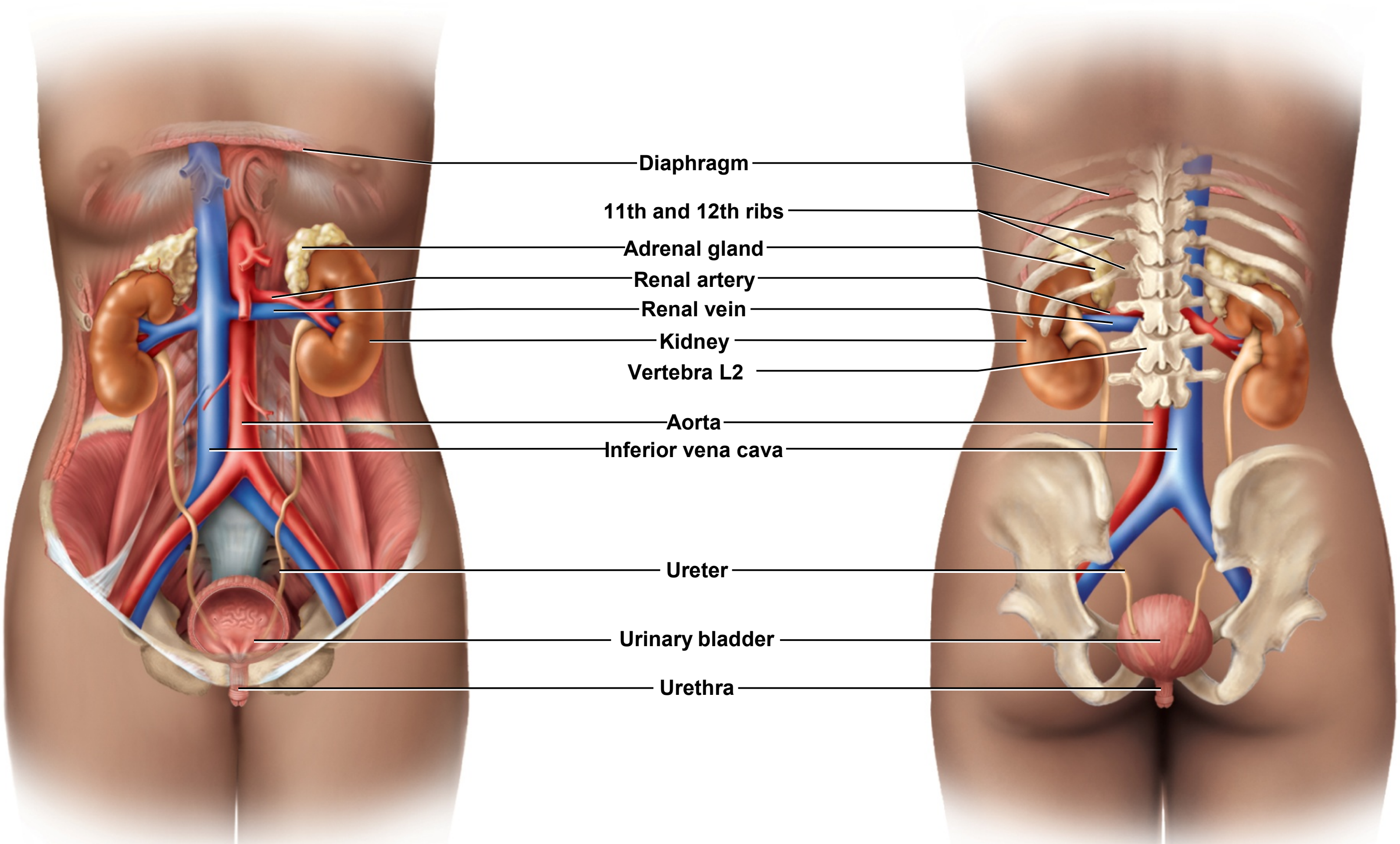
Waste Products & Kidney Function

- **urinary system** – principal means of metabolic waste removal
- urinary system is closely associated with reproductive system
  - ‘urogenital system’
  - share embryonic development
  - share adult anatomical relationship
  - male urethra serves as a common passage for urine and sperm

Urinary System



(a) Anterior view

(b) Posterior view

urinary system consists of 6 organs: 2 kidneys, 2 ureters, urinary bladder, and urethra

Figure 23.1a-b

Kidney Location

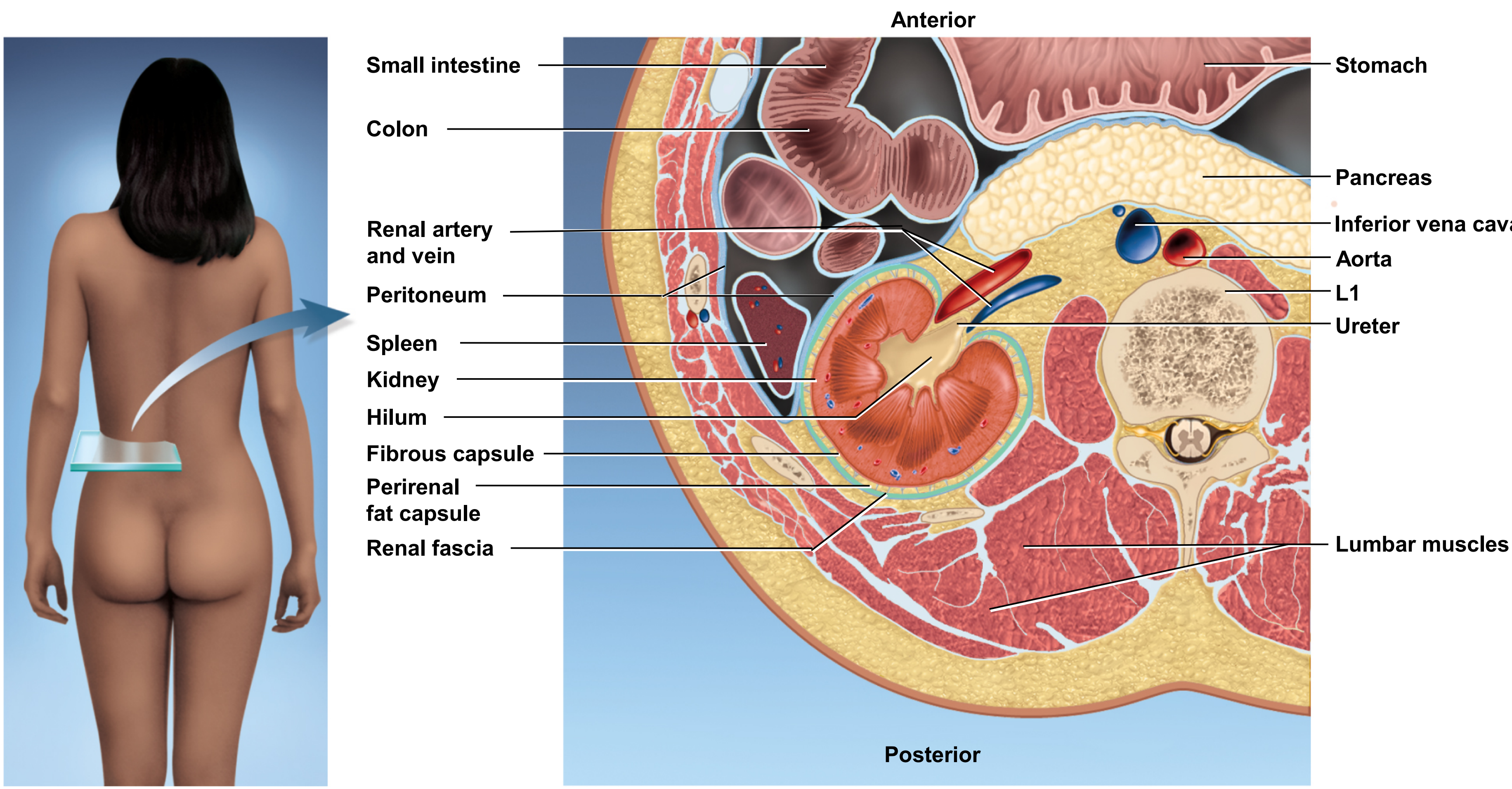


Figure 23.3 a-b

Functions of the Kidney

- Filters blood plasma, separates waste from useful chemicals, **eliminates wastes**
- Regulates
  - **blood volume, pressure, osmolarity, pH**
- Produces
  - ***renin***, activates hormone that control blood pressure and electrolyte balance
  - ***erythropoietin***, hormone which stimulates the production of red blood cells
  - ***calcitriol***, which contributes to calcium homeostasis (last step)

Nitrogenous Wastes

- **metabolic waste** – waste substance produced by the body
- **urea formation**
  - proteins → amino acids → NH_2 removed → forms **ammonia**, liver converts to urea
- **uric acid**
  - product of nucleic acid catabolism
- **creatinine**
  - product of creatine phosphate catabolism

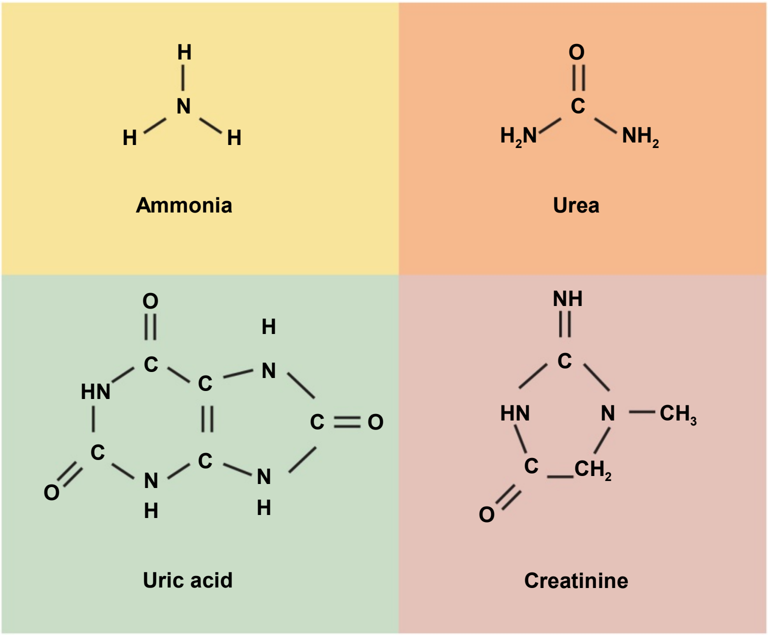
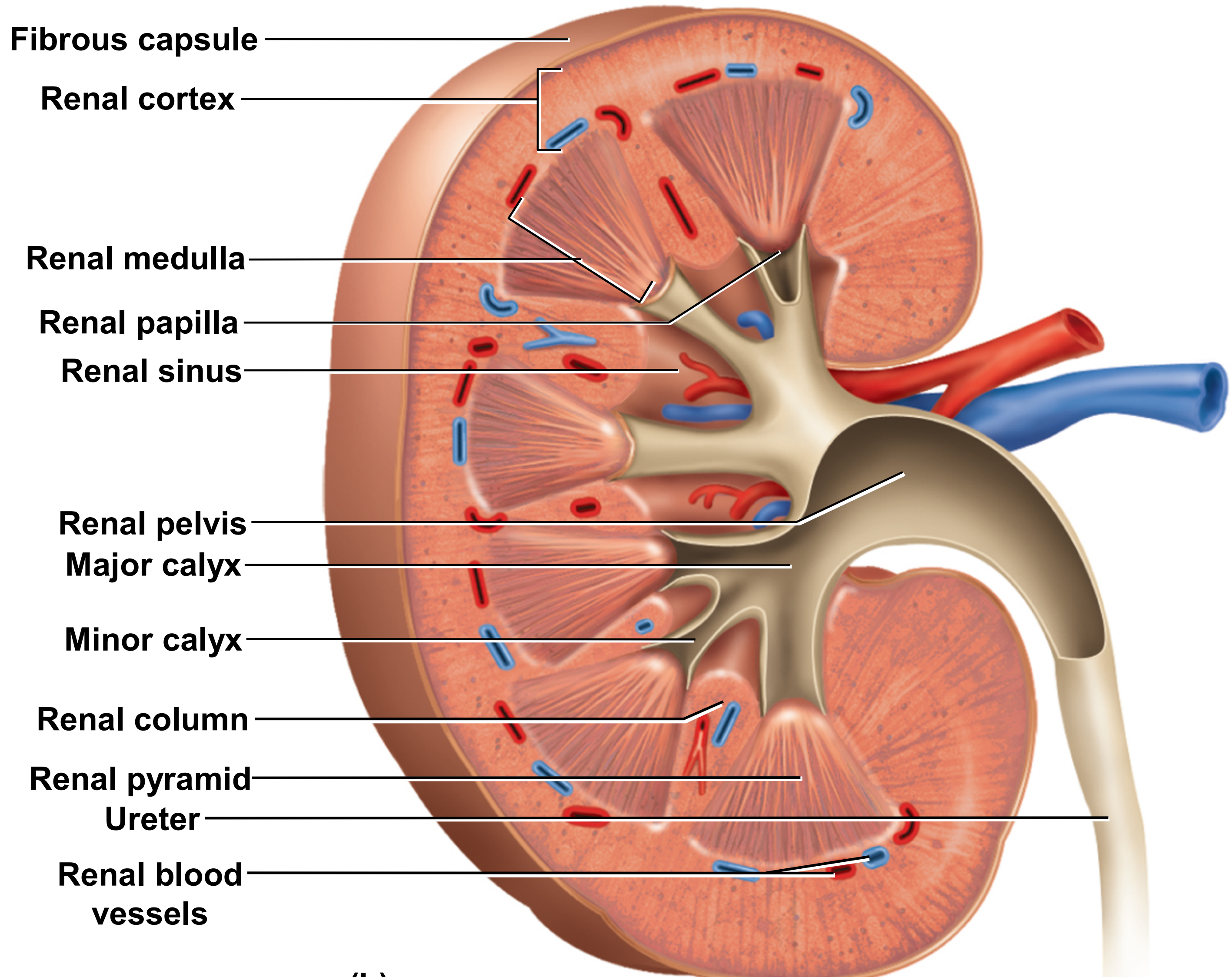


Figure 23.2

Anatomy of Kidney



(b)

Figure 23.4b

Renal Circulation

- kidneys account for only 0.4% of body weight, they receive about 21% of the cardiac output (**renal fraction**)

- **renal artery**

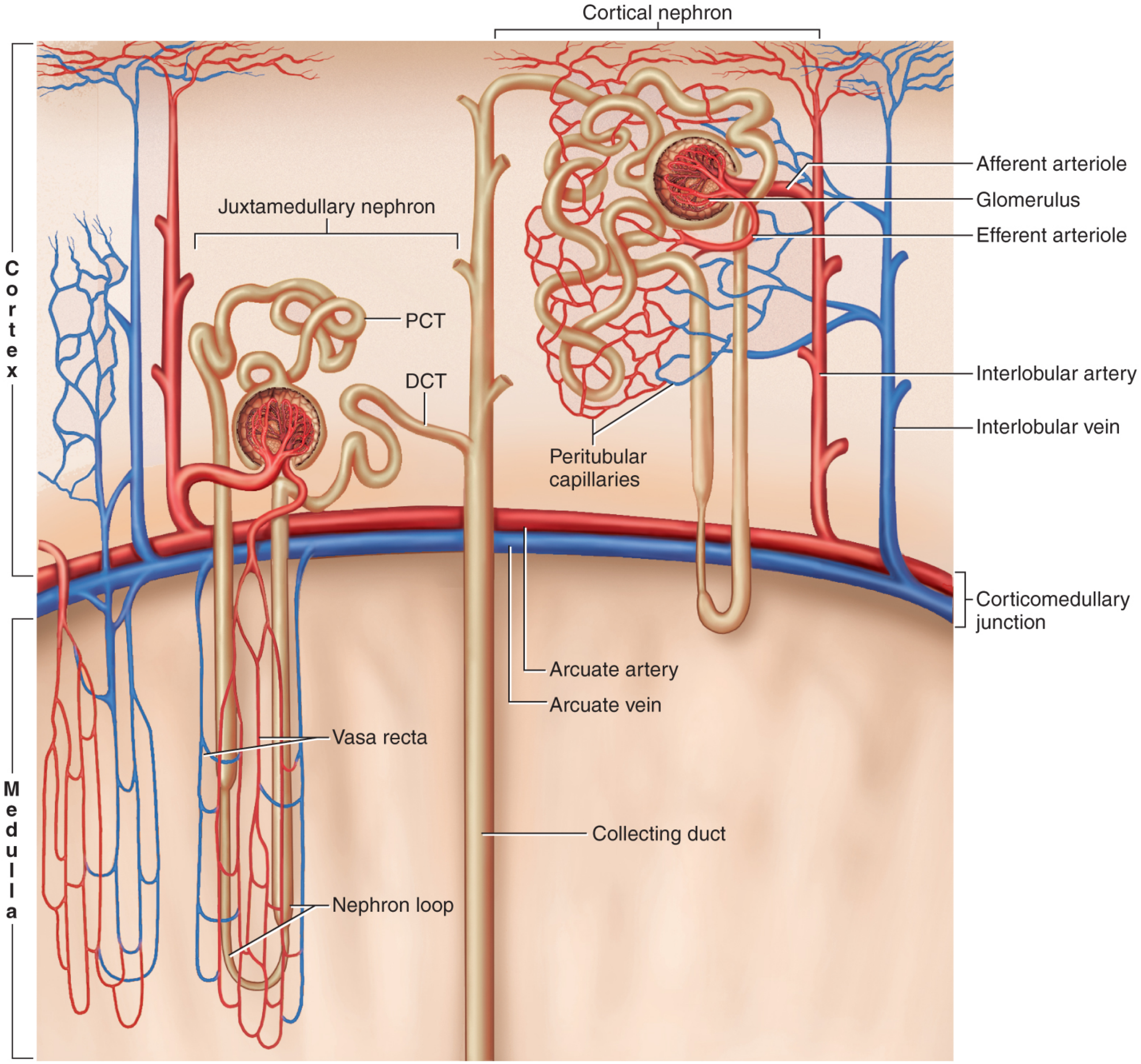
- branch into **afferent arterioles -** each supplying **one nephron**

    - leads to a ball of capillaries - **glomerulus**

- blood is drained from the glomerulus by **efferent arterioles**

- lead to either **peritubular capillaries** or **vasa recta** around portion of the renal tubule

- **renal vein** empties into **inferior vena cava**


Cortical nephron
Juxtamedullary nephron
Cortex
Medulla
PCT
DCT
Peritubular capillaries
Afferent arteriole
Glomerulus
Efferent arteriole
Interlobular artery
Interlobular vein
Corticomedullary junction
Arcuate artery
Arcuate vein
Vasa recta
Nephron loop
Collecting duct

The Nephron

- each kidney has about 1.2 million nephrons
- each composed of two principal parts:
  - **renal corpuscle** – filters the blood plasma
  - **renal tubule** – long coiled tube that converts the filtrate into urine
- **renal corpuscle** consists of the **glomerulus** and a two-layered **glomerular (Bowman) capsule** that encloses glomerulus

Renal Corpuscle

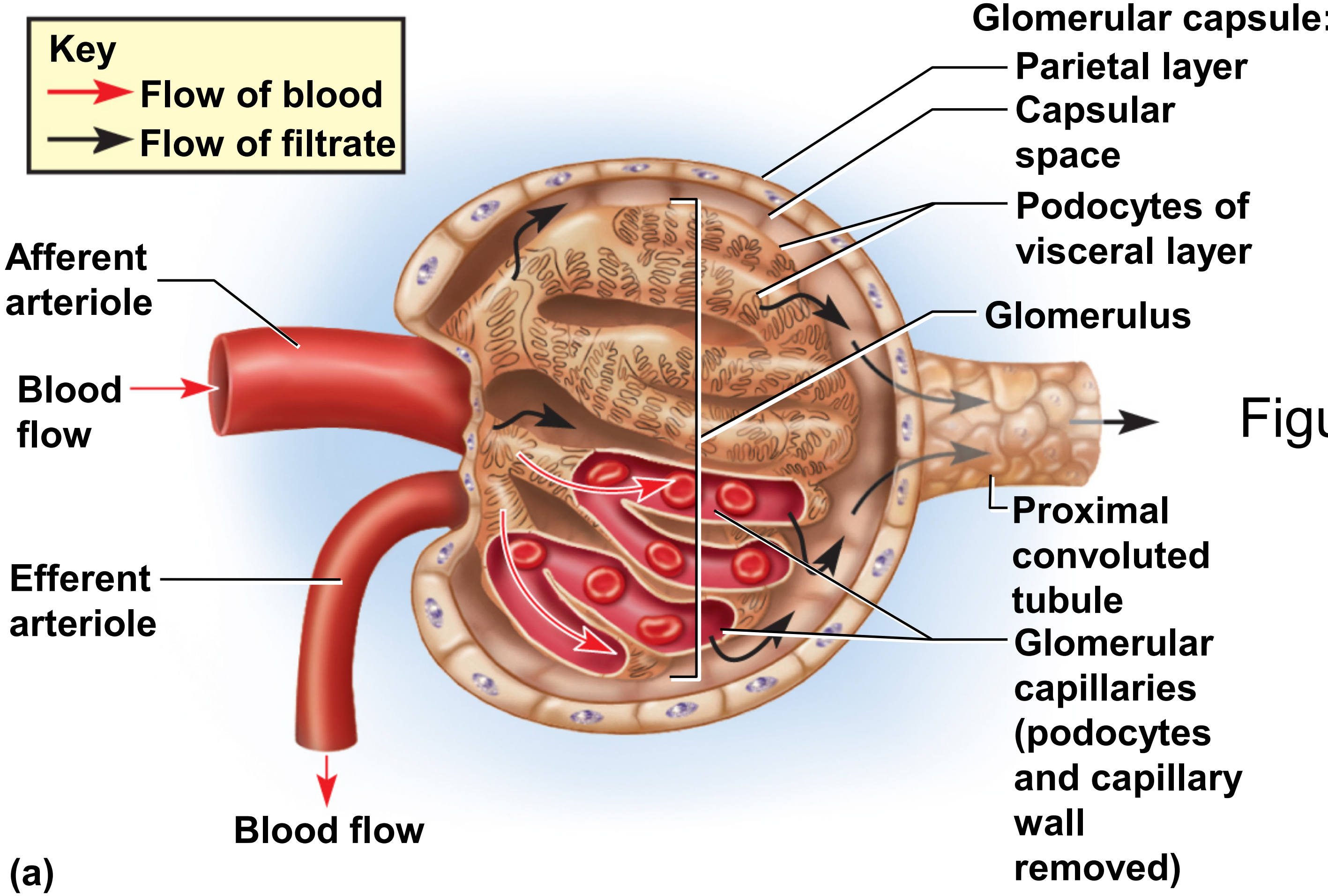


Figure 23.7a

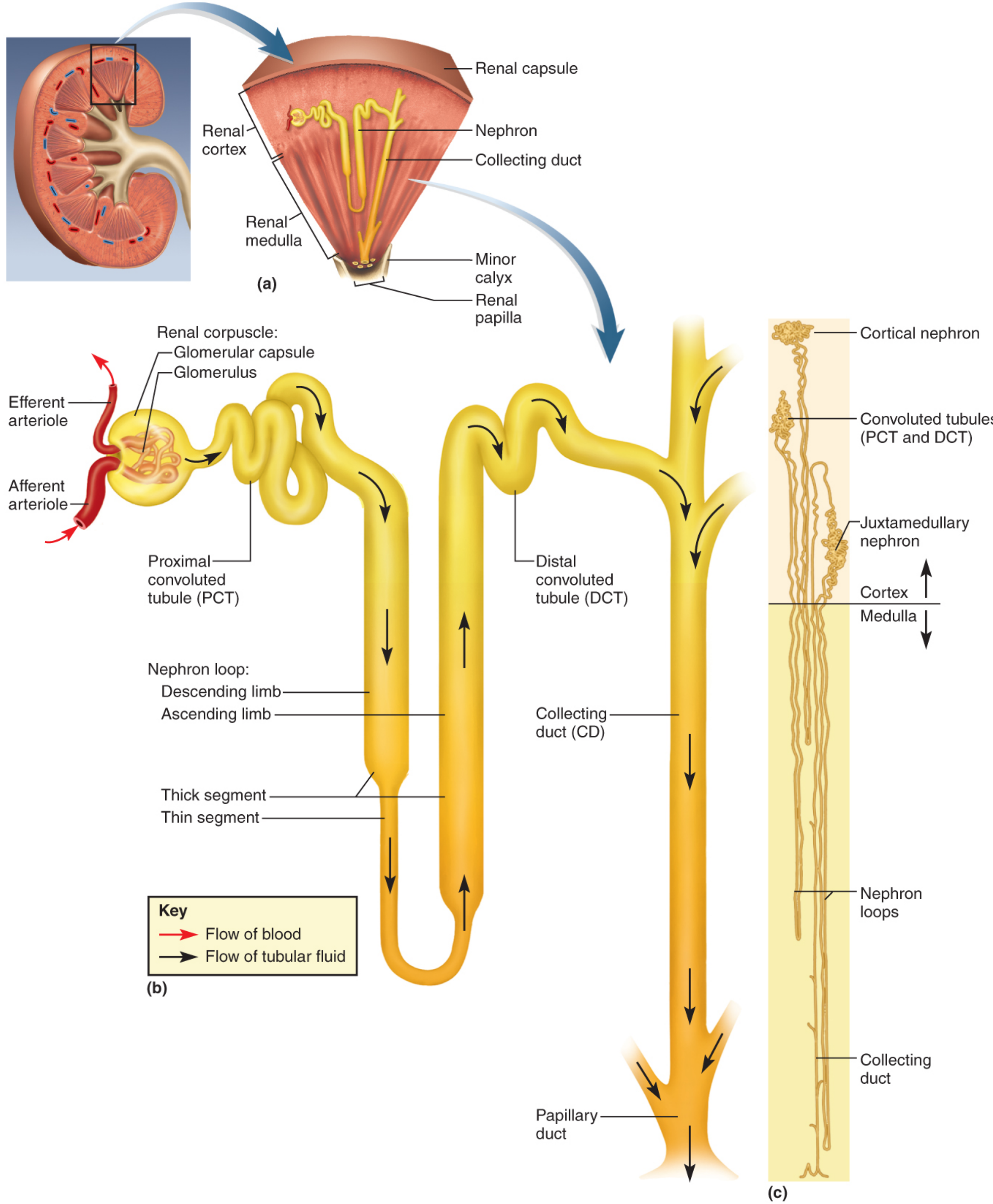
- glomerular filtrate collects in capsular space, flows into proximal convoluted tubule. Note the vascular and urinary poles. Note the afferent arteriole is larger than the efferent arteriole.

Renal Tubule

- **renal tubule** – a duct that leads away from the glomerular capsule and ends at the tip of the medullary pyramid
- **divided into four regions** –
  - ***proximal convoluted tubule***, ***nephron loop***, ***distal convoluted tubule*** – parts of one nephron
  - ***collecting duct*** receives fluid from many nephrons
- **proximal convoluted tubule** (PCT) – arises from glomerular capsule
  - longest and most coiled region
  - simple cuboidal epithelium with **prominent microvilli** for majority of absorption
- **nephron loop (loop of Henle)** – long U-shaped portion of renal tubule
  - descending limb and ascending limb
- **thick segments**
    - initial part of descending limb and part or all of the ascending limb
    - heavily engaged in the active transport of salts
- **thin segment**
    - forms lower part of descending limb
    - cells very permeable to water

Renal Tubule

- **distal convoluted tubule** (DCT) – begins shortly after the ascending limb reenters the cortex
  - shorter and less coiled that PCT
  - DCT is the end of the nephron
- **collecting duct** – receives fluid from the DCTs of several nephrons as it passes back into the medulla
  - numerous collecting ducts converge toward the tip of the medullary pyramid


Renal capsule
Renal cortex
Nephron
Collecting duct
Renal medulla
Minor calyx
Renal papilla
(a)
Renal corpuscle:
Glomerular capsule
Glomerulus
Efferent arteriole
Afferent arteriole
Proximal convoluted tubule (PCT)
Distal convoluted tubule (DCT)
Nephron loop:
Descending limb
Ascending limb
Thick segment
Thin segment
Collecting duct (CD)
Papillary duct
Key
Flow of blood
Flow of tubular fluid
(b)
Cortical nephron
Convoluted tubules (PCT and DCT)
Juxtamedullary nephron
Cortex
Medulla
Nephron loops
Collecting duct
(c)

Cortical and Juxtamedullary Nephrons

- **cortical nephrons**
  - 85% of all nephrons
  - short nephron loops
  - efferent arterioles branch into **peritubular capillaries** around PCT and DCT
- **juxtamedullary nephrons**
  - 15% of all nephrons
  - very long nephron loops, maintain salinity gradient in the medulla and helps conserve water
  - efferent arterioles branch into **vasa recta** around long nephron loop

Overview of Urine Formation

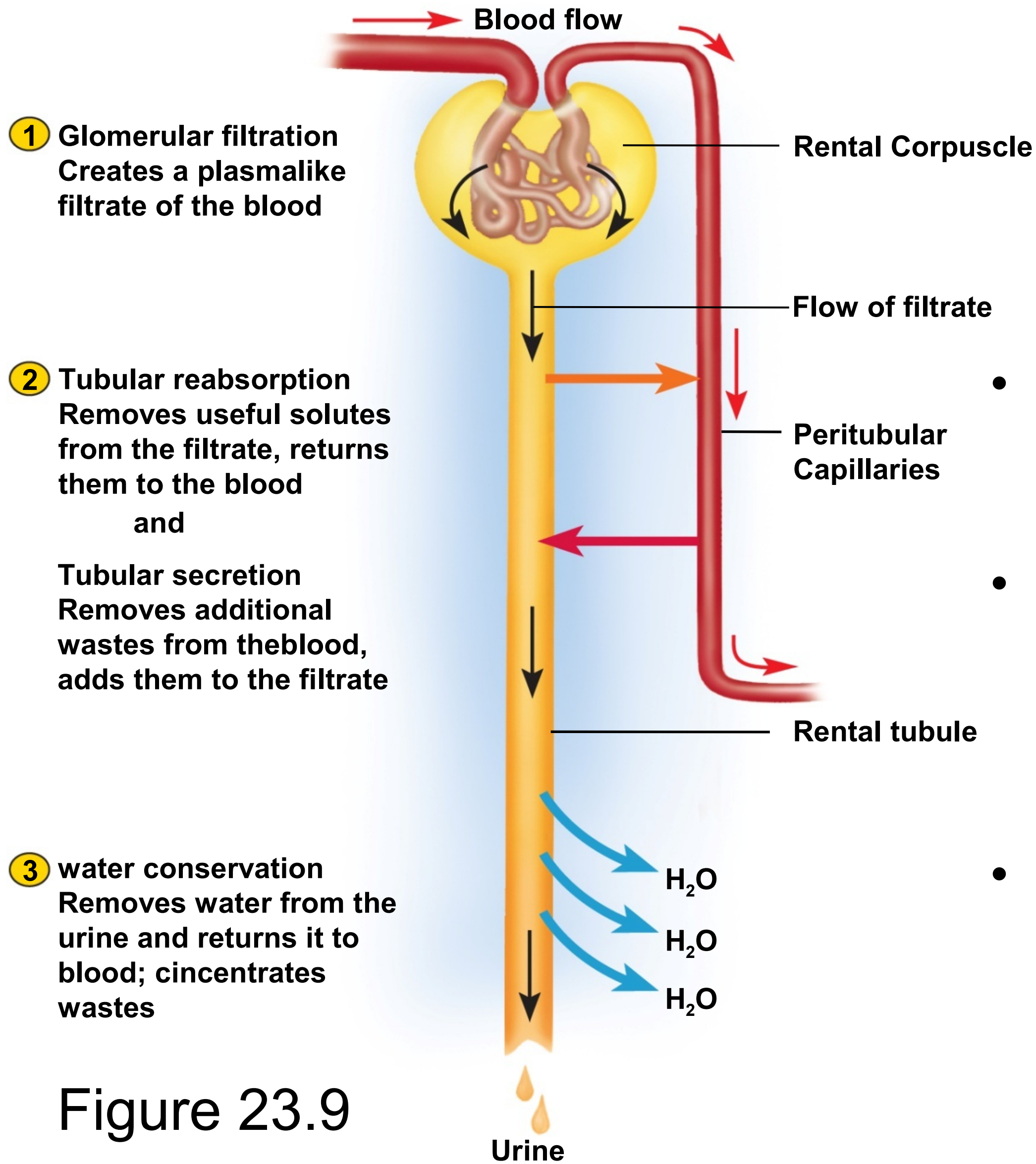


Figure 23.9

- kidneys convert blood plasma to urine in three stages
  - **glomerular filtration**
  - **tubular reabsorption and secretion**
  - **water conservation**
- **glomerular filtrate**
  - fluid in capsular space
  - blood plasma without protein
- **tubular fluid**
  - fluid in renal tubule
  - similar to above except tubular cells have removed and added substances
- **urine**
  - once it enters the collecting duct
  - only remaining change is water content

Filtration Pores and Slits

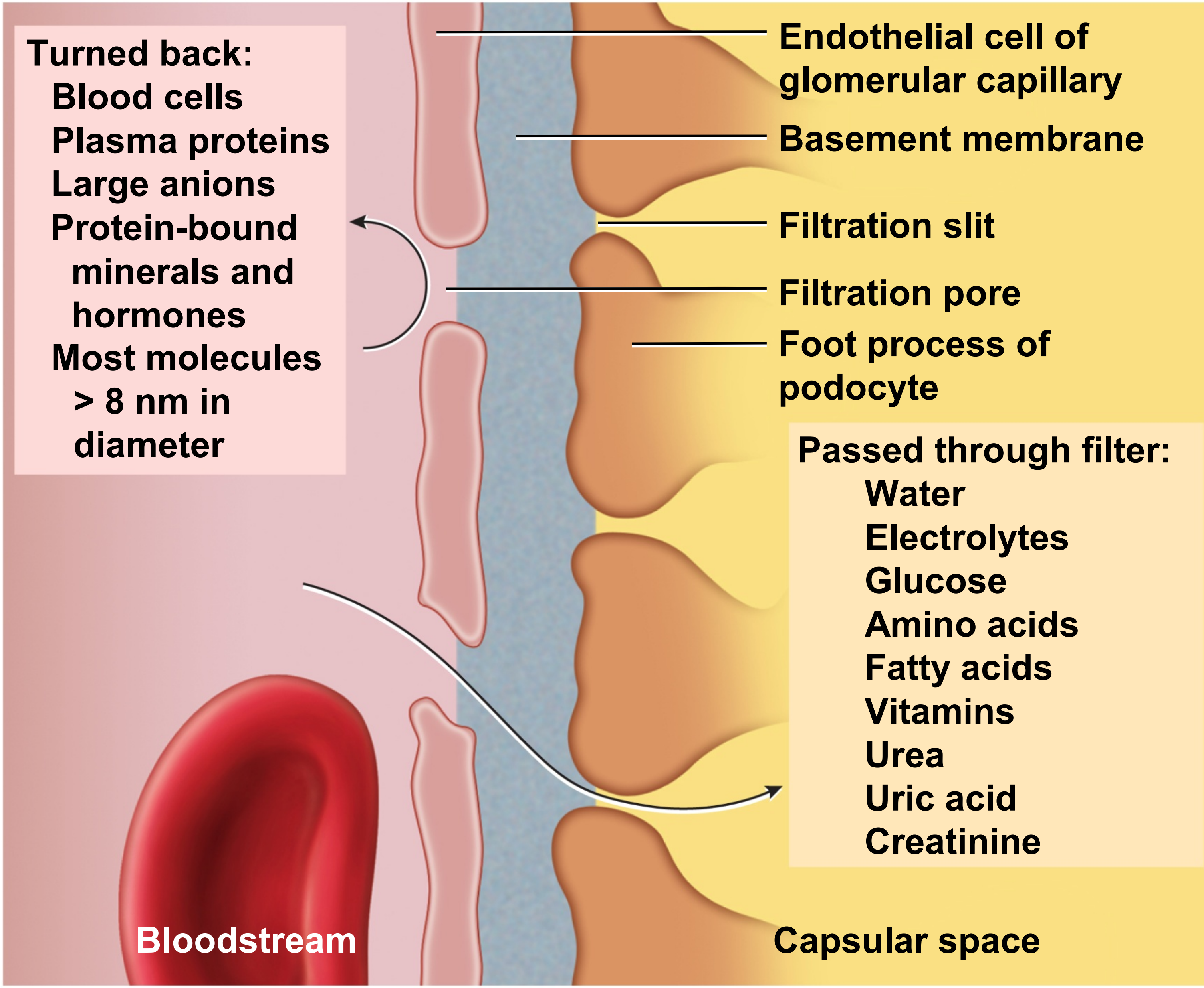
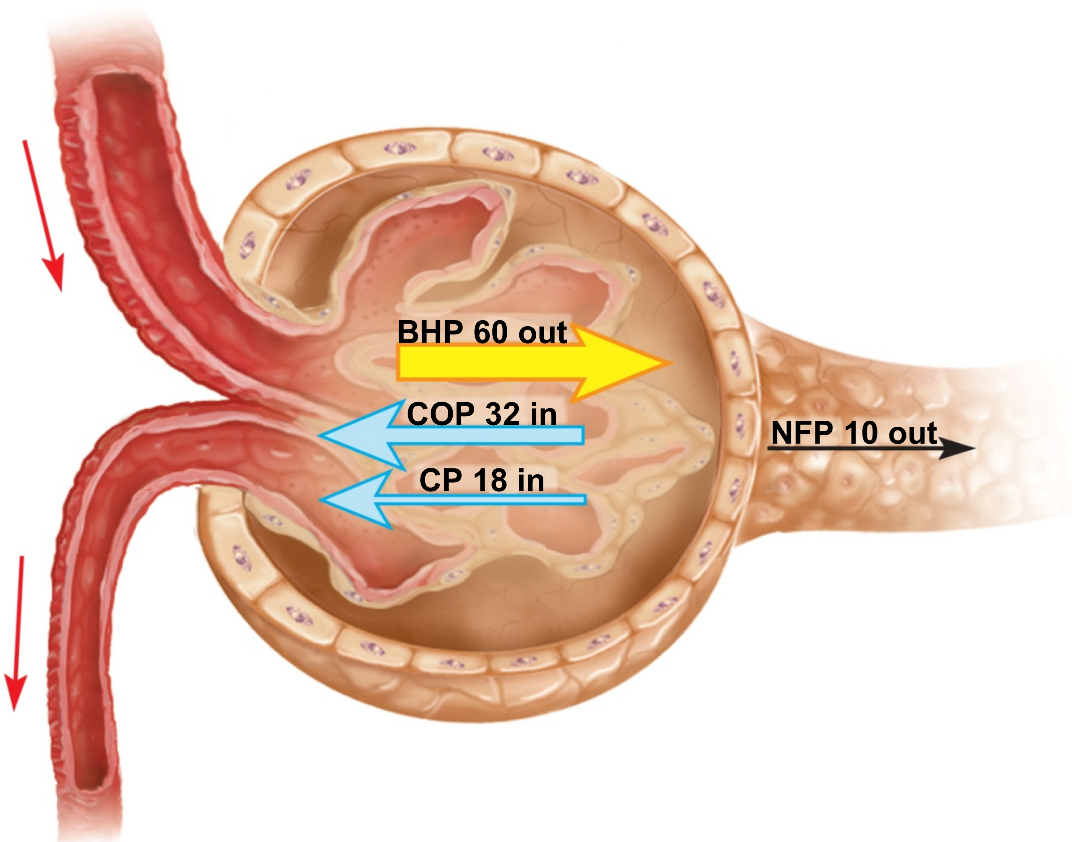


Figure 23.11

Filtration Pressure

- **blood hydrostatic pressure** (BHP)
  - much higher in glomerular capillaries (60 mm Hg compared to 10 to 15 in most other capillaries)
  - because afferent arteriole is larger than efferent arteriole
  - larger inlet and smaller outlet

Filtration Pressure



Blood hydrostatic pressure (BHP)	60 mm Hg_{out}
Colloid osmotic pressure (COP)	–32 mm Hg_{in}
Capsular pressure (CP)	–18 mm Hg_{in}
Net filtration pressure (NFP)	10 mm Hg_{out}

Figure 23.12

- high BP in glomerulus makes kidneys vulnerable to hypertension
- it can lead to rupture of glomerular capillaries, produce scarring of the kidneys (nephrosclerosis), and atherosclerosis of renal blood vessels, ultimately leading to renal failure

Glomerular Filtration Rate (GFR)

- **glomerular filtration rate** (GFR) – the amount of filtrate formed per minute by the 2 kidneys combined

- 99% of filtrate is reabsorbed since only 1 to 2 liters urine excreted / day

Regulation of Glomerular Filtration

- **GFR too high**
  - fluid flows through the renal tubules too rapidly for them to reabsorb the usual amount of water and solutes
  - urine output rises
  - chance of dehydration and electrolyte depletion

- **GFR too low**
  - wastes reabsorbed

- **GFR controlled** by adjusting **glomerular blood pressure** from moment to moment

- **GFR control is achieved by three homeostatic mechanisms**
  - renal autoregulation
  - sympathetic control
  - hormonal control

Renal Autoregulation of GFR

- **renal autoregulation –** the ability of the nephrons to adjust their own blood flow and GFR without external (nervous or hormonal) control
- enables them to maintain a relatively stable GFR in spite of changes in systemic arterial blood pressure
- two methods of autoregulation: **myogenic mechanism** and **tubuloglomerular feedback**
- **myogenic mechanism** – based on the tendency of smooth muscle to contract when stretched
  - increased arterial blood pressure stretches the afferent arteriole
  - arteriole constricts and prevents blood flow into the glomerulus from changing much
  - when blood pressure falls
  - the afferent arteriole relaxes
  - allows blood flow more easily into glomerulus
  - filtration remains stable

Renal Autoregulation of GFR

- **tubuloglomerular feedback** – mechanism by which glomerulus receives feedback on the status of the downstream tubular fluid and adjust filtration to regulate the composition of the fluid, stabilize its own performance, and compensate for fluctuation in systemic blood pressure
  - **juxtaglomerular apparatus** – complex structure found at the very end of the nephron loop where it has just reentered the renal cortex
  - loop comes into contact with the afferent and efferent arterioles at the vascular pole of the renal corpuscle

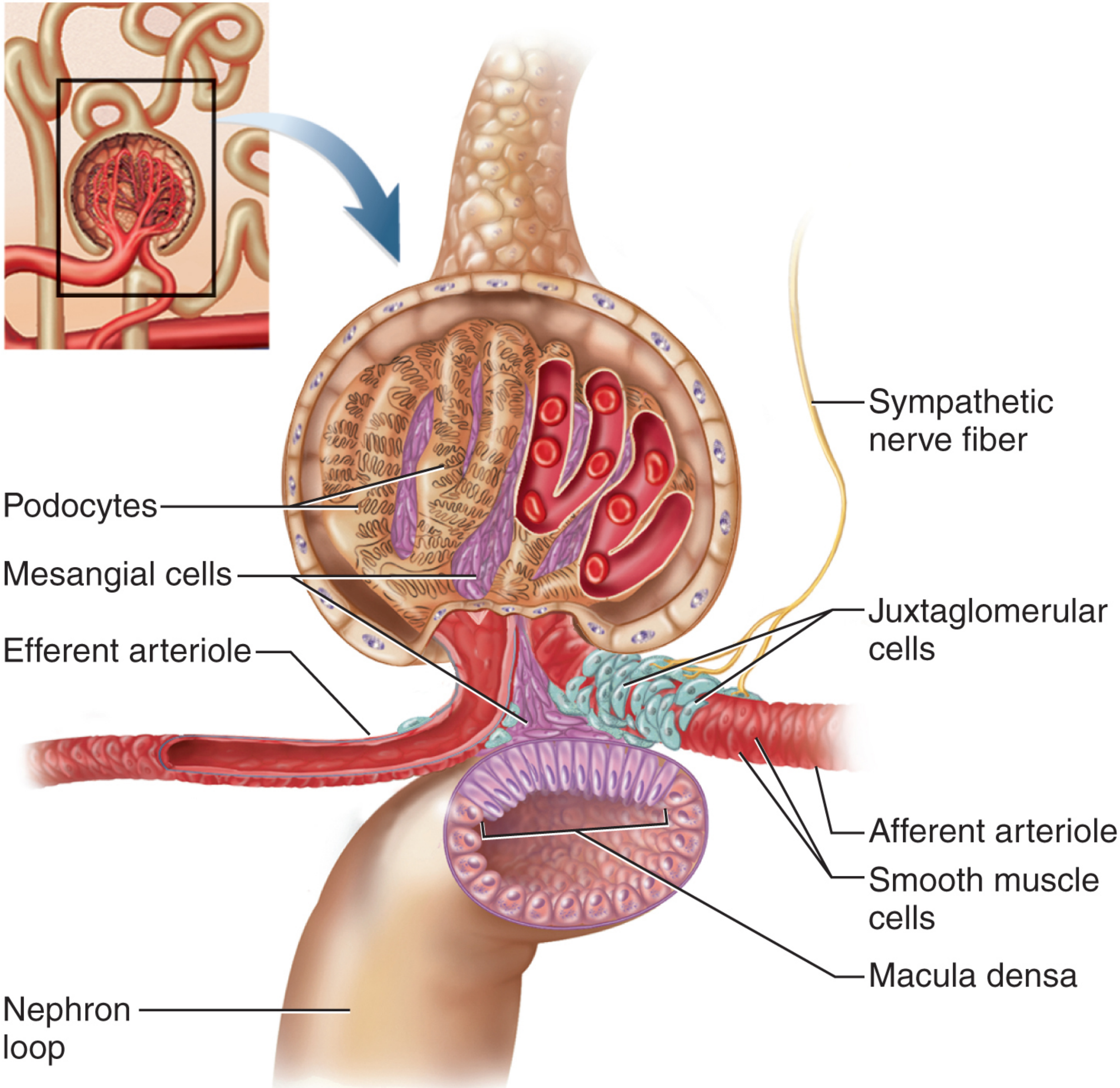
Renal Autoregulation of GFR

- **three special kind of cells** occur in the juxtaglomerular apparatus:
  - **macula densa** – patch of slender, closely spaced epithelial cells at end of the nephron loop on the side of the tubules facing the arterioles
    - senses variations in flow or fluid composition and secretes a paracrine that stimulates JG cells
  - **juxtaglomerular (JG) cells** – enlarged smooth muscle cells in the afferent arteriole directly across from macula densa
    - when stimulated by the macula
    - they dilate or constrict the arterioles
    - they also contain granules of renin, which they secrete in response to drop in blood pressure
  - **mesangial cells** – in the cleft between the afferent and efferent arterioles and among the capillaries of the glomerulus
    - connected to macula densa and JG cells by gap junctions and communicate by means of paracrines
    - build supportive matrix for glomerulus, constrict or relax capillaries to regulate flow

Juxtaglomerular Apparatus

- **if GFR rises**
  - the flow of tubular fluid increases and more NaCl is reabsorbed
  - macula densa stimulates JG cells with a paracrine
  - JG cells contract which constricts afferent arteriole, reducing GFR to normal OR
  - mesangial cells may contract, constricting the capillaries and reducing filtration

- **if GFR falls**
  - macula relaxes afferent arterioles and mesangial cells
  - blood flow increases and GFR rises back to normal.


Sympathetic
nerve fiber
Podocytes
Mesangial cells
Efferent arteriole
Juxtaglomerular
cells
Afferent arteriole
Smooth muscle
cells
Macula densa
Nephron
loop

Effectiveness of Autoregulation

- maintains a dynamic equilibrium - GFR fluctuates within narrow limits only
  - blood pressure changes do affect GFR and urine output somewhat

- renal autoregulation can not compensate for extreme blood pressure variation

Negative Feedback Control of GFR

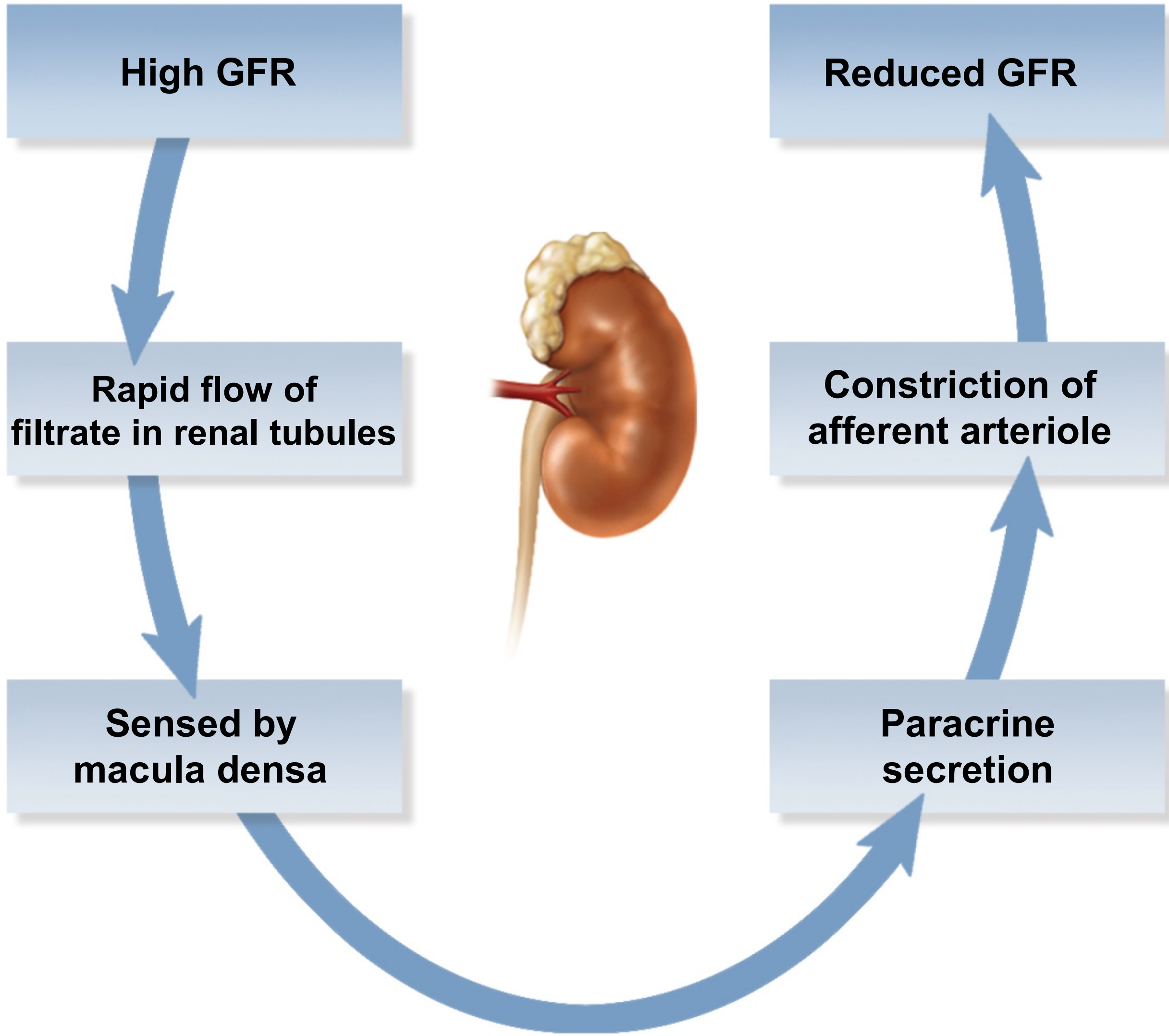
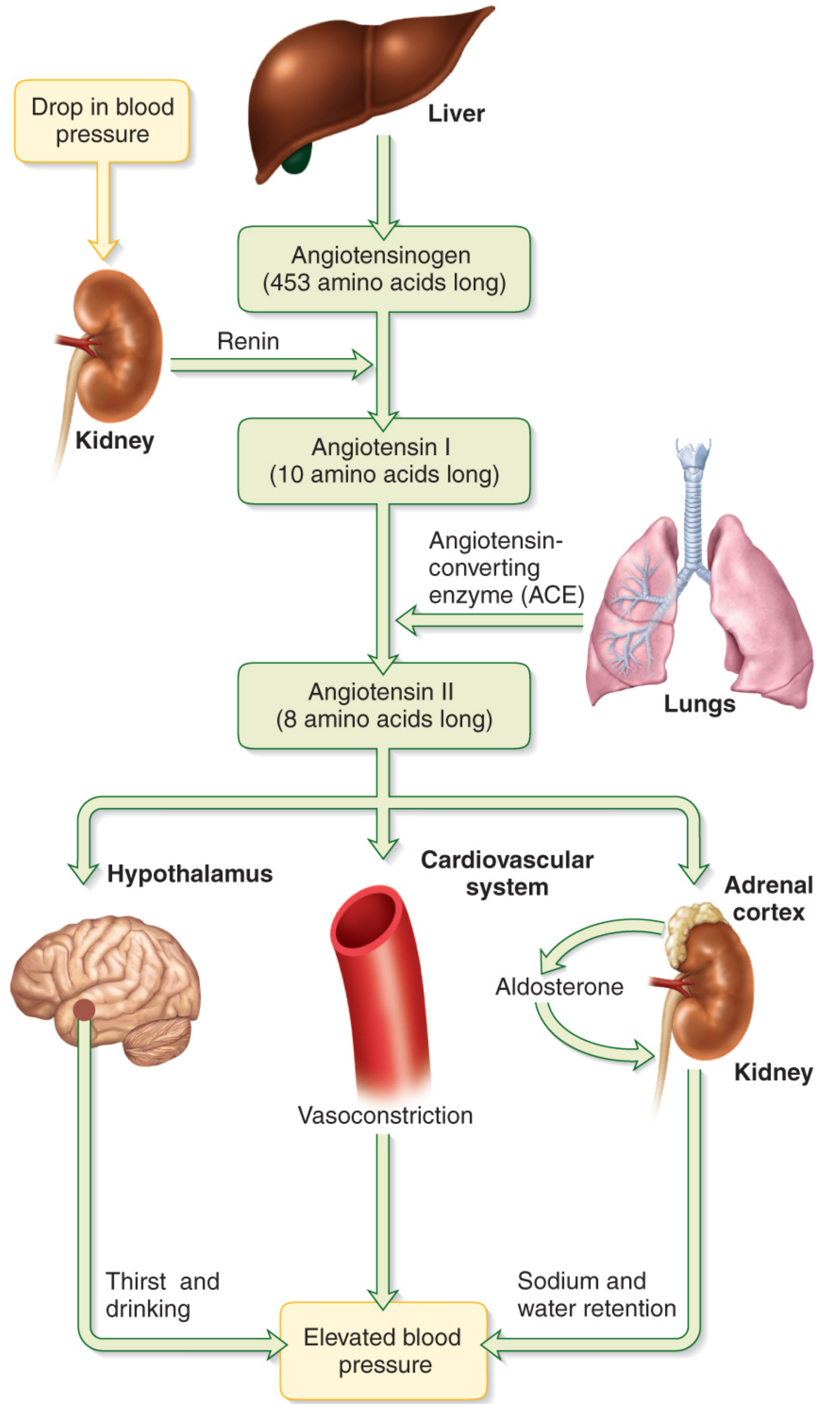


Figure 23.14

Renin-Angiotensin-Aldosterone Mechanism

- ***renin*** secreted by juxtaglomerular cells if BP drops dramatically
- renin converts **angiotensinogen**, a blood protein, into **angiotensin I**
- in the **lungs and kidneys**, **angiotensin-converting enzyme (ACE)** converts angiotensin I to **angiotensin II**, the active hormone
  - works in several ways to restore fluid volume and BP


Drop in blood pressure
Liver
Angiotensinogen (453 amino acids long)
Renin
Kidney
Angiotensin I (10 amino acids long)
Angiotensin-converting enzyme (ACE)
Lungs
Angiotensin II (8 amino acids long)
Hypothalamus
Cardiovascular system
Adrenal cortex
Aldosterone
Kidney
Vasoconstriction
Thirst and drinking
Sodium and water retention
Elevated blood pressure

Hormonal Control Blood Pressure

- High Blood Pressure
  - ANP (atrial natriuretic peptide) secreted
  - Increase water loss, decrease blood volume
  - Decrease blood pressure
- Low Blood Pressure
  - Renin leads to Angiotensin II activation
  - Angiotensin II causes release of Aldosterone and ADH (antidiuretic hormone)
  - Water retention, increased blood volume
  - Increase blood pressure

Blood Pressure Homones

- ANP – decrease blood volume – decrease blood pressure
- Aldosterone and ADH – increase blood volume – increase blood pressure