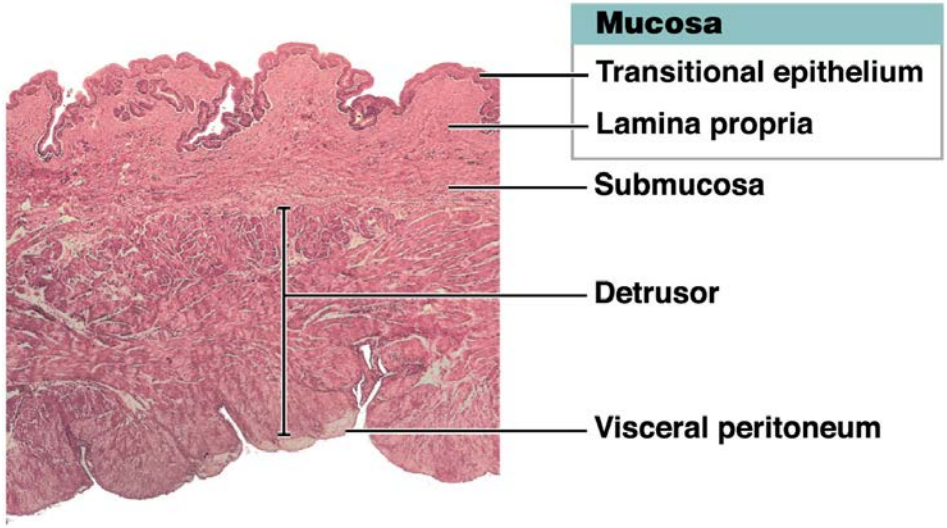
Module 24.16: Conduction and storage of urine

Wall of the urinary bladder (continued)

- Muscularis layer has three layers
  - Inner longitudinal layer
  - Circular layer
  - Outer longitudinal layer
- Collectively, the layers form the **detrusor muscle**



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Module 24.16: Conduction and storage of urine

Wall of the urethra

- Lined with stratified epithelium that varies by location
  - Transitional at the neck
  - Stratified columnar at midpoint
  - Stratified squamous near the external urethral orifice

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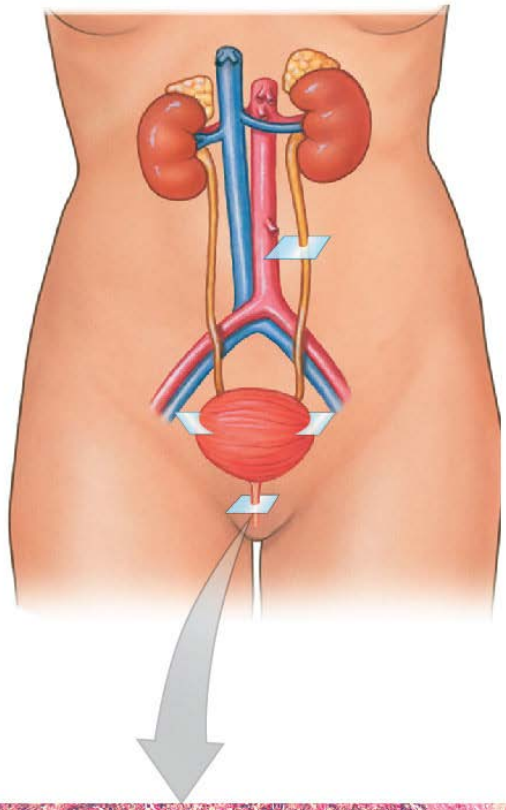
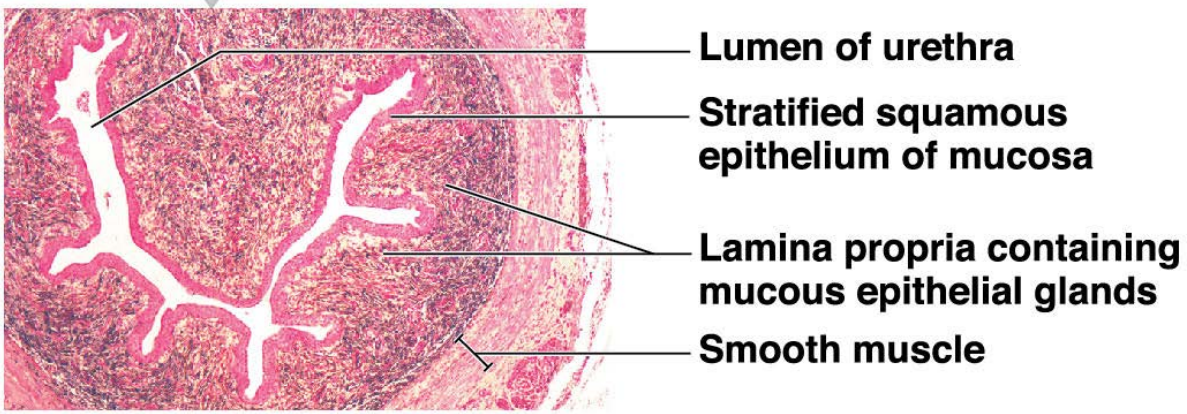
Module 24.16: Conduction and storage of urine



Wall of the urethra (continued)

- Thick, elastic lamina propria
- Longitudinal folds in the mucous membrane
  - Mucin-secreting cells in the epithelial pockets



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Module 24.16: Review

A. Urine is transported by the _____, stored within the _____, and eliminated through the _____.
B. What has to happen to the external urethral sphincter to allow urination?
C. Name the specialized smooth muscle of the urinary bladder, and describe its function.

Learning Outcome: Describe the structures and functions of the ureters, urinary bladder, and urethra.

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Module 24.17: Urinary reflexes coordinate urine storage and voiding

Micturation reflex

- Coordinates the process of urination
- Involves both:
  - Local reflex pathway
  - Central pathway through the cerebral cortex

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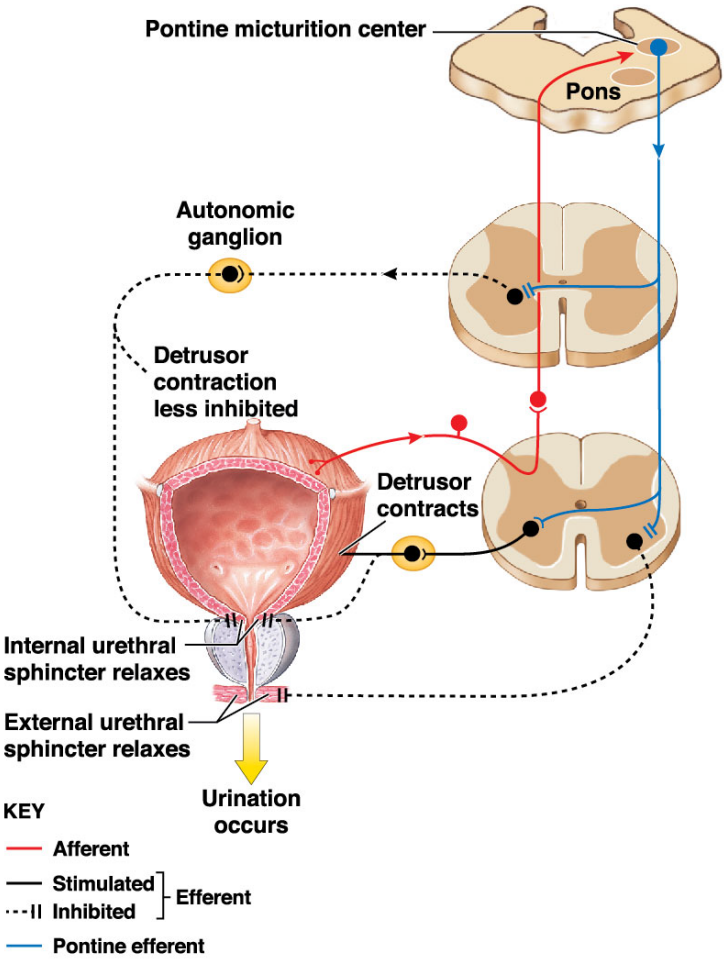
Module 24.17: Urination

Micturation reflex (continued)

- **Urine storage reflex**
  - Stretch receptors of urinary bladder wall distort as it fills
  - Afferent impulses stimulate sympathetic stimulation to detrusor and stimulate contraction of internal urethral sphincter
  - **Pontine storage center** decreases parasympathetic activity and increases somatic motor nerve activity of external urethral sphincter



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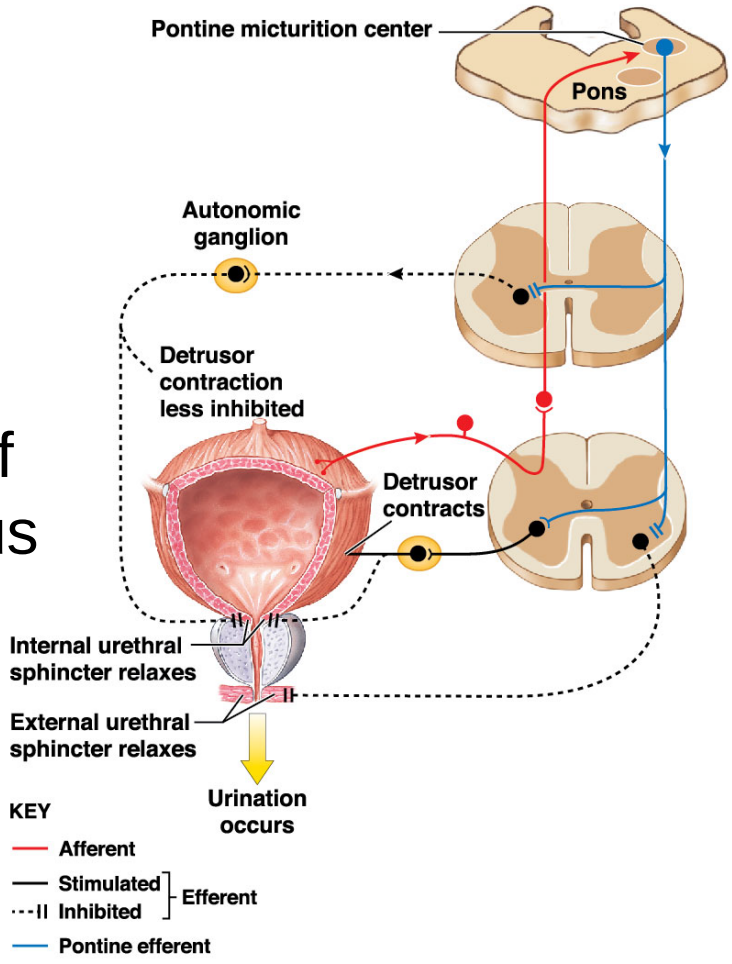
Module 24.17: Urination

Micturation reflex (continued)

- **Urine voiding reflex** through **pontine micturition center**
  - Interneuron relays sensation of bladder fullness to the thalamus
  - Projection fibers relay the information to the cerebral cortex
  - Voluntary relaxation of the external urethral sphincter
    - Causes relaxation of the internal urethral sphincter
  - Since pressure is already increased, relaxing the sphincters leads to urination



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Module 24.17: Review

A. What are the two reflexes that control urination?
B. The ability to consciously control urination depends on your ability to control which muscle?

Learning Outcome: Describe the urine storage and urine voiding reflexes.

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Module 24.18: Clinical Module: Urinary disorders can often be detected by physical examinations and laboratory tests

Primary signs of urinary disorders

- Change in volume and appearance of urine
  - **Polyuria**
    - Excessive urine production
    - Results from hormonal or metabolic problems
      - Possibly diabetes or glomerulonephritis
  - **Oliguria**
    - Reduced urine production (50–500 mL/day)
  - **Anuria**
    - Severely reduced urine production (0–50 mL/day)
  - Oliguria and anuria indicate serious kidney problems and potential renal failure

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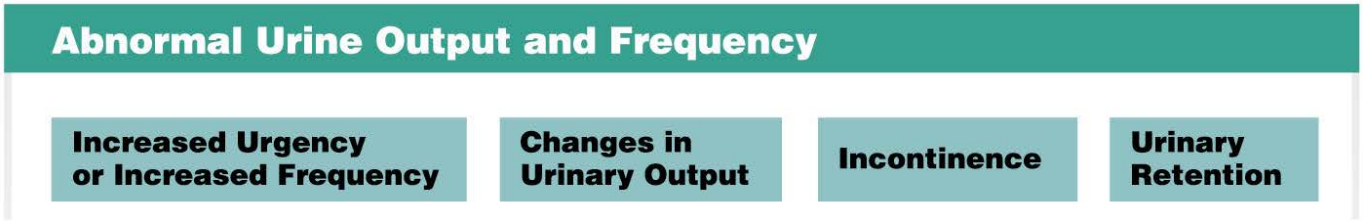
Module 24.18: Urinary disorders

Primary signs of urinary disorders (continued)

- **Change in frequency**
  - Increased urgency or frequency
    - Can be from irritation of the lining of the ureters or urinary bladder
  - **Incontinence**
    - Inability to control urination voluntarily
    - May involve periodic involuntary leakage (**stress incontinence**), inability to delay urination (**urge incontinence**), or continual trickle of urine from full bladder (**overflow incontinence**)



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Module 24.18: Urinary disorders

Primary signs of urinary disorders (continued)

- Change in frequency (continued)
  - **Urinary retention**
    - Initially normal renal function
    - Urination does not occur
    - In males, commonly results from enlarged prostate gland and compression of prostatic urethra

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Module 24.18: Urinary disorders

Primary signs of urinary disorders (continued)

- Pain
  - Pain in the superior pubic region
    - Associated with urinary bladder disorders
  - Pain in the superior lumbar region or in the flank that radiates to the right or left upper quadrants
    - Associated with kidney infections (**pyelonephritis**)
    - Also associated with kidney stones (**renal calculi**)
  - **Dysuria**
    - Painful or difficult urination
    - Can occur with cystitis or urethritis or urinary obstructions (possibly enlarged prostate in males)

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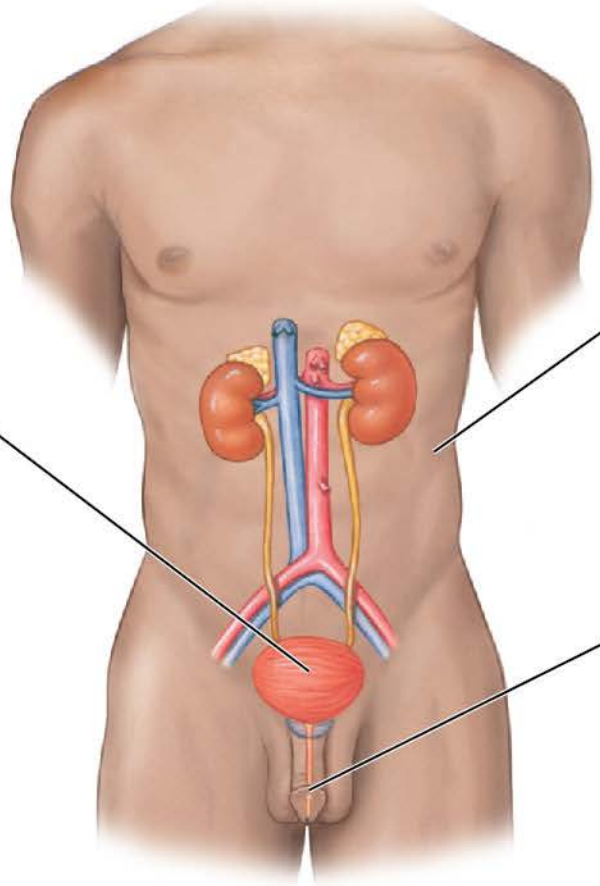
Urinary disorders



Pain in the superior pubic region may be associated with urinary bladder disorders.

Pain in the superior lumbar region or in the flank that radiates to the right upper quadrant or left upper quadrant can be caused by kidney infections such as **pyelonephritis**, or by **renal calculi** (kidney stones).

Dysuria (painful or difficult urination) can occur with cystitis (bladder inflammation) or urethritis (ureter inflammation), or with urinary obstructions. In males, enlargement of the prostate can compress the urethra and lead to dysuria.

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Module 24.18: Urinary disorders

Clinical signs of urinary system disorders

- **Edema** (swelling)
  - Occurs when renal disorders lead to **proteinuria** (protein in the urine)
  - Facial swelling, especially around the eyes, is common
- **Fever**
  - Commonly develops when urinary system is infected with pathogens
    - **Cystitis** (bladder infection)—usually low-grade fever
    - **Pyelonephritis** (kidney infection) can produce very high fevers

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Module 24.18: Review

A. What is the term for painful or difficult urination?
B. Why is urinary obstruction at the urethra more dangerous than at the ureter?

Learning Outcome: Describe common urinary disorders related to output and frequency.

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