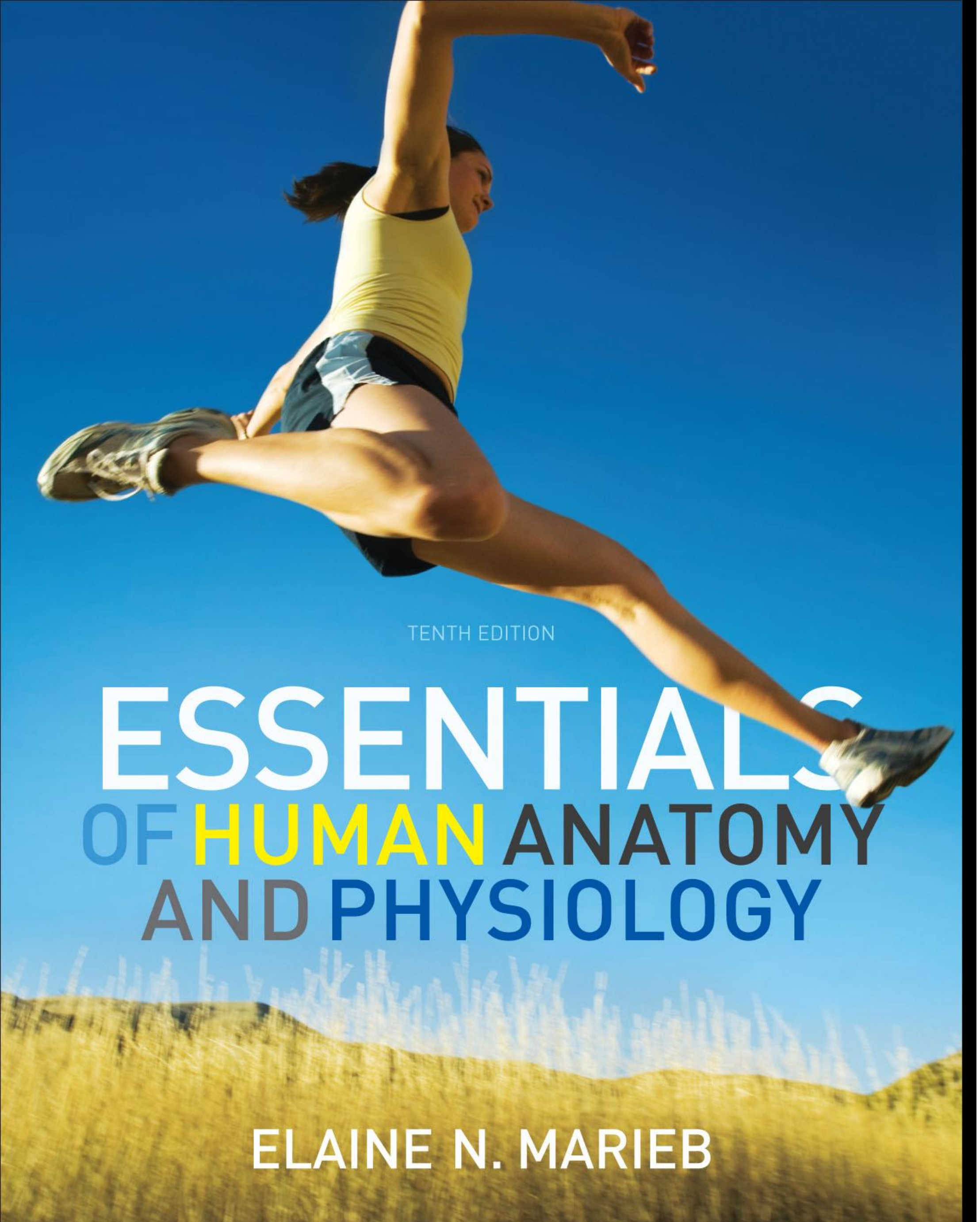


PowerPoint® Lecture Slides

Prepared by Patty Bostwick-Taylor,
Florence-Darlington Technical College

CHAPTER **15**

The Urinary System

Functions of the Urinary System

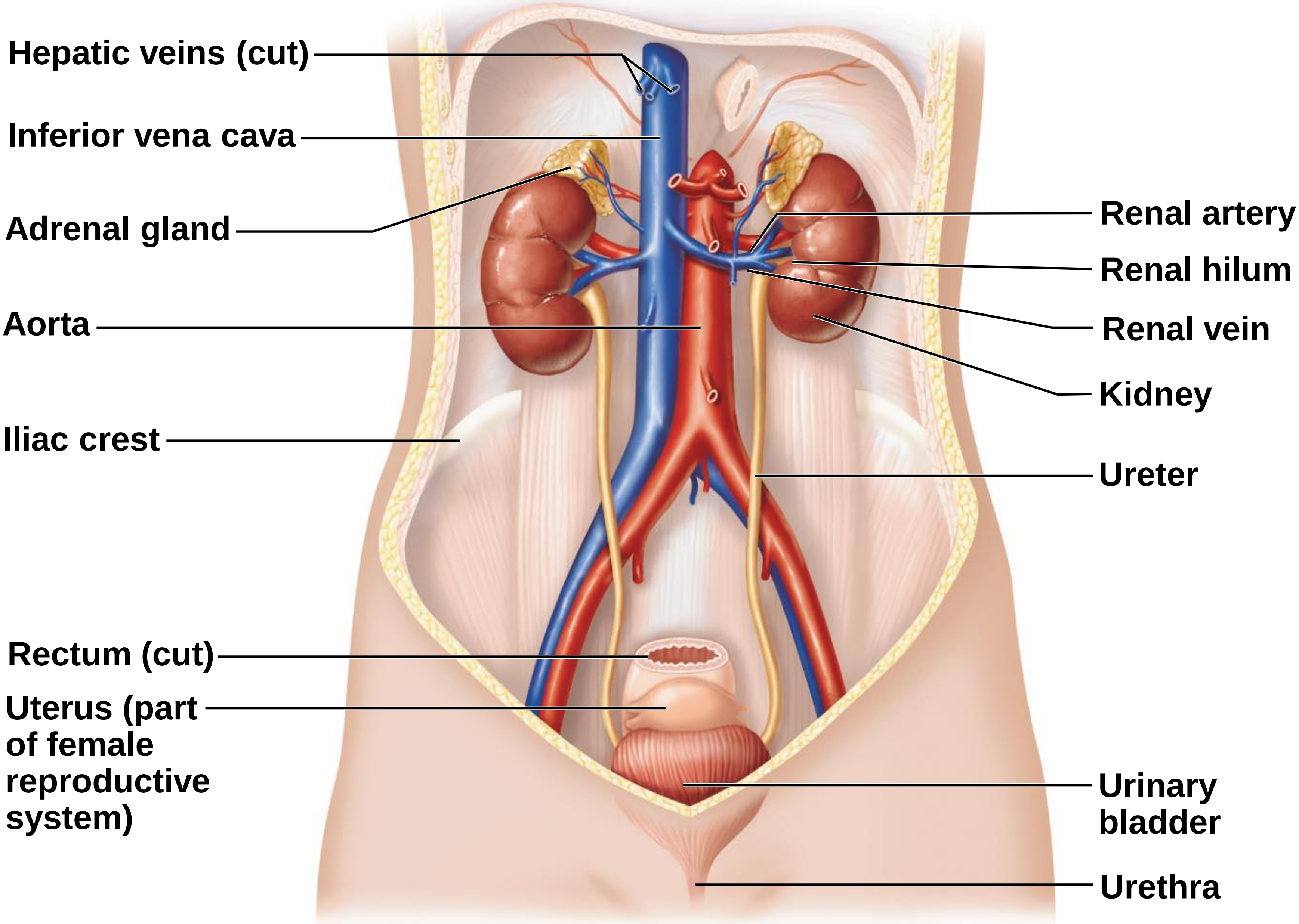
- Elimination of waste products
  - Nitrogenous wastes
  - Toxins
  - Drugs

Functions of the Urinary System

- Regulate aspects of homeostasis
  - Water balance
  - Electrolytes
  - Acid-base balance in the blood
  - Blood pressure
  - Red blood cell production
  - Activation of vitamin D

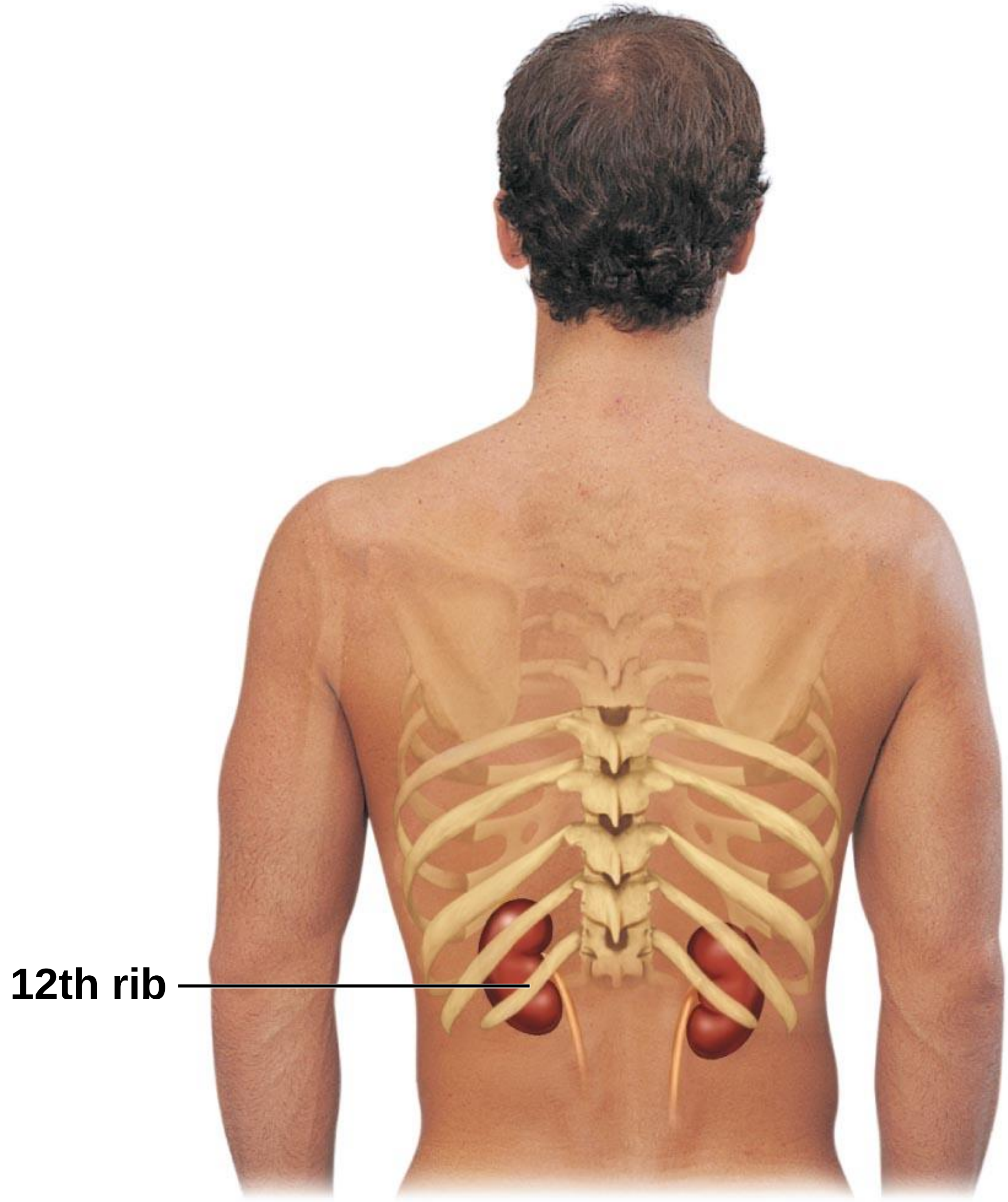
Organs of the Urinary System

- Kidneys
- Ureters
- Urinary bladder
- Urethra



(a)

Figure 15.1a



(b)

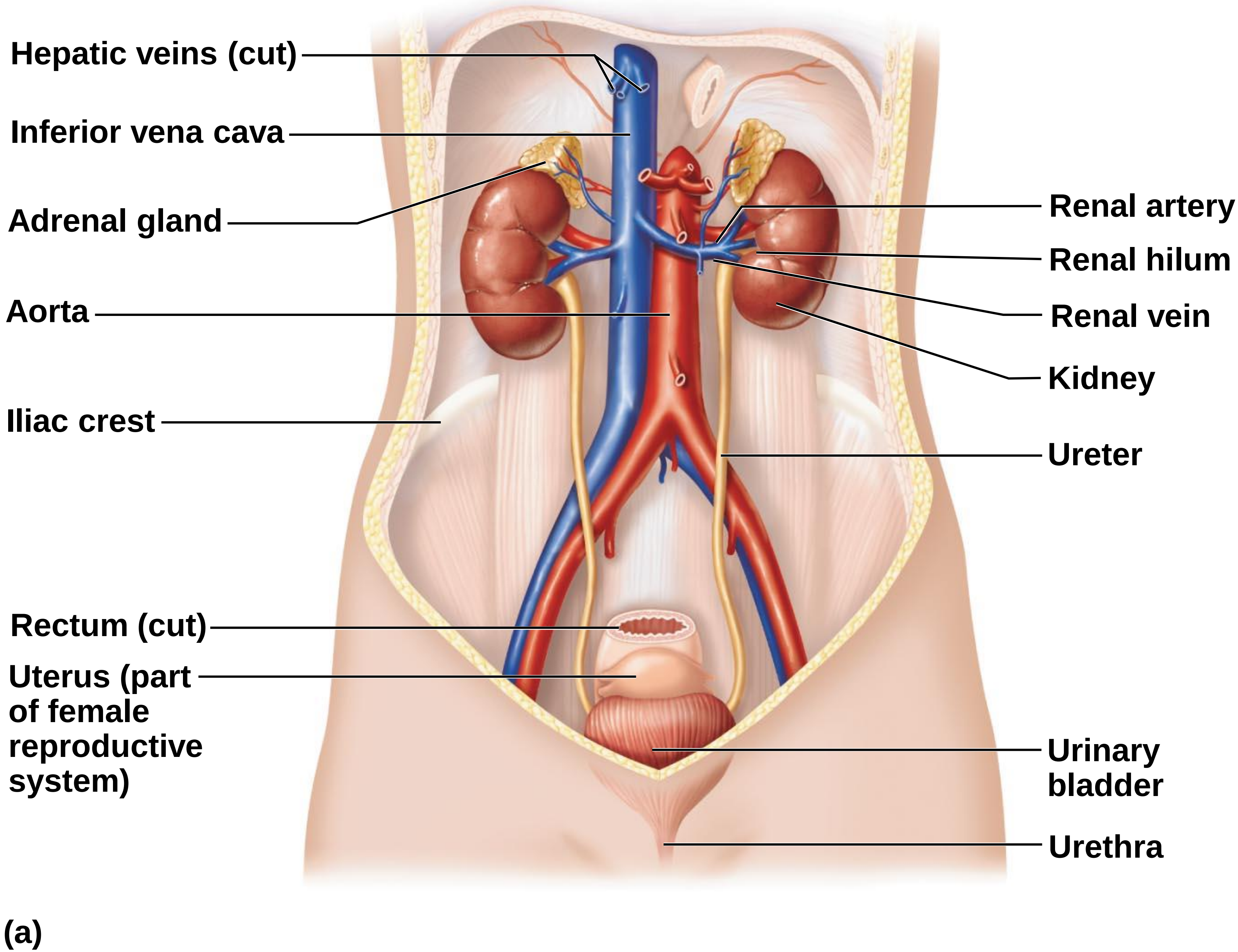
Figure 15.1b

Location of the Kidneys

- Against the dorsal body wall in a retroperitoneal position (behind the parietal peritoneum)
- At the level of the T_{12} to L_3 vertebrae
- The right kidney is slightly lower than the left (due to position of the liver)

Kidney Features

- **Renal hilum**
  - A medial indentation where several structures enter or exit the kidney (ureters, renal blood vessels, and nerves)
- An adrenal gland sits atop each kidney



Hepatic veins (cut)
Inferior vena cava
Adrenal gland
Aorta
Iliac crest
Rectum (cut)
Uterus (part of female reproductive system)
Renal artery
Renal hilum
Renal vein
Kidney
Ureter
Urinary bladder
Urethra
(a)

Figure 15.1a

Coverings of the Kidneys

- **Fibrous capsule**
  - Surrounds each kidney
- **Perirenal fat capsule**
  - Surrounds the kidney and cushions against blows
- **Renal fascia**
  - Outermost capsule that helps hold the kidney in place against the muscles of the trunk wall

Regions of the Kidney

- **Renal cortex**—outer region
- **Renal medulla**—inside the cortex
- **Renal pelvis**—inner collecting tube

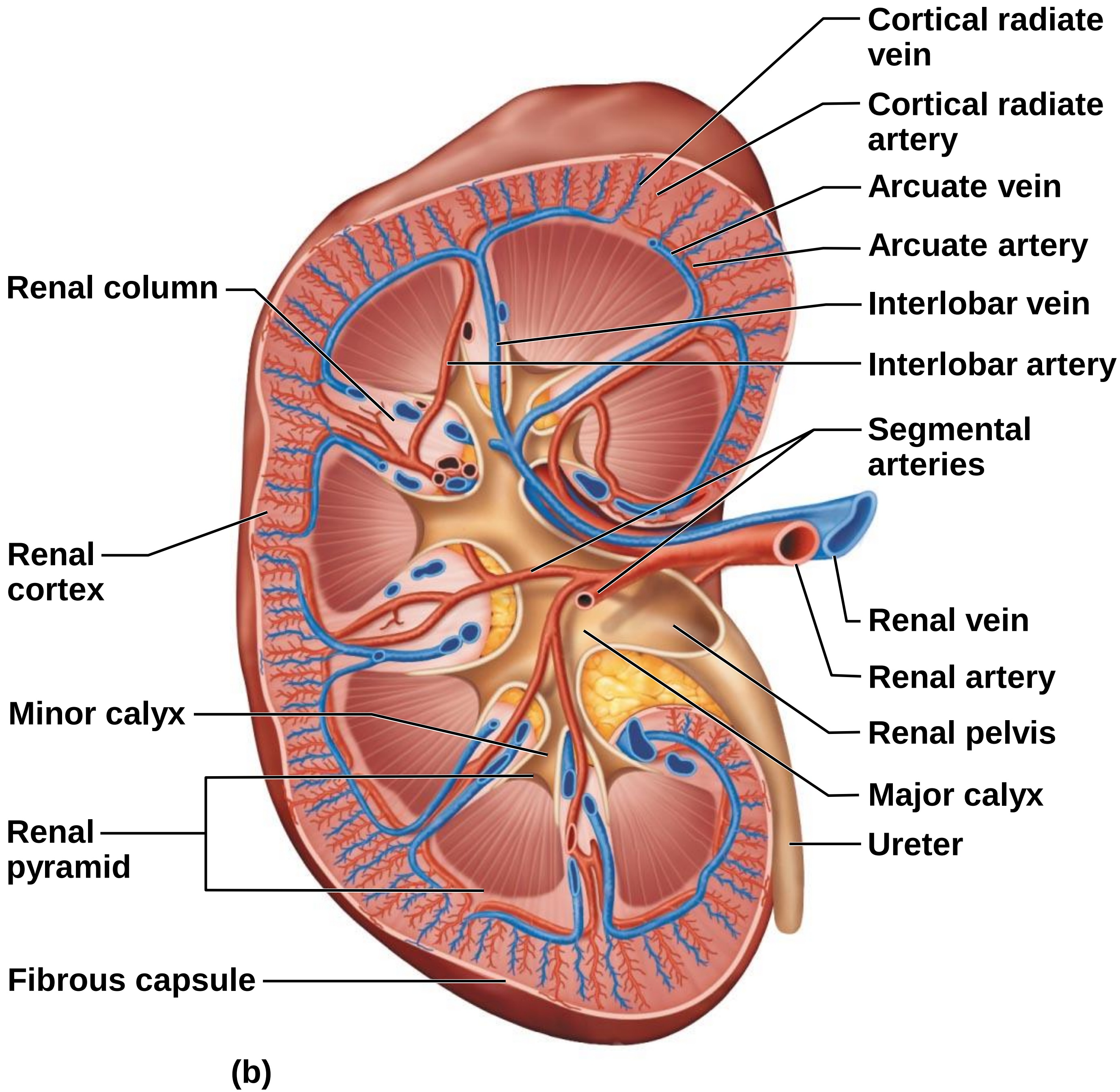
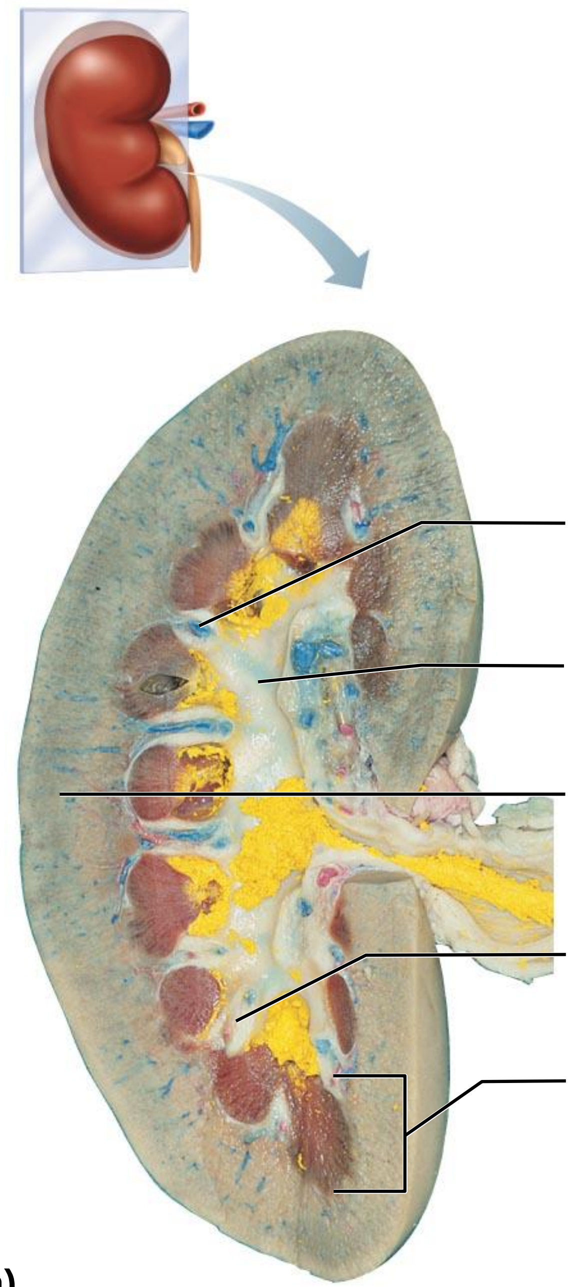

Cortical radiate vein
Cortical radiate artery
Arcuate vein
Arcuate artery
Interlobar vein
Interlobar artery
Segmental arteries
Renal vein
Renal artery
Renal pelvis
Major calyx
Ureter
Renal column
Renal cortex
Minor calyx
Renal pyramid
Fibrous capsule
(b)

Figure 15.2b

Kidney Structures

- **Renal or medullary pyramids**—triangular regions of tissue in the medulla
- **Renal columns**—extensions of cortex-like material inward that separate the pyramids
- **Calyces**—cup-shaped structures that funnel urine towards the renal pelvis



(a)

Figure 15.2a

Blood Supply

- One-quarter of the total blood supply of the body passes through the kidneys each minute
- Renal artery provides each kidney with arterial blood supply
- Renal artery divides into segmental arteries → interlobar arteries → arcuate arteries → cortical radiate arteries

Blood Supply

- Venous blood flow
  - Cortical radiate veins → arcuate veins → interlobar veins → renal vein
- There are no segmental veins

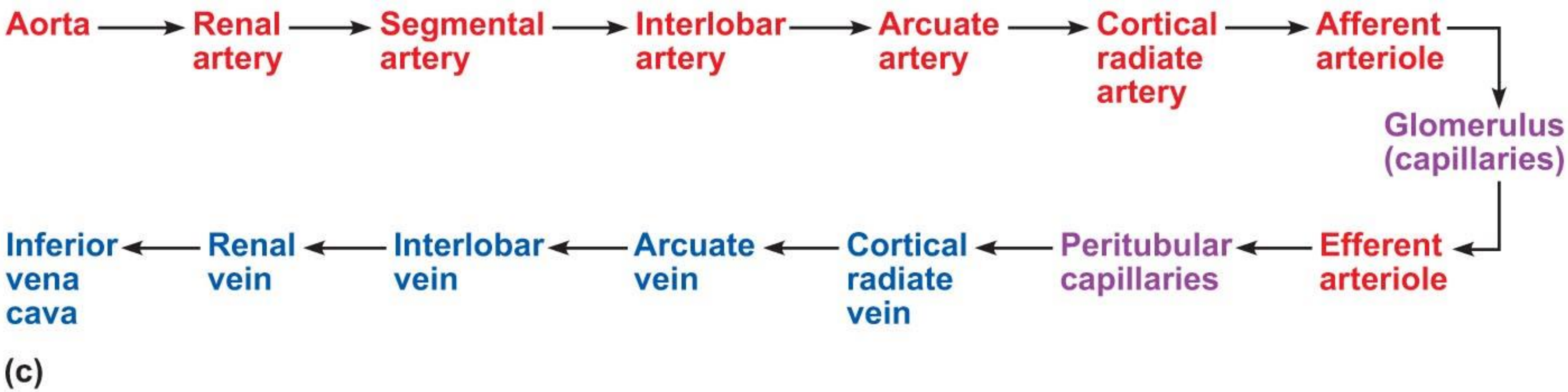
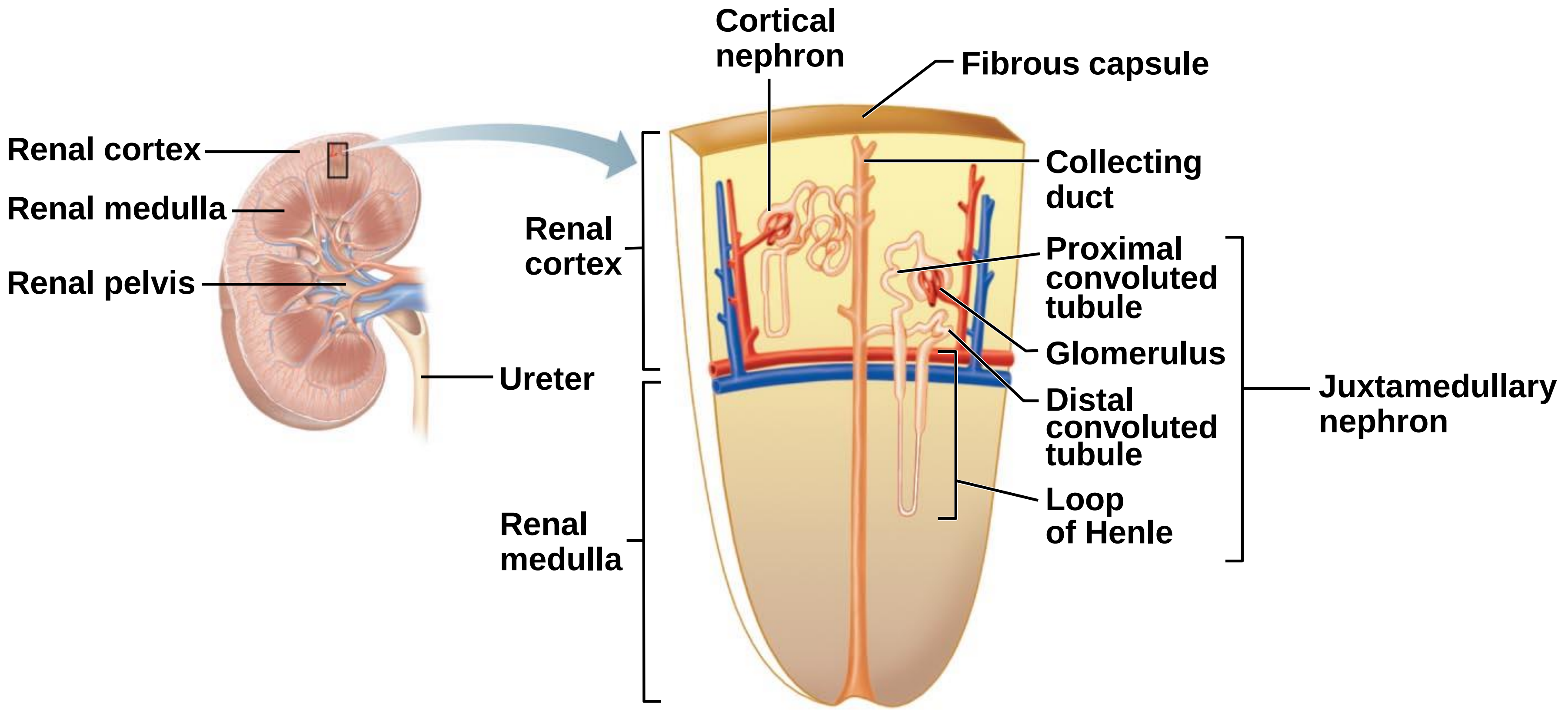

Aorta
Renal artery
Segmental artery
Interlobar artery
Arcuate artery
Cortical radiate artery
Afferent arteriole
Glomerulus (capillaries)
Efferent arteriole
Peritubular capillaries
Cortical radiate vein
Arcuate vein
Interlobar vein
Renal vein
Inferior vena cava
(c)

Figure 15.2c

Nephron Anatomy and Physiology

- The structural and functional units of the kidneys
- Responsible for forming urine
- Main structures of the **nephrons**
  - **Glomerulus**
  - **Renal tubule**



(a)

Figure 15.3a

Nephron Anatomy

- **Glomerulus**
  - Knot of capillaries
  - Capillaries are covered with **podocytes** from the renal tubule
  - Glomerulus sits within a **glomerular (Bowman's) capsule** (the first part of the renal tubule)
    - Inner layer of the capsule contains podocytes
    - Podocytes have *filtration slits* and *foot processes* that stick to the glomerulus

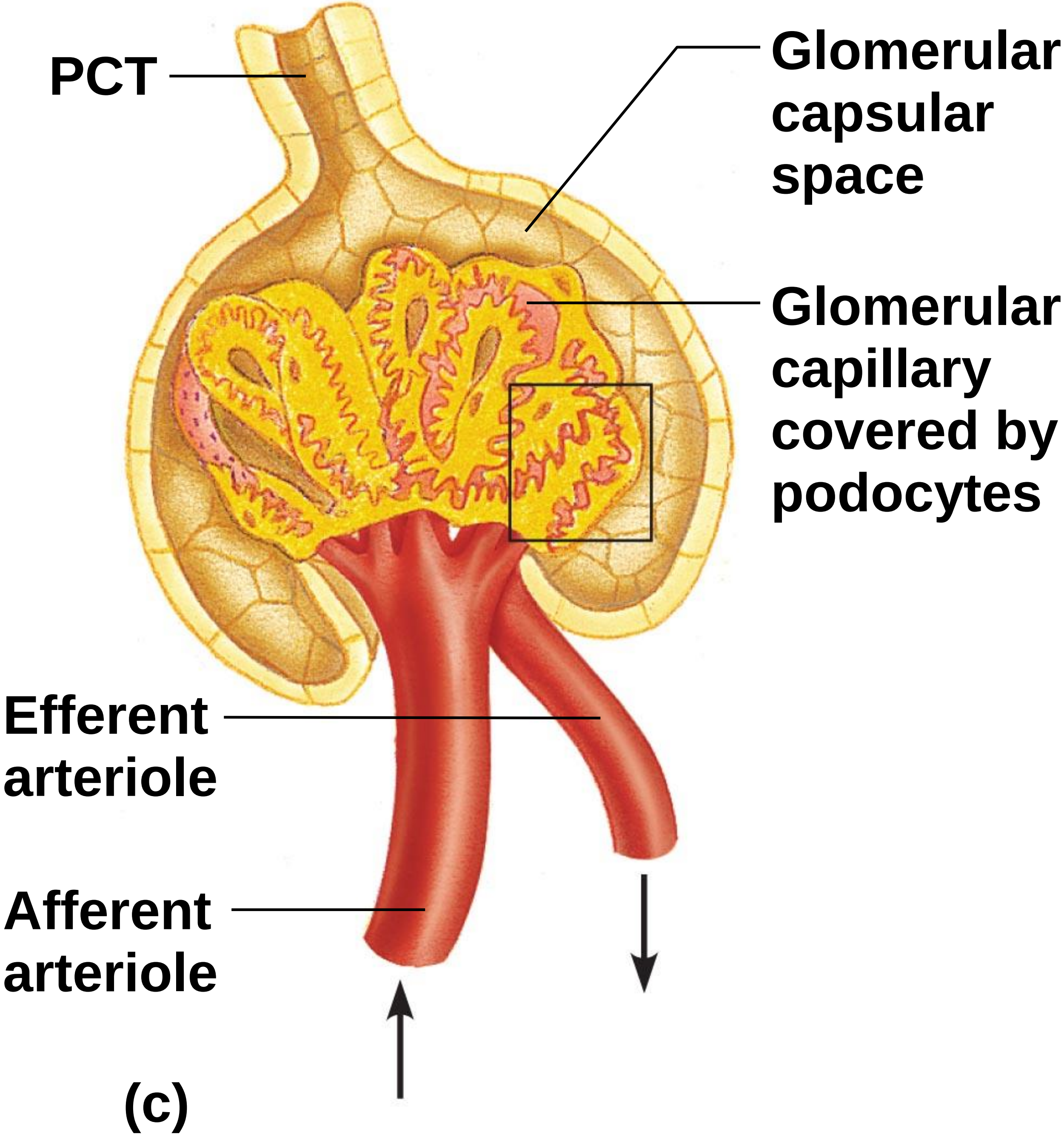
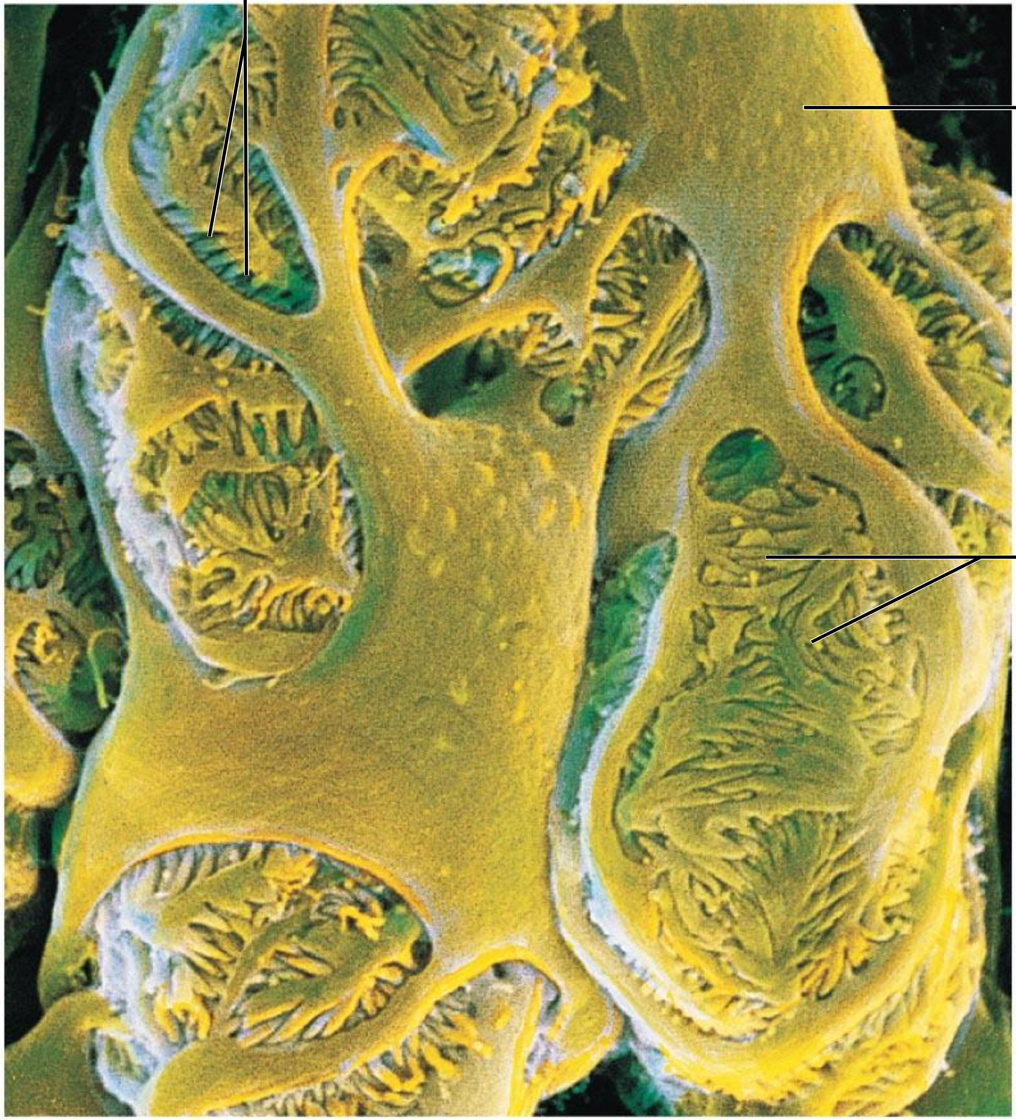

PCT
Glomerular capsular space
Glomerular capillary covered by podocytes
Efferent arteriole
Afferent arteriole
(c)

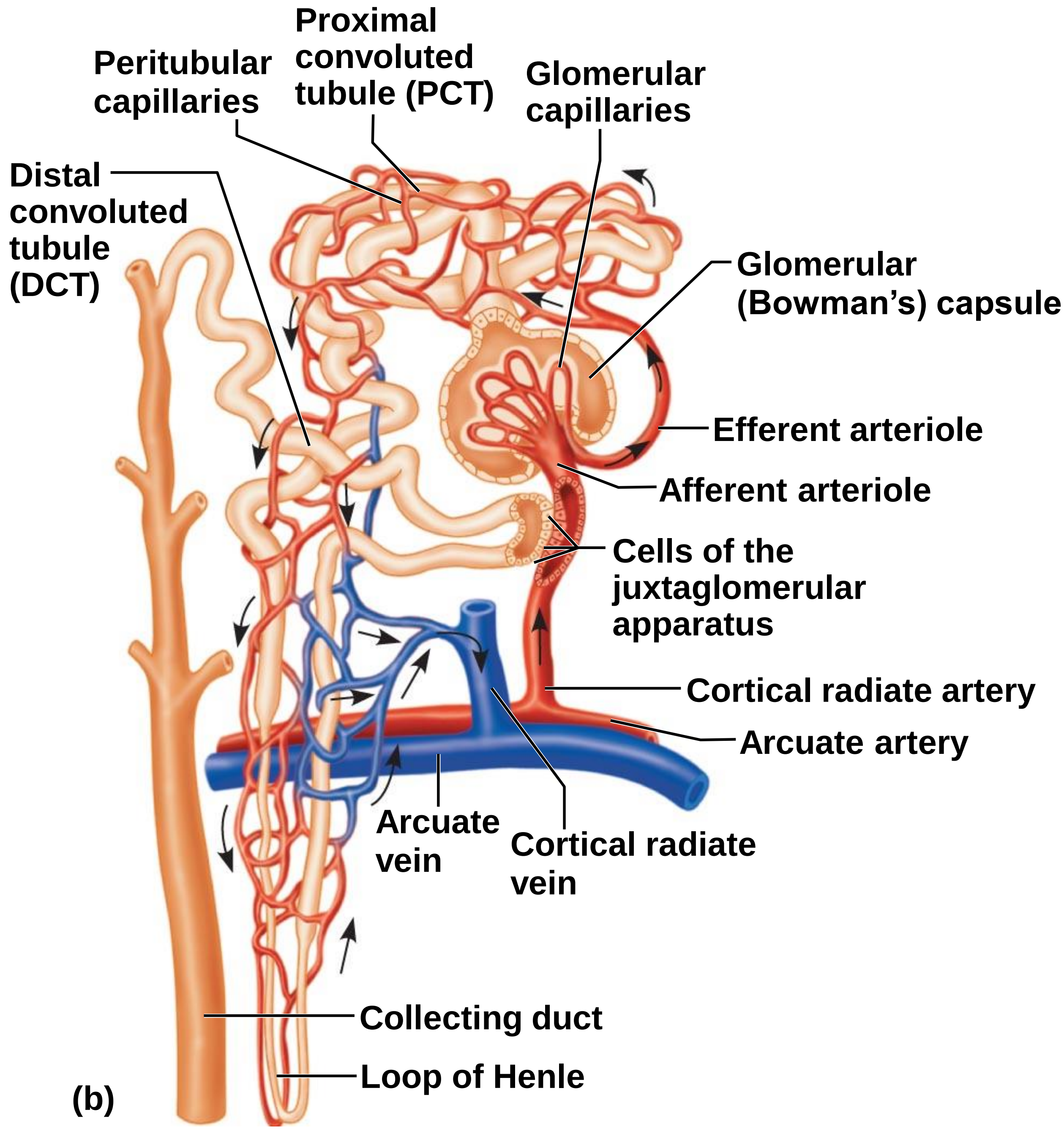
Figure 15.3c



(d)

Nephron Anatomy

- Renal tubule extends from glomerular capsule and ends at the collecting duct
  - **Glomerular (Bowman's) capsule**
  - **Proximal convoluted tubule (PCT)**
  - **Loop of Henle**
  - **Distal convoluted tubule (DCT)**

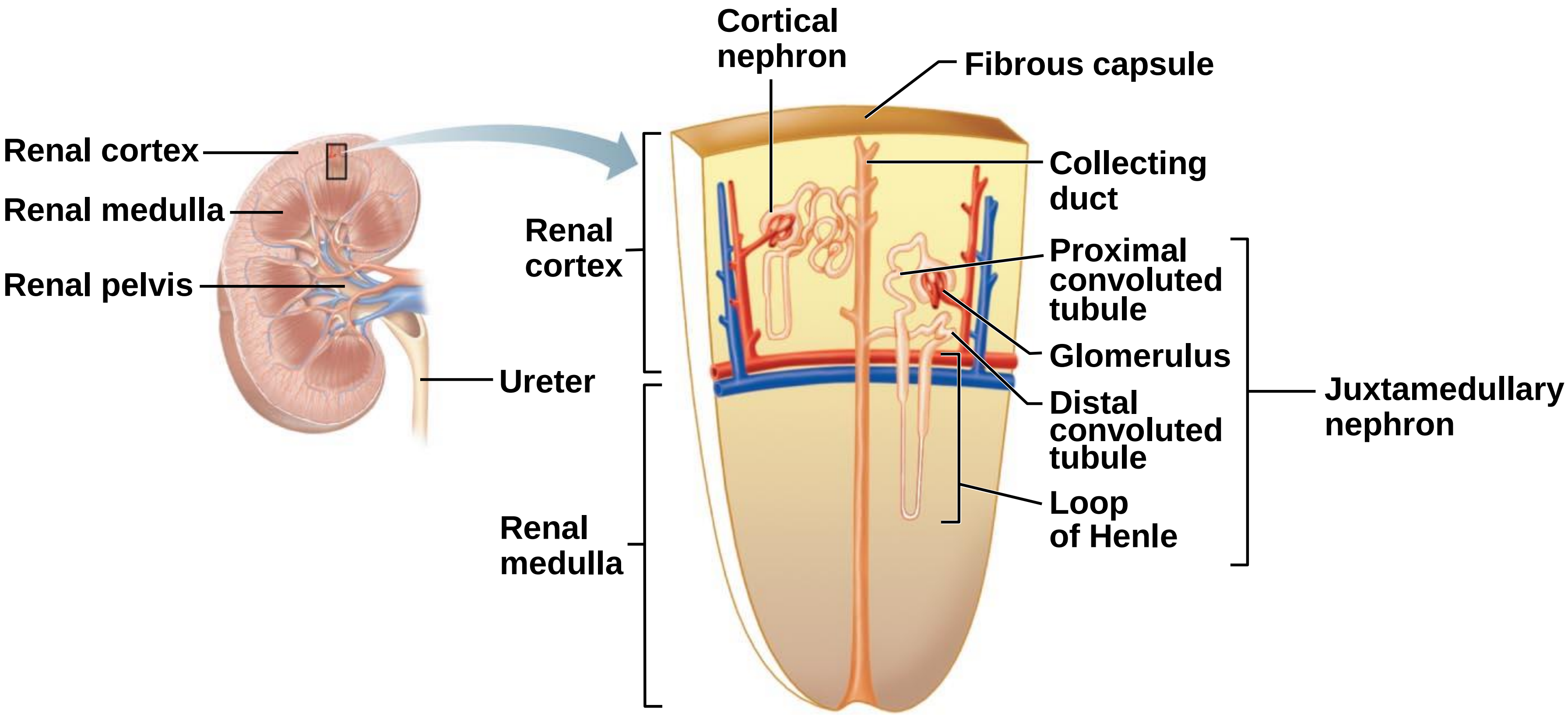


Proximal convoluted tubule (PCT)
Peritubular capillaries
Glomerular capillaries
Distal convoluted tubule (DCT)
Glomerular (Bowman's) capsule
Efferent arteriole
Afferent arteriole
Cells of the juxtaglomerular apparatus
Cortical radiate artery
Arcuate artery
Arcuate vein
Cortical radiate vein
Collecting duct
Loop of Henle
(b)

Figure 15.3b

Types of Nephrons

- **Cortical nephrons**
  - Located entirely in the cortex
  - Includes most nephrons
- **Juxtamedullary nephrons**
  - Found at the boundary of the cortex and medulla



(a)

Figure 15.3a

Collecting Duct

- Receives urine from many nephrons
- Run through the medullary pyramids
- Deliver urine into the calyces and renal pelvis

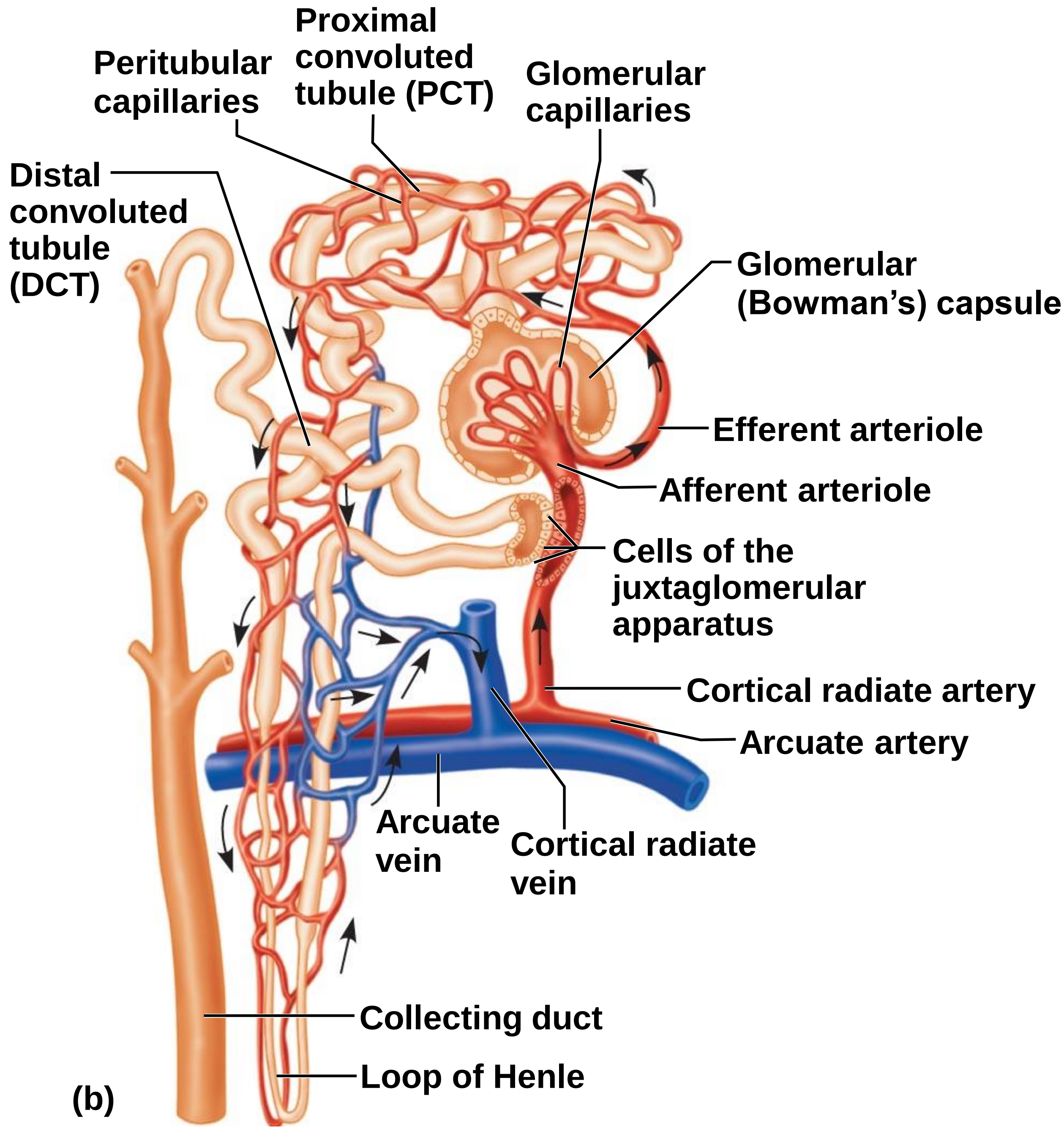

Proximal convoluted tubule (PCT)
Peritubular capillaries
Glomerular capillaries
Distal convoluted tubule (DCT)
Glomerular (Bowman's) capsule
Efferent arteriole
Afferent arteriole
Cells of the juxtaglomerular apparatus
Cortical radiate artery
Arcuate artery
Arcuate vein
Cortical radiate vein
Collecting duct
Loop of Henle
(b)

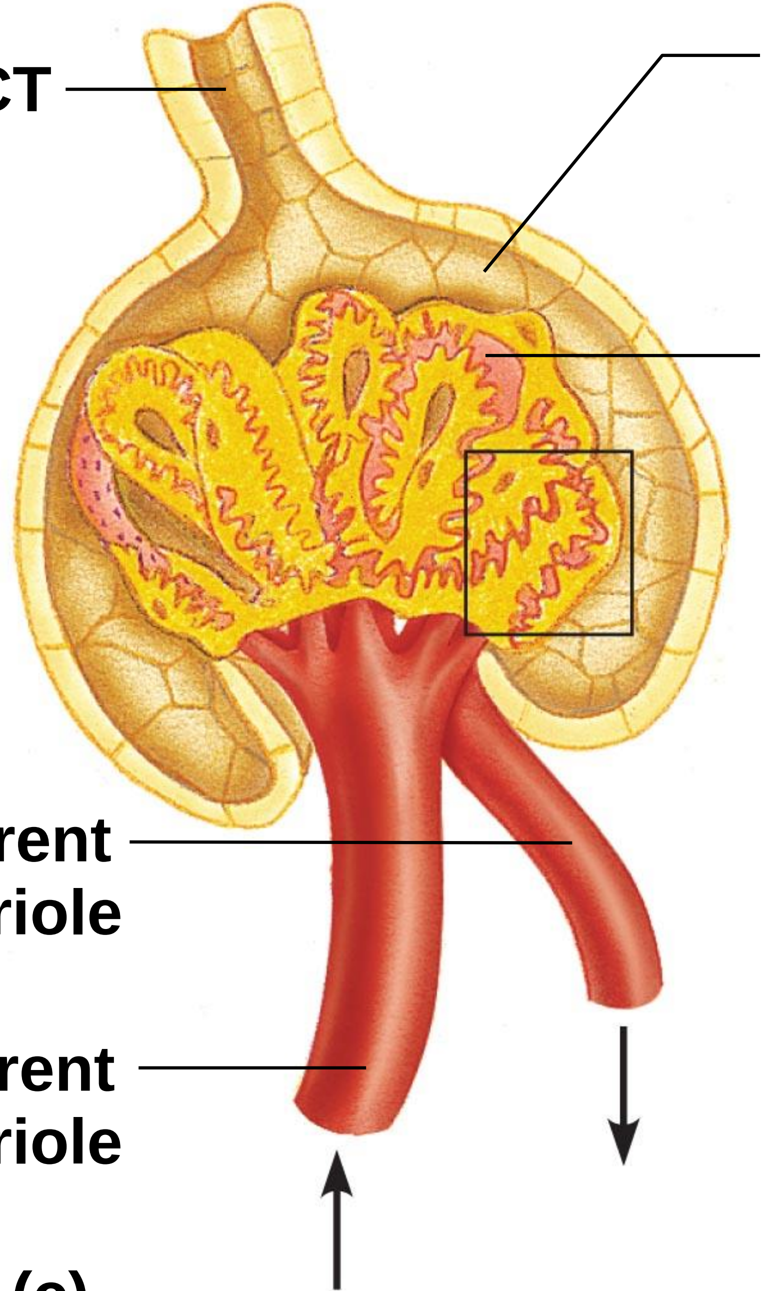
Figure 15.3b

Nephron Anatomy

- Nephrons are associated with two capillary beds
  - **Glomerulus**
  - **Peritubular capillary bed**

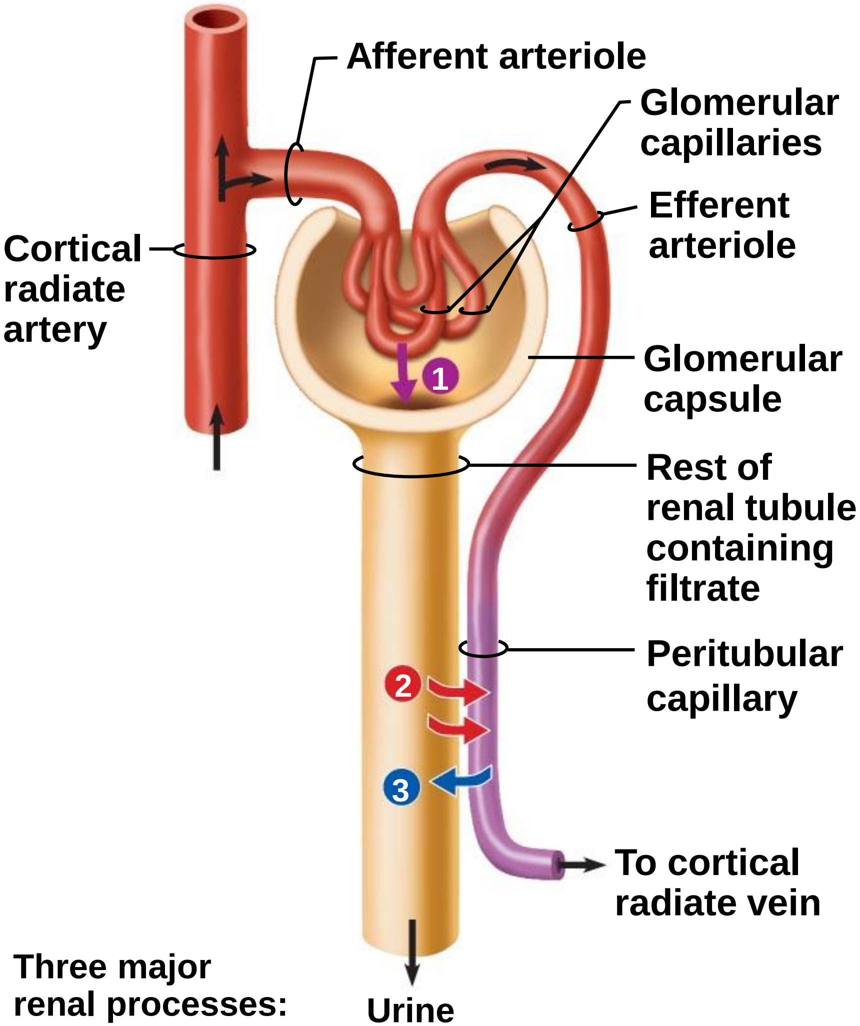
Glomerulus

- Fed and drained by arterioles
  - **Afferent arteriole**—arises from a cortical radiate artery and feeds the glomerulus
  - **Efferent arteriole**—receives blood that has passed through the glomerulus
- Specialized for filtration
- High pressure forces fluid and solutes out of blood and into the glomerular capsule



PCT
Glomerular capsular space
Glomerular capillary covered by podocytes
Efferent arteriole
Afferent arteriole
(c)

Figure 15.3c



Three major renal processes:

1 Glomerular filtration: Water and solutes smaller than proteins are forced through the capillary walls and pores of the glomerular capsule into the renal tubule.

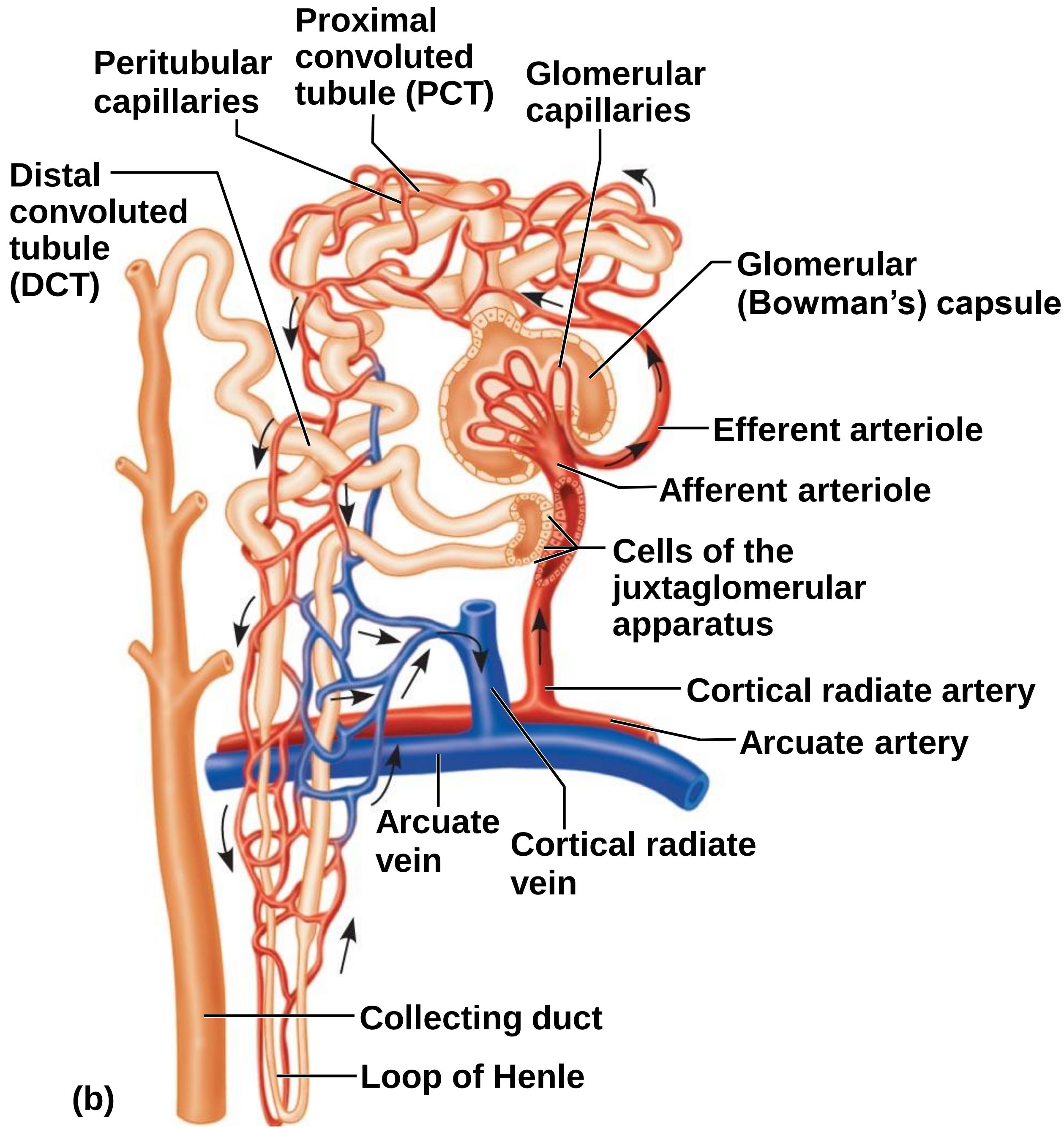
2 Tubular reabsorption: Water, glucose, amino acids, and needed ions are transported out of the filtrate into the tubule cells and then enter the capillary blood.

3 Tubular secretion: H^+, K^+, creatinine, and drugs are removed from the peritubular blood and secreted by the tubule cells into the filtrate.

Figure 15.4

Peritubular Capillary Beds

- Arise from efferent arteriole of the glomerulus
- Normal, low pressure capillaries
- Adapted for absorption instead of filtration
- Cling close to the renal tubule to reabsorb (reclaim) some substances from collecting tubes

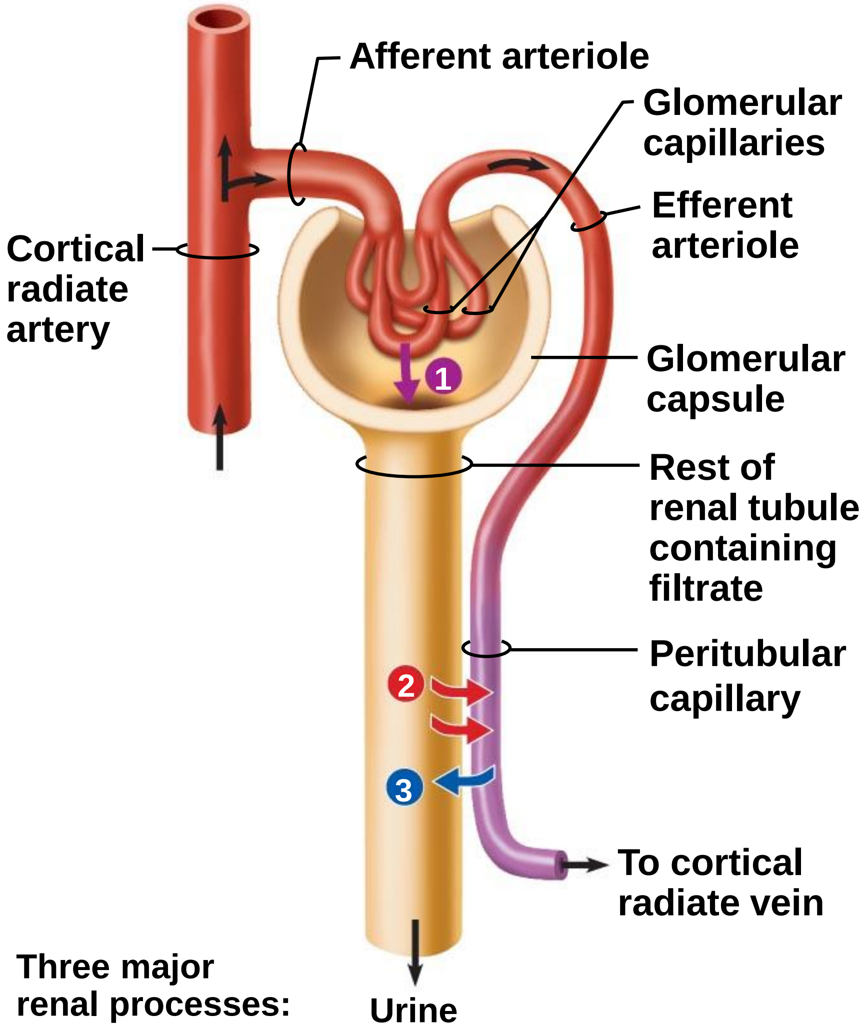


Proximal convoluted tubule (PCT)
Peritubular capillaries
Glomerular capillaries
Distal convoluted tubule (DCT)
Glomerular (Bowman's) capsule
Efferent arteriole
Afferent arteriole
Cells of the juxtaglomerular apparatus
Cortical radiate artery
Arcuate artery
Arcuate vein
Cortical radiate vein
Collecting duct
Loop of Henle
(b)

Figure 15.3b

Urine Formation

- Glomerular filtration
- Tubular reabsorption
- Tubular secretion



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3 Tubular secretion: H^+, K^+, creatinine, and drugs are removed from the peritubular blood and secreted by the tubule cells into the filtrate.

Figure 15.4

Glomerular Filtration

- Nonselective passive process
- Water and solutes smaller than proteins are forced through capillary walls
- Proteins and blood cells are normally too large to pass through the filtration membrane
- Filtrate is collected in the glomerular capsule and leaves via the renal tubule

Tubular Reabsorption

- The peritubular capillaries reabsorb useful substances
  - Water
  - Glucose
  - Amino acids
  - Ions
- Some reabsorption is passive, most is active
- Most reabsorption occurs in the proximal convoluted tubule

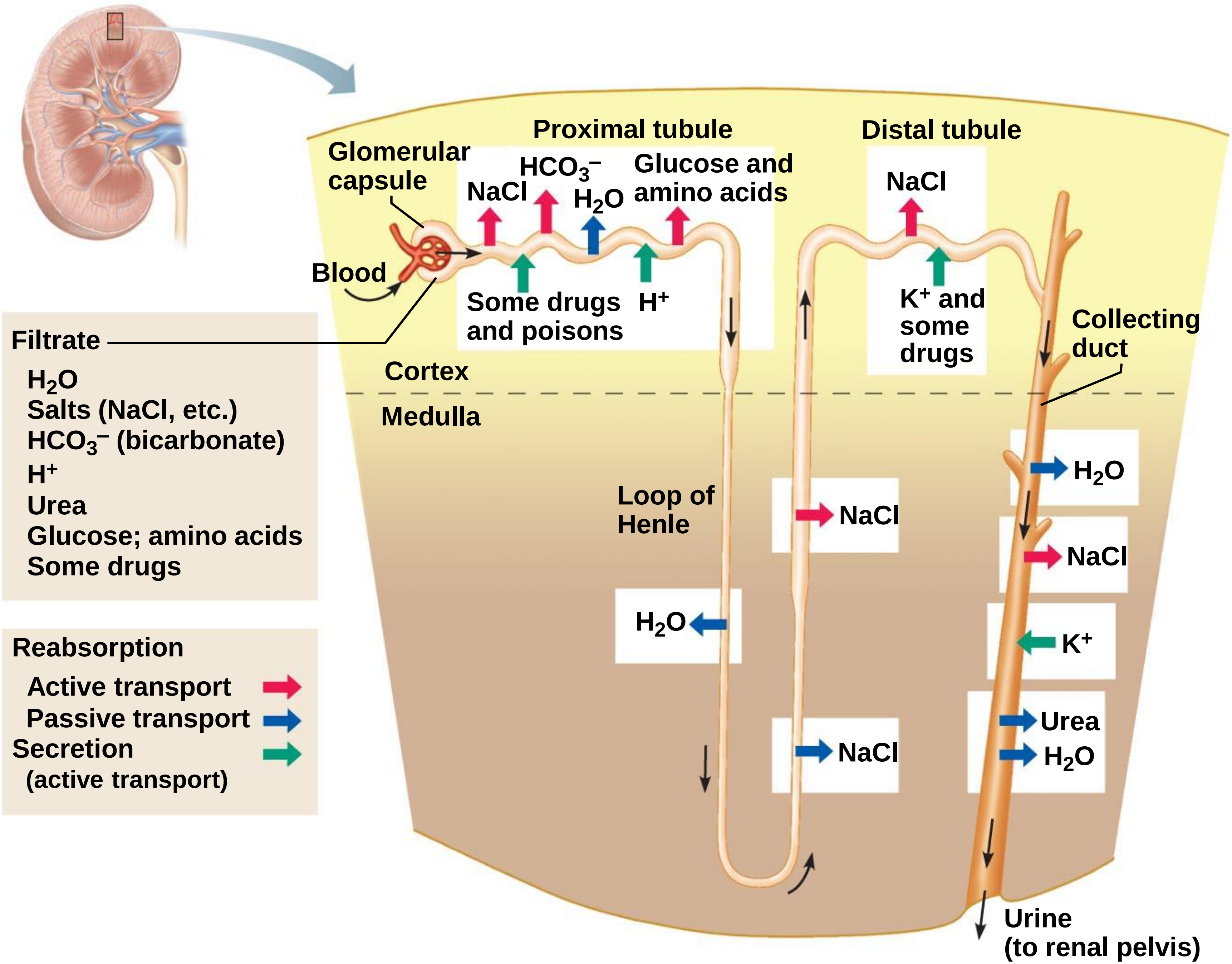

Glomerular capsule
Blood
Proximal tubule
NaCl
HCO_3^-
H_2O
Glucose and amino acids
Some drugs and poisons
H^+
Distal tubule
NaCl
K^+ and some drugs
Collecting duct
Cortex
Medulla
Loop of Henle
H_2O
NaCl
NaCl
H_2O
NaCl
K^+
Urea
H_2O
Urine (to renal pelvis)
Filtrate
H_2O
Salts (NaCl, etc.)
HCO_3^- (bicarbonate)
H^+
Urea
Glucose; amino acids
Some drugs
Reabsorption
Active transport
Passive transport
Secretion (active transport)

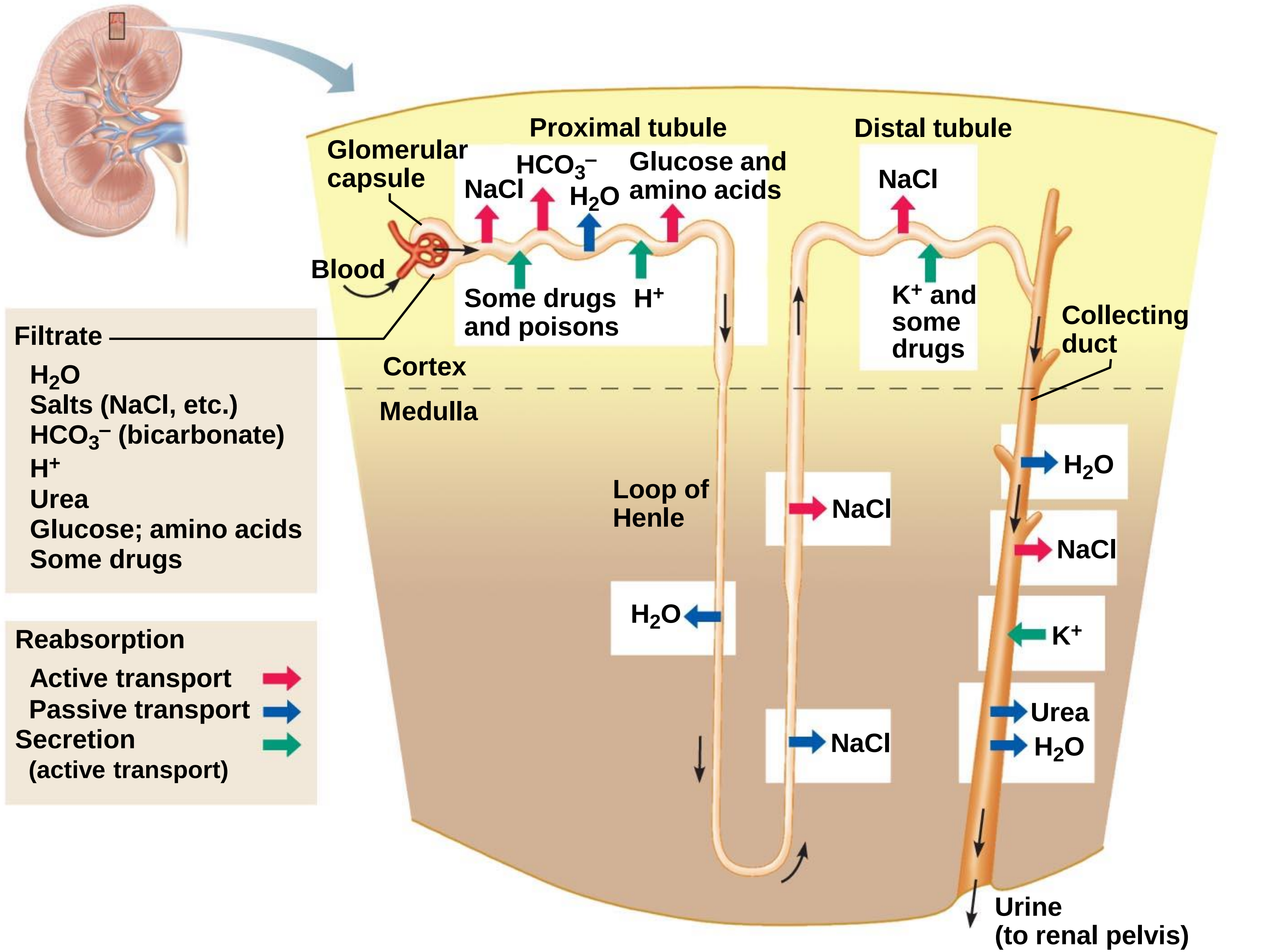
Figure 15.5

Tubular Reabsorption

- What materials are *not* reabsorbed?
  - Nitrogenous waste products
    - **Urea**—protein breakdown
    - **Uric acid**—nucleic acid breakdown
    - **Creatinine**—associated with creatine metabolism in muscles

Tubular Secretion: Reabsorption in Reverse

- Some materials move from the blood of the peritubular capillaries into the renal tubules
  - Hydrogen and potassium ions
  - Creatinine
- Process is important for getting rid of substances not already in the filtrate
- Materials left in the renal tubule move toward the ureter



Proximal tubule
Distal tubule
Glomerular capsule
HCO_3^-
NaCl
H_2O
Glucose and amino acids
NaCl
Blood
Some drugs and poisons
H^+
K^+ and some drugs
Collecting duct
Filtrate
H_2O
Salts (NaCl, etc.)
HCO_3^- (bicarbonate)
H^+
Urea
Glucose; amino acids
Some drugs
Cortex
Medulla
Loop of Henle
NaCl
H_2O
H_2O
NaCl
K^+
NaCl
Urea
H_2O
Reabsorption
Active transport
Passive transport
Secretion (active transport)
Urine (to renal pelvis)

Figure 15.5

Characteristics of Urine

- In 24 hours, about 1.0 to 1.8 liters of urine are produced

- Urine and filtrate are different
  - Filtrate contains everything that blood plasma does (except proteins)

  - Urine is what remains after the filtrate has lost most of its water, nutrients, and necessary ions through reabsorption

  - Urine contains nitrogenous wastes and substances that are not needed

Characteristics of Urine

- Yellow color due to the pigment urochrome (from the destruction of hemoglobin) and solutes
  - Dilute urine is a pale, straw color
- Sterile
- Slightly aromatic
- Normal pH of around 6
- Specific gravity of 1.001 to 1.035

Characteristics of Urine

- Solutes normally found in urine
  - Sodium and potassium ions
  - Urea, uric acid, creatinine
  - Ammonia
  - Bicarbonate ions

Characteristics of Urine

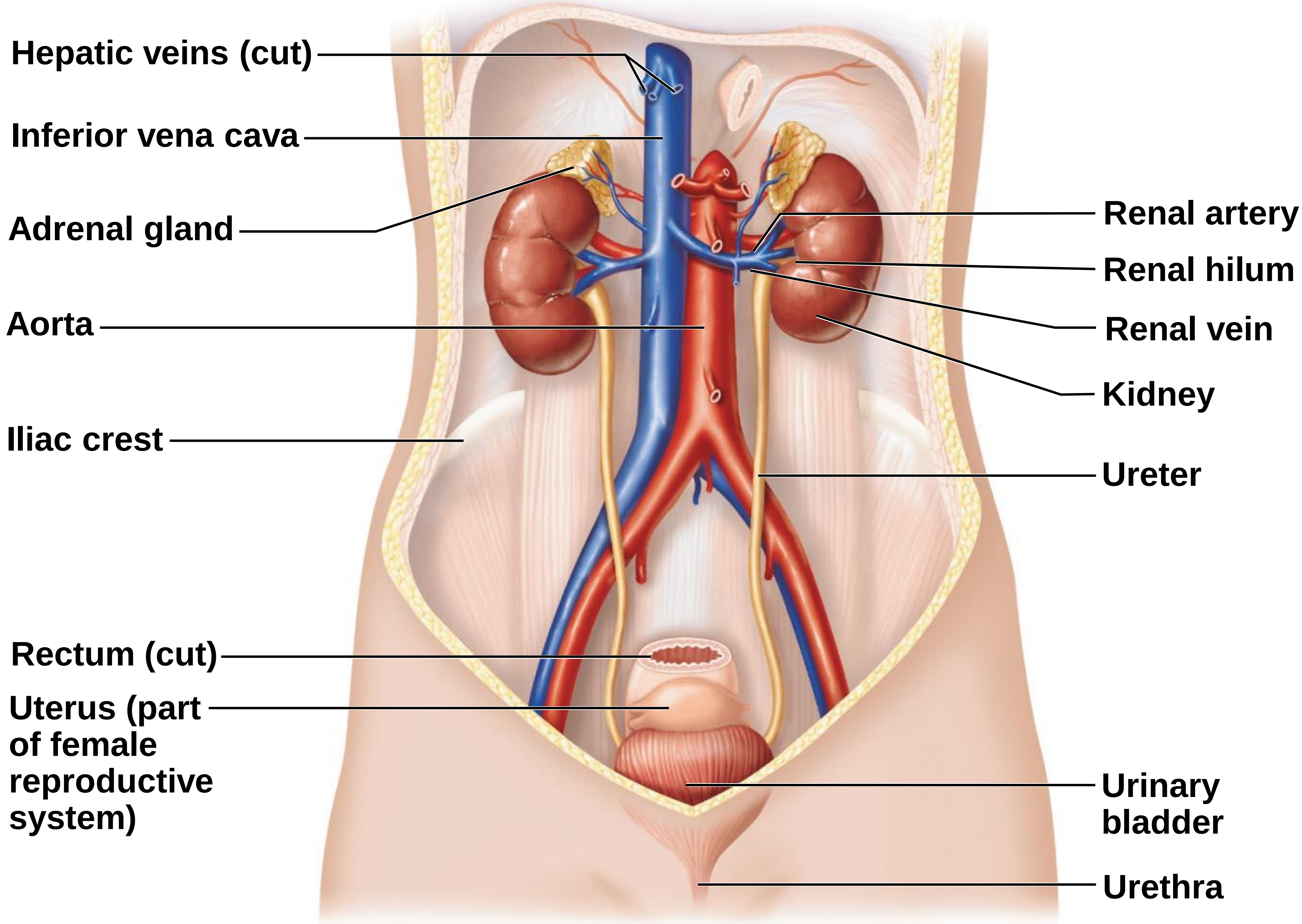
- Solutes NOT normally found in urine
  - Glucose
  - Blood proteins
  - Red blood cells
  - Hemoglobin
  - White blood cells (pus)
  - Bile

Abnormal Urine Constituents

Substance	Name of Condition	Possible Causes
Glucose	**Glucosuria**	**Excess sugary intake; diabetes mellitus**
Proteins	**Proteinuria**	**Physical exertion, pregnancy; glomerulonephritis, hypertension**
Pus (WBCs and bacteria)	**Pyuria**	**Urinary tract infection**
RBCs	**Hematuria**	**Bleeding in the urinary tract**
Hemoglobin	**Hemoglobinuria**	**Various: transfusion reaction, hemolytic anemia**
Bile pigments	**Bilirubinuria**	**Liver disease (hepatitis)**

Ureters

- Slender tubes attaching the kidney to the bladder
  - Continuous with the renal pelvis
  - Enter the posterior aspect of the bladder
- Runs behind the peritoneum
- Peristalsis aids gravity in urine transport



(a)

Figure 15.1a

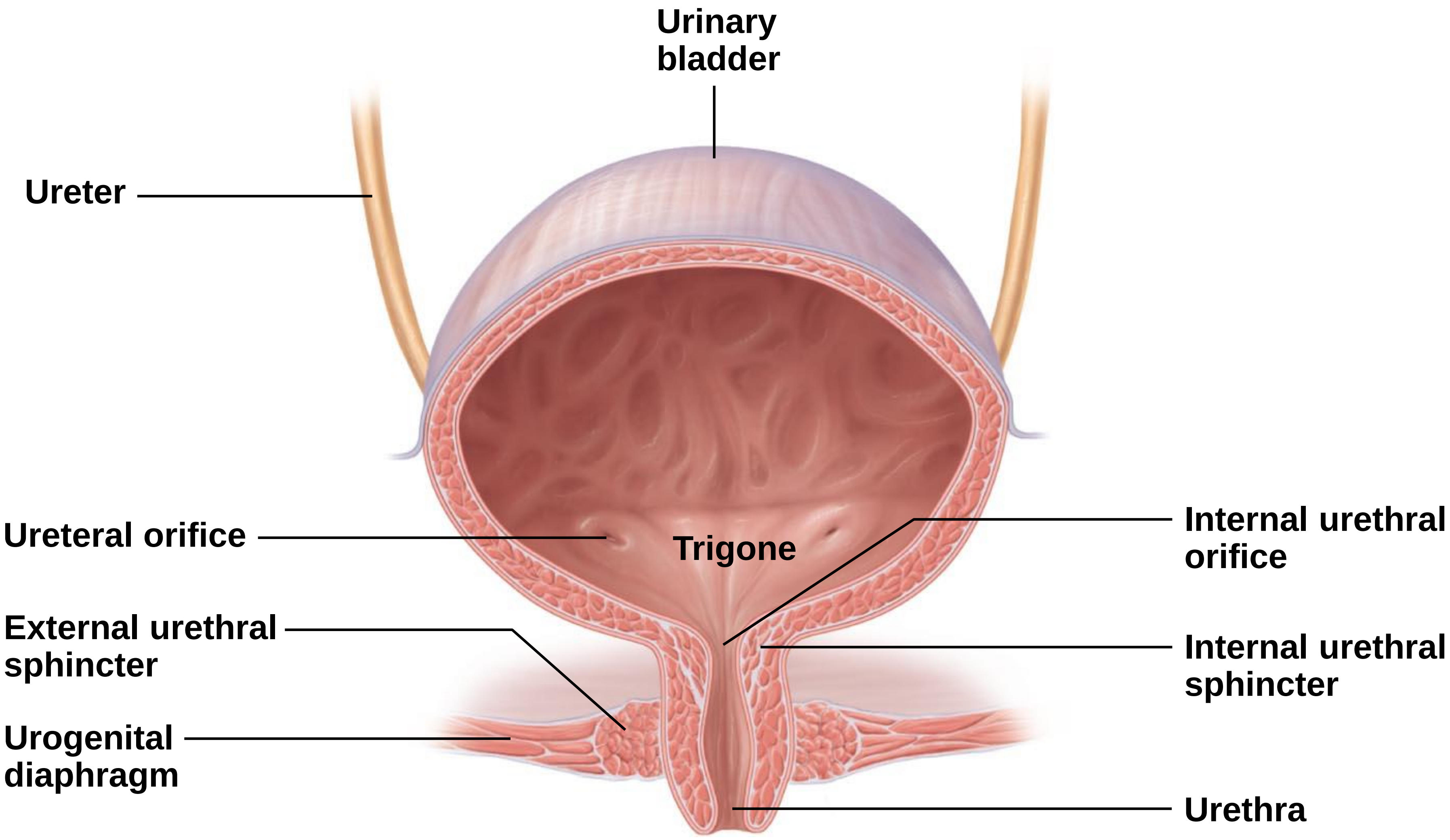

Urinary bladder
Ureter
Ureteral orifice
Trigone
Internal urethral orifice
External urethral sphincter
Internal urethral sphincter
Urogenital diaphragm
Urethra

Figure 15.6

Urinary Bladder

- Smooth, collapsible, muscular sac
- Temporarily stores urine
- **Trigone**—triangular region of the bladder base
  - Three openings
    - Two from the ureters
    - One to the urethra
  - In males, the prostate gland surrounds the neck of the bladder

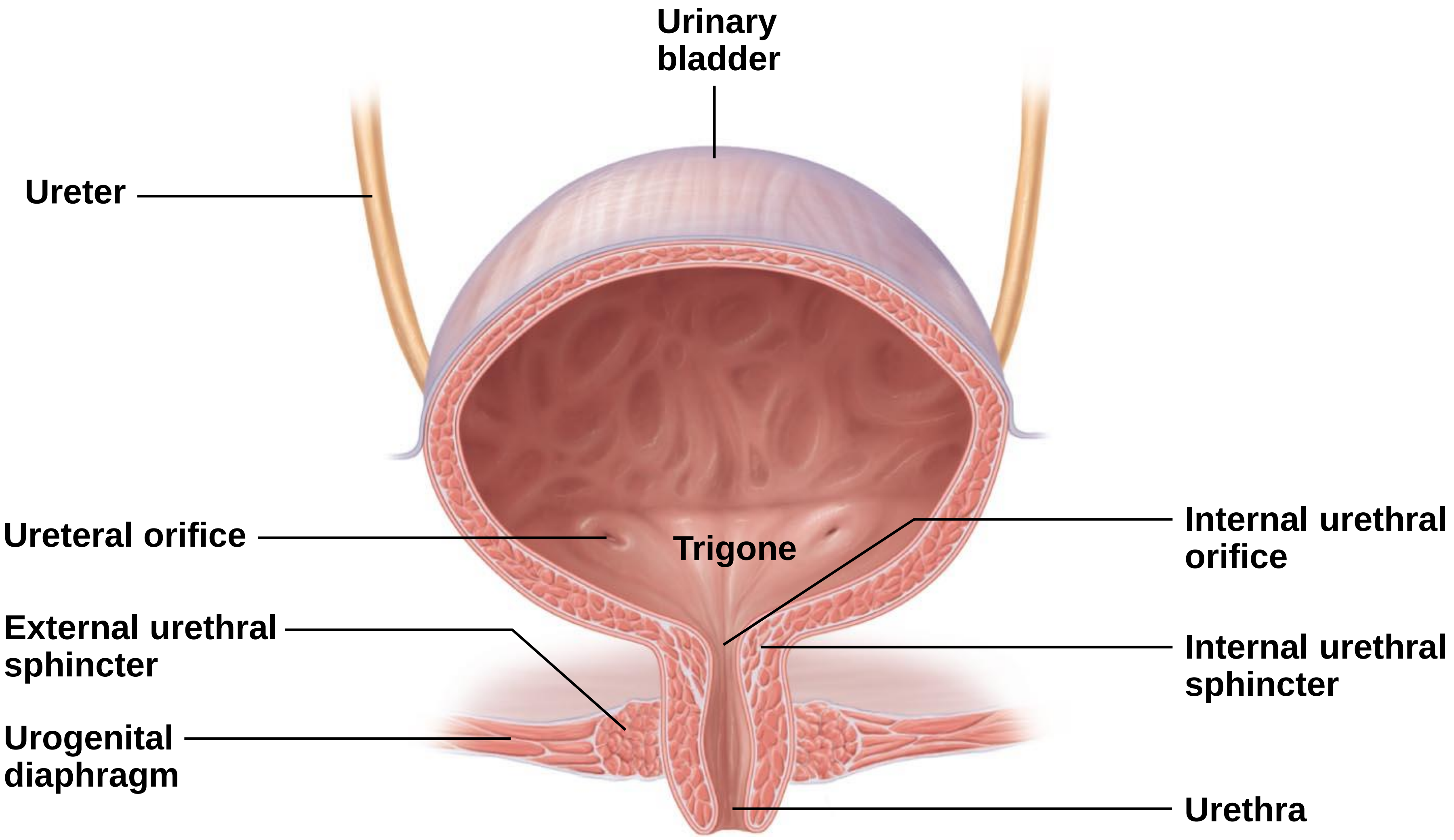

Urinary bladder
Ureter
Ureteral orifice
Trigone
Internal urethral orifice
External urethral sphincter
Internal urethral sphincter
Urogenital diaphragm
Urethra

Figure 15.6

Urinary Bladder Wall

- Three layers of smooth muscle collectively called the **detrusor muscle**
- Mucosa made of transitional epithelium
- Walls are thick and folded in an empty bladder
- Bladder can expand significantly without increasing internal pressure

Urinary Bladder Capacity

- A moderately full bladder is about 5 inches long and holds about 500 mL of urine
- Capable of holding twice that amount of urine

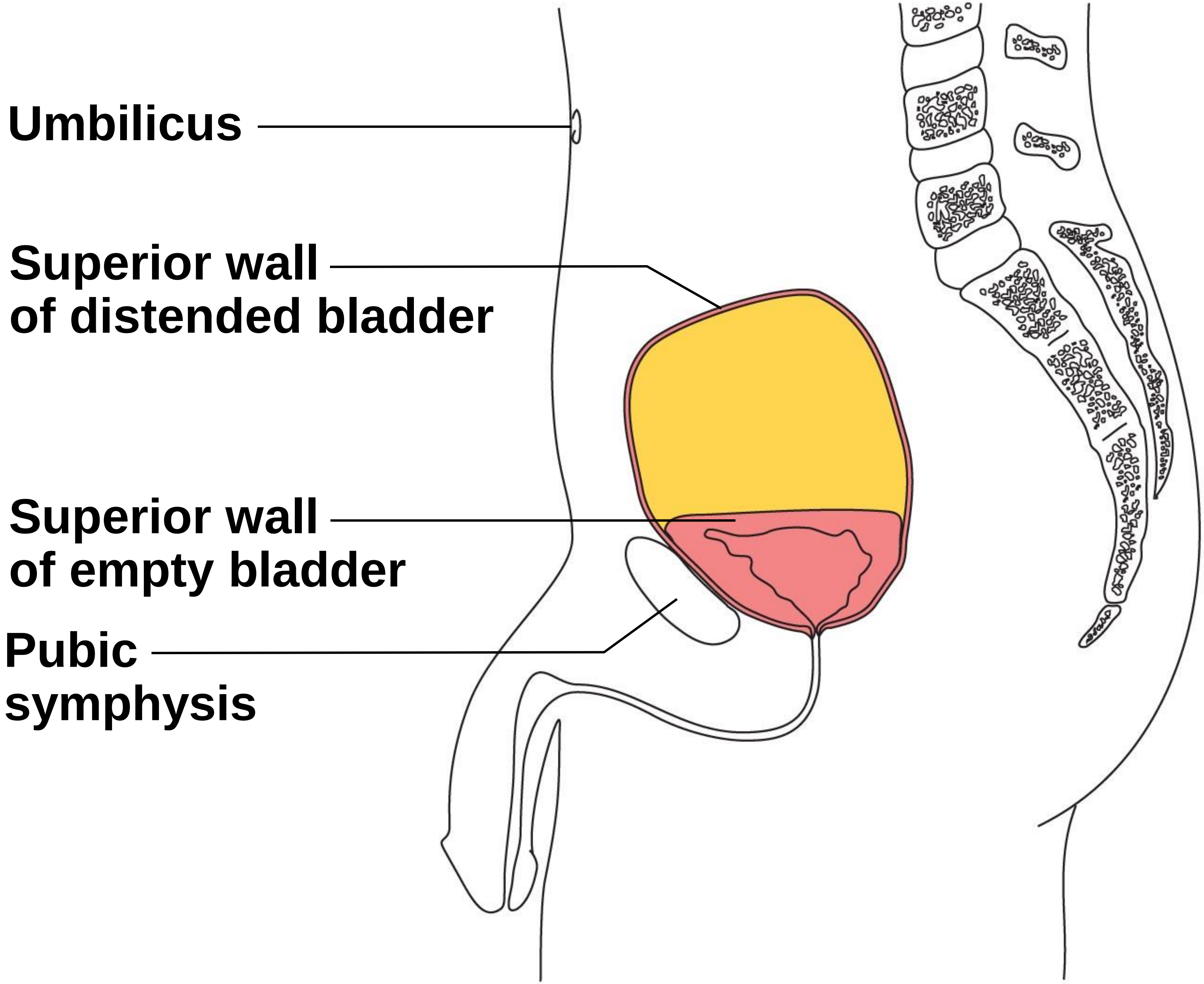

Umbilicus
Superior wall of distended bladder
Superior wall of empty bladder
Pubic symphysis

Figure 15.7

Urethra

- Thin-walled tube that carries urine from the bladder to the outside of the body by **peristalsis**
- Release of urine is controlled by two sphincters
  - **Internal urethral sphincter**
    - Involuntary and made of smooth muscle
  - **External urethral sphincter**
    - Voluntary and made of skeletal muscle

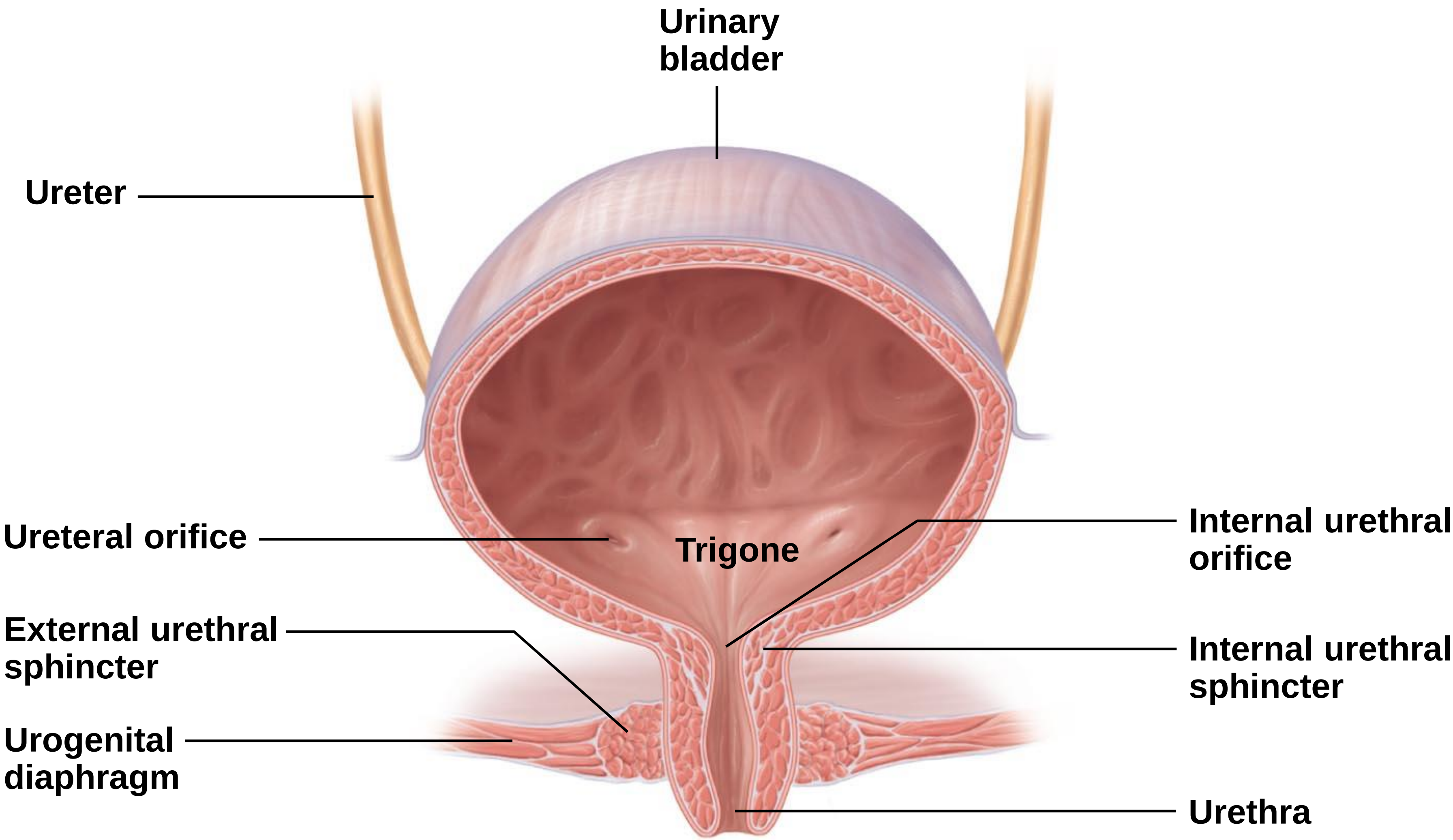

Urinary bladder
Ureter
Ureteral orifice
Trigone
Internal urethral orifice
External urethral sphincter
Internal urethral sphincter
Urogenital diaphragm
Urethra

Figure 15.6

Urethra Gender Differences

- **Length**
  - Females is 3 to 4 cm (1 inch)
  - Males is 20 cm (8 inches)

- **Location**
  - Females—anterior to the vaginal opening
  - Males—travels through the prostate and penis
    - Prostatic urethra
    - Membranous urethra
    - Spongy urethra

Urethra Gender Differences

- **Function**
  - Females—only carries urine
  - Males—carries urine and is a passageway for sperm cells and semen

Micturition (Voiding)

- Both sphincter muscles must open to allow voiding
- The internal urethral sphincter is relaxed after stretching of the bladder
- Pelvic splanchnic nerves initiate bladder to go into reflex contractions
- Urine is forced past the internal urethra sphincter and the person feels the urge to void
- The external urethral sphincter must be voluntarily relaxed to void

Fluid, Electrolyte, and Acid-Base Balance

- Blood composition depends on three factors
  - Diet
  - Cellular metabolism
  - Urine output

Fluid, Electrolyte, and Acid-Base Balance

- Kidneys have four roles in maintaining blood composition
  - Excretion of nitrogen-containing wastes (previously discussed)
  - Maintaining water balance of the blood
  - Maintaining electrolyte balance of the blood
  - Ensuring proper blood pH

Maintaining Water Balance

- Normal amount of water in the human body
  - Young adult females = 50 percent
  - Young adult males = 60 percent
  - Babies = 75 percent
  - The elderly = 45 percent
- Water is necessary for many body functions, and levels must be maintained

Distribution of Body Fluid

- **Intracellular fluid (ICF)**
  - Fluid inside cells
  - About two-thirds of body fluid
- **Extracellular fluid (ECF)**
  - Fluids outside cells that includes
    - Interstitial fluid
    - Blood plasma

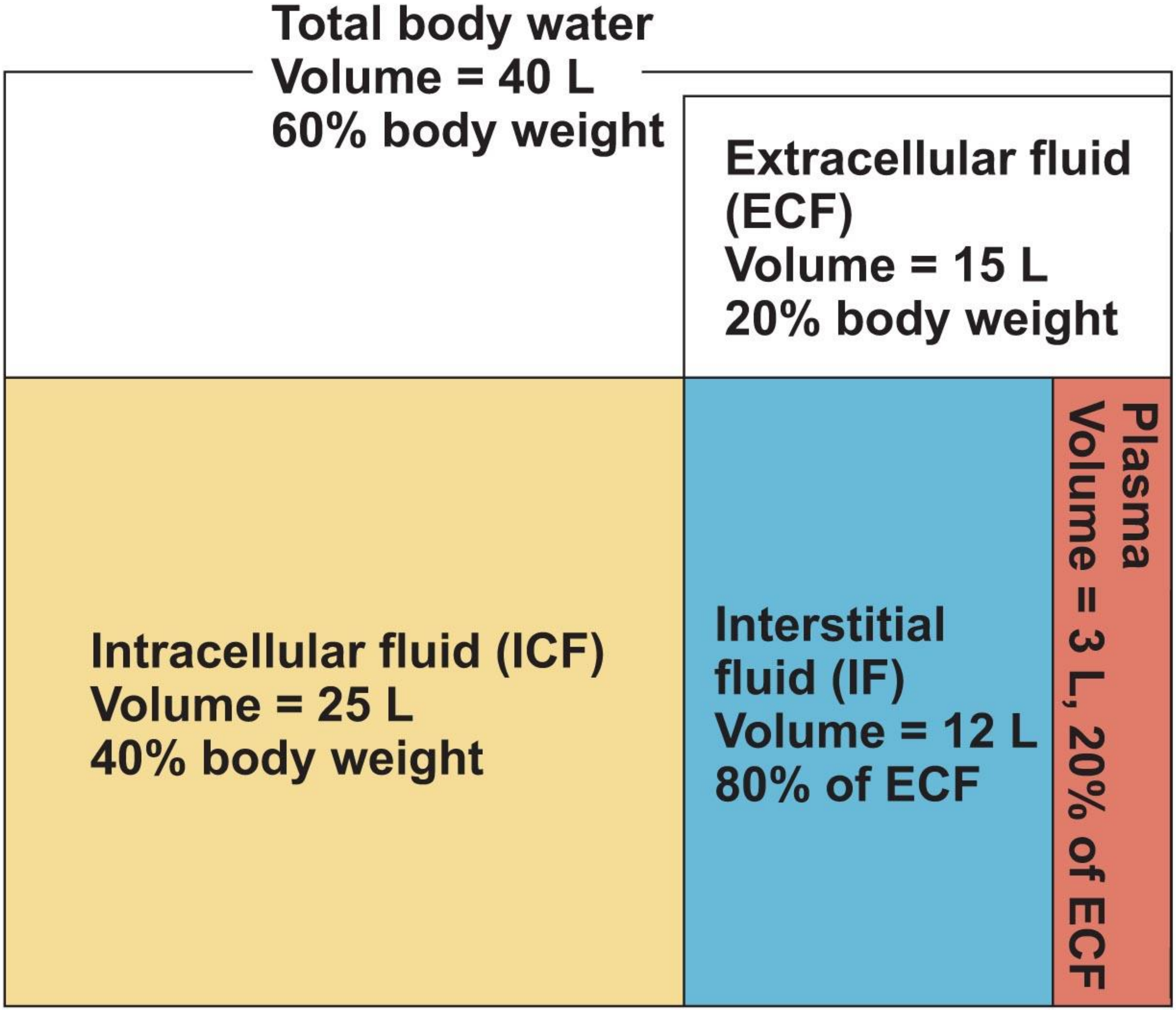
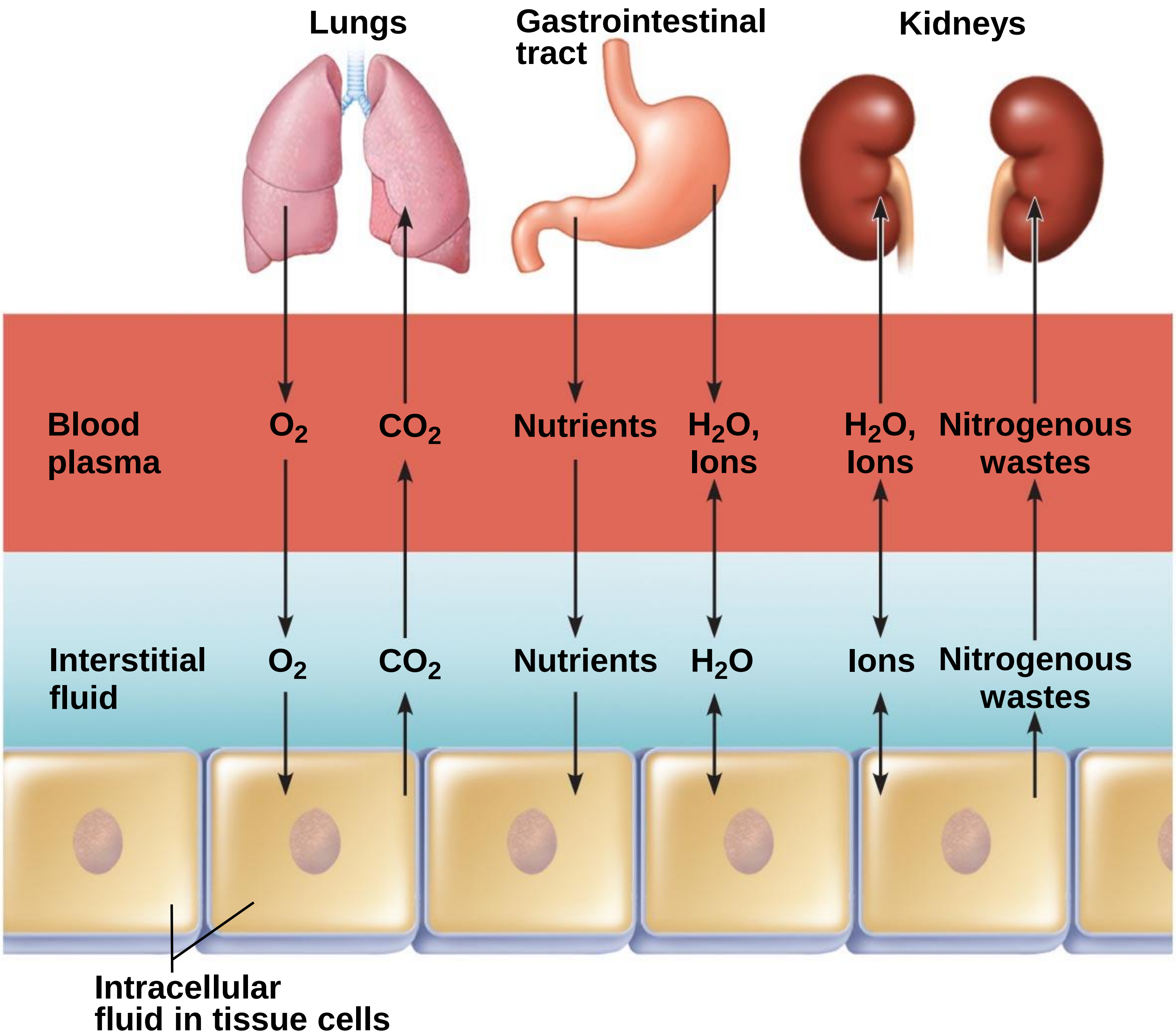

Total body water
Volume = 40 L
60% body weight
Extracellular fluid (ECF)
Volume = 15 L
20% body weight
Intracellular fluid (ICF)
Volume = 25 L
40% body weight
Interstitial fluid (IF)
Volume = 12 L
80% of ECF
Plasma
Volume = 3 L, 20% of ECF

Figure 15.8



Lungs
Gastrointestinal tract
Kidneys
Blood plasma
O_2
CO_2
Nutrients
H_2O, Ions
H_2O, Ions
Nitrogenous wastes
Interstitial fluid
O_2
CO_2
Nutrients
H_2O
Ions
Nitrogenous wastes
Intracellular fluid in tissue cells

Figure 15.9

The Link Between Water and Salt

- Solutes in the body include electrolytes like sodium, potassium, and calcium ions

- Changes in electrolyte balance causes water to move from one compartment to another
  - Alters blood volume and blood pressure
  - Can impair the activity of cells

Maintaining Water Balance

- Water intake must equal water output
- Sources for water intake
  - Ingested foods and fluids
  - Water produced from metabolic processes
- Thirst mechanism is the driving force for water intake

Maintaining Water Balance

- Sources for water output
  - Vaporization out of the lungs (*insensible* since we cannot sense the water leaving)
  - Lost in perspiration
  - Leaves the body in the feces
  - Urine production

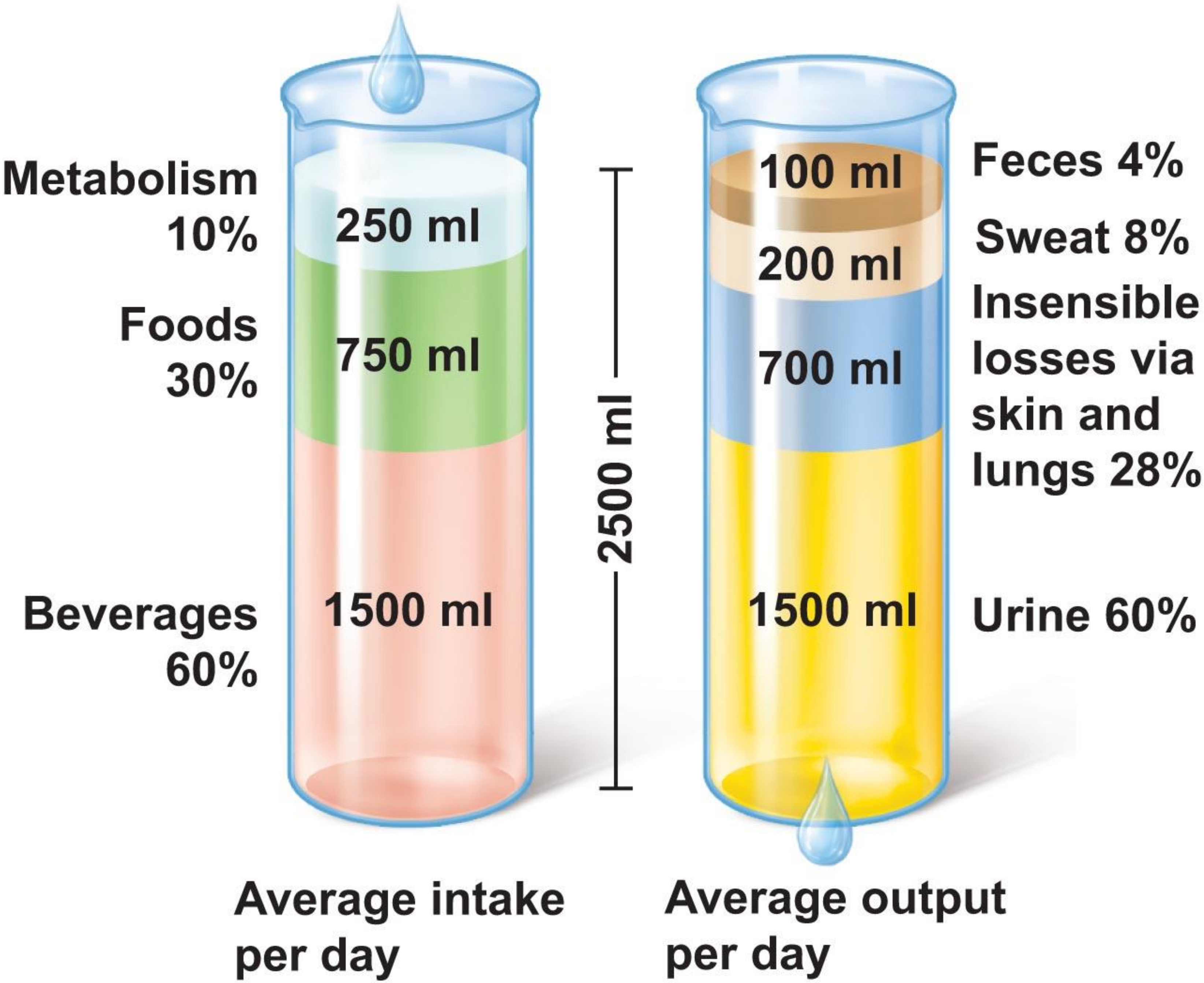

Metabolism 10%
250 ml
Foods 30%
750 ml
Beverages 60%
1500 ml
2500 ml
100 ml
Feces 4%
200 ml
Sweat 8%
700 ml
Insensible losses via skin and lungs 28%
1500 ml
Urine 60%
Average intake per day
Average output per day

Figure 15.10

Maintaining Water Balance

- Dilute urine is produced if water intake is excessive
- Less urine (concentrated) is produced if large amounts of water are lost
- Proper concentrations of various electrolytes must be present

Regulation of Water and Electrolyte Reabsorption

- **Osmoreceptors**
  - Sensitive cells in the hypothalamus
  - React to small changes in solute blood composition by becoming more active
  - When activated, the thirst center in the hypothalamus is notified
  - A dry mouth due to decreased saliva also promotes the thirst mechanism

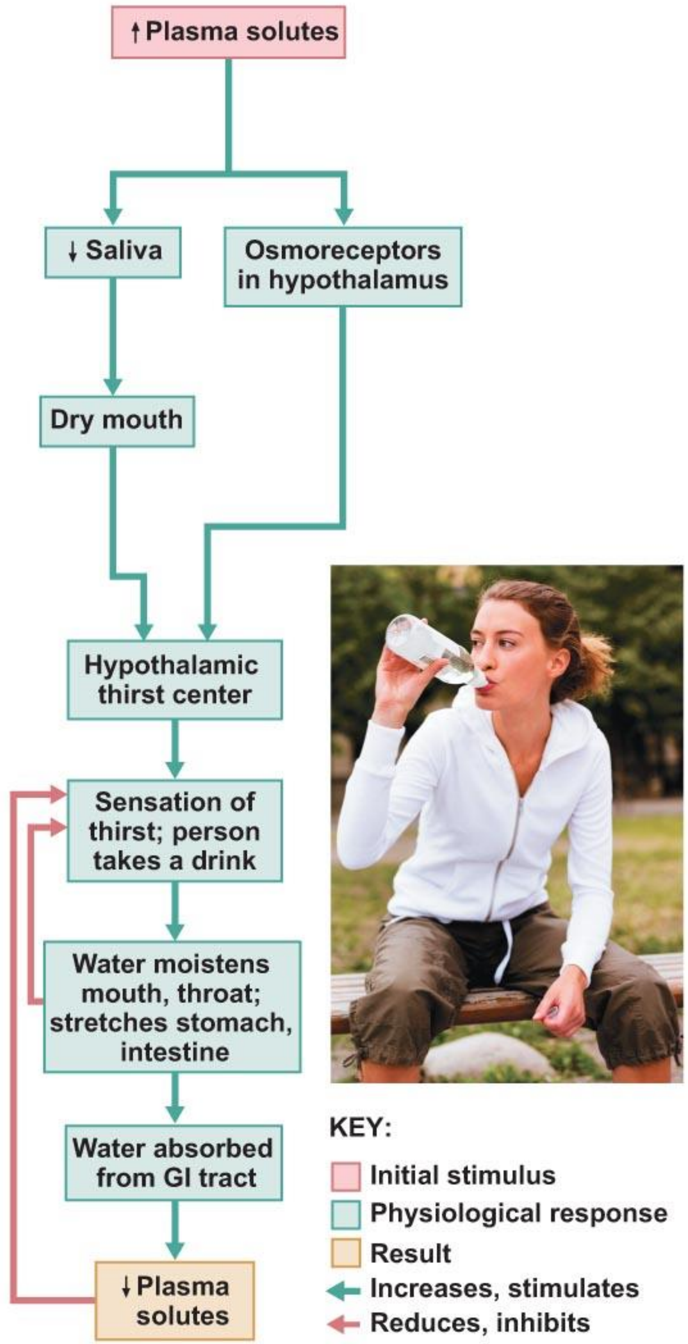

↑ Plasma solutes
↓ Saliva
Osmoreceptors in hypothalamus
Dry mouth
Hypothalamic thirst center
Sensation of thirst; person takes a drink
Water moistens mouth, throat; stretches stomach, intestine
Water absorbed from GI tract
↓ Plasma solutes
KEY:
Initial stimulus
Physiological response
Result
Increases, stimulates
Reduces, inhibits

Figure 15.11

Regulation of Water and Electrolyte Reabsorption

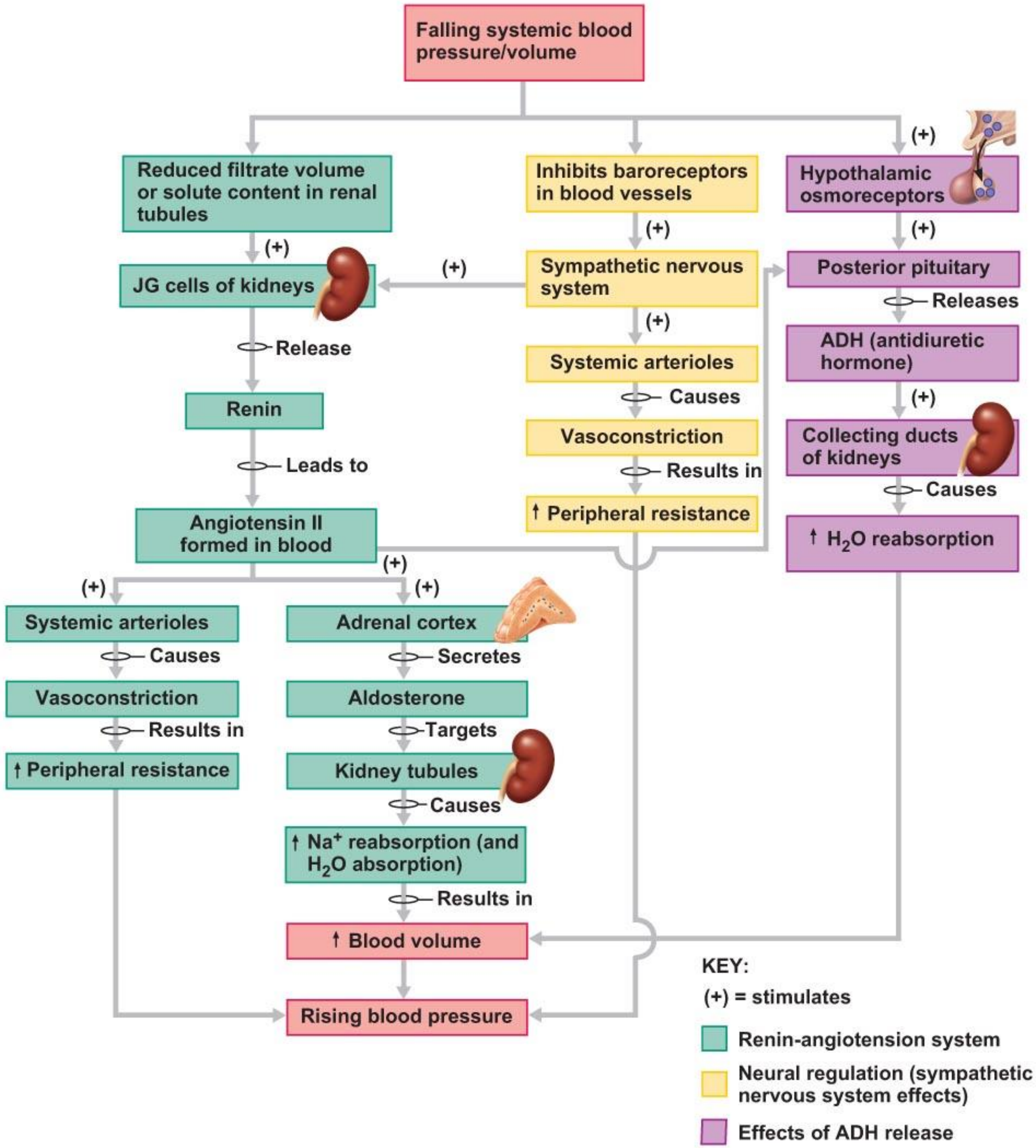
- Regulation occurs primarily by **hormones**
  - Antidiuretic hormone (ADH)
    - Prevents excessive water loss in urine
    - Causes the kidney’s collecting ducts to reabsorb more water
  - Diabetes insipidus
    - Occurs when ADH is not released
    - Leads to huge outputs of dilute urine

Regulation of Water and Electrolyte Reabsorption

- Regulation occurs primarily by hormones (continued)
  - **Aldosterone**
    - Regulates sodium ion content of ECF
    - Sodium is the electrolyte most responsible for osmotic water flows
    - Aldosterone promotes reabsorption of sodium ions
    - Remember, water follows salt!

Regulation of Water and Electrolyte Reabsorption

- Renin-angiotensin mechanism
  - Mediated by the **juxtaglomerular (JG) apparatus** of the renal tubules
  - When cells of the JG apparatus are stimulated by low blood pressure, the enzyme renin is released into blood
  - Renin produces **angiotensin II**
  - Angiotensin causes vasoconstriction and aldosterone release
  - Result is increase in blood volume and blood pressure



Falling systemic blood pressure/volume
Reduced filtrate volume or solute content in renal tubules
Inhibits baroreceptors in blood vessels
Hypothalamic osmoreceptors
(+)
JG cells of kidneys
Sympathetic nervous system
Posterior pituitary
Releases
Release
Renin
Systemic arterioles
ADH (antidiuretic hormone)
Causes
Vasoconstriction
Collecting ducts of kidneys
Leads to
Results in
Causes
Angiotensin II formed in blood
↑ Peripheral resistance
↑ H_2O reabsorption
Systemic arterioles
Adrenal cortex
Causes
Secretes
Vasoconstriction
Aldosterone
Results in
Targets
↑ Peripheral resistance
Kidney tubules
Causes
↑ Na^+ reabsorption (and H_2O absorption)
Results in
↑ Blood volume
Rising blood pressure
KEY:
(+) = stimulates
Renin-angiotensin system
Neural regulation (sympathetic nervous system effects)
Effects of ADH release

Figure 15.12

Maintaining Acid-Base Balance in Blood

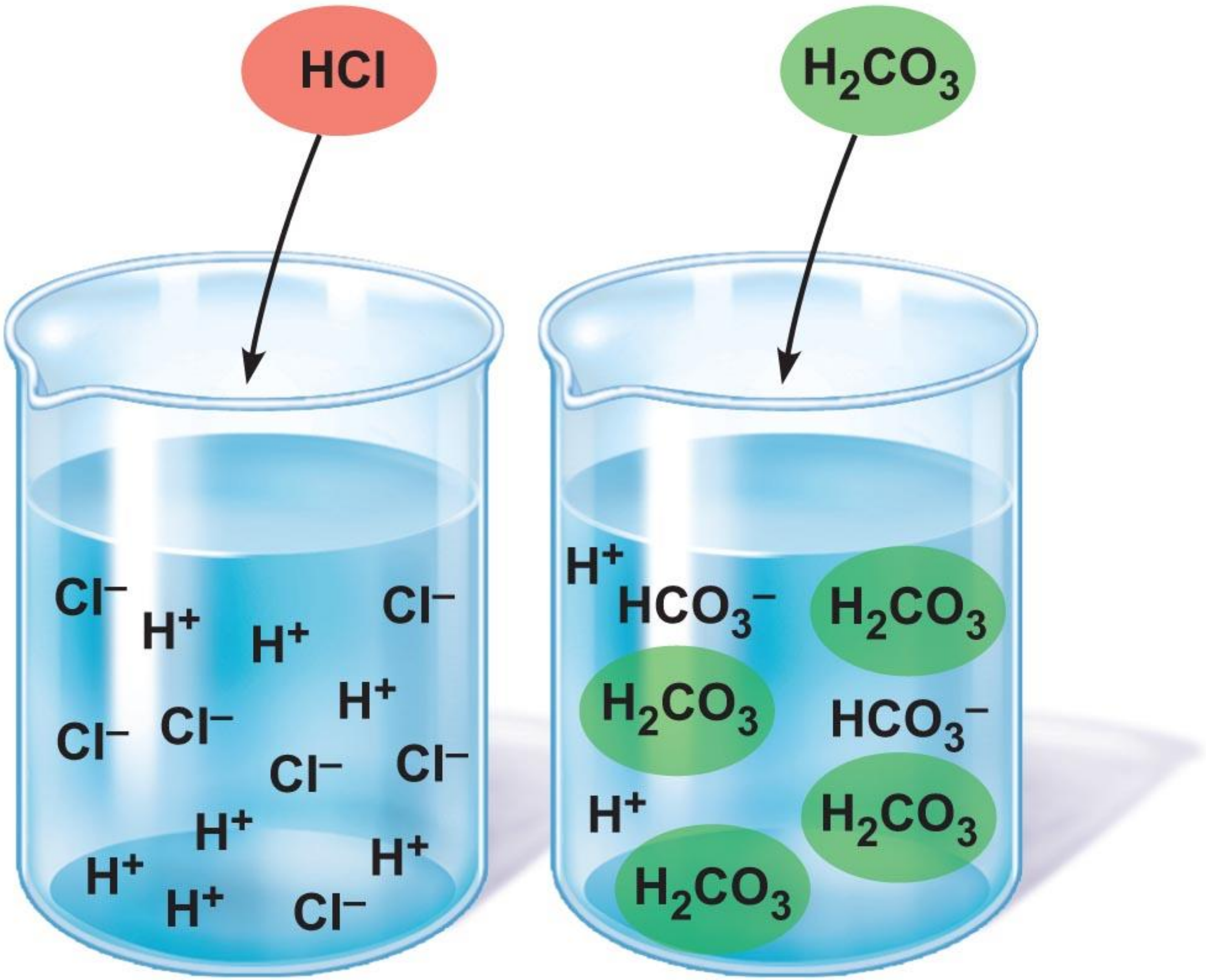
- Blood pH must remain between 7.35 and 7.45 to maintain homeostasis
  - Alkalosis—pH above 7.45
  - Acidosis—pH below 7.35
  - Physiological acidosis—pH between 7.35 and 7.0
- Most ions originate as by-products of cellular metabolism

Maintaining Acid-Base Balance in Blood

- Acids produced by the body
  - Phosphoric acid, lactic acid, fatty acids
  - Carbon dioxide forms carbonic acid
  - Ammonia
- Most acid-base balance is maintained by the kidneys
- Other acid-base controlling systems
  - Blood buffers
  - Respiration

Blood Buffers

- **Acids are proton (H^+) donors**
  - Strong acids dissociate completely and liberate all of their H^+ in water
  - Weak acids, such as carbonic acid, dissociate only partially
- **Bases are proton (H^+) *acceptors***
  - Strong bases dissociate easily in water and tie up H^+
  - Weak bases, such as bicarbonate ion and ammonia, are slower to accept H^+



(a) A strong acid such as HCl dissociates completely into its ions.

(b) A weak acid such as H_2CO_3 does *not* dissociate completely.

Figure 15.13

Blood Buffers

- Molecules react to prevent dramatic changes in hydrogen ion (H^+) concentrations
  - Bind to H^+ when pH drops
  - Release H^+ when pH rises
- Three major chemical buffer systems
  - **Bicarbonate** buffer system
  - **Phosphate** buffer system
  - **Protein** buffer system

The Bicarbonate Buffer System

- Mixture of carbonic acid (H_2CO_3) and sodium bicarbonate ($NaHCO_3$)
  - Carbonic acid is a weak acid that does not dissociate much in neutral or acid solutions
  - Bicarbonate ions (HCO_3^-) react with strong acids to change them to weak acids

$$\underset{\text{strong acid}}{HCl} + \underset{\text{weak base}}{NaHCO_3} \rightarrow \underset{\text{weak acid}}{H_2CO_3} + \underset{\text{salt}}{NaCl}$$

The Bicarbonate Buffer System

- Carbonic acid dissociates in the presence of a strong base to form a weak base and water

$$NaOH + H_2CO_3 \rightarrow NaHCO_3 + H_2O$$

strong base   weak acid   weak base   water

Respiratory System Controls of Acid-Base Balance

- Carbon dioxide in the blood is converted to bicarbonate ion and transported in the plasma
- Increases in hydrogen ion concentration produces more carbonic acid
- Excess hydrogen ion can be blown off with the release of carbon dioxide from the lungs
- Respiratory rate can rise and fall depending on changing blood pH

Renal Mechanisms of Acid-Base Balance

- Excrete bicarbonate ions if needed
- Conserve (reabsorb) or generate new bicarbonate ions if needed

Renal Mechanisms of Acid-Base Balance

- When **blood pH rises**
  - Bicarbonate ions are excreted
  - Hydrogen ions are retained by kidney tubules
- When **blood pH falls**
  - Bicarbonate ions are reabsorbed
  - Hydrogen ions are secreted
- Urine pH varies from 4.5 to 8.0

Developmental Aspects of the Urinary System

- Functional kidneys are developed by the third month of fetal life

- Urinary system of a newborn
  - Bladder is small
  - Urine cannot be concentrated for first 2 months
  - Void 5 to 40 times per day

Developmental Aspects of the Urinary System

- Control of the voluntary urethral sphincter does not start until age 18 months
- Complete nighttime control may not occur until the child is 4 years old
- Urinary infections are the only common problems before old age
  - *Escherichia coli* (*E. coli*), a type of bacteria, accounts for 80 percent of UTI (urinary tract infections)

Aging and the Urinary System

- There is a progressive decline in urinary function
- The bladder shrinks and loses bladder tone with aging

Aging and the Urinary System

- Associated problems with aging
  - **Urgency**—feeling that it is necessary to void
  - **Frequency**—frequent voiding of small amounts of urine
  - **Nocturia**—need to get up during the night to urinate
  - **Incontinence**—loss of control
  - **Urinary retention**—common in males, often the result of hypertrophy of the prostate gland