(a) The urinary system

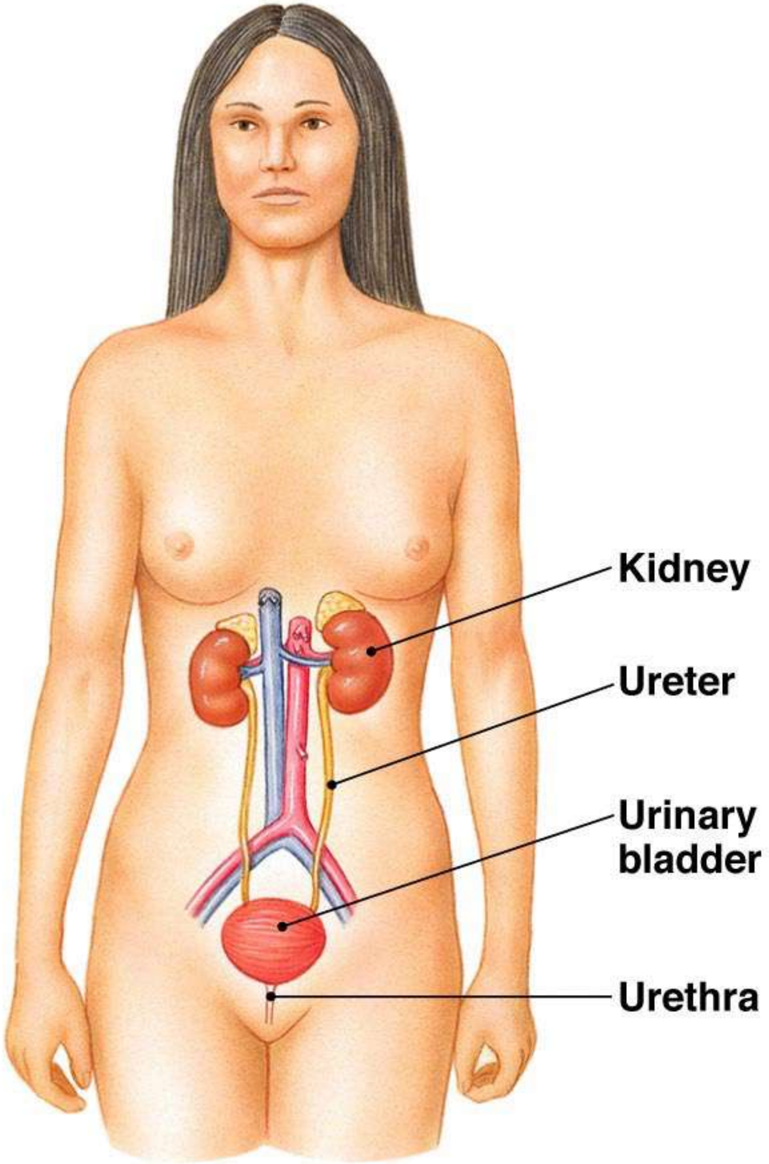


Figure 19-1a

(b) The kidneys are located retroperitoneally at the level of the lower ribs.

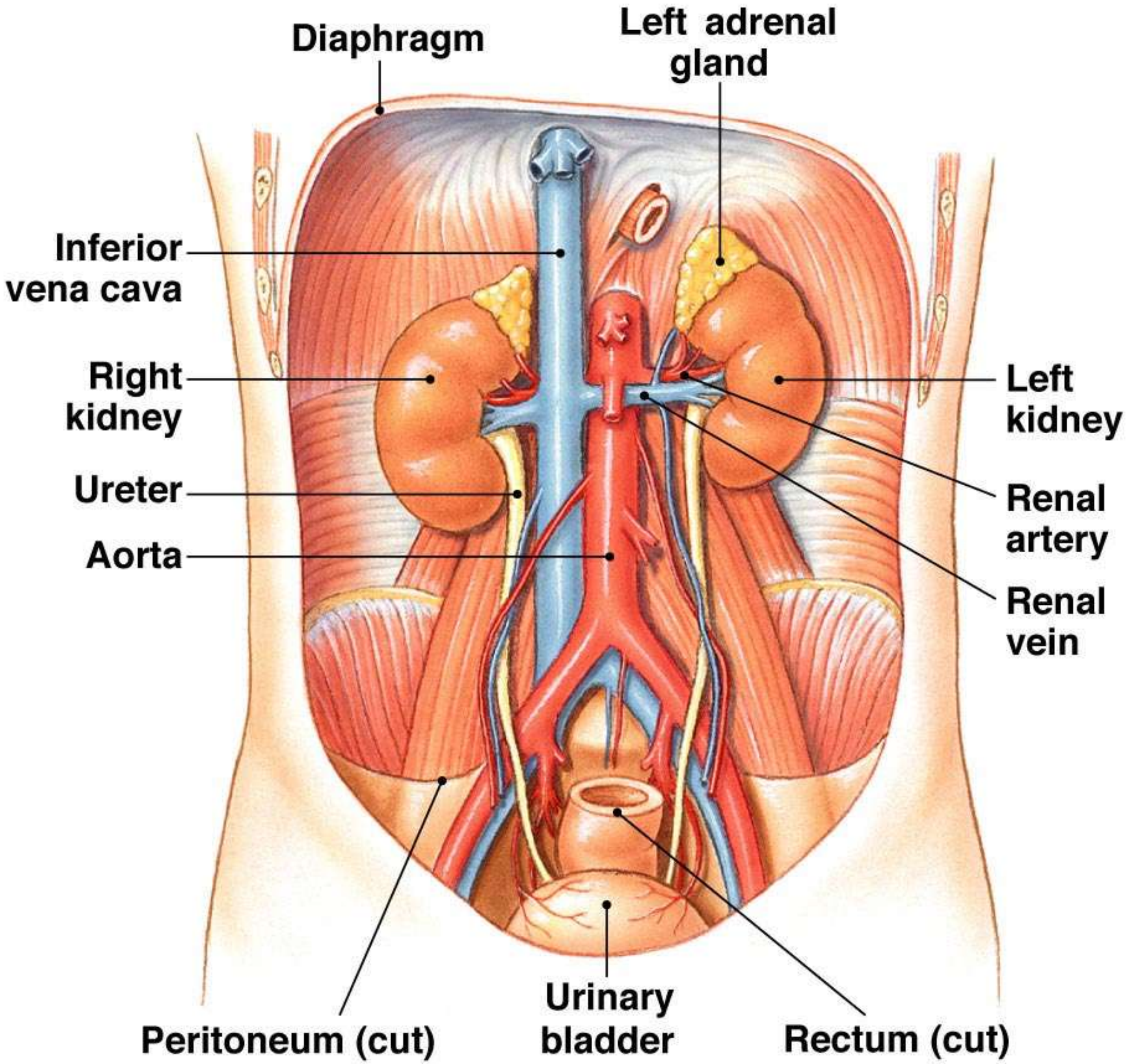


Figure 19-1b

(c) In cross section, the kidney is divided into an outer cortex and an inner medulla. Urine leaving the nephrons flows into the renal pelvis prior to passing through the ureter into the bladder.

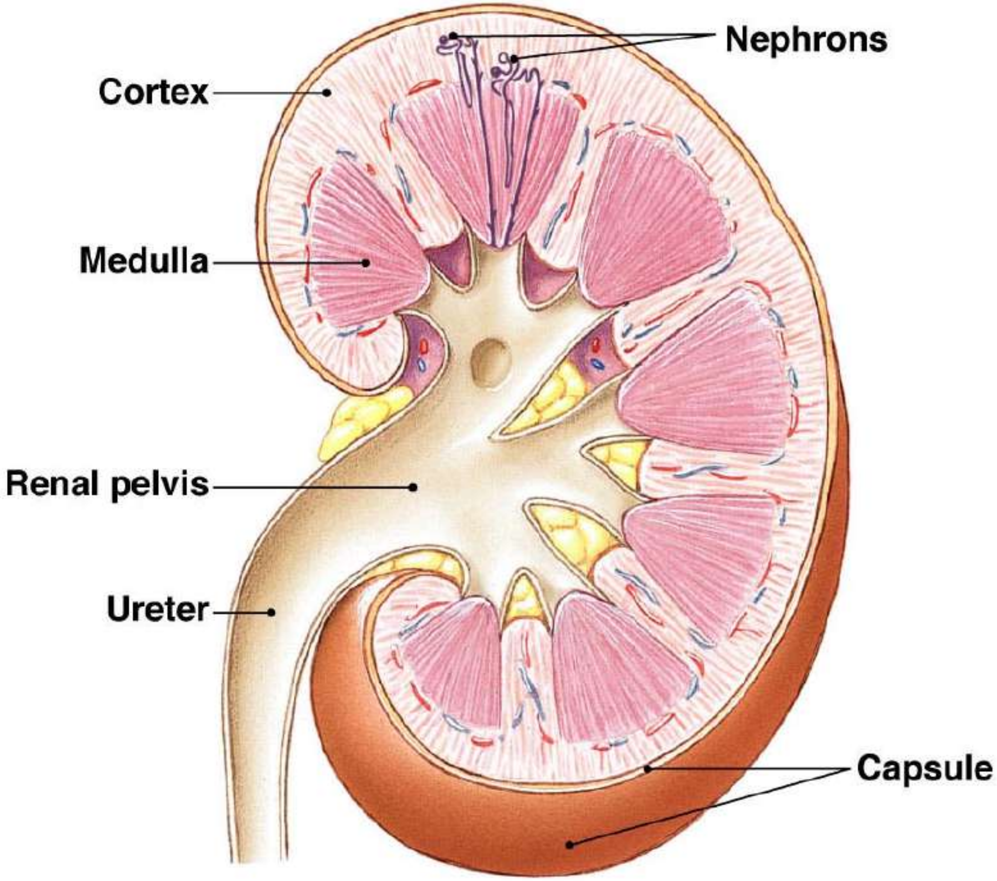
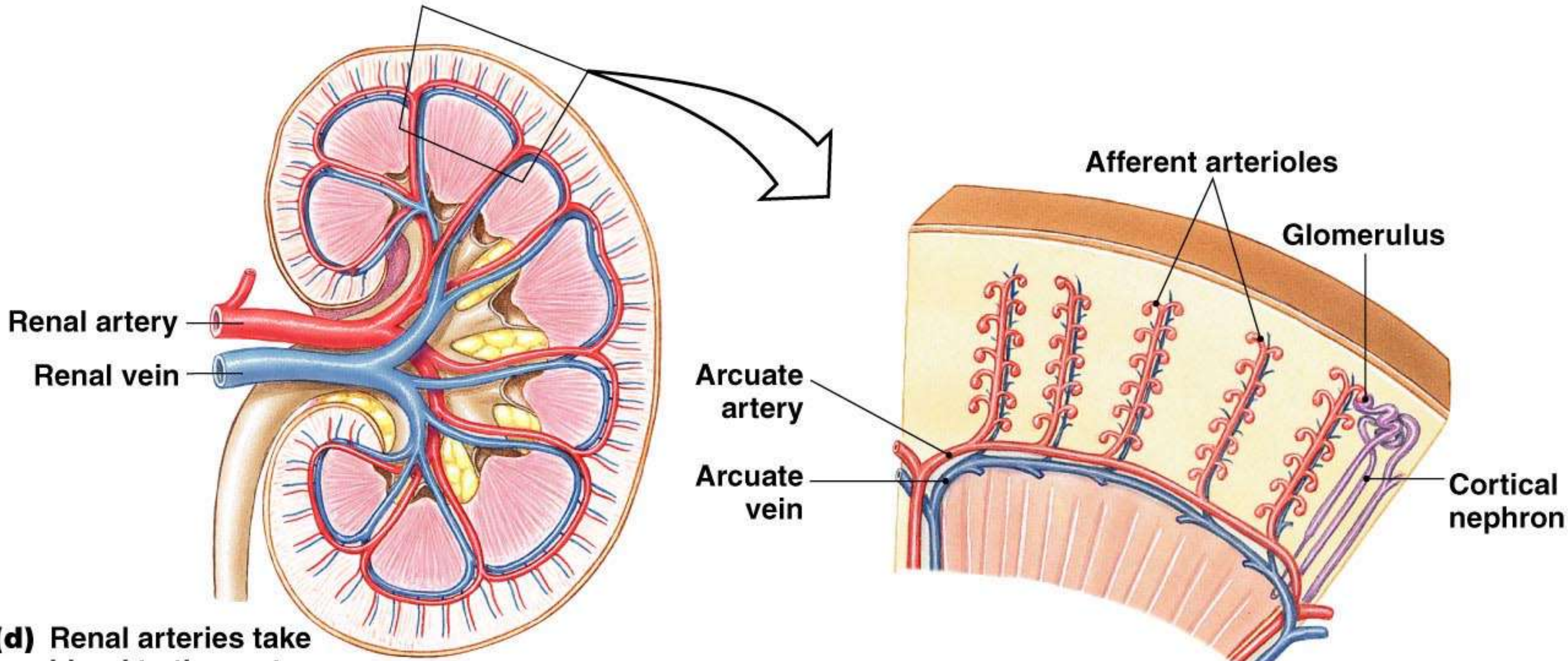


Figure 19-1c

STRUCTURE OF THE KIDNEY

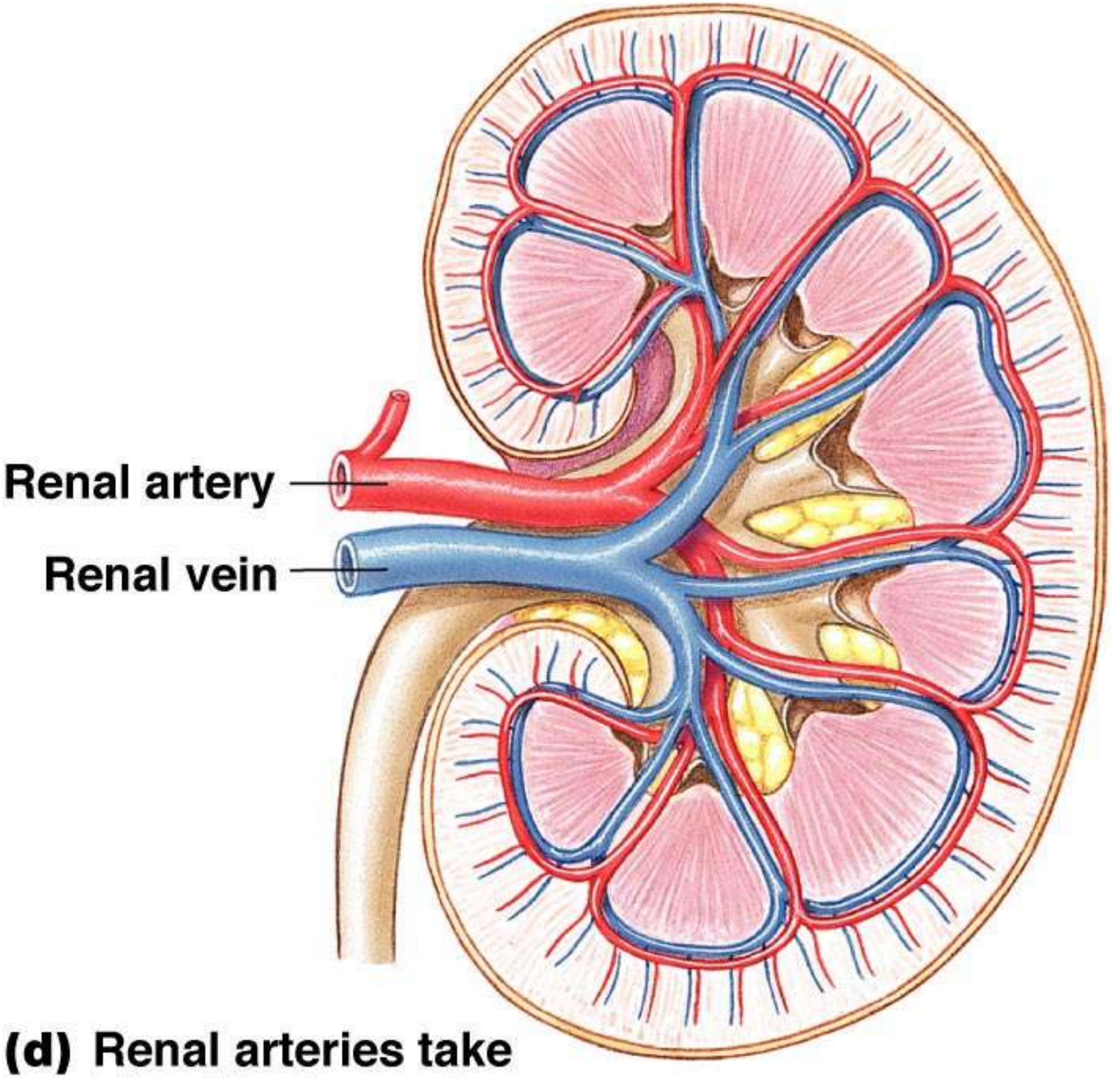


(d) Renal arteries take blood to the cortex.

(e) Afferent arterioles and glomeruli are all found in the cortex.

Figure 19-1d–e

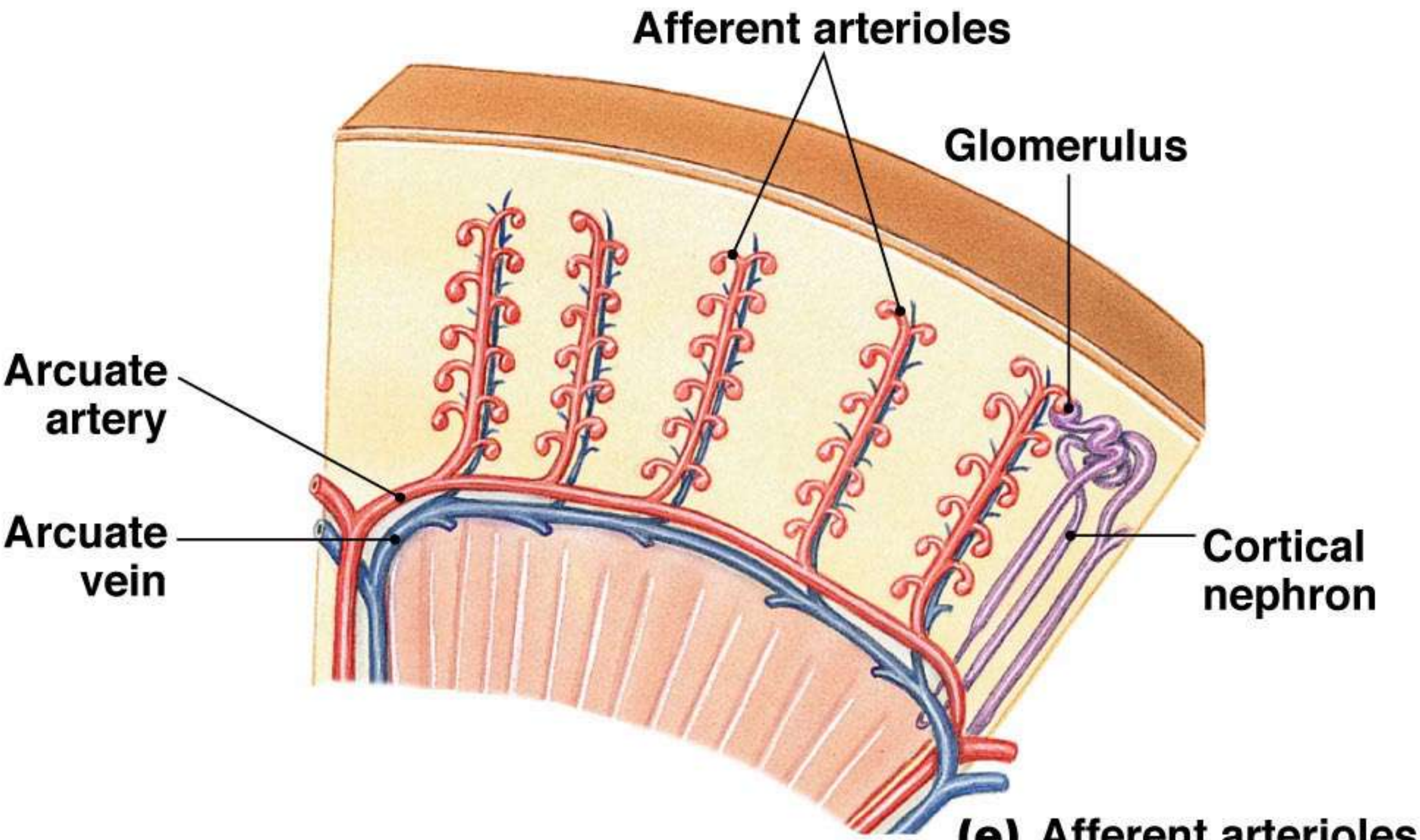
STRUCTURE OF THE KIDNEY



(d) Renal arteries take blood to the cortex.

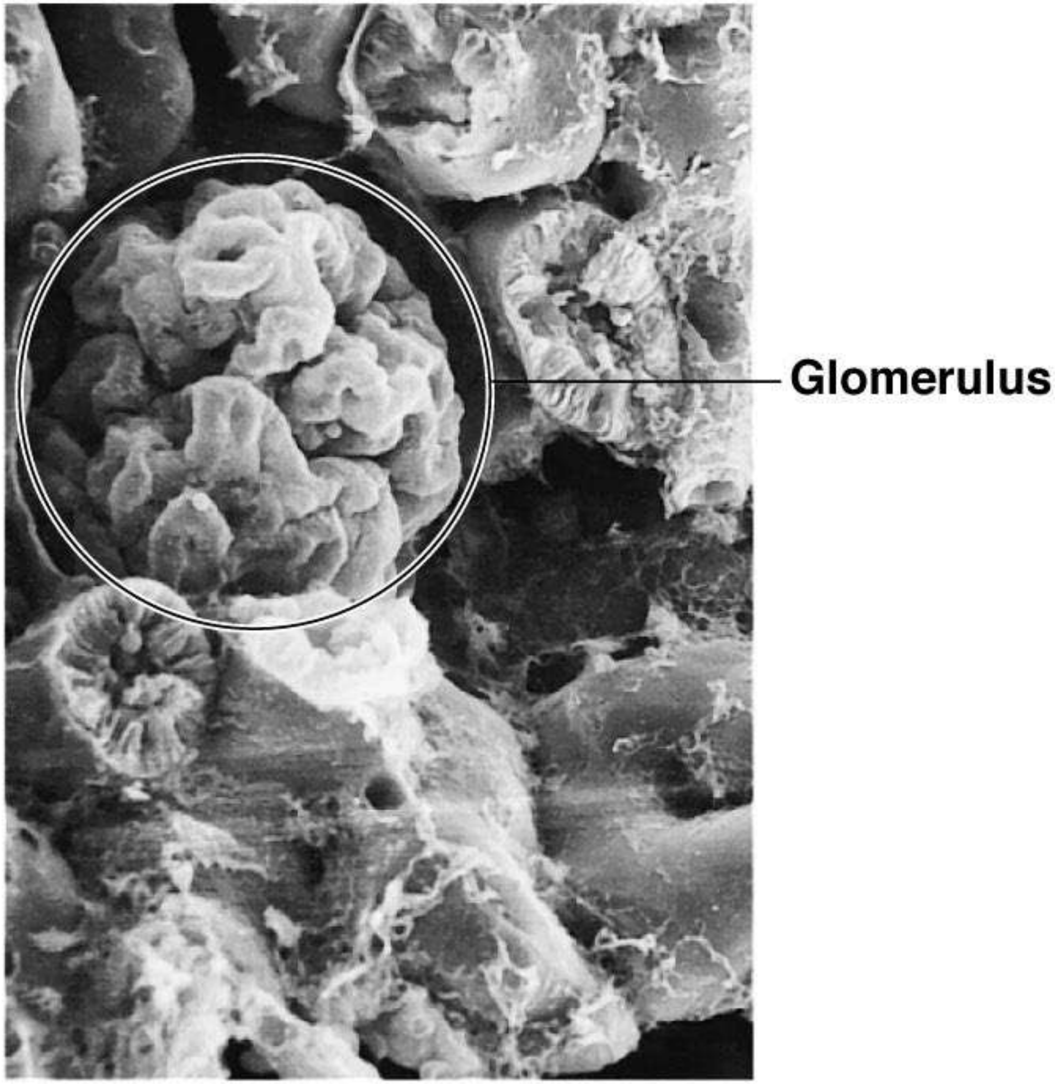
Figure 19-1d

STRUCTURE OF THE KIDNEY



(e) **Afferent arterioles and glomeruli are all found in the cortex.**

(f) The capillaries of the glomerulus form a ball-like mass.



(g) Each nephron has two arterioles and two sets of capillaries associated with it.

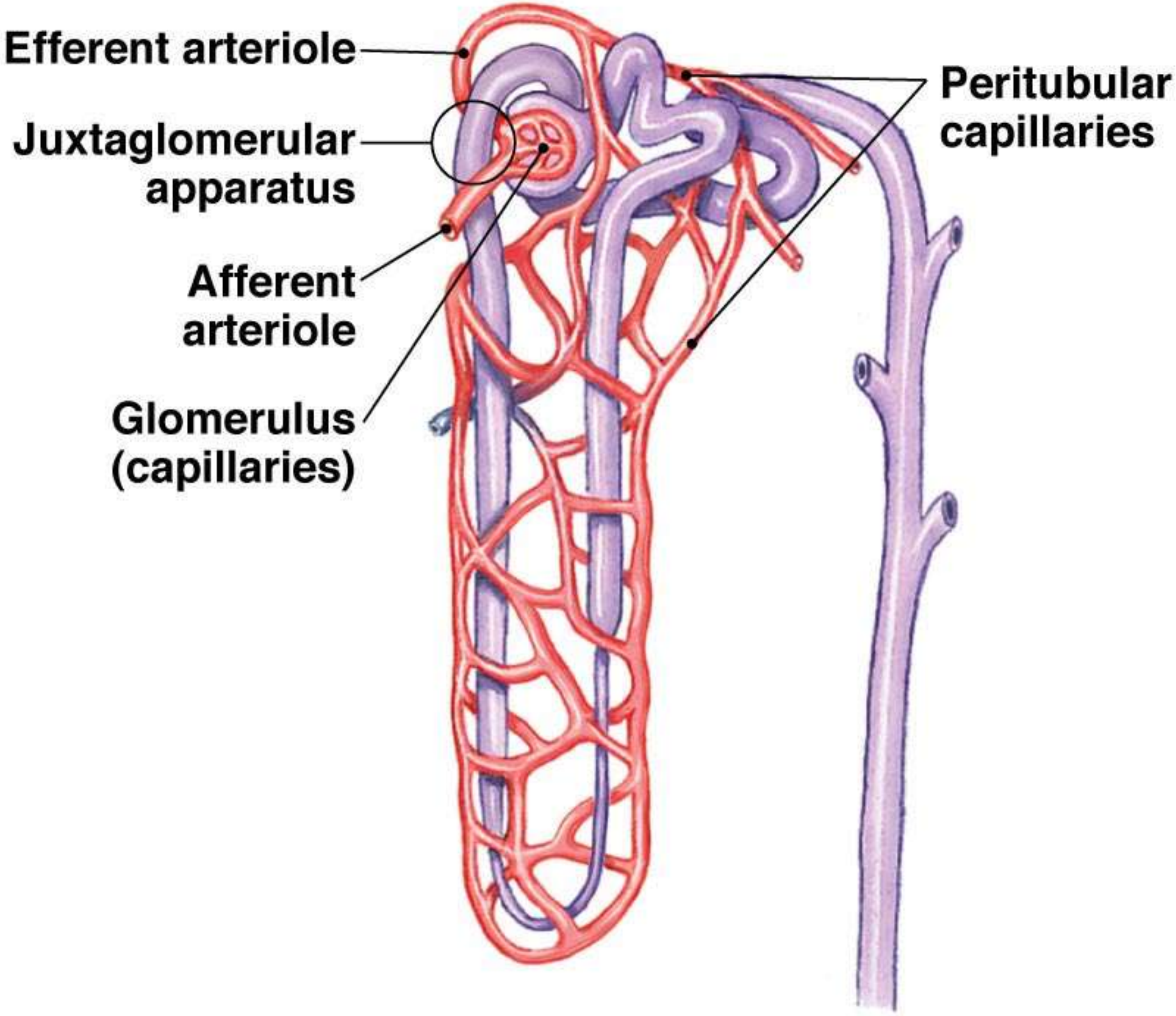


Figure 19-1g

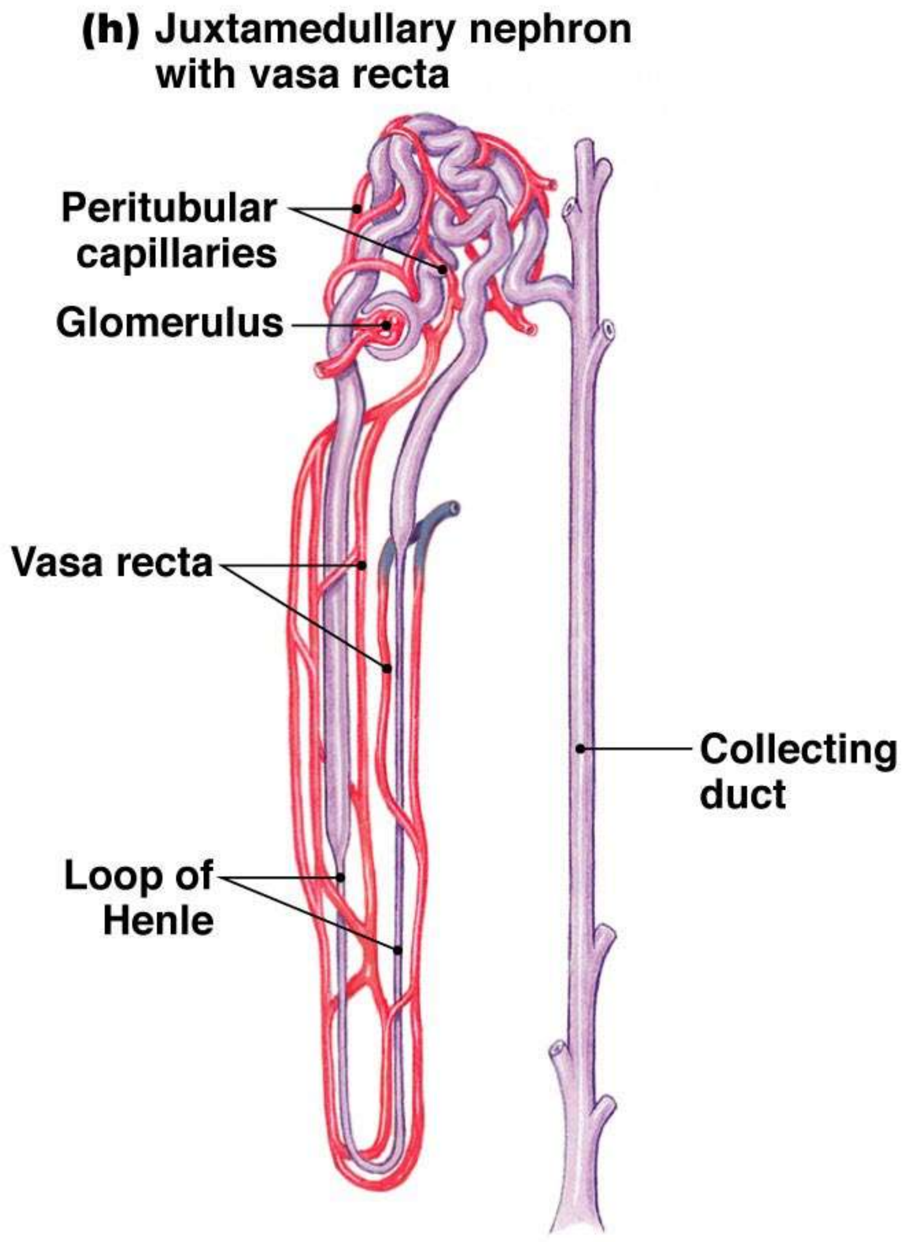
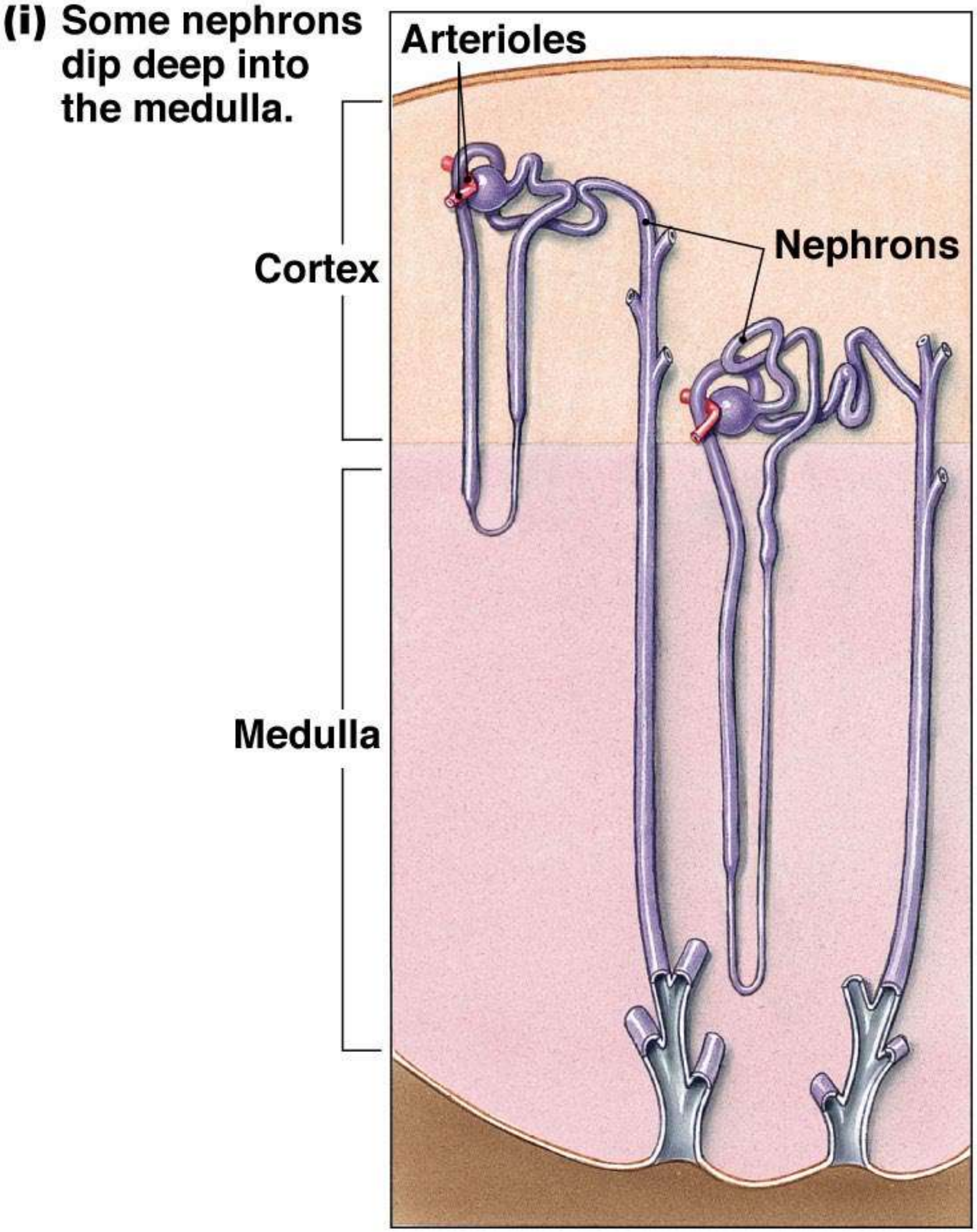

(h) Juxtamedullary nephron
with vasa recta
Peritubular
capillaries
Glomerulus
Vasa recta
Loop of
Henle
Collecting
duct

Figure 19-1h



(i) Some nephrons dip deep into the medulla.
Arterioles
Nephrons
Cortex
Medulla

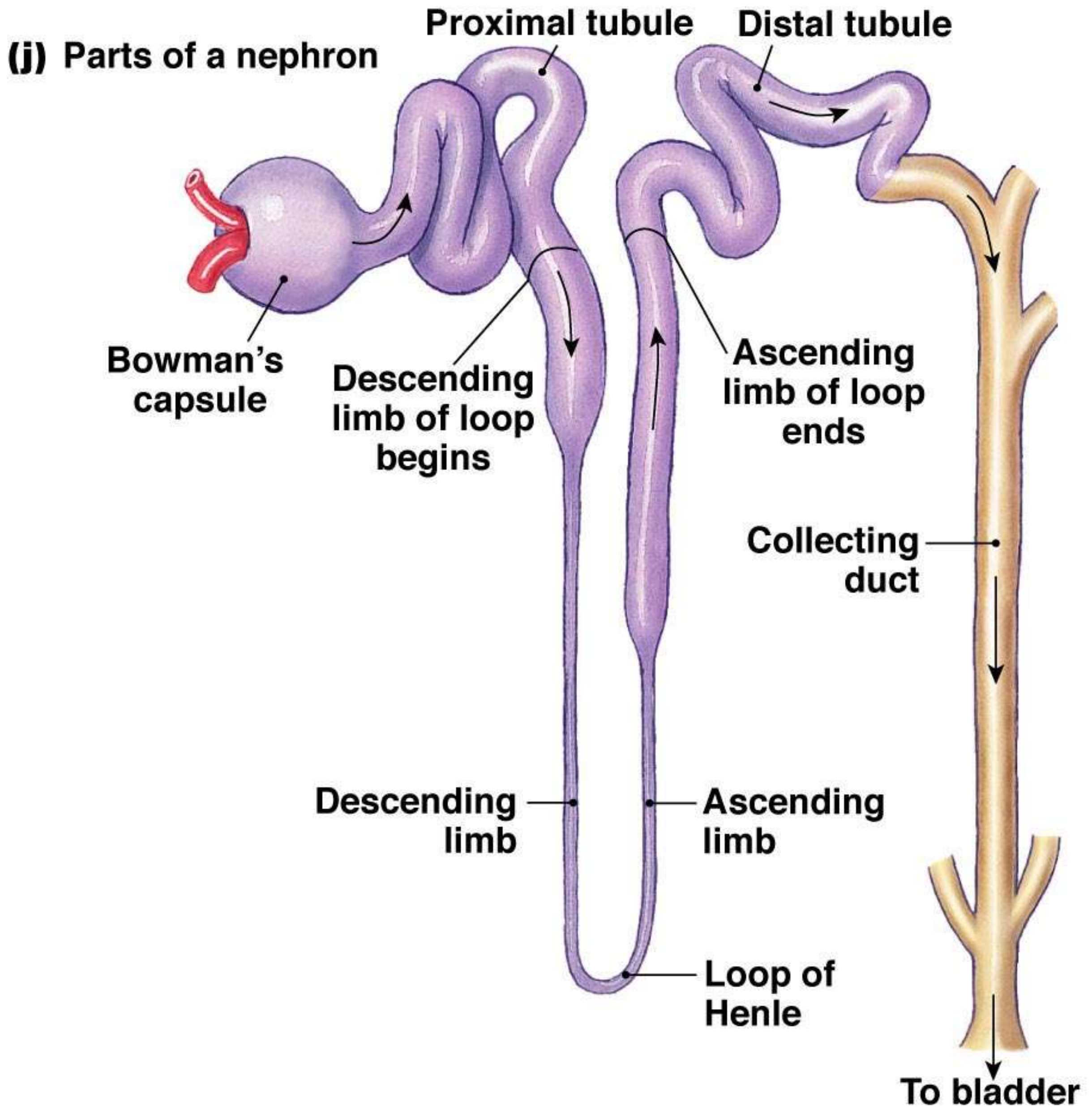

(j) Parts of a nephron
Proximal tubule
Distal tubule
Bowman's capsule
Descending limb of loop begins
Ascending limb of loop ends
Collecting duct
Descending limb
Ascending limb
Loop of Henle
To bladder

Figure 19-1j

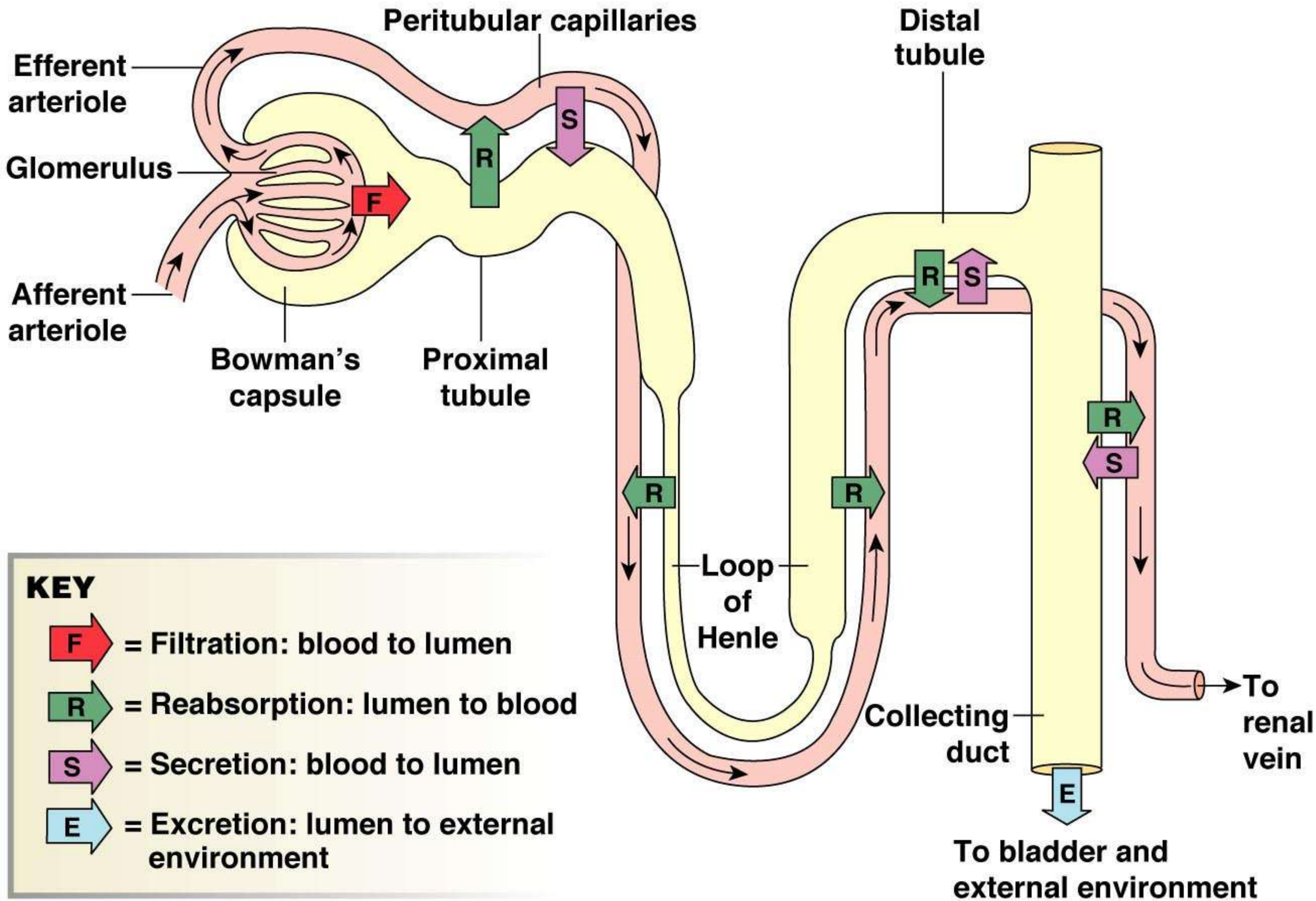
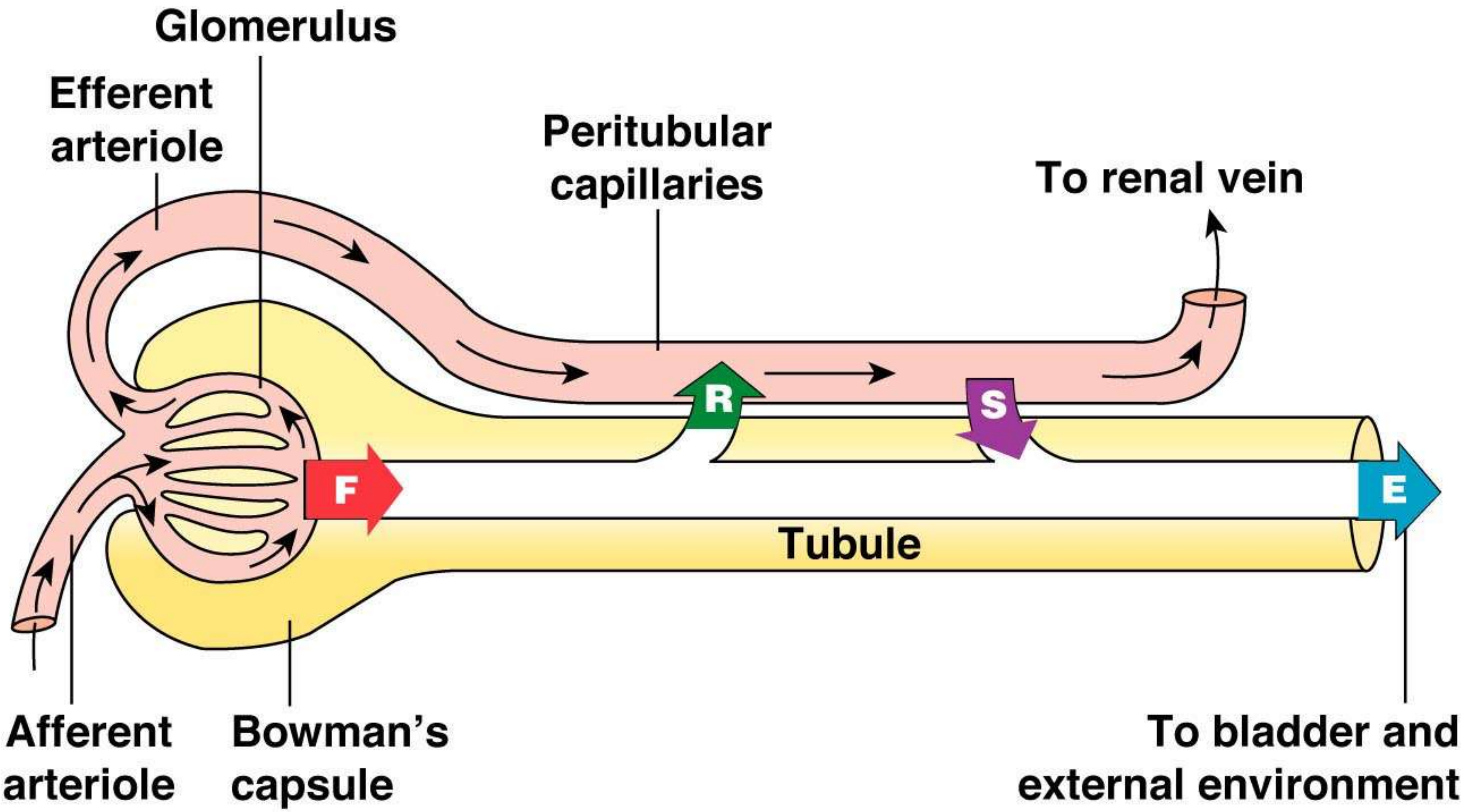

Peritubular capillaries
Distal tubule
Efferent arteriole
Glomerulus
Afferent arteriole
Bowman's capsule
Proximal tubule
F
R
S
R
S
R
R
R
S
Loop of Henle
Collecting duct
To renal vein
E
To bladder and external environment
KEY
F = Filtration: blood to lumen
R = Reabsorption: lumen to blood
S = Secretion: blood to lumen
E = Excretion: lumen to external environment

Figure 19-2

TABLE 19-1 Changes in Filtrate Volume and Osmolarity Along the Nephron

LOCATION IN NEPHRON	VOLUME OF FLUID	OSMOLARITY OF FLUID
Bowman's capsule	180 L/day	300 mOsM
End of proximal tubule	54 L/day	300 mOsM
End of loop of Henle	18 L/day	100 mOsM
End of collecting duct (final urine)	1.5 L/day (average)	50–1200 mOsM



Amount filtered (F) − amount reabsorbed (R) + amount secreted (S) = Amount of solute excreted (E)

Figure 19-3

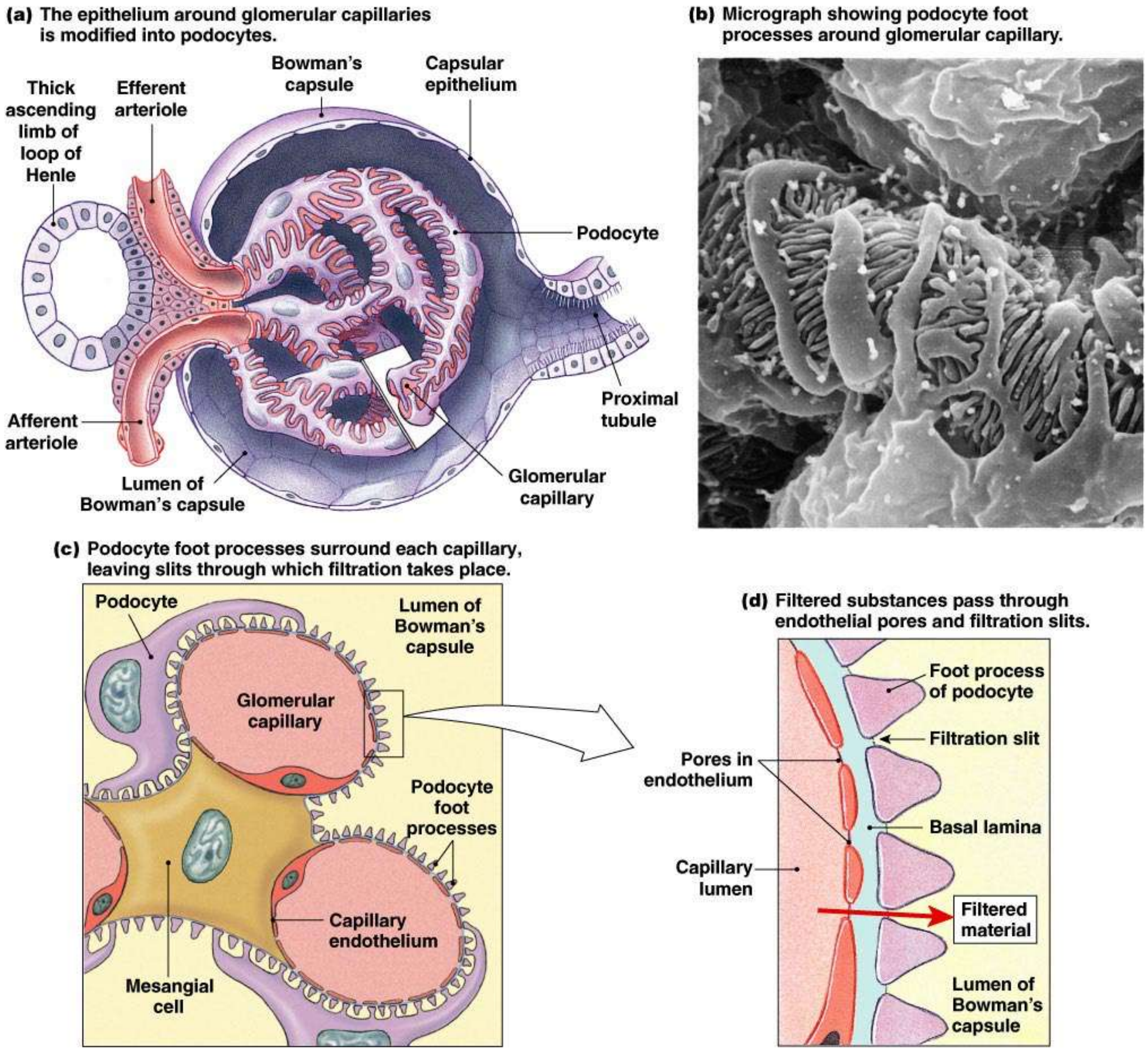


Figure 19-4 Overview

(a) The epithelium around glomerular capillaries is modified into podocytes.

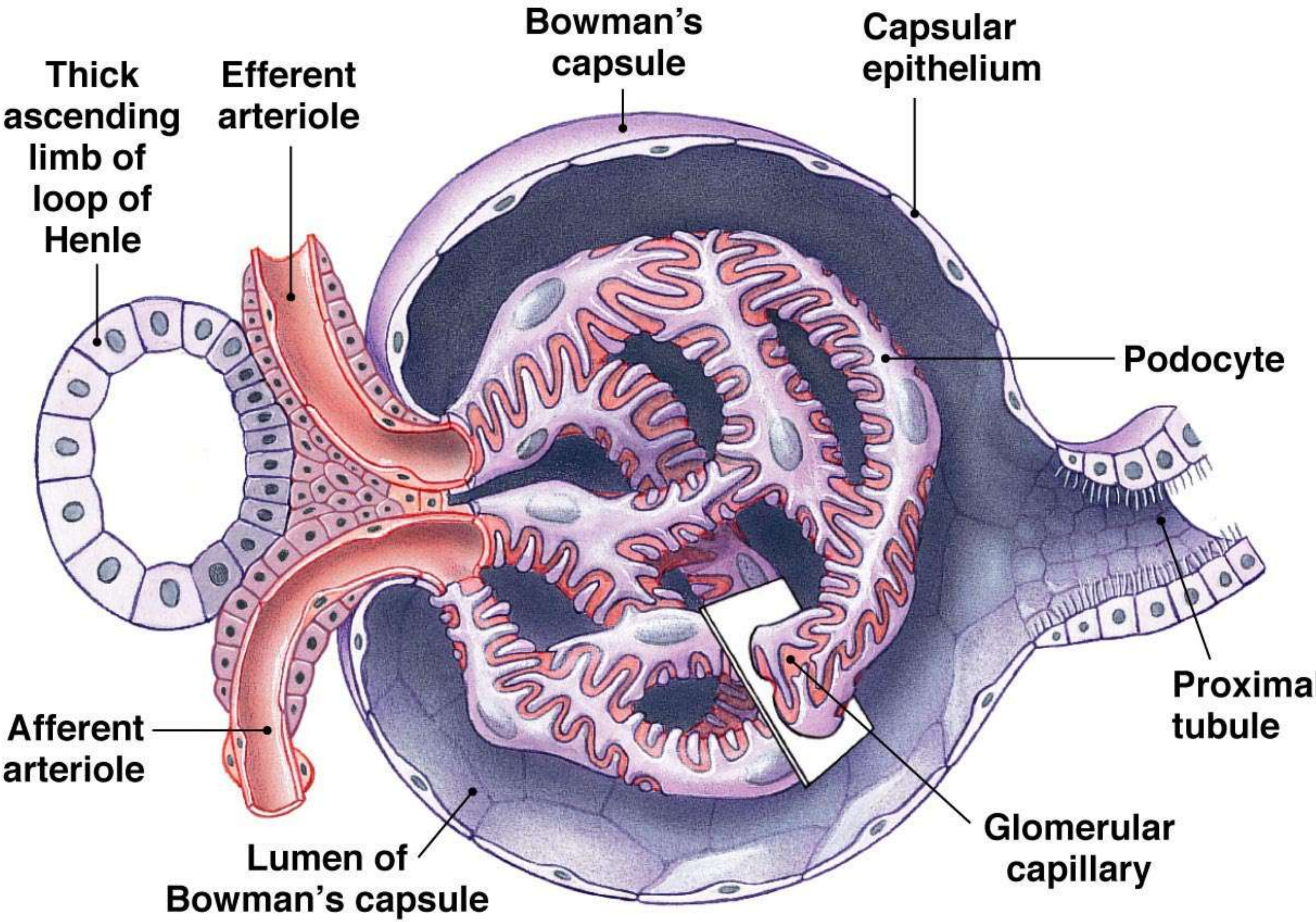


Figure 19-4a

(b) Micrograph showing podocyte foot processes around glomerular capillary.

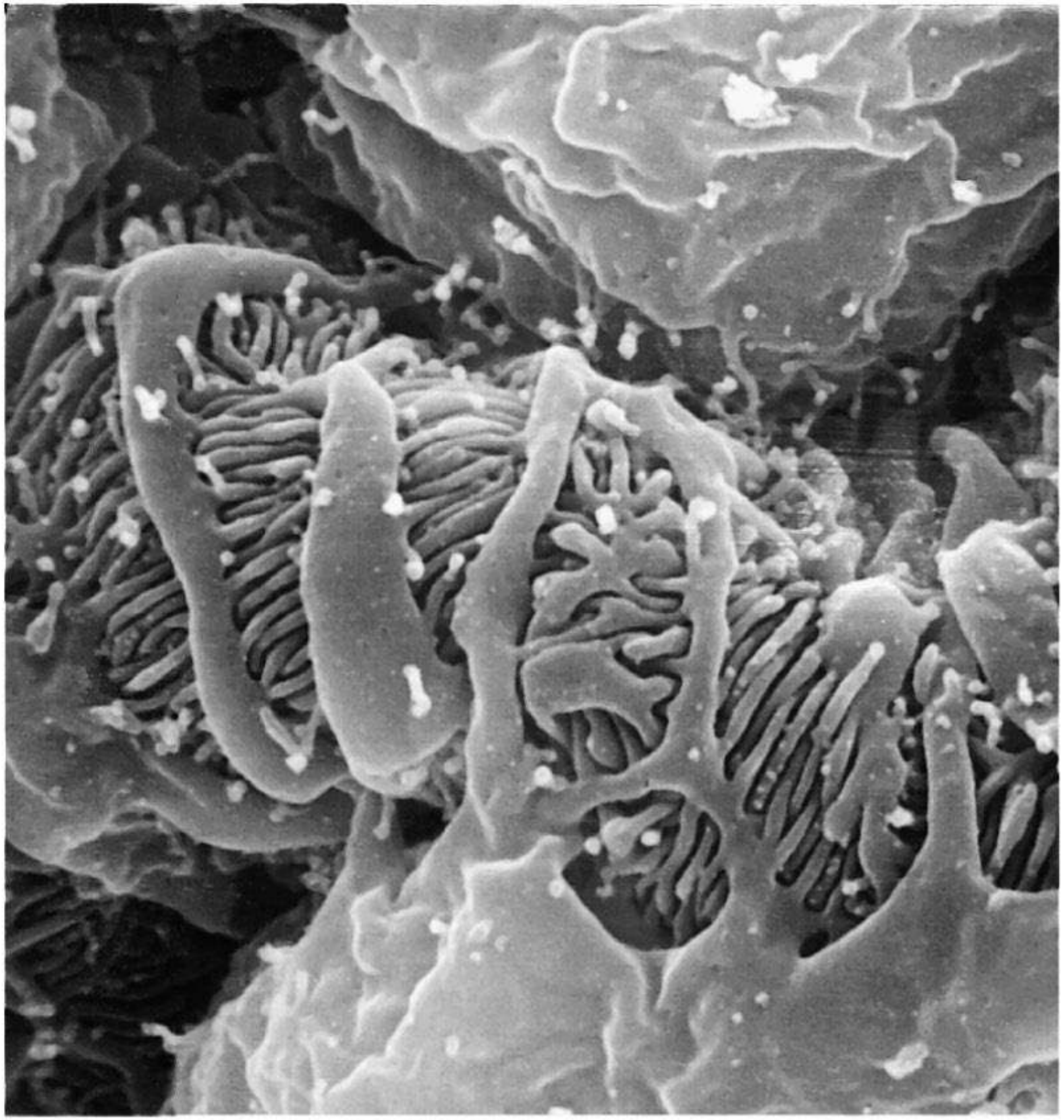


Figure 19-4b

(c) Podocyte foot processes surround each capillary, leaving slits through which filtration takes place.

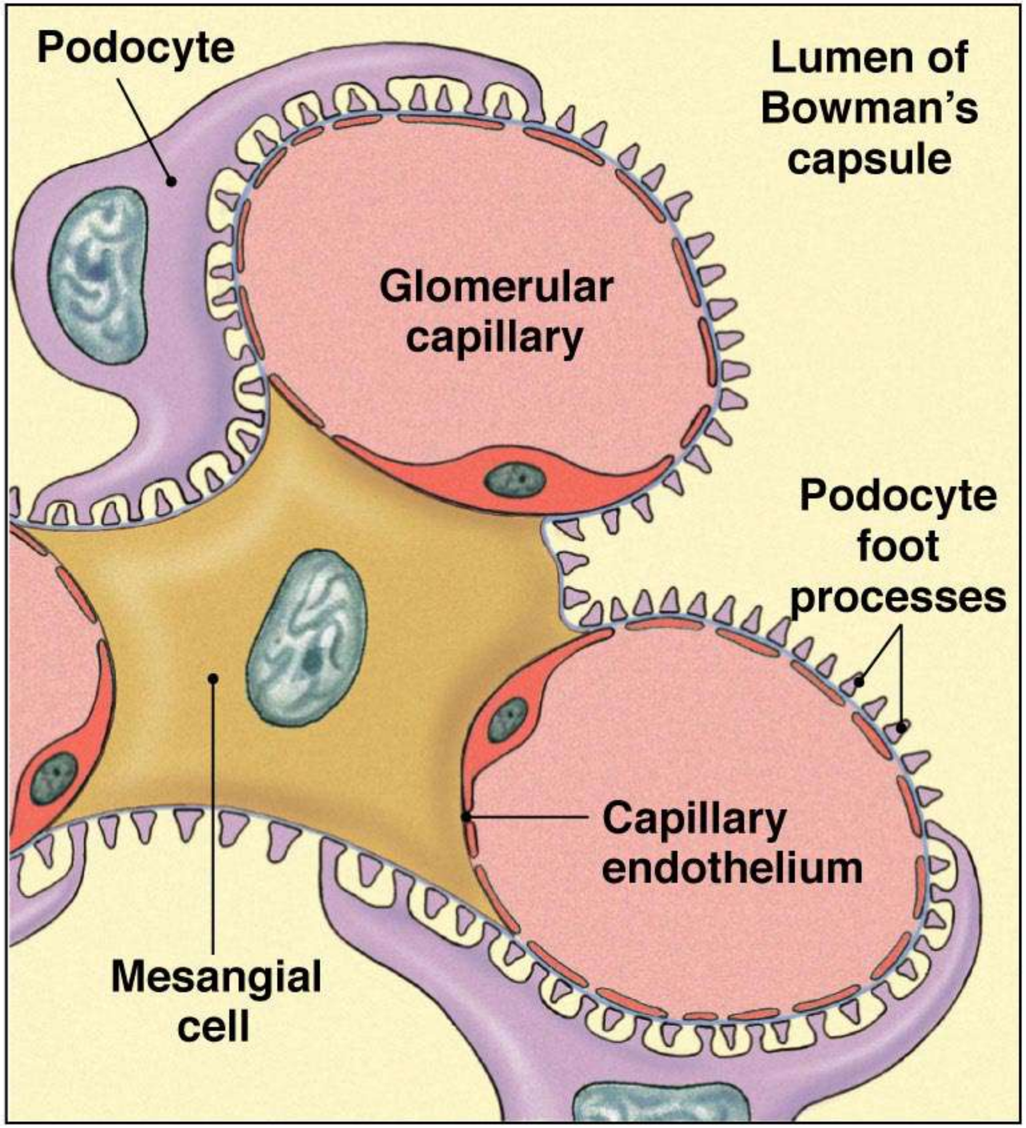


Figure 19-4c

(d) Filtered substances pass through endothelial pores and filtration slits.

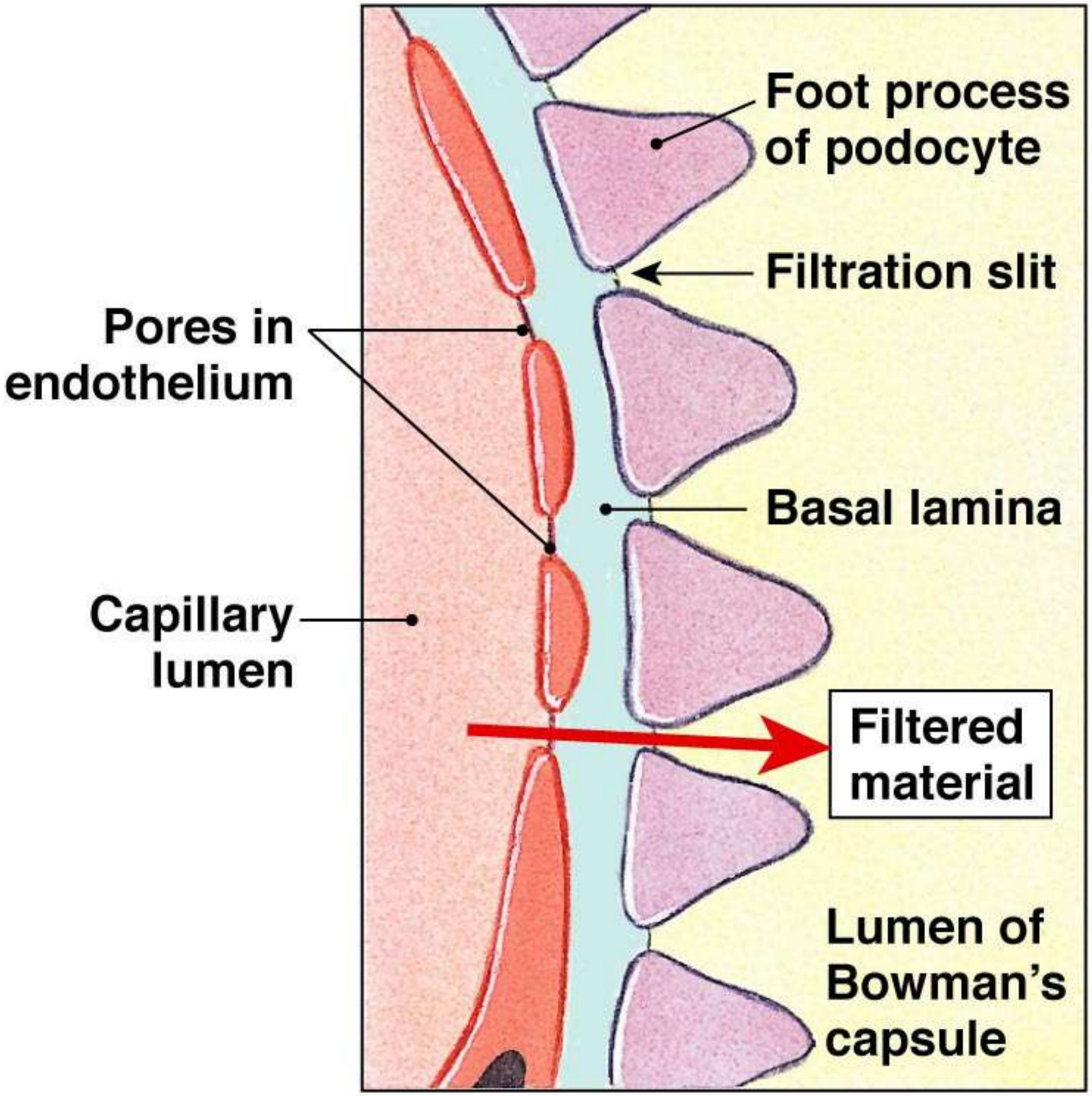


Figure 19-4d

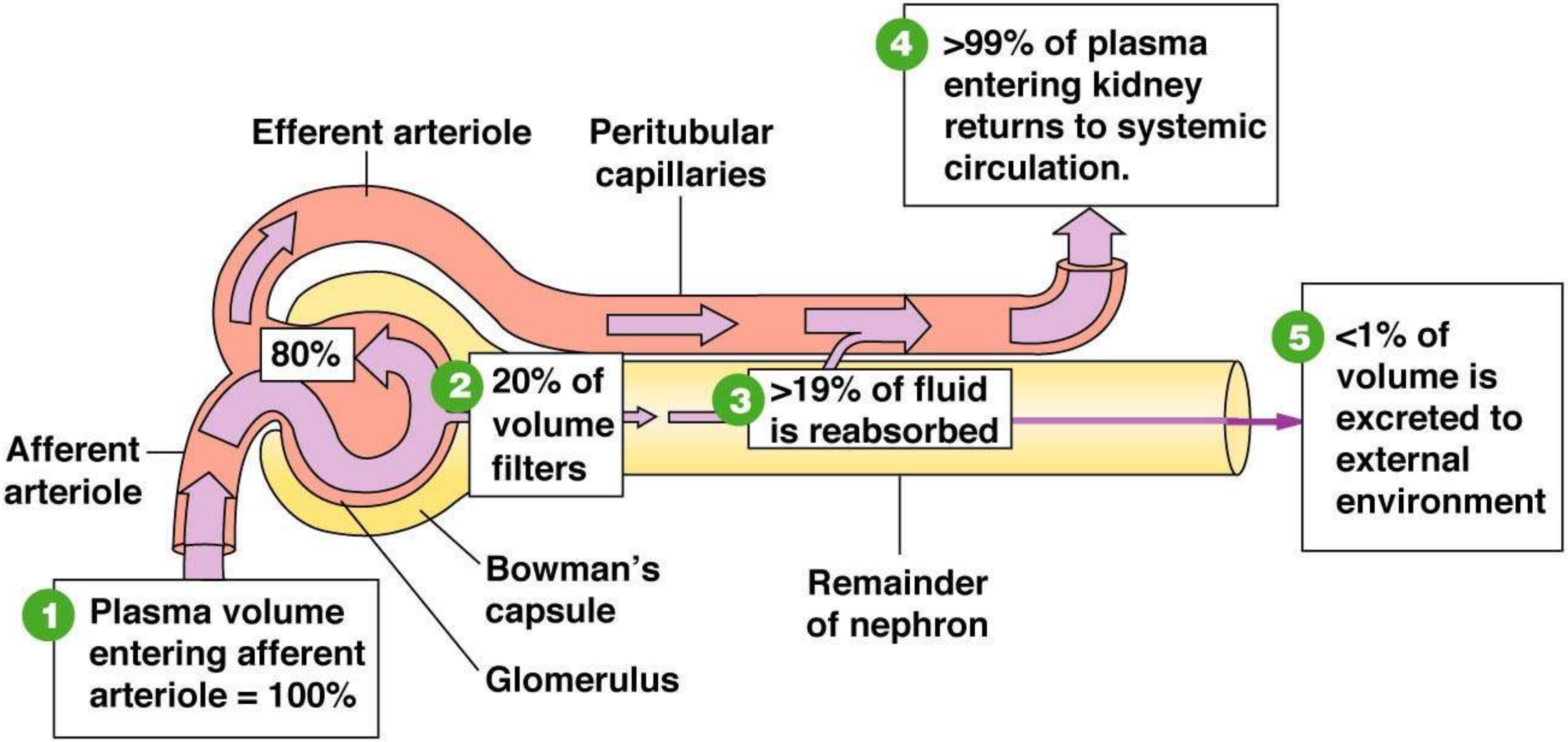
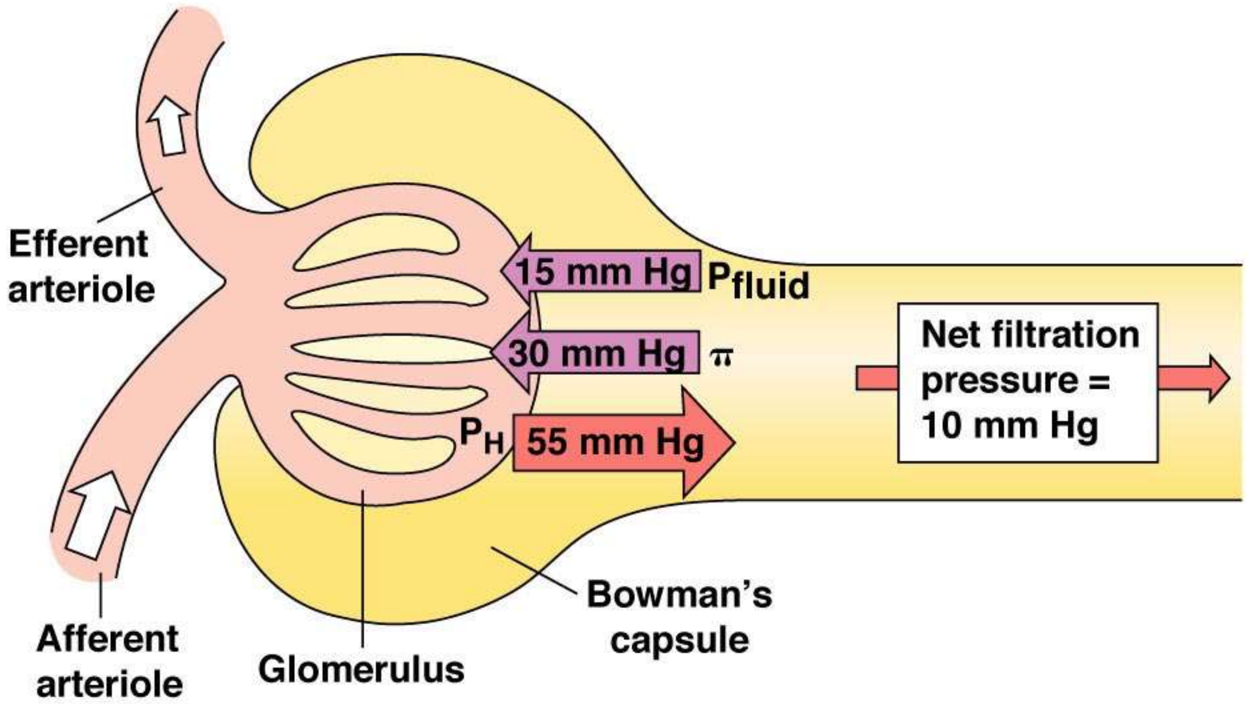

Efferent arteriole
Peritubular capillaries
4 >99% of plasma entering kidney returns to systemic circulation.
80%
2 20% of volume filters
3 >19% of fluid is reabsorbed
5 <1% of volume is excreted to external environment
Afferent arteriole
Bowman's capsule
Remainder of nephron
1 Plasma volume entering afferent arteriole = 100%
Glomerulus

Figure 19-5



$$P_H - \pi - P_{fluid} = \text{net filtration pressure}$$

$$55 \text{ mm Hg} - 30 \text{ mm Hg} - 15 \text{ mm Hg} = 10 \text{ mm Hg}$$

KEY

P_H = Hydrostatic pressure (blood pressure)

π = Colloid osmotic pressure gradient due to proteins in plasma but not in Bowman's capsule

P_{fluid} = Fluid pressure created by fluid in Bowman's capsule

Figure 19-6

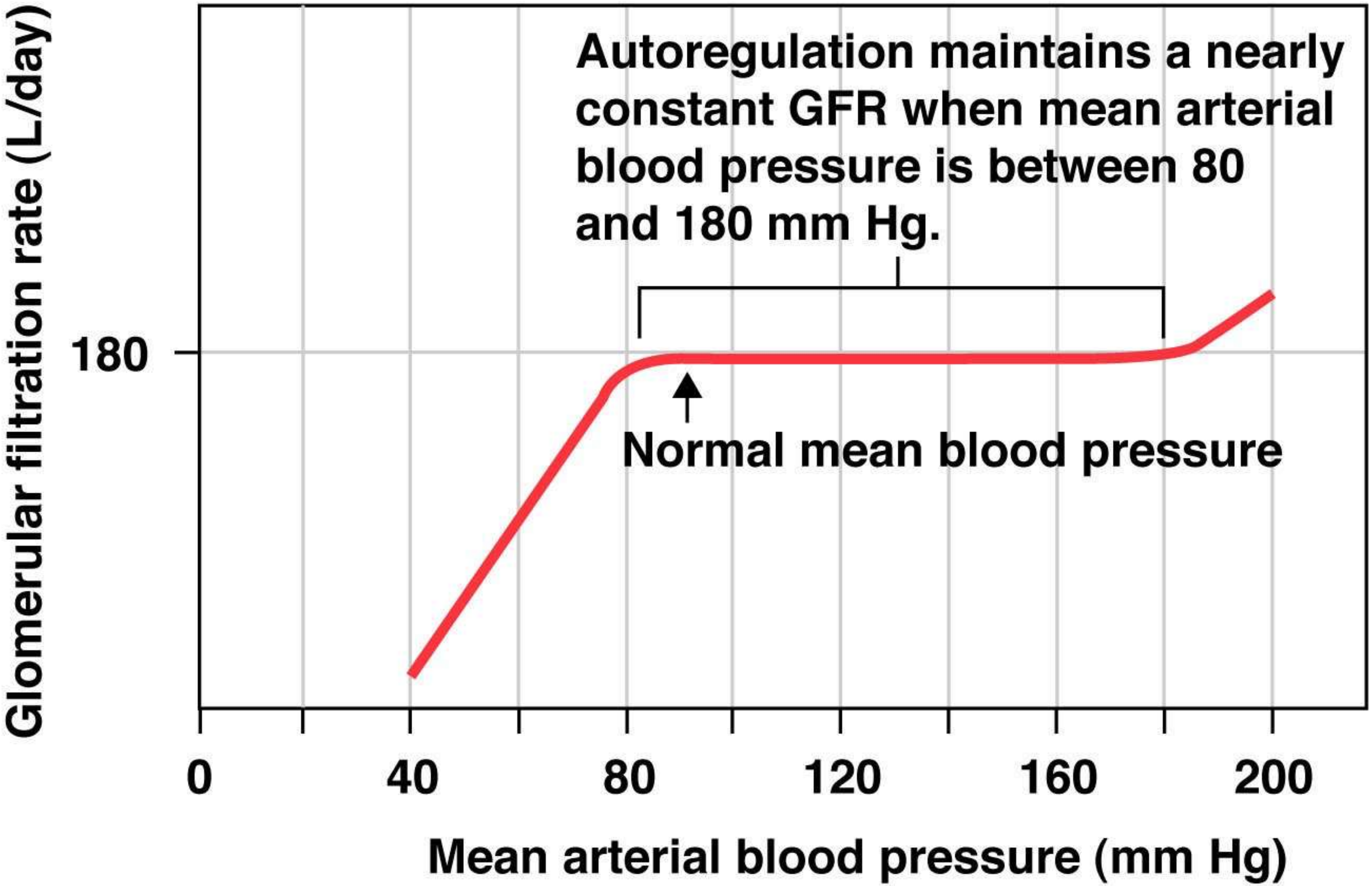

Glomerular filtration rate (L/day)
180
Autoregulation maintains a nearly constant GFR when mean arterial blood pressure is between 80 and 180 mm Hg.
Normal mean blood pressure
0
40
80
120
160
200
Mean arterial blood pressure (mm Hg)

Figure 19-7

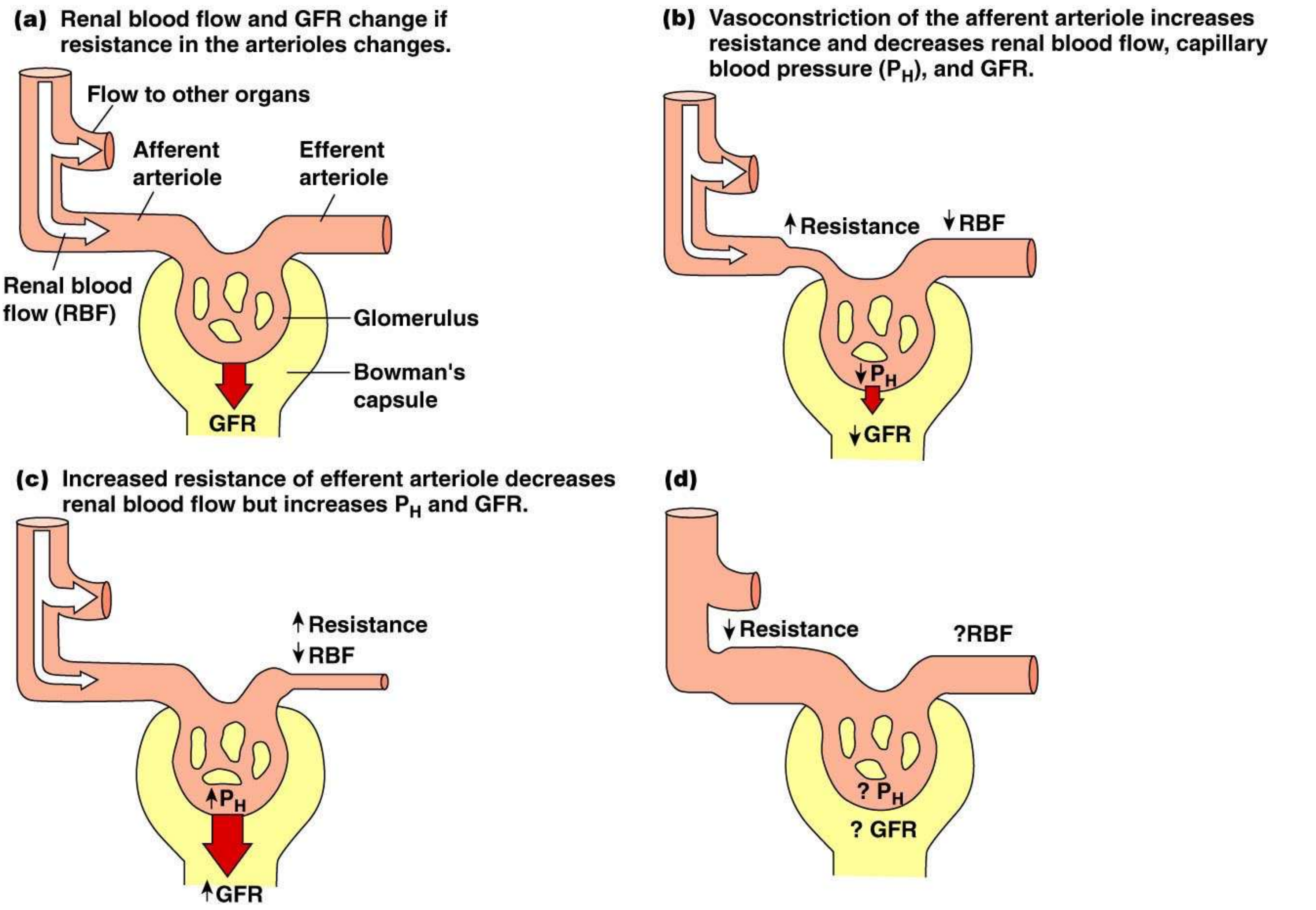


Figure 19-8 Overview

(a) Renal blood flow and GFR change if resistance in the arterioles changes.

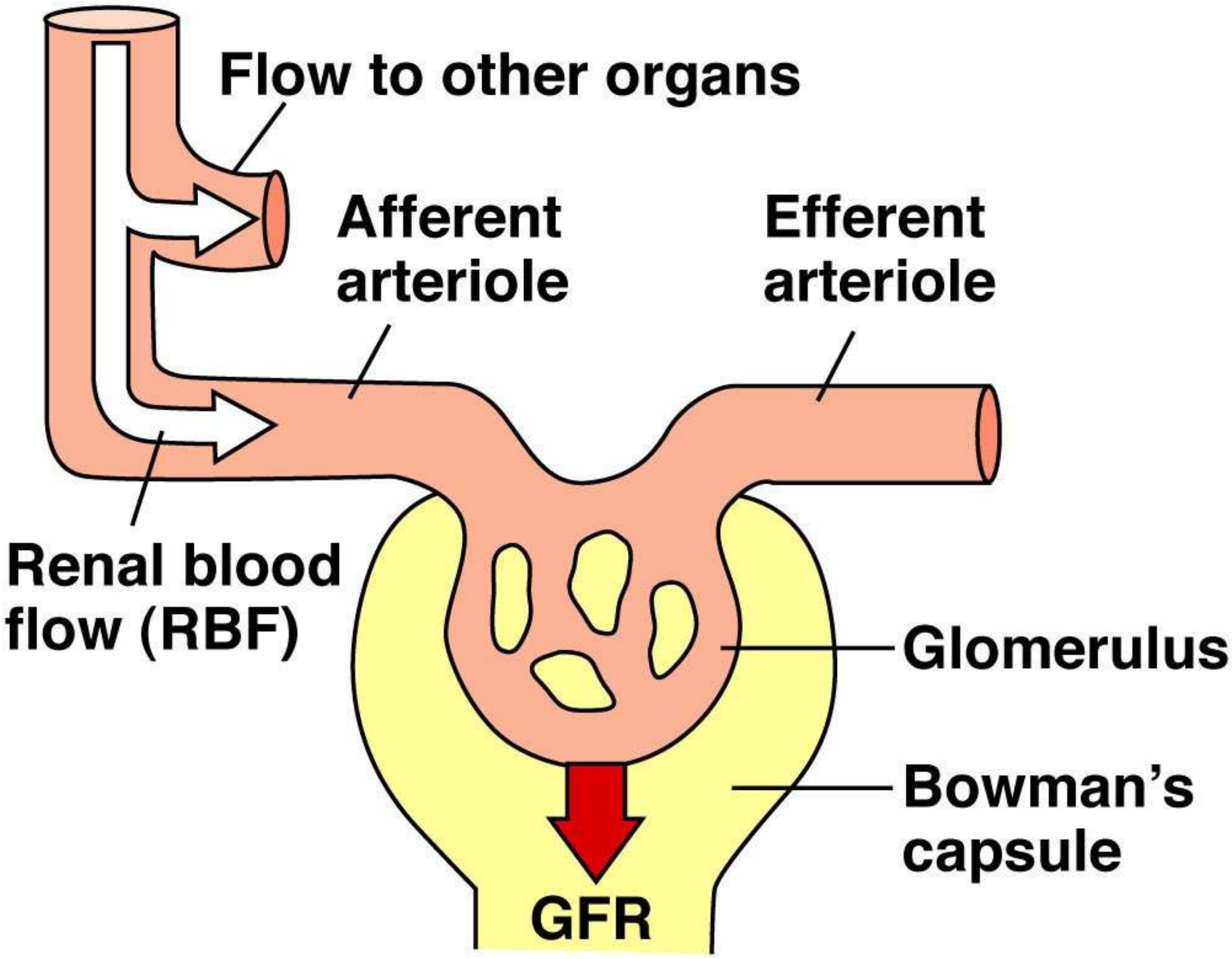


Figure 19-8a

(b) Vasoconstriction of the afferent arteriole increases resistance and decreases renal blood flow, capillary blood pressure (P_H), and GFR.

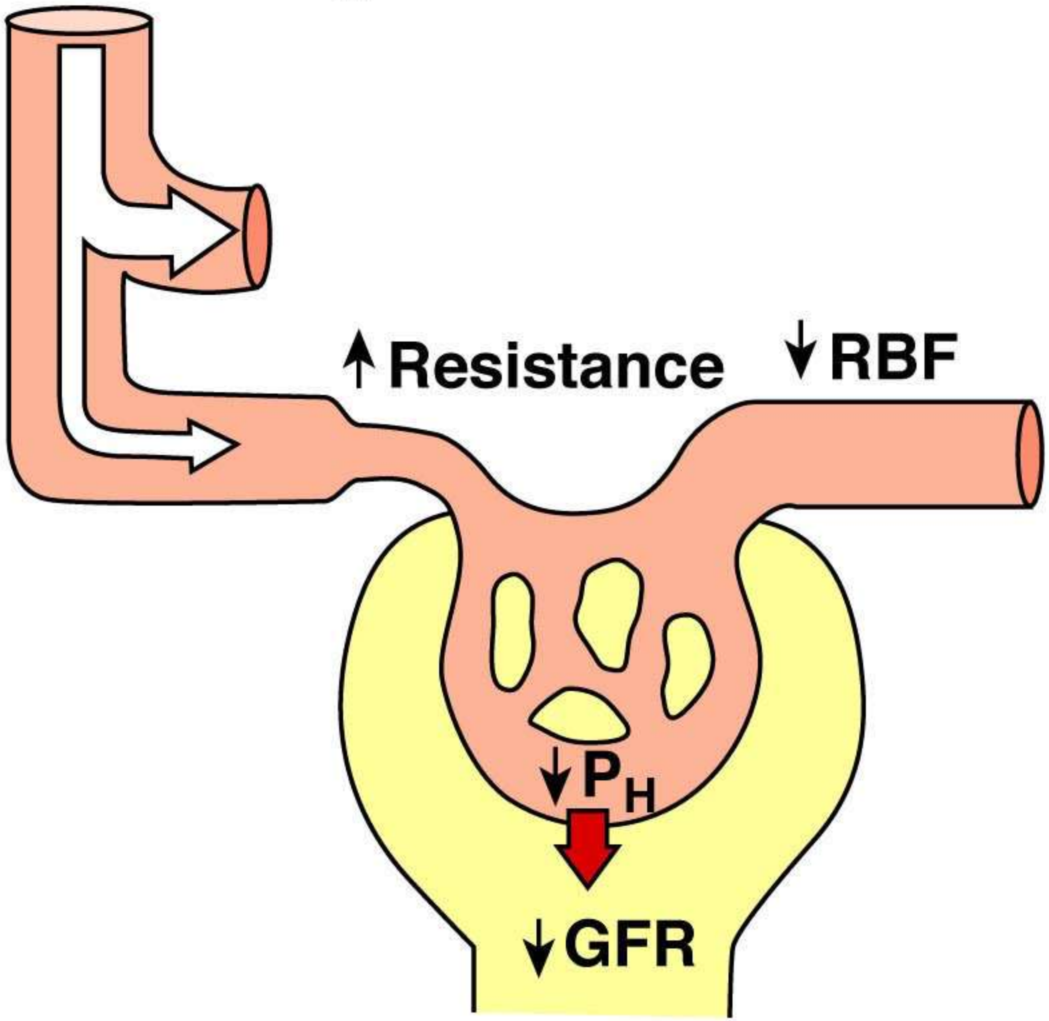


Figure 19-8b

(c) Increased resistance of efferent arteriole decreases renal blood flow but increases P_H and GFR.

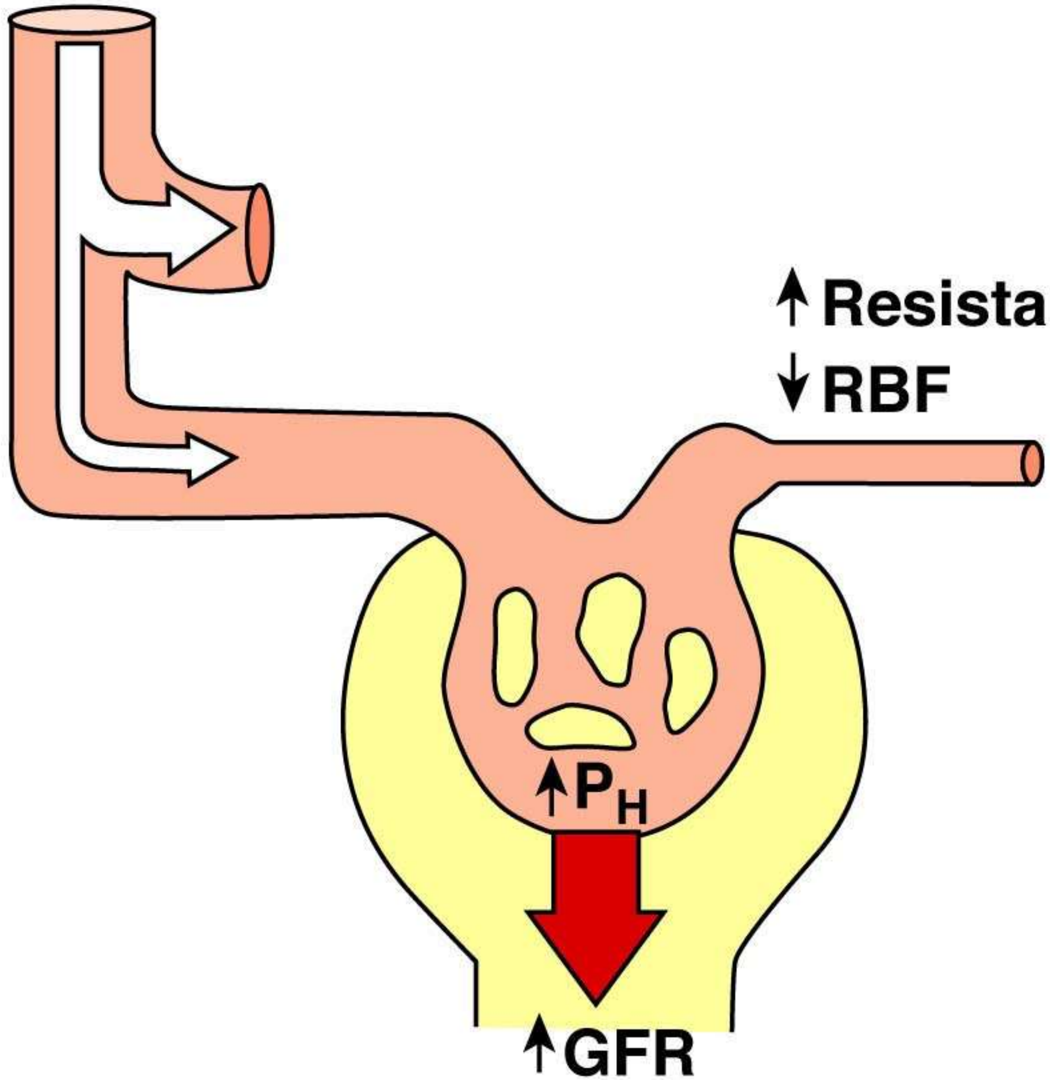


Figure 19-8c

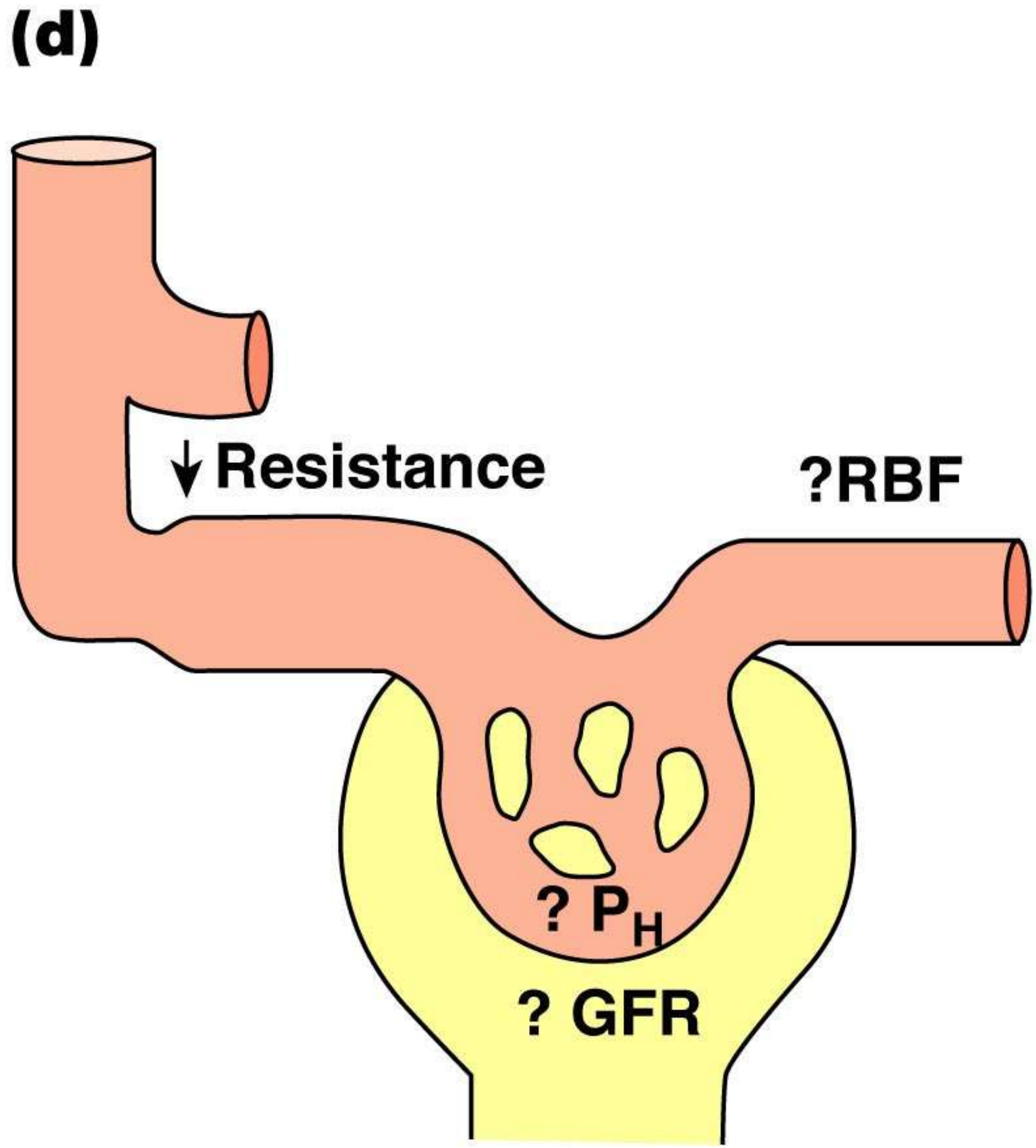


Figure 19-8d

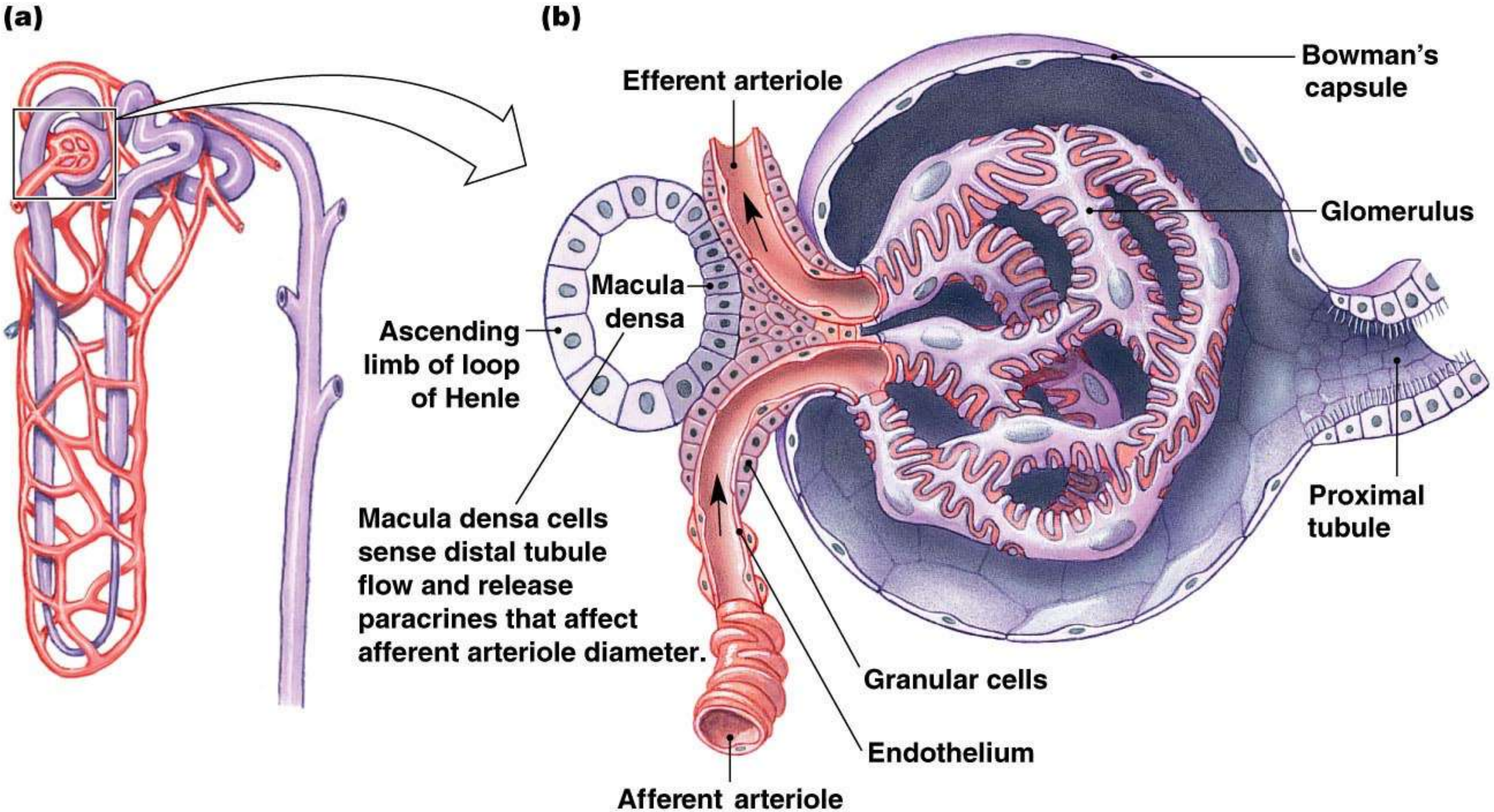


Figure 19-9 - Overview

(a)

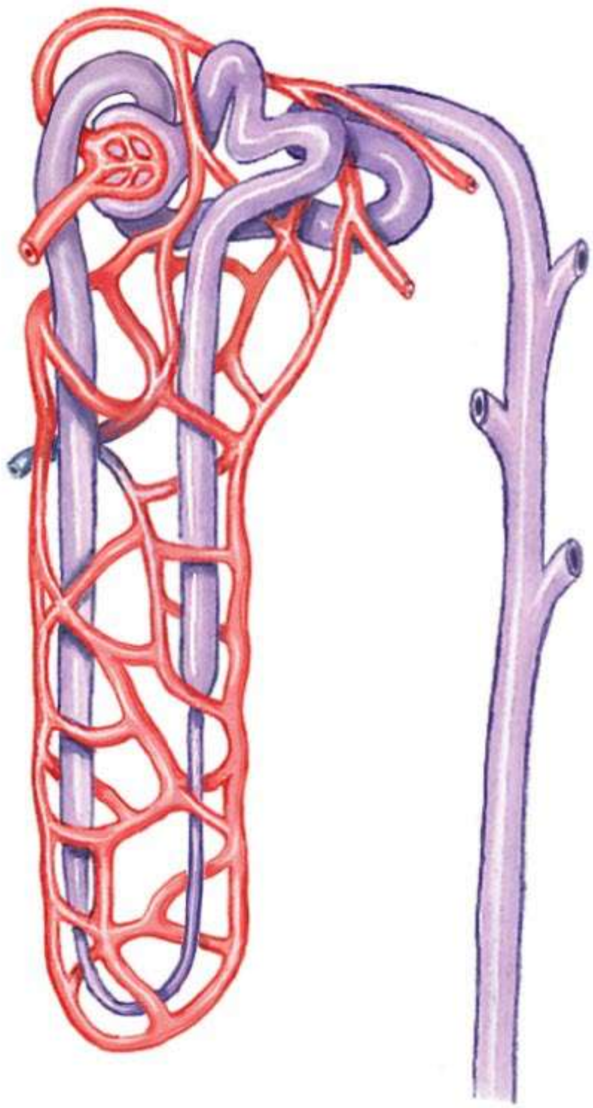


Figure 19-9a

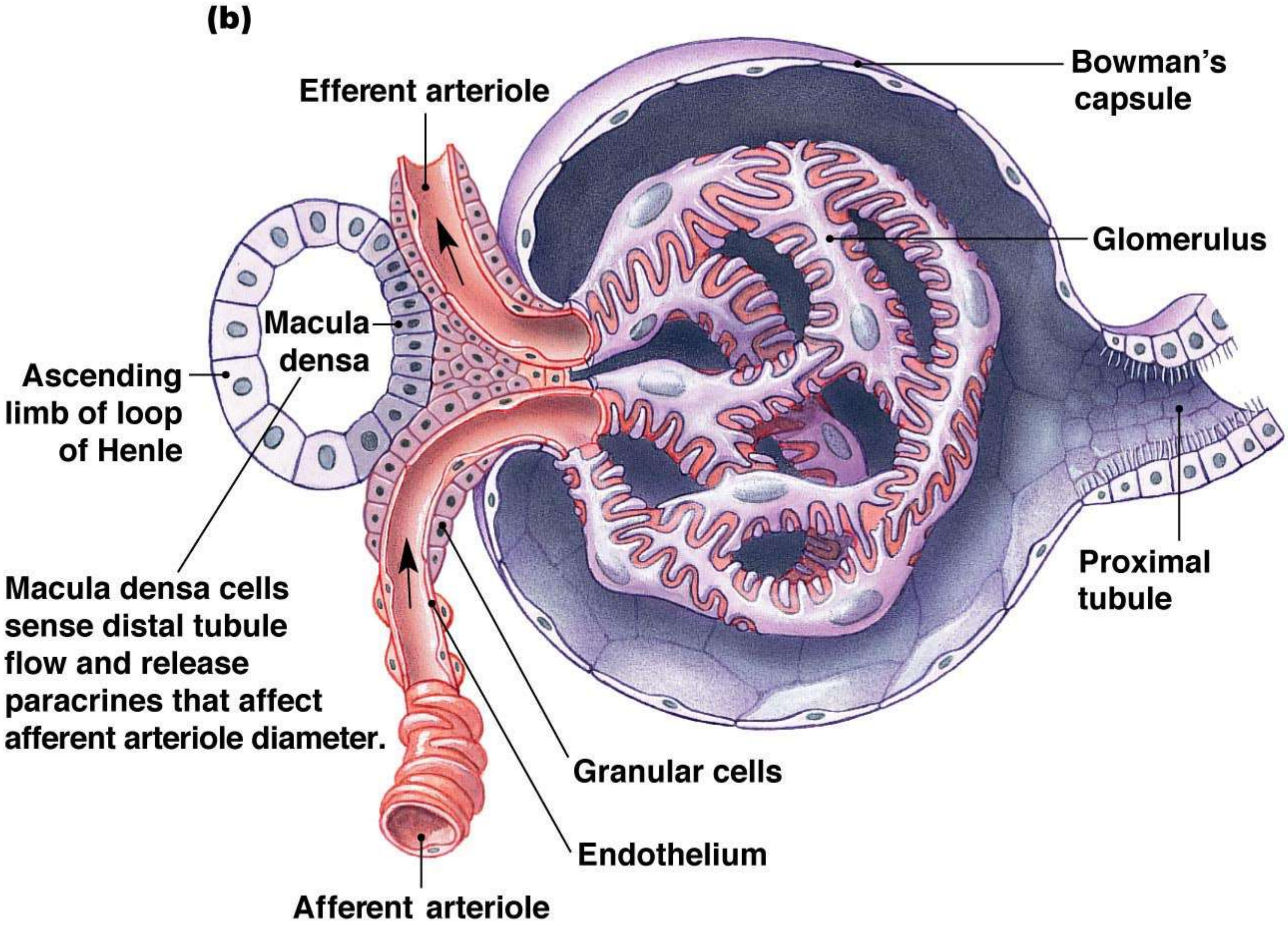

(b)
Efferent arteriole
Bowman's capsule
Glomerulus
Macula densa
Ascending limb of loop of Henle
Proximal tubule
Macula densa cells sense distal tubule flow and release paracrines that affect afferent arteriole diameter.
Granular cells
Endothelium
Afferent arteriole

Figure 19-9b

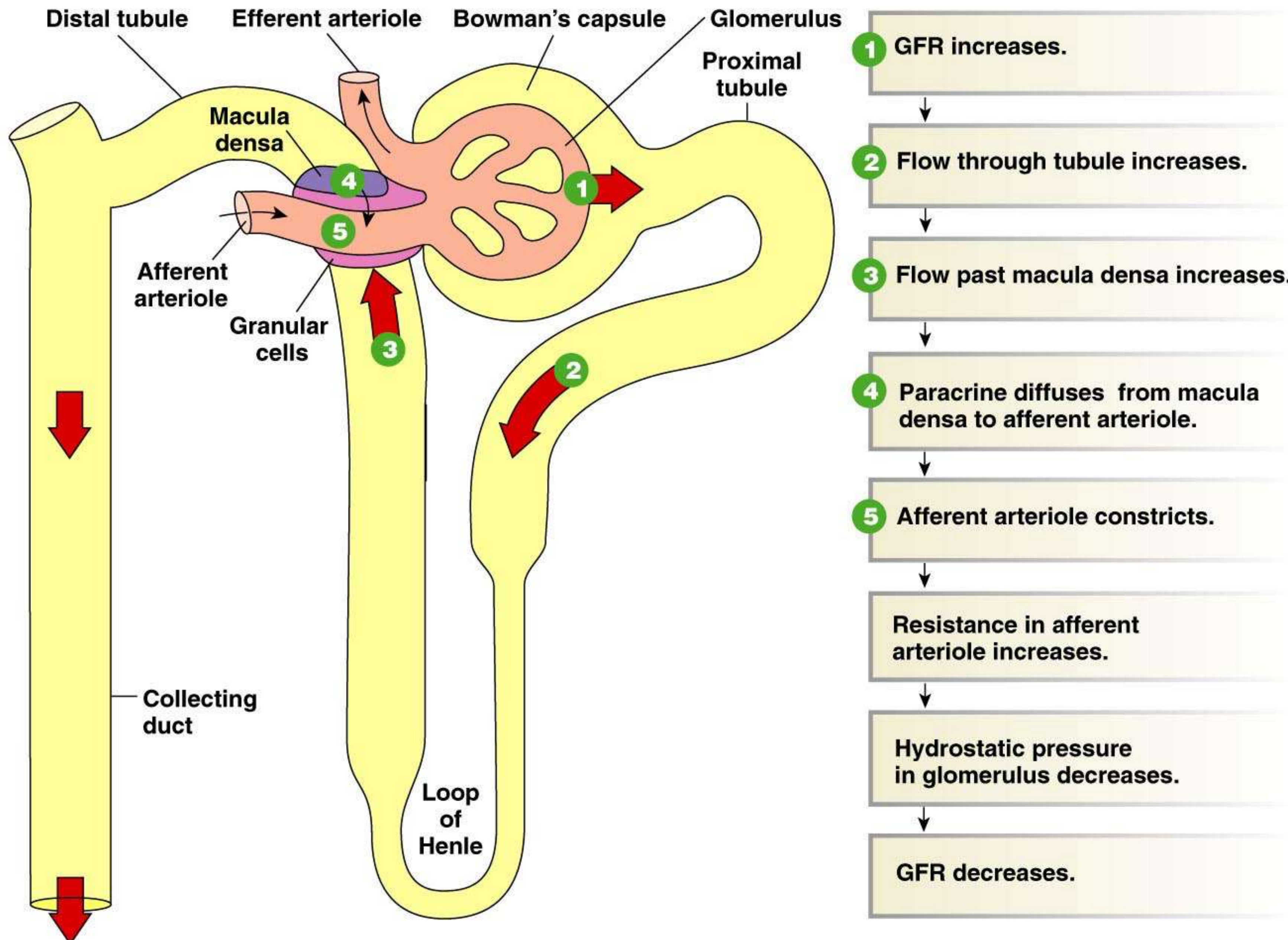


Figure 19-10: Overview

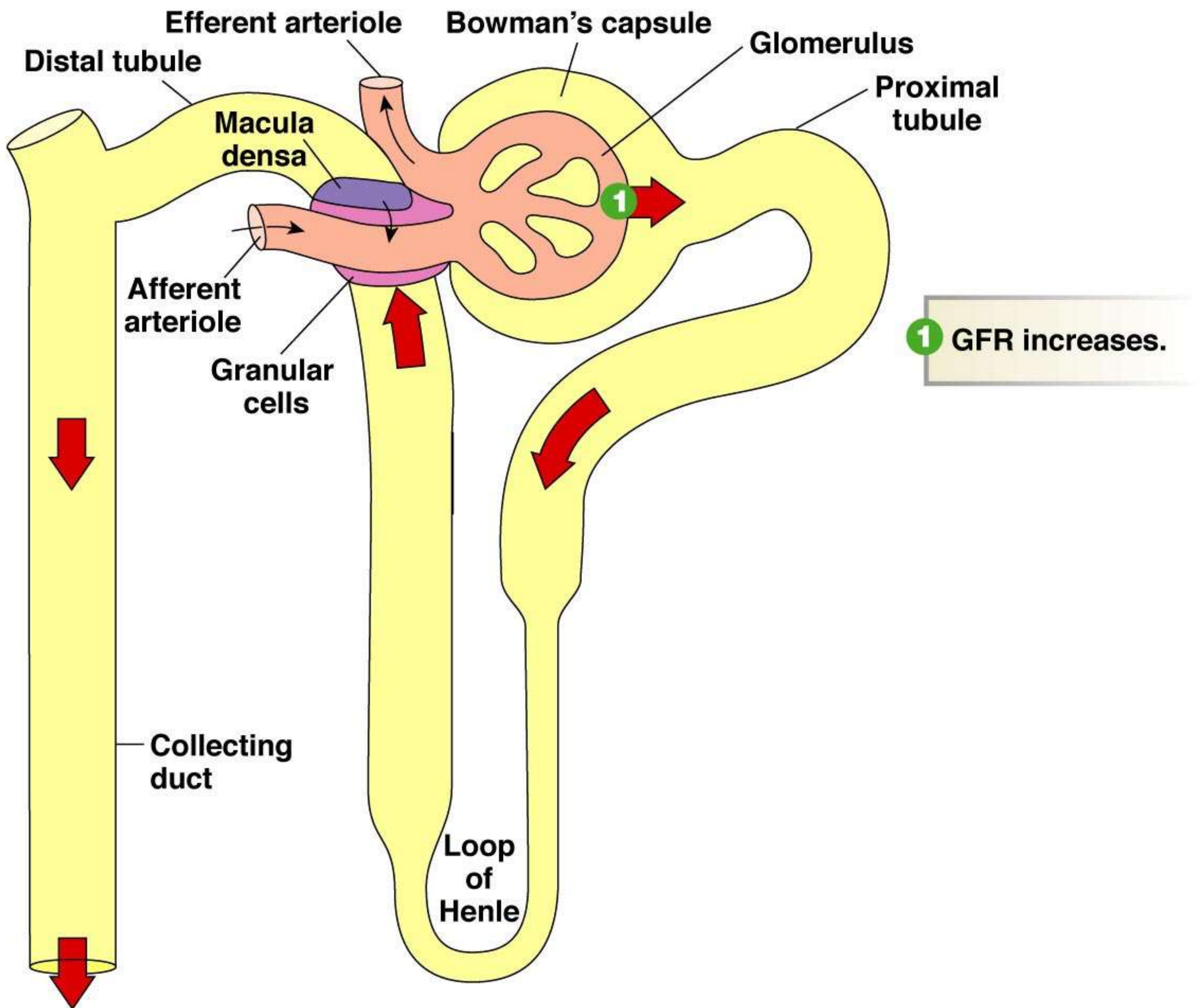


Figure 19-10, step 1

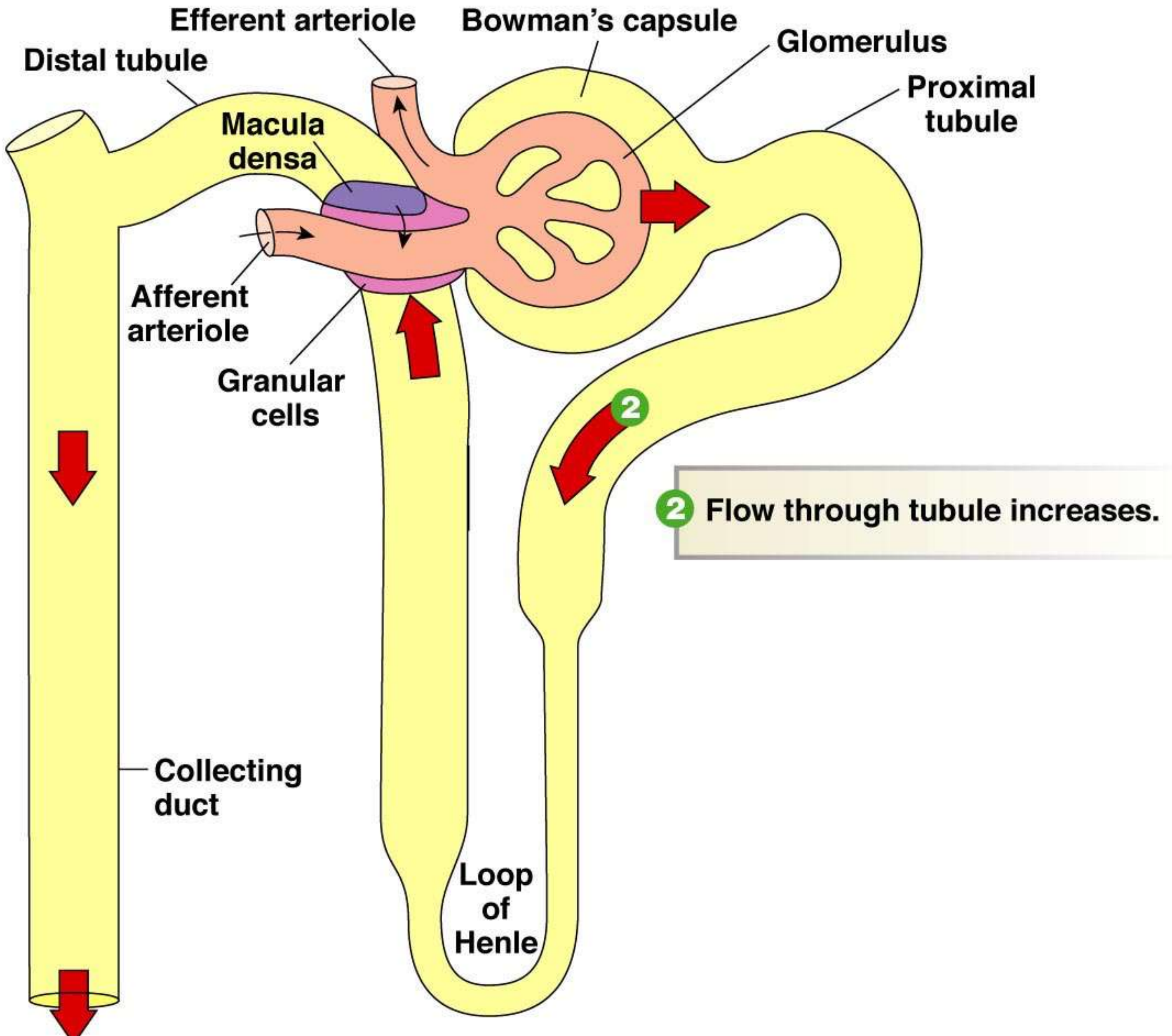


Figure 19-10, step 2

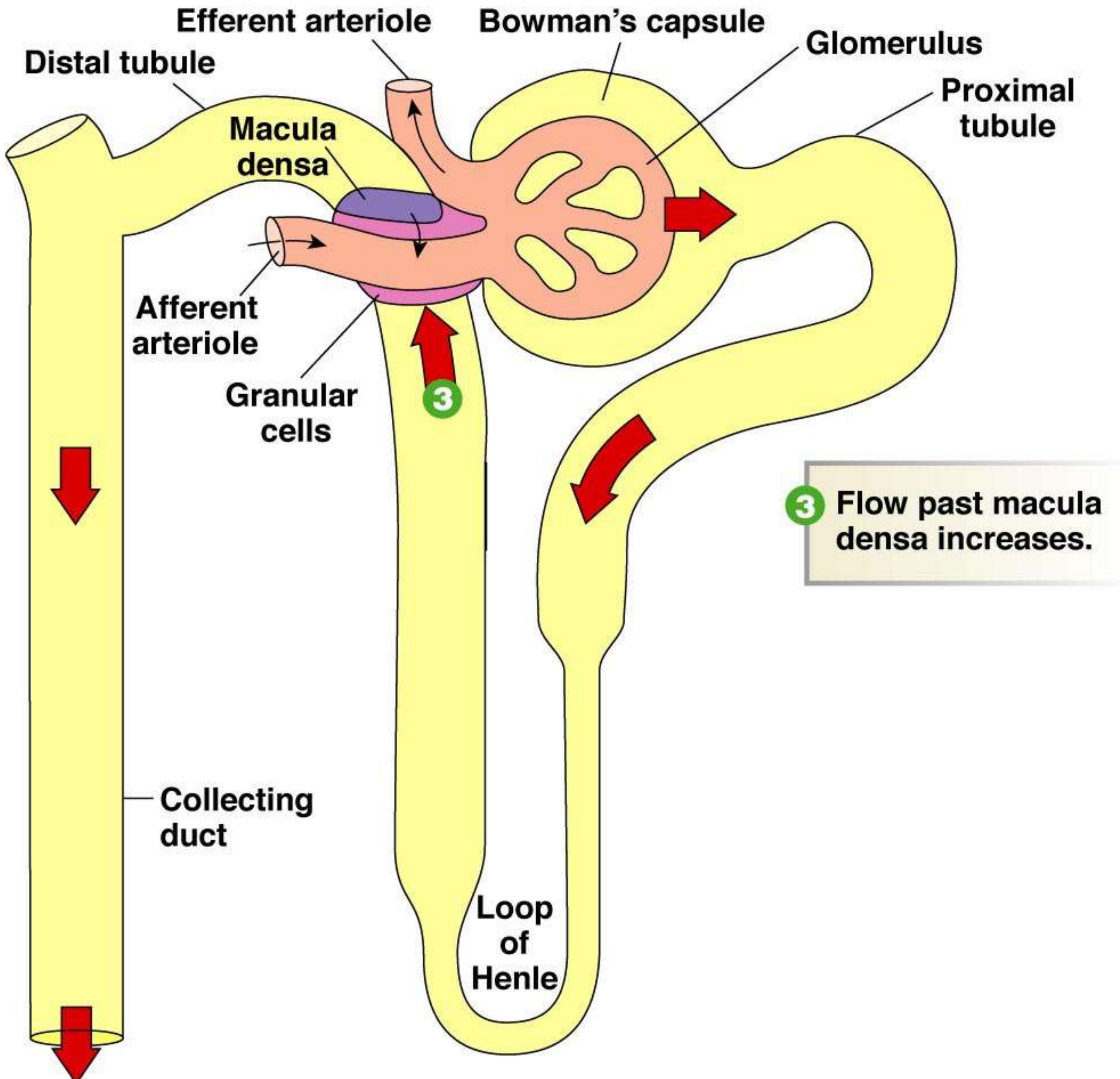


Figure 19-10, step 3

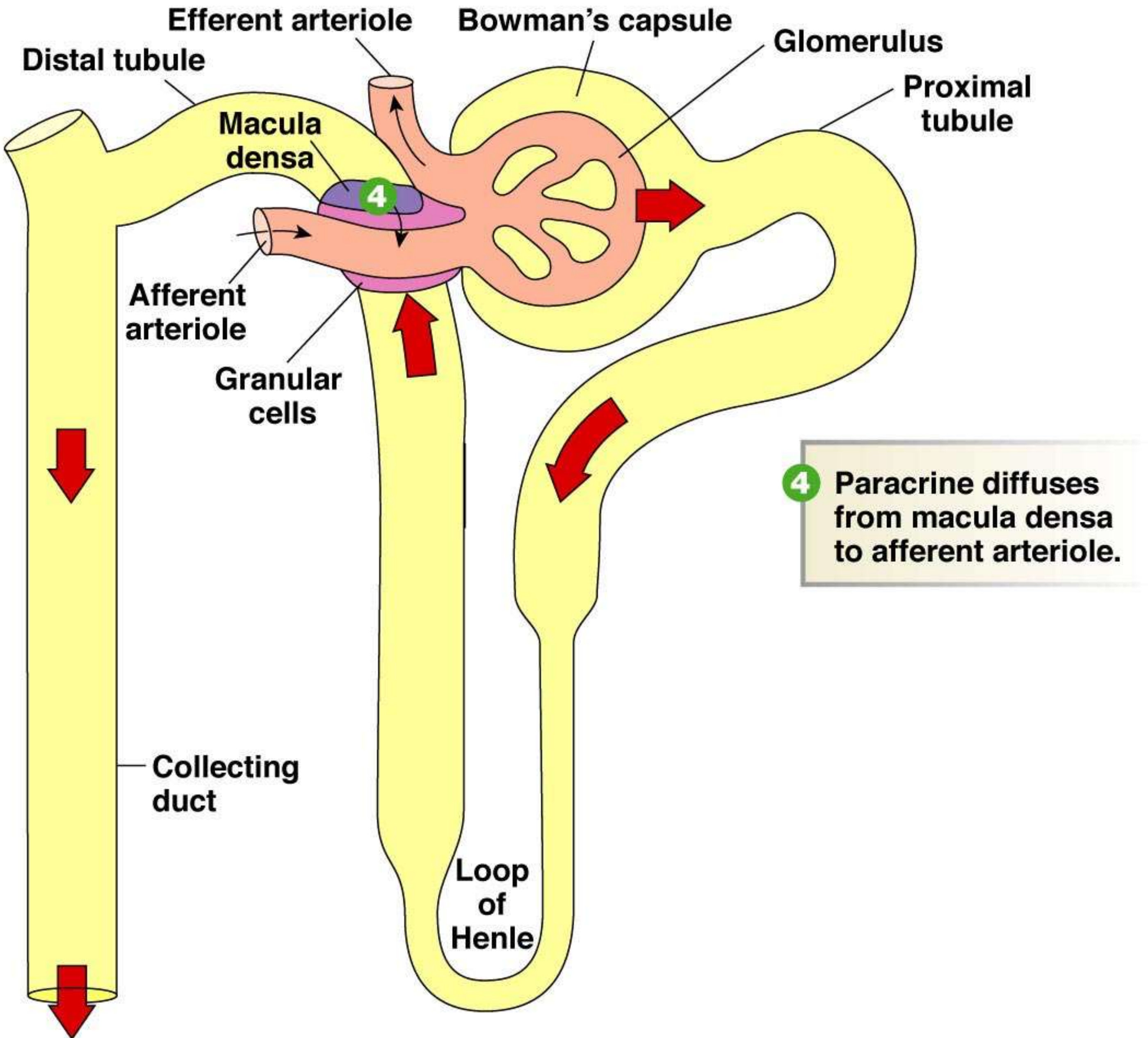


Figure 19-10, step 4

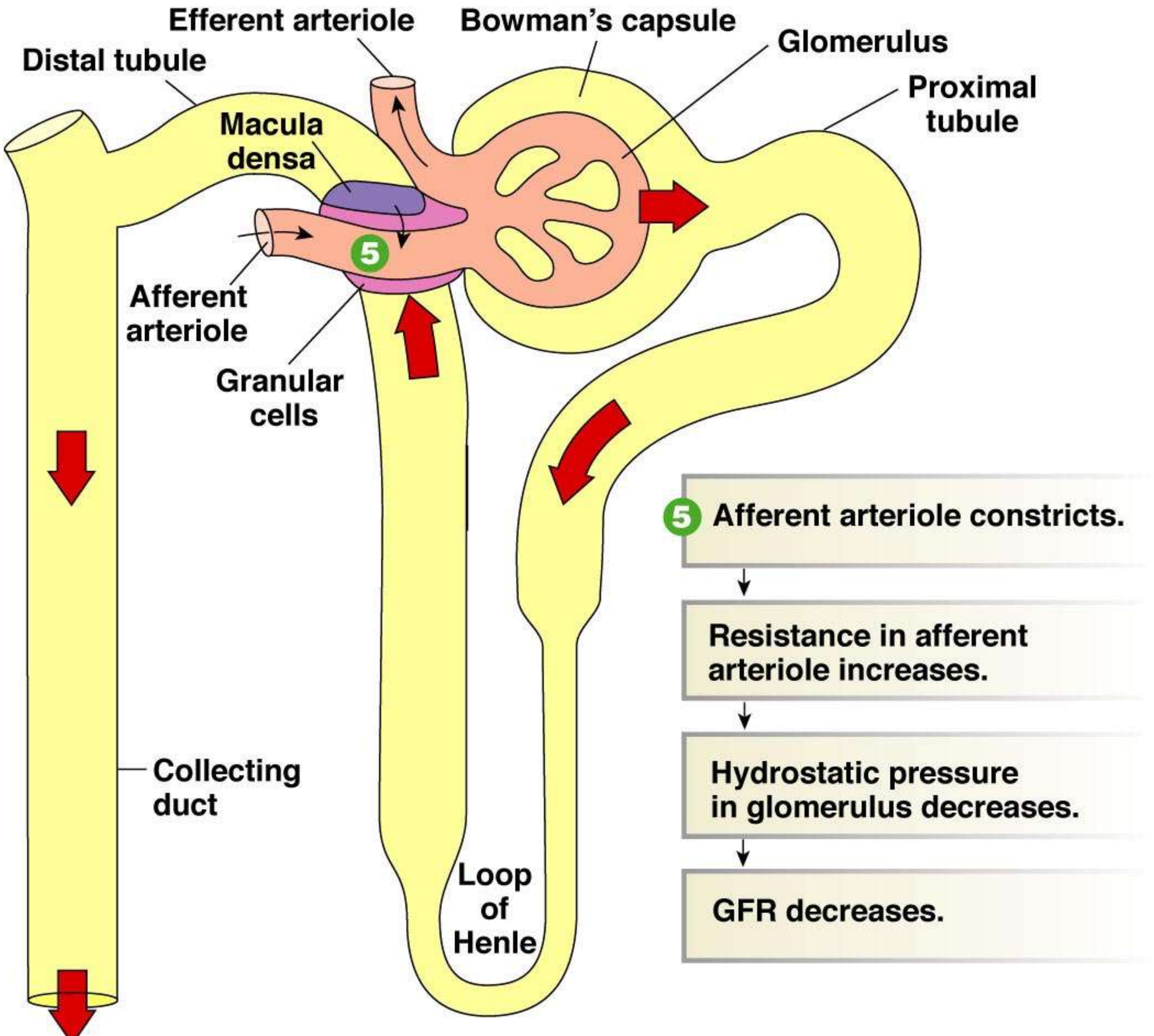
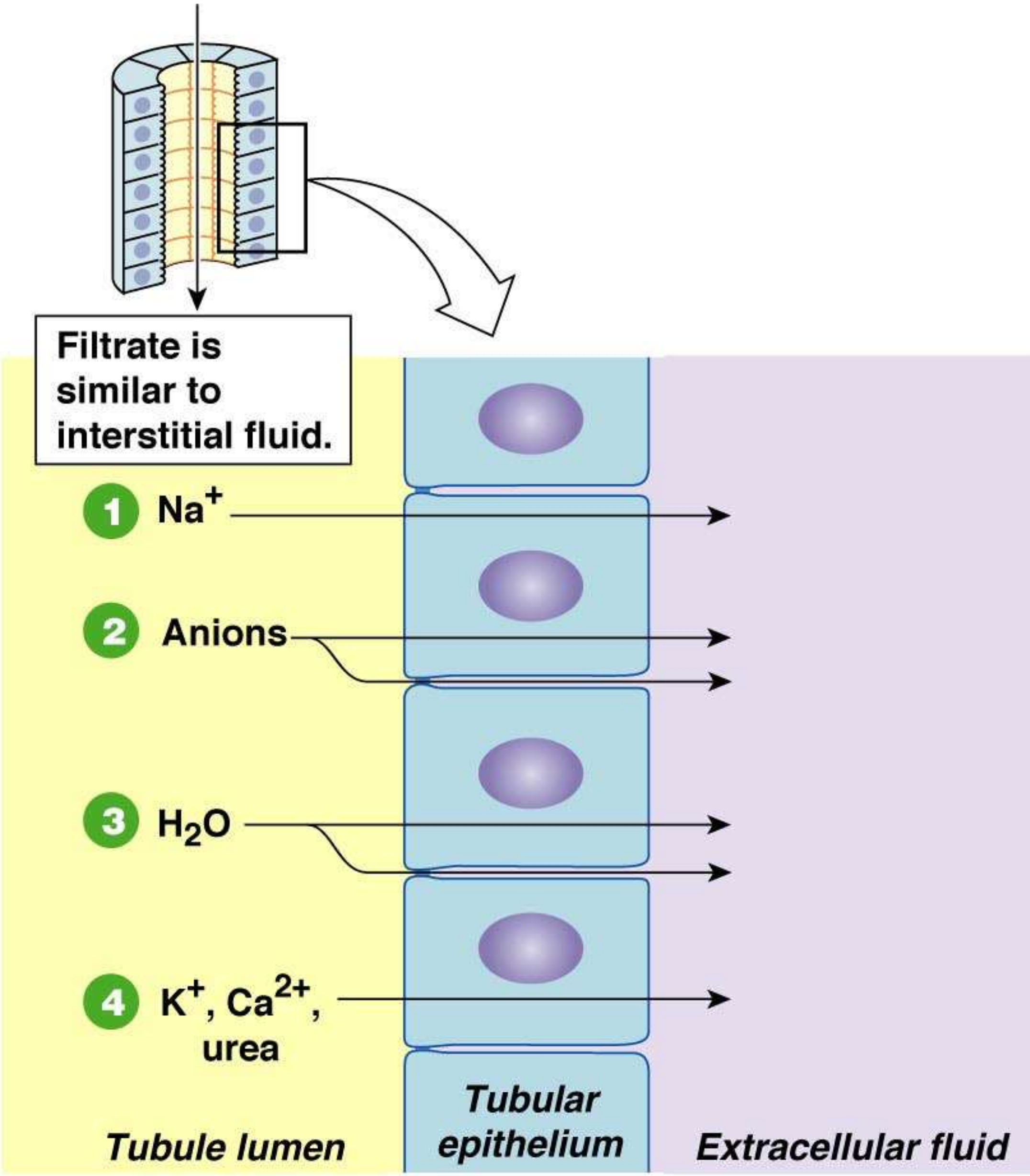
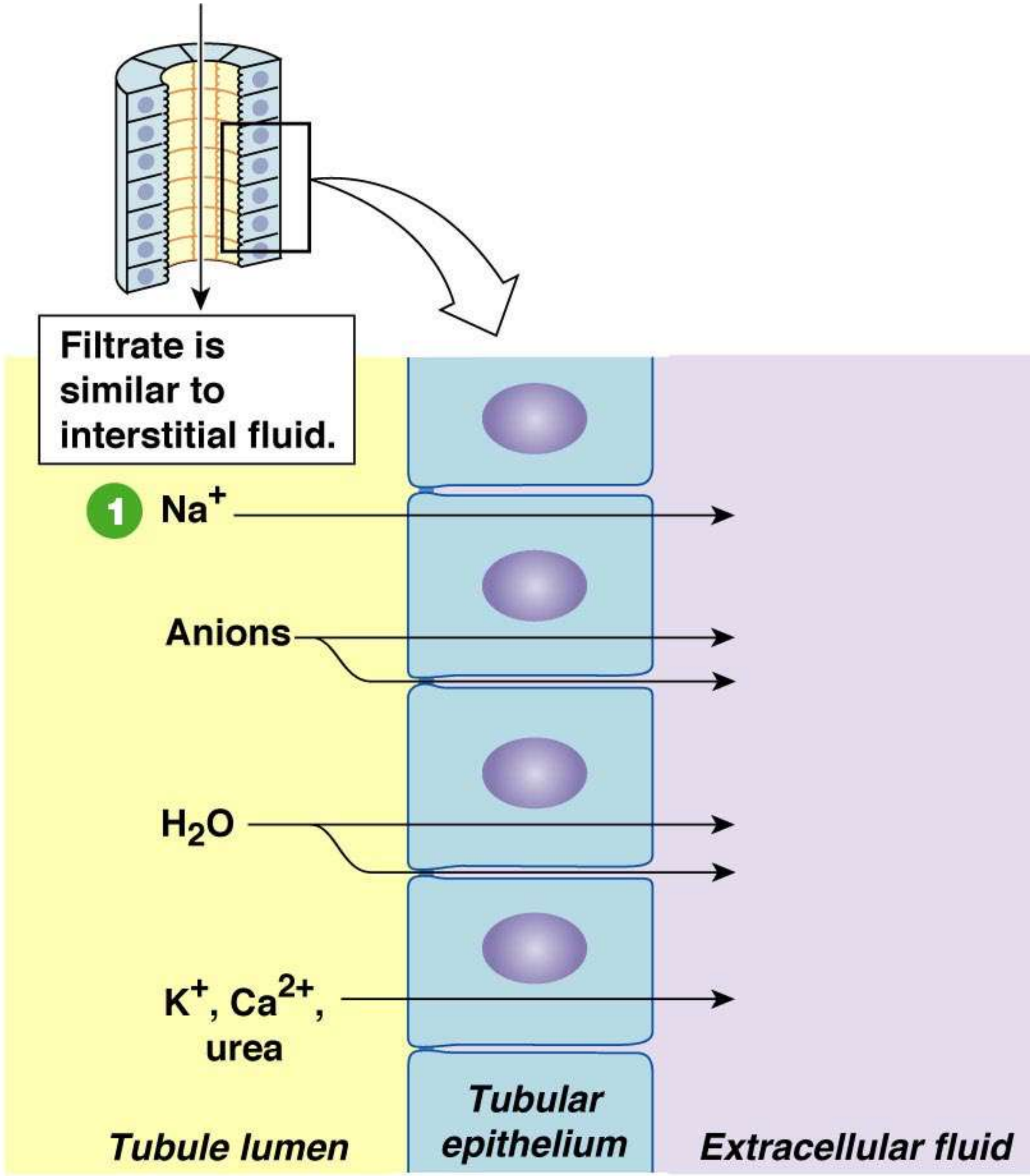


Figure 19-10, step 5



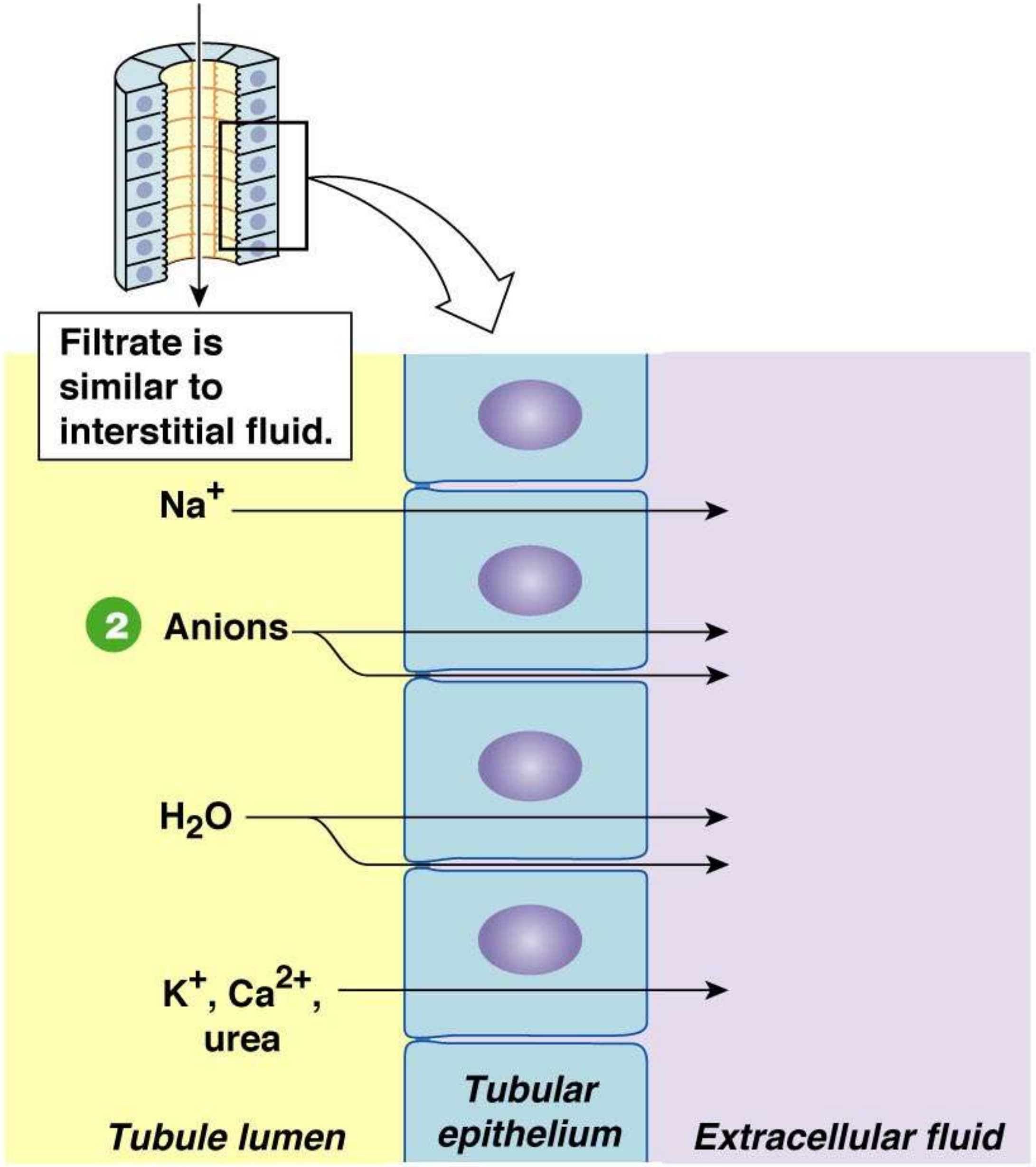
1. Na^+ is reabsorbed by active transport.
2. Electrochemical gradient drives anion reabsorption.
3. Water moves by osmosis, following solute reabsorption.
4. Concentrations of other solutes increase as fluid volume in lumen decreases. Permeable solutes are reabsorbed by diffusion.

Figure 19-11 Overview



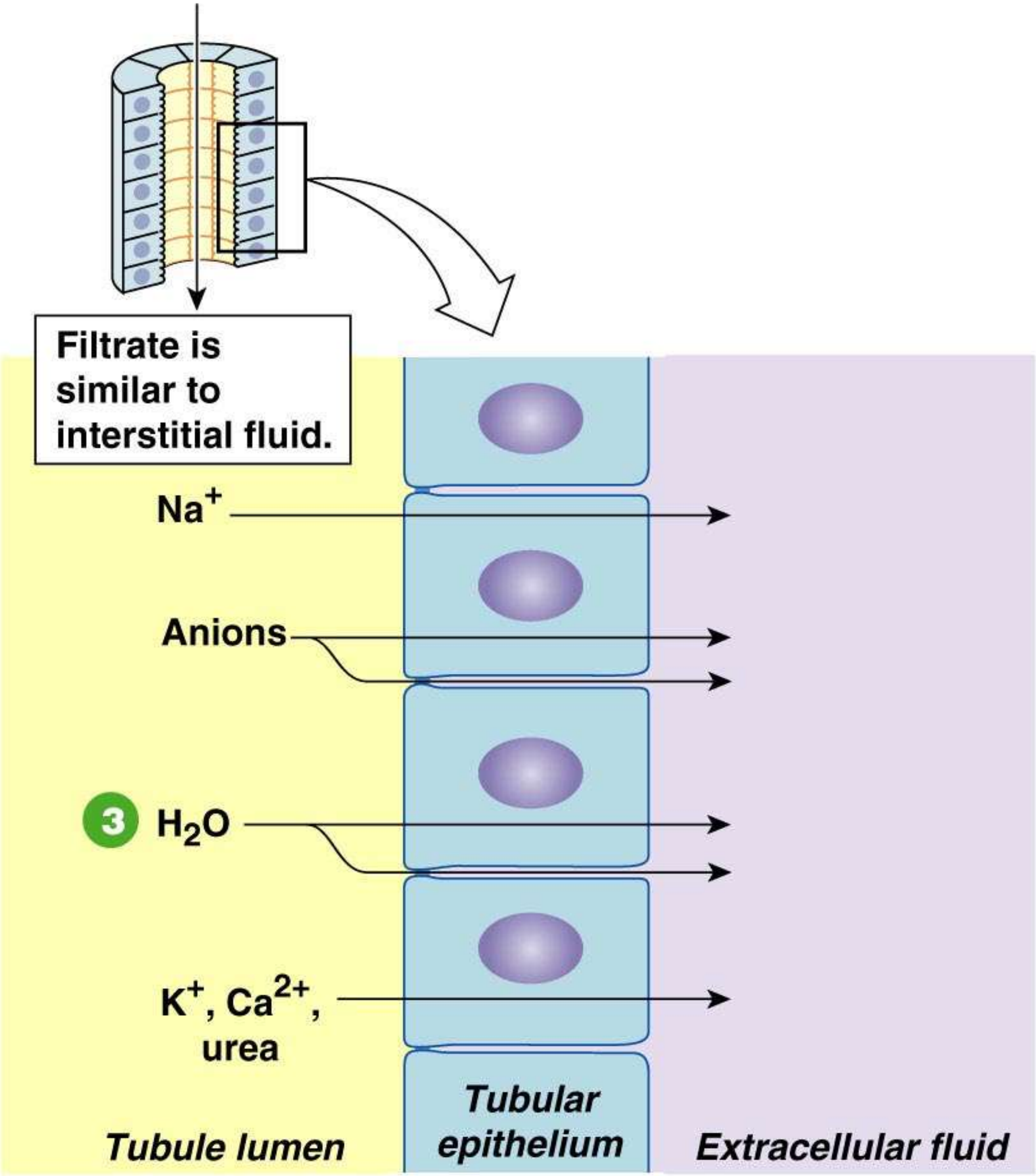
1 Na^+ is reabsorbed by active transport.

Figure 19-11, step 1



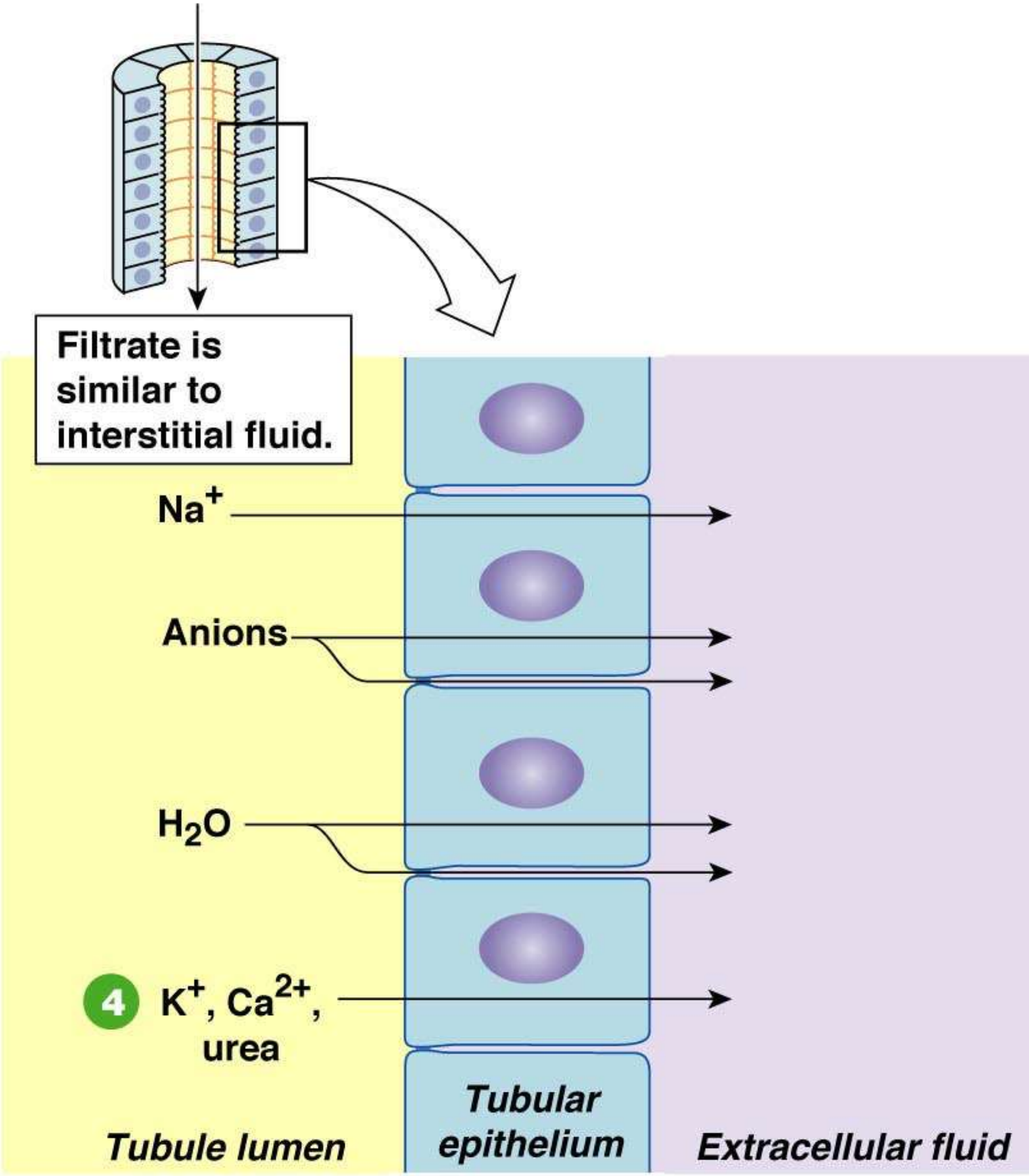
2 Electrochemical gradient drives anion reabsorption.

Figure 19-11, step 2



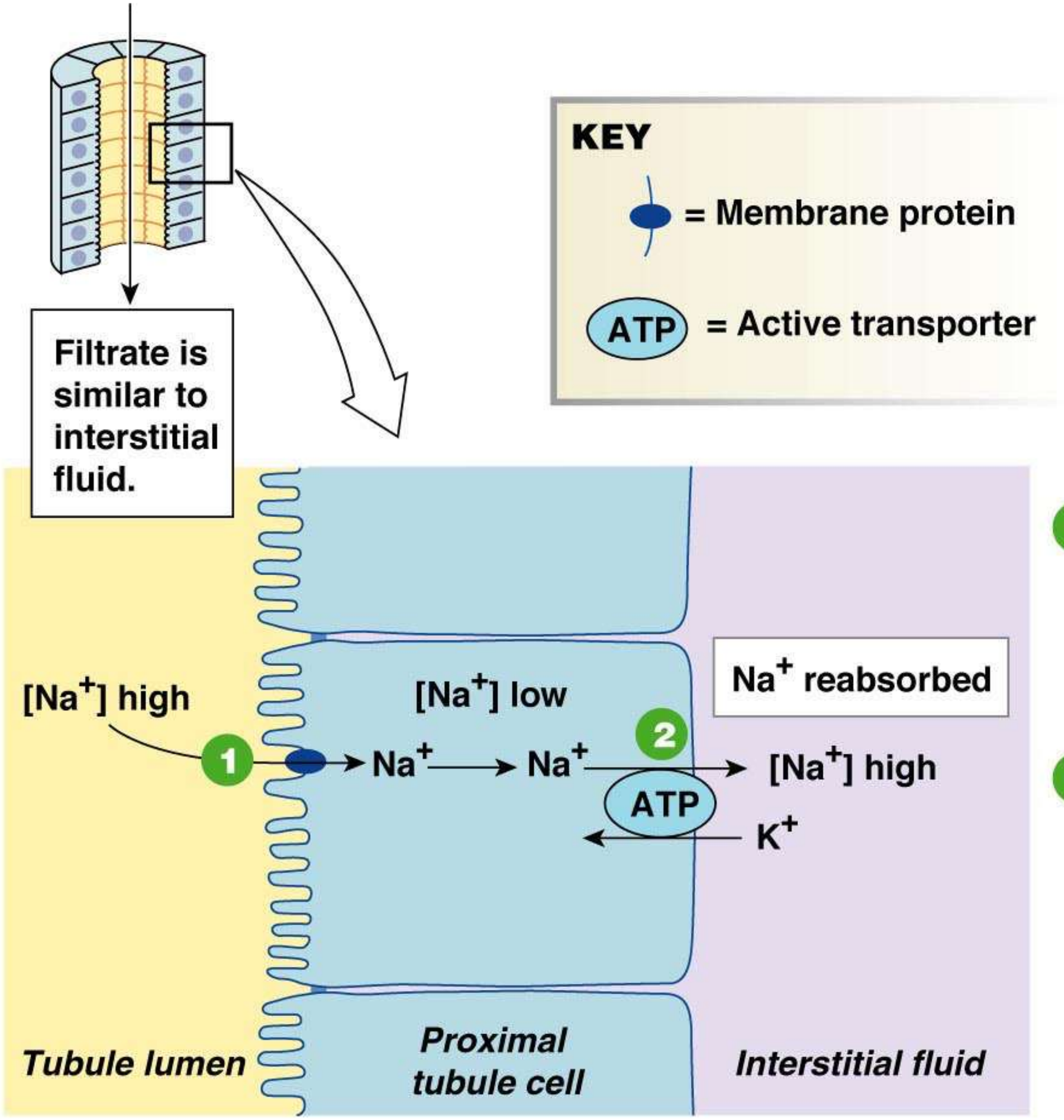
3 Water moves by osmosis, following solute reabsorption.

Figure 19-11, step 3



4 Concentrations of other solutes increase as fluid volume in lumen decreases. Permeable solutes are reabsorbed by diffusion.

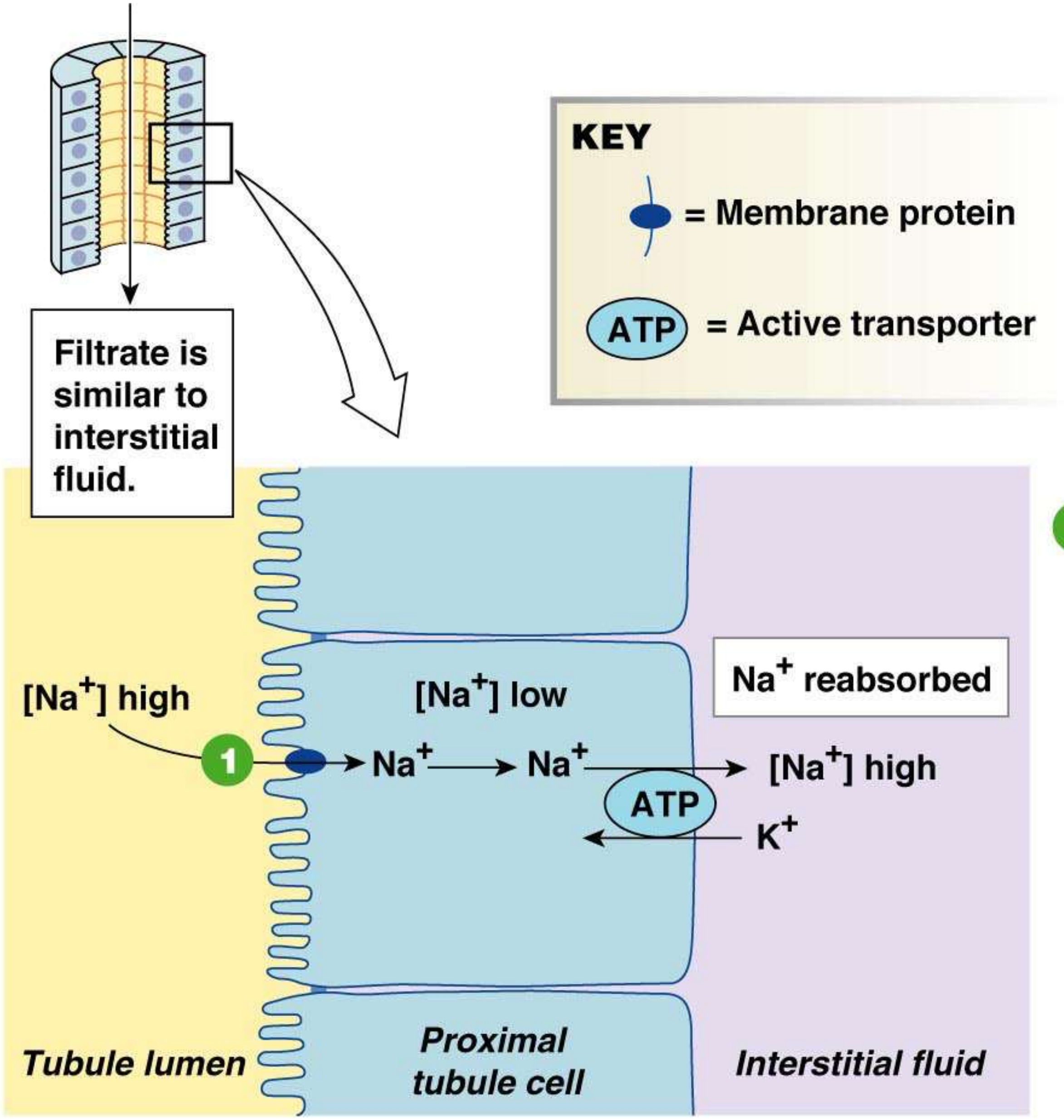
Figure 19-11, step 4



1. Na^+ enters cell through membrane proteins, moving down its electrochemical gradient.

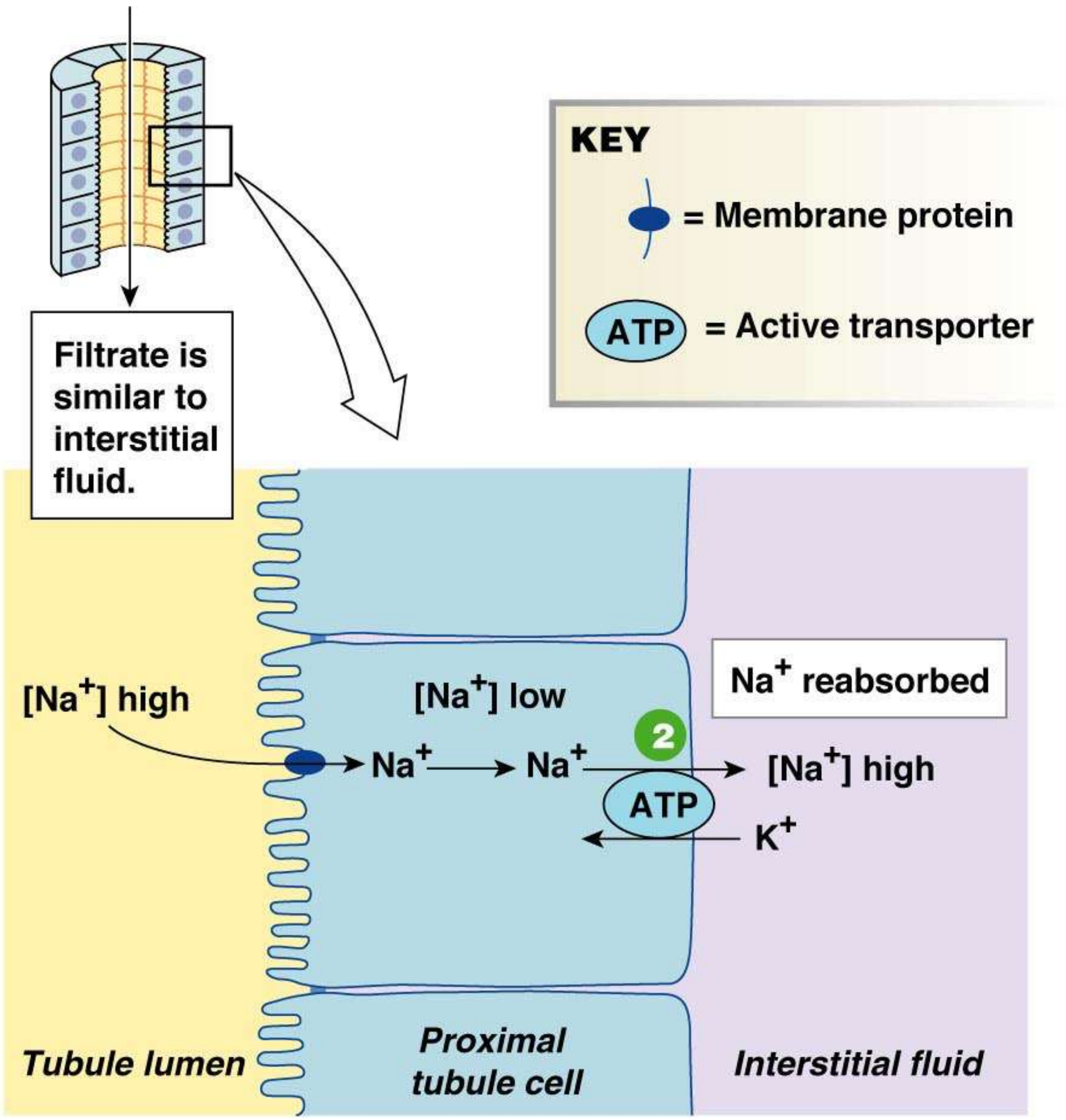
2. Na^+ is pumped out the basolateral side of cell by the Na^+-K^+- ATPase.

Figure 19-12 Overview



1 Na^+ enters cell through membrane proteins, moving down its electrochemical gradient.

Figure 19-12, step 1



2 Na^+ is pumped out the basolateral side of cell by the Na^+-K^+- ATPase.

Figure 19-12, step 2

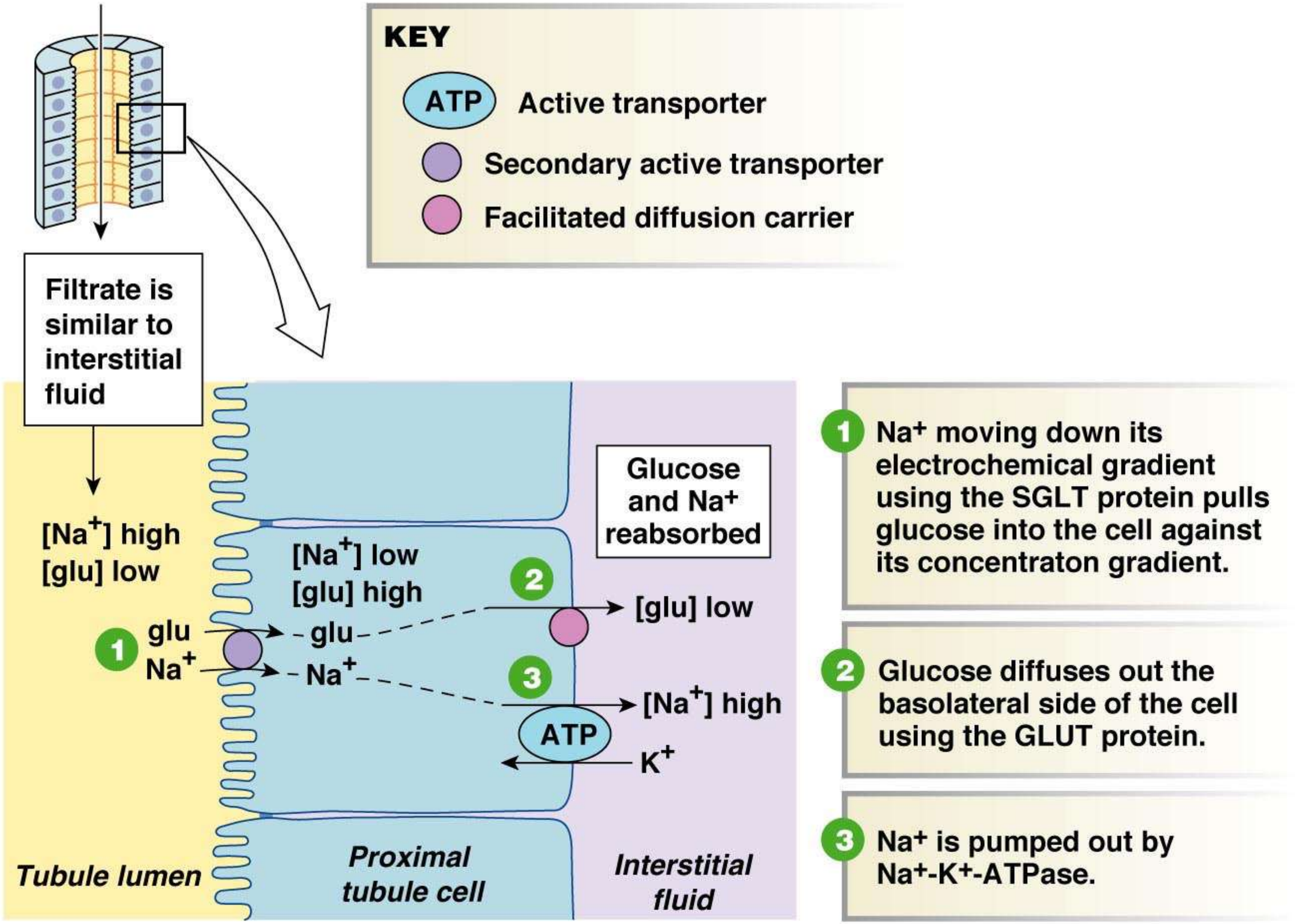
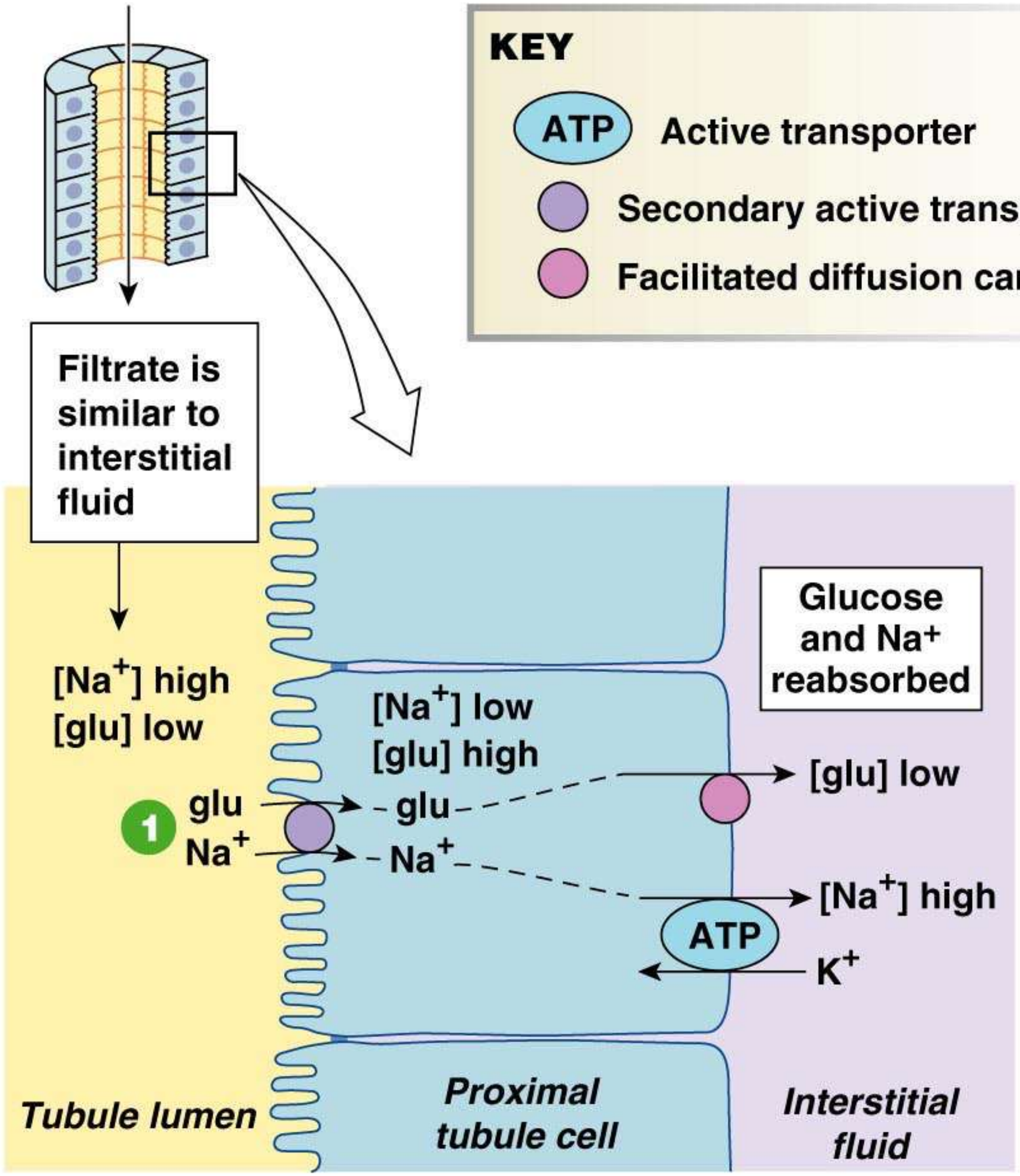
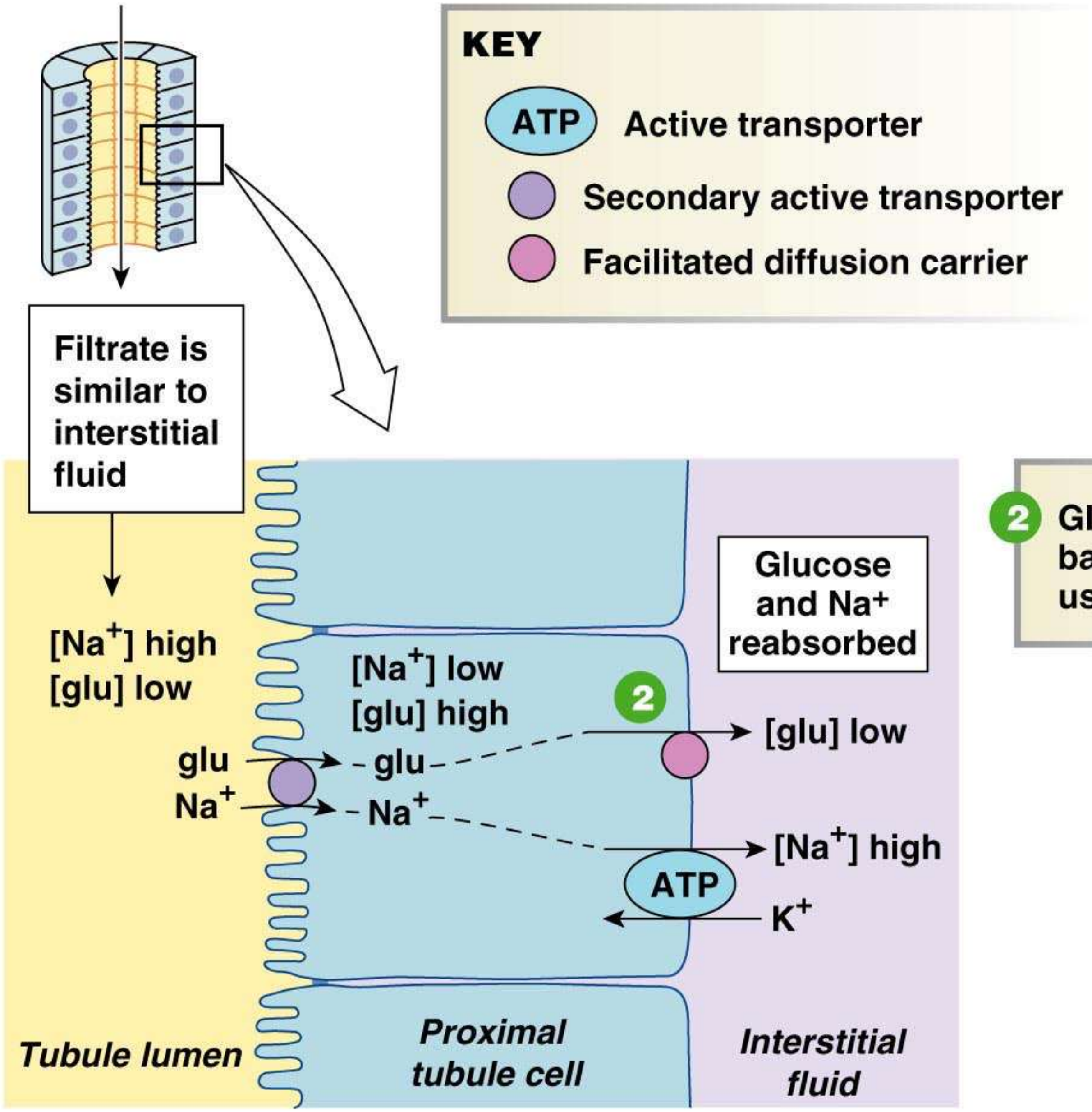


Figure 19-13 Overview



1 Na+ moving down its electrochemical gradient using the SGLT protein pulls glucose into the cell against its concentraton gradient.

Figure 19-13, step 1



2 Glucose diffuses out the basolateral side of the cell using the GLUT protein.

Figure 19-13, step 2

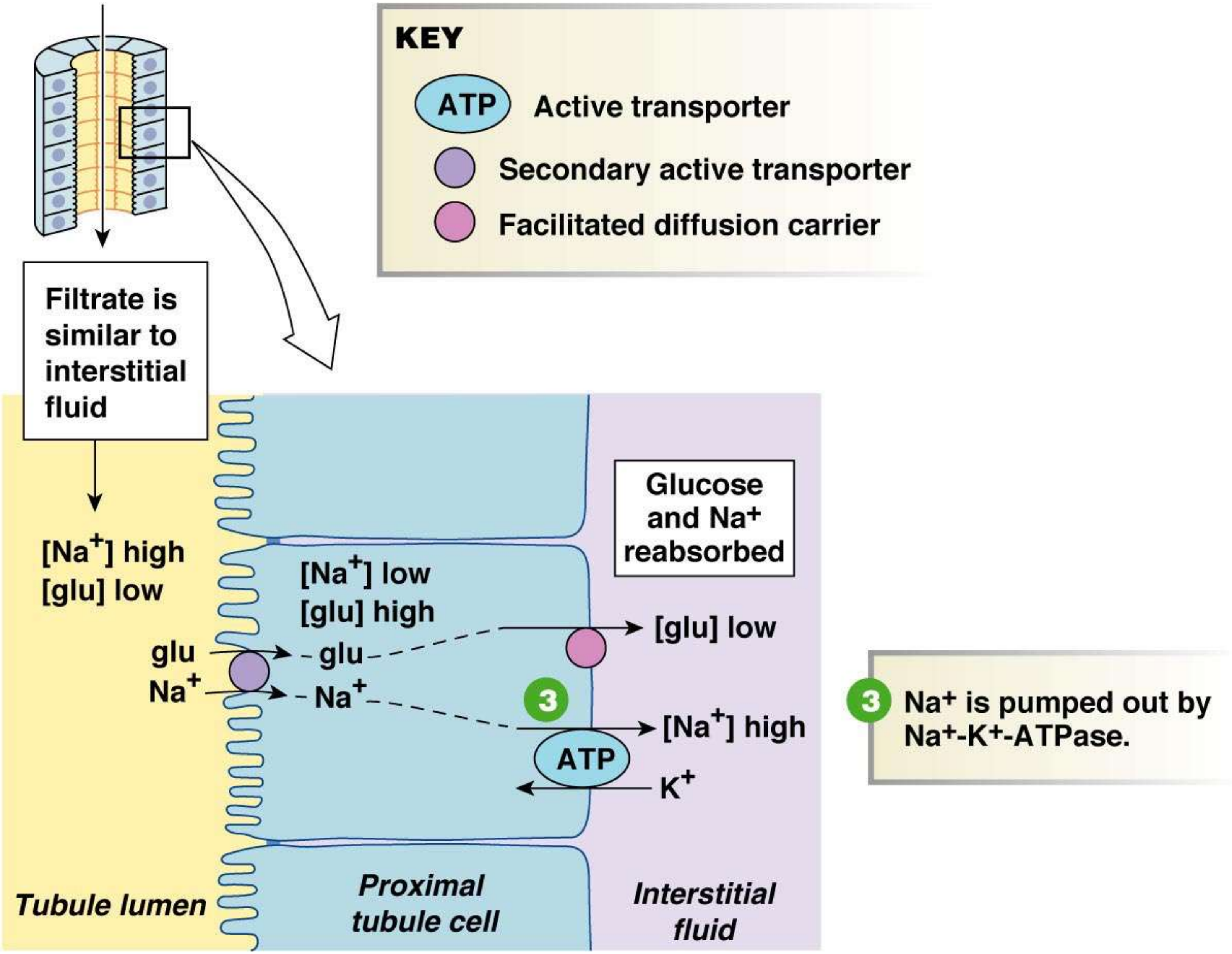
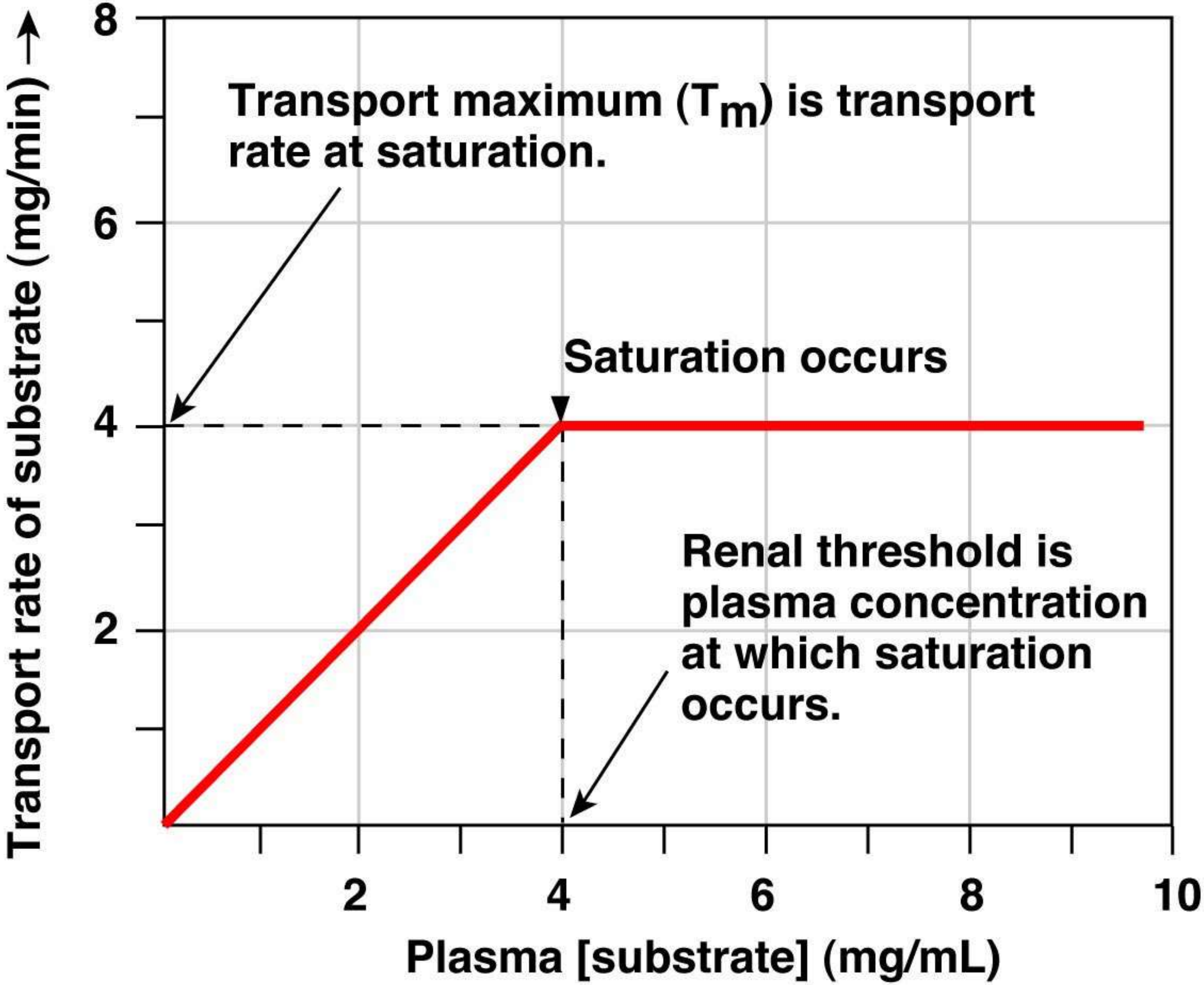
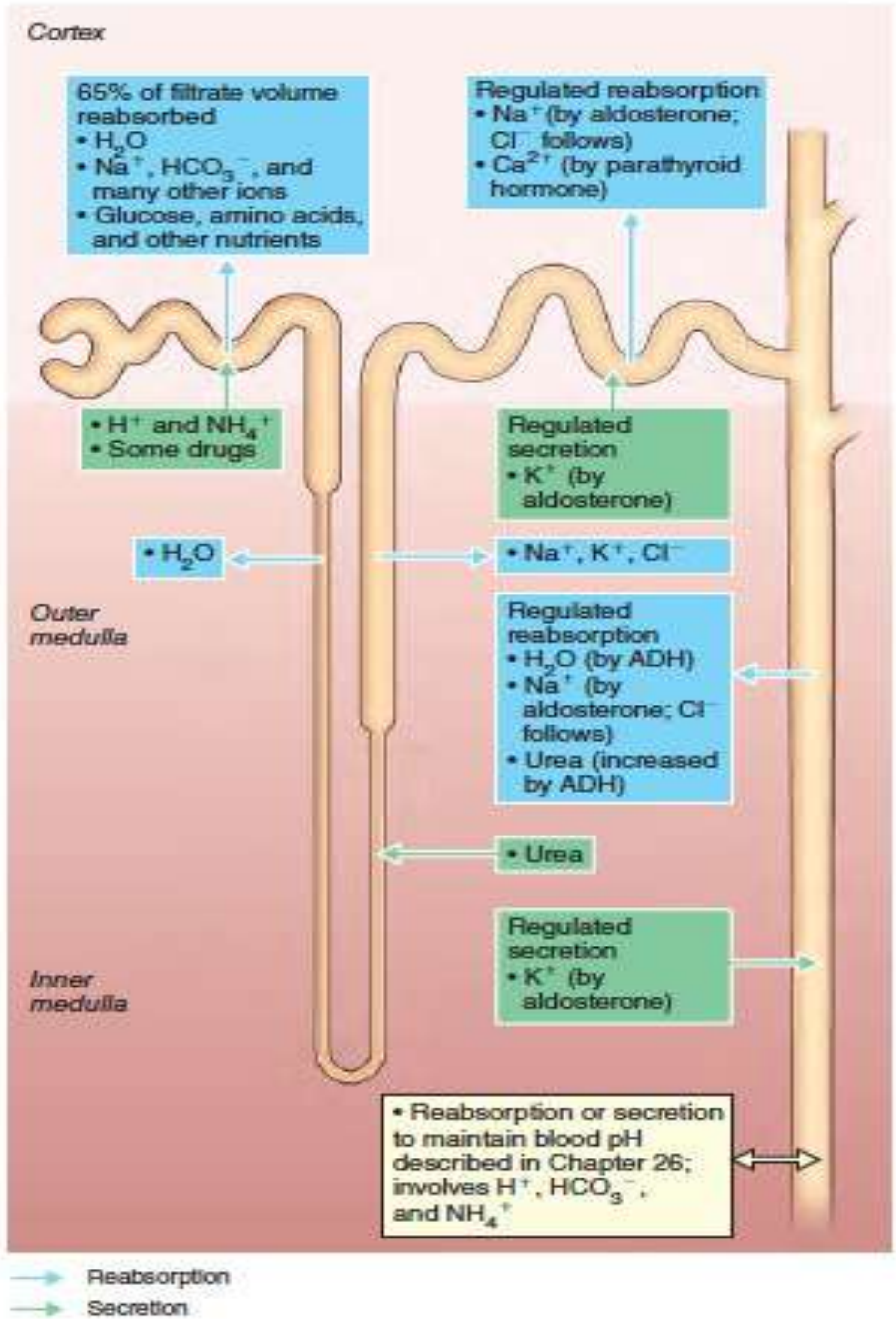


Figure 19-13, step 3



Transport rate of substrate (mg/min)
8
6
4
2
Transport maximum (T_m) is transport rate at saturation.
Saturation occurs
Renal threshold is plasma concentration at which saturation occurs.
2
4
6
8
10
Plasma [substrate] (mg/mL)

Figure 19-14


Cortex
65% of filtrate volume reabsorbed
• H_2O
• Na^+, HCO_3^-, and many other ions
• Glucose, amino acids, and other nutrients
Regulated reabsorption
• Na^+ (by aldosterone; Cl^- follows)
• Ca^{2+} (by parathyroid hormone)
• H^+ and NH_4^+
• Some drugs
Regulated secretion
• K^+ (by aldosterone)
• H_2O
• Na^+, K^+, Cl^-
Outer medulla
Regulated reabsorption
• H_2O (by ADH)
• Na^+ (by aldosterone; Cl^- follows)
• Urea (increased by ADH)
• Urea
Inner medulla
Regulated secretion
• K^+ (by aldosterone)
• Reabsorption or secretion to maintain blood pH described in Chapter 26; involves H^+, HCO_3^-, and NH_4^+
Reabsorption
Secretion

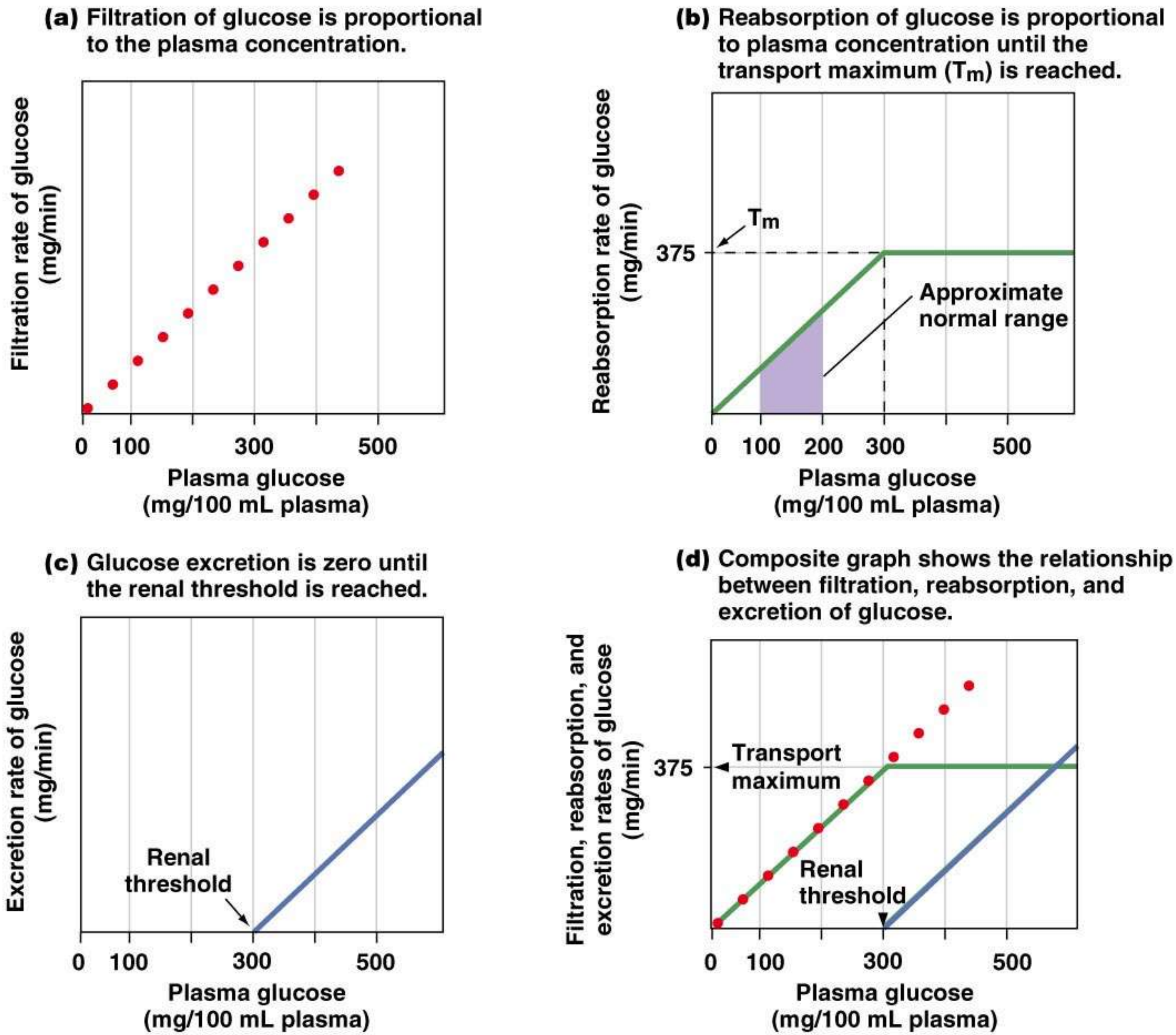


Figure 19-15 Overview

(a) Filtration of glucose is proportional to the plasma concentration.

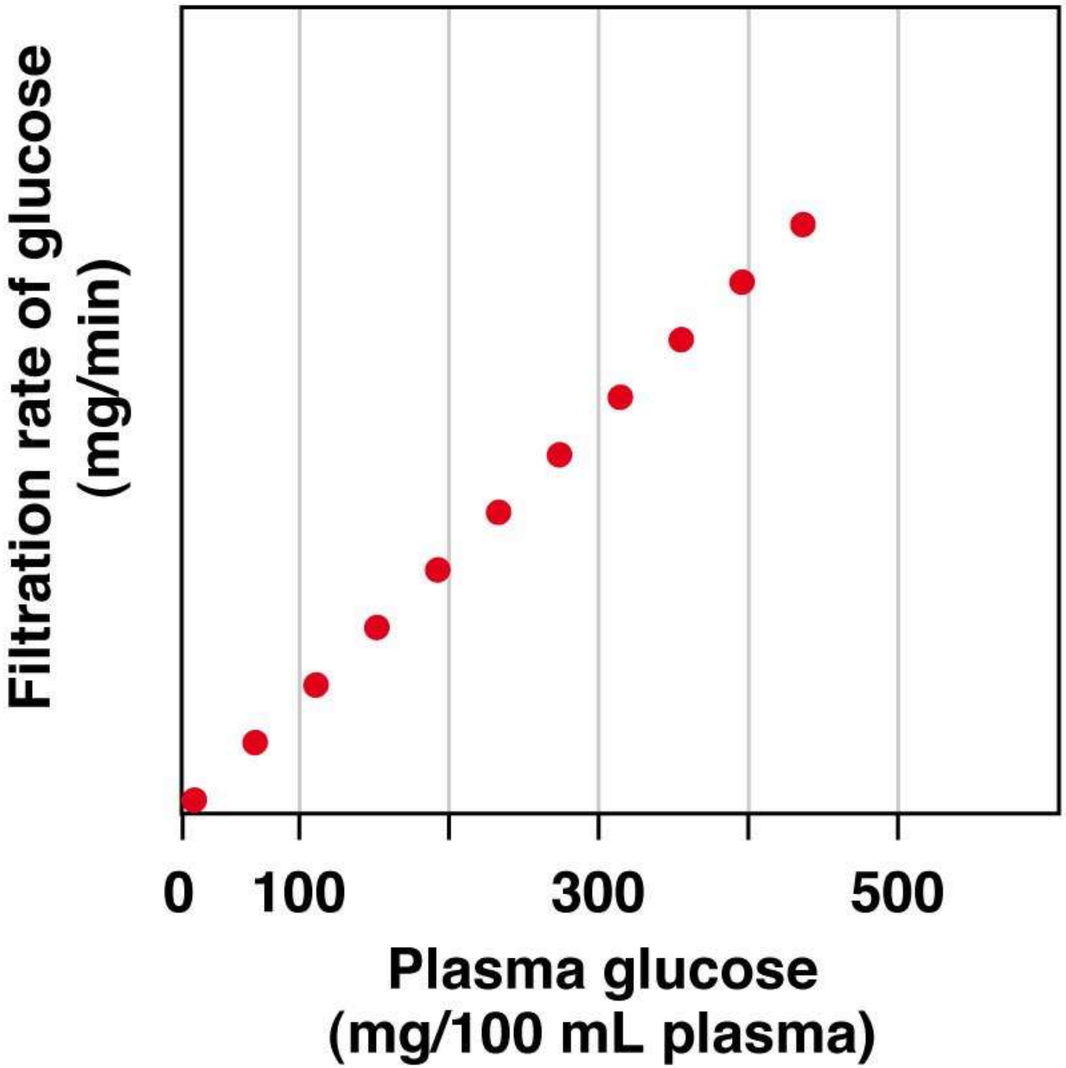


Figure 19-15a

(b) Reabsorption of glucose is proportional to plasma concentration until the transport maximum (T_m) is reached.

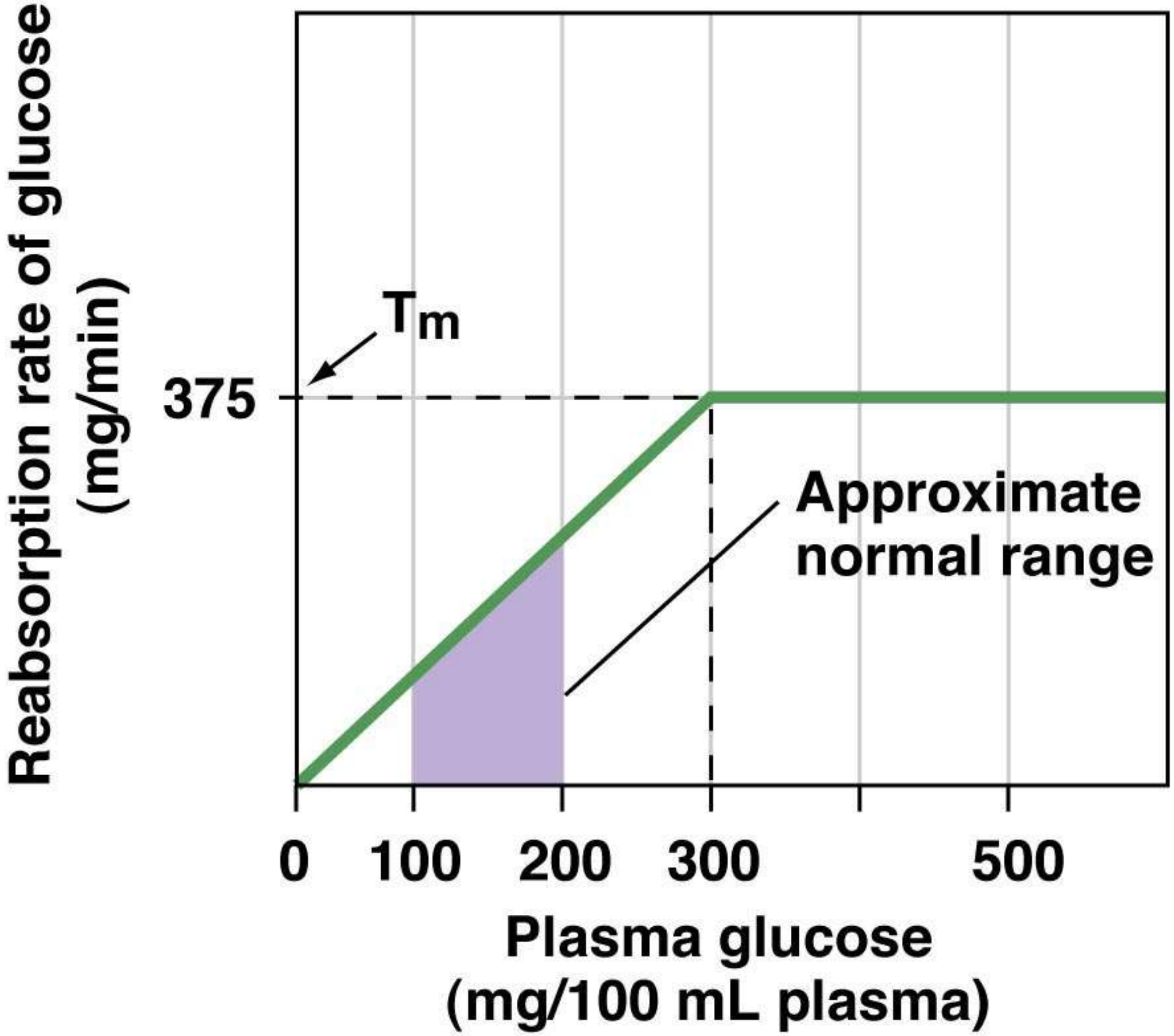


Figure 19-15b

(c) Glucose excretion is zero until the renal threshold is reached.

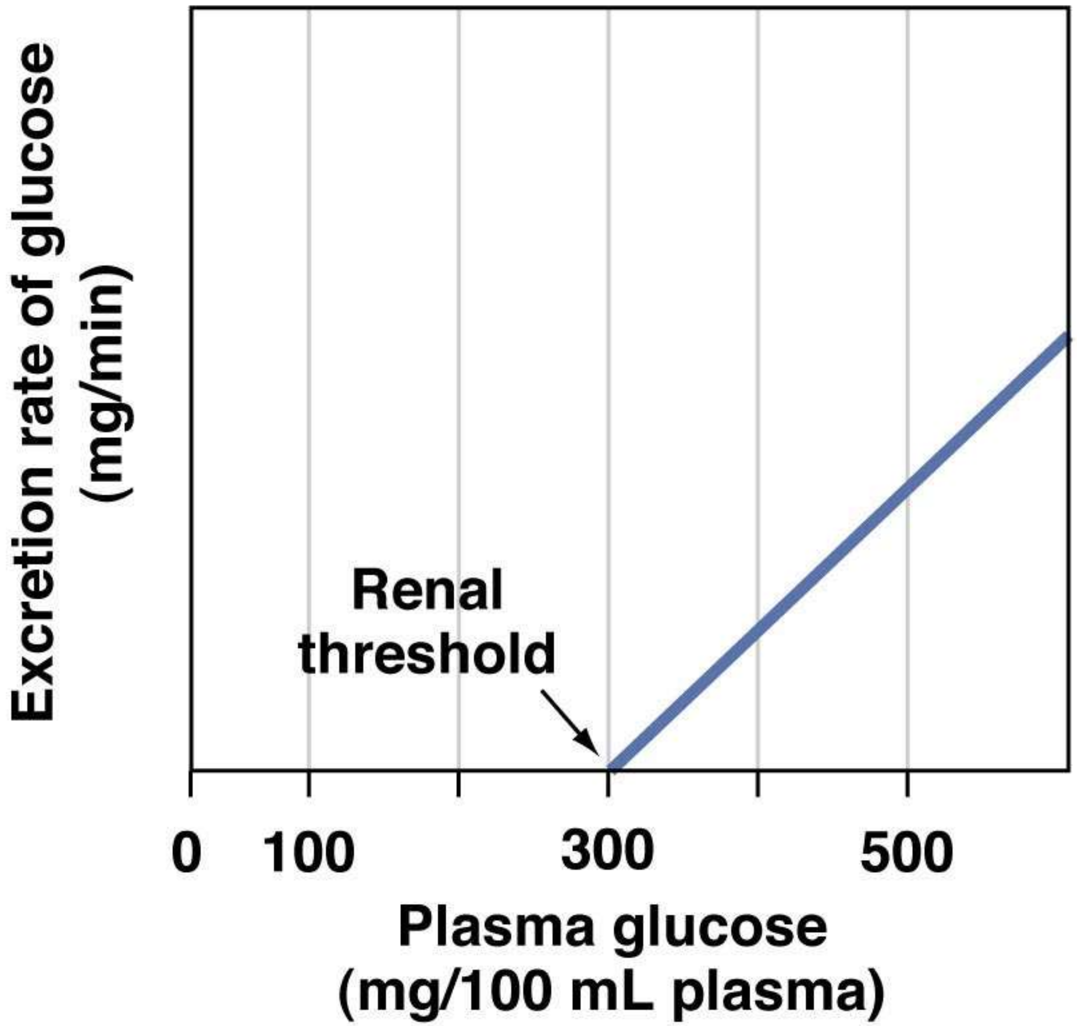


Figure 19-15c

(d) Composite graph shows the relationship between filtration, reabsorption, and excretion of glucose.

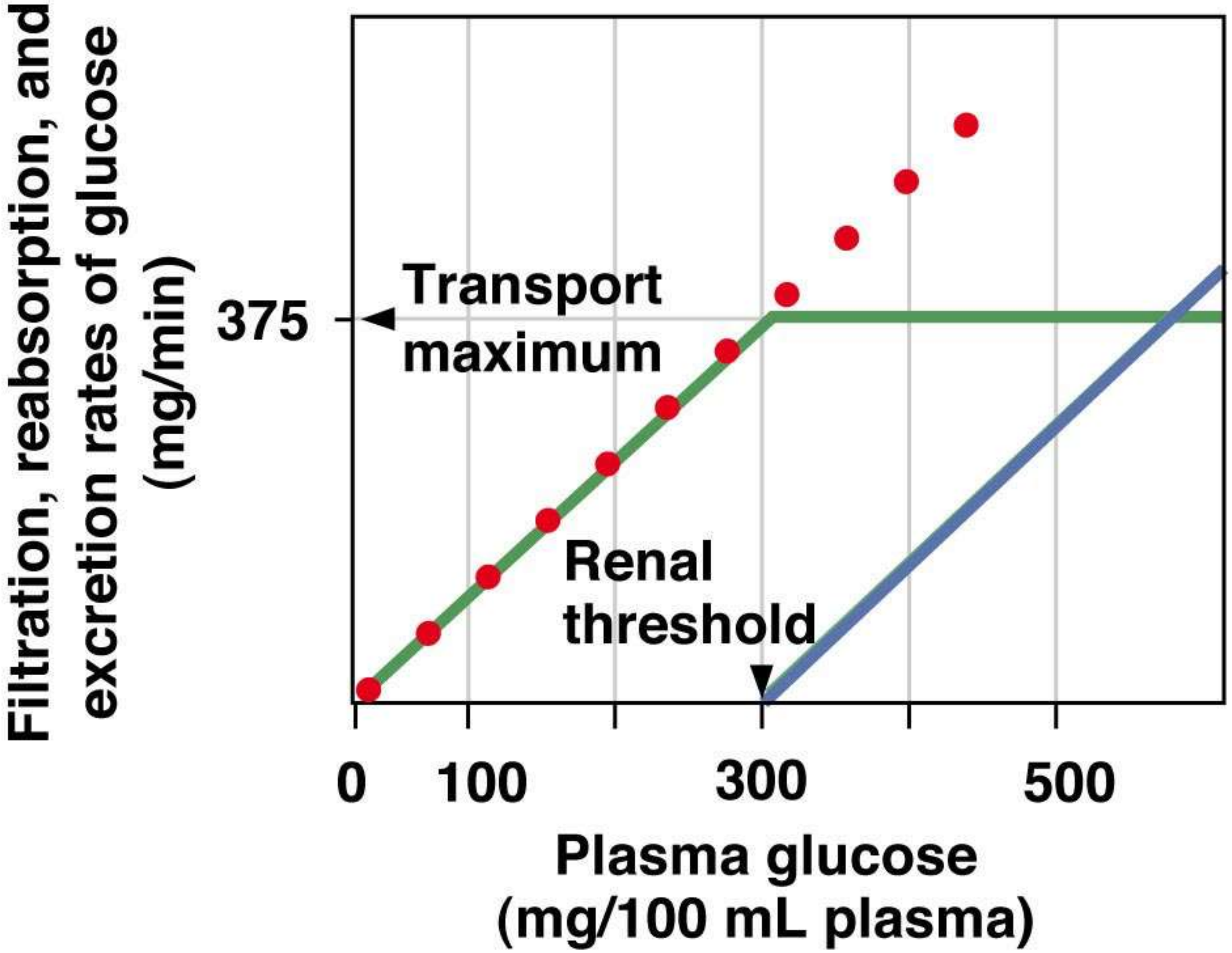
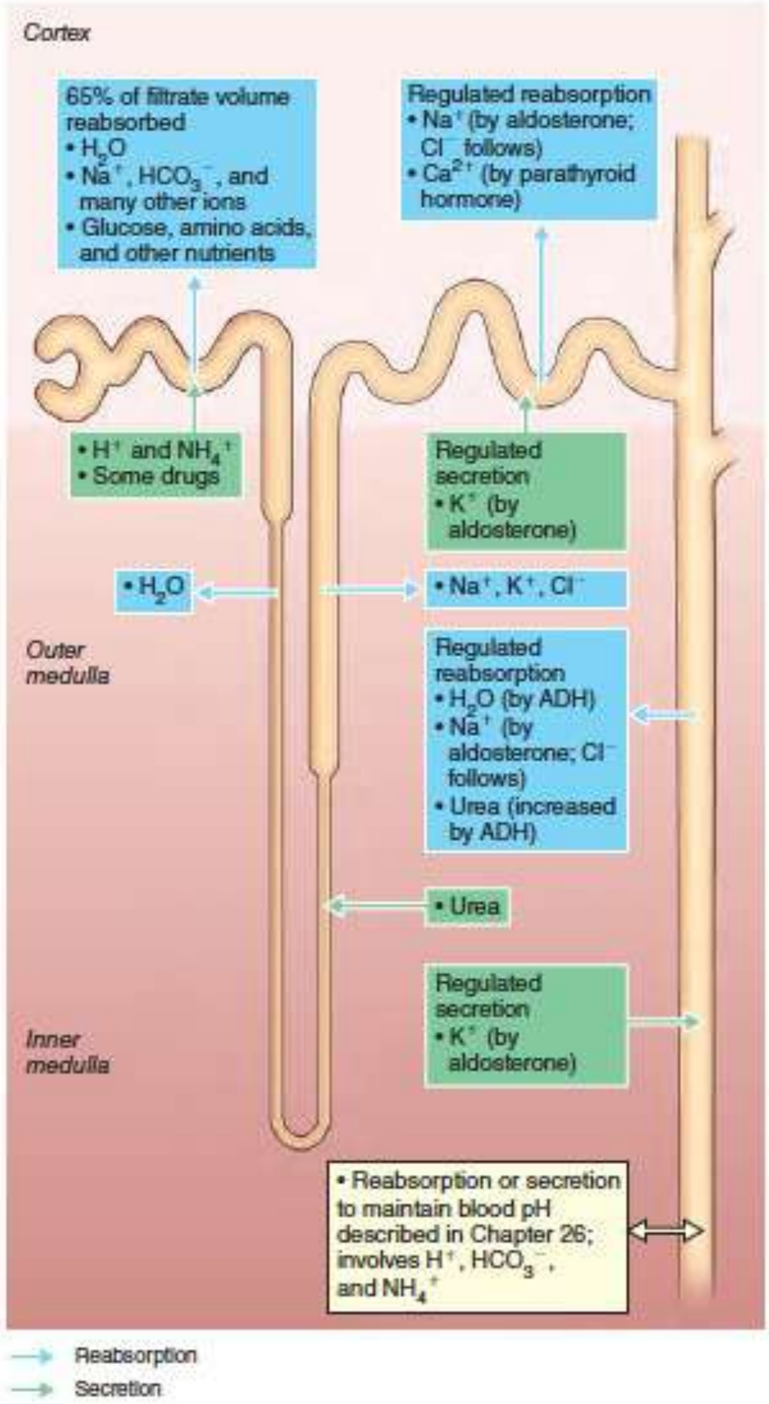


Figure 19-15d



Cortex
65% of filtrate volume reabsorbed
• H_2O
• Na^+, HCO_3^-, and many other ions
• Glucose, amino acids, and other nutrients
Regulated reabsorption
• Na^+ (by aldosterone; Cl^- follows)
• Ca^{2+} (by parathyroid hormone)
• H^+ and NH_4^+
• Some drugs
Regulated secretion
• K^+ (by aldosterone)
• H_2O
• Na^+, K^+, Cl^-
Outer medulla
Regulated reabsorption
• H_2O (by ADH)
• Na^+ (by aldosterone; Cl^- follows)
• Urea (increased by ADH)
• Urea
Regulated secretion
• K^+ (by aldosterone)
Inner medulla
• Reabsorption or secretion to maintain blood pH described in Chapter 26; involves H^+, HCO_3^-, and NH_4^+
Reabsorption
Secretion

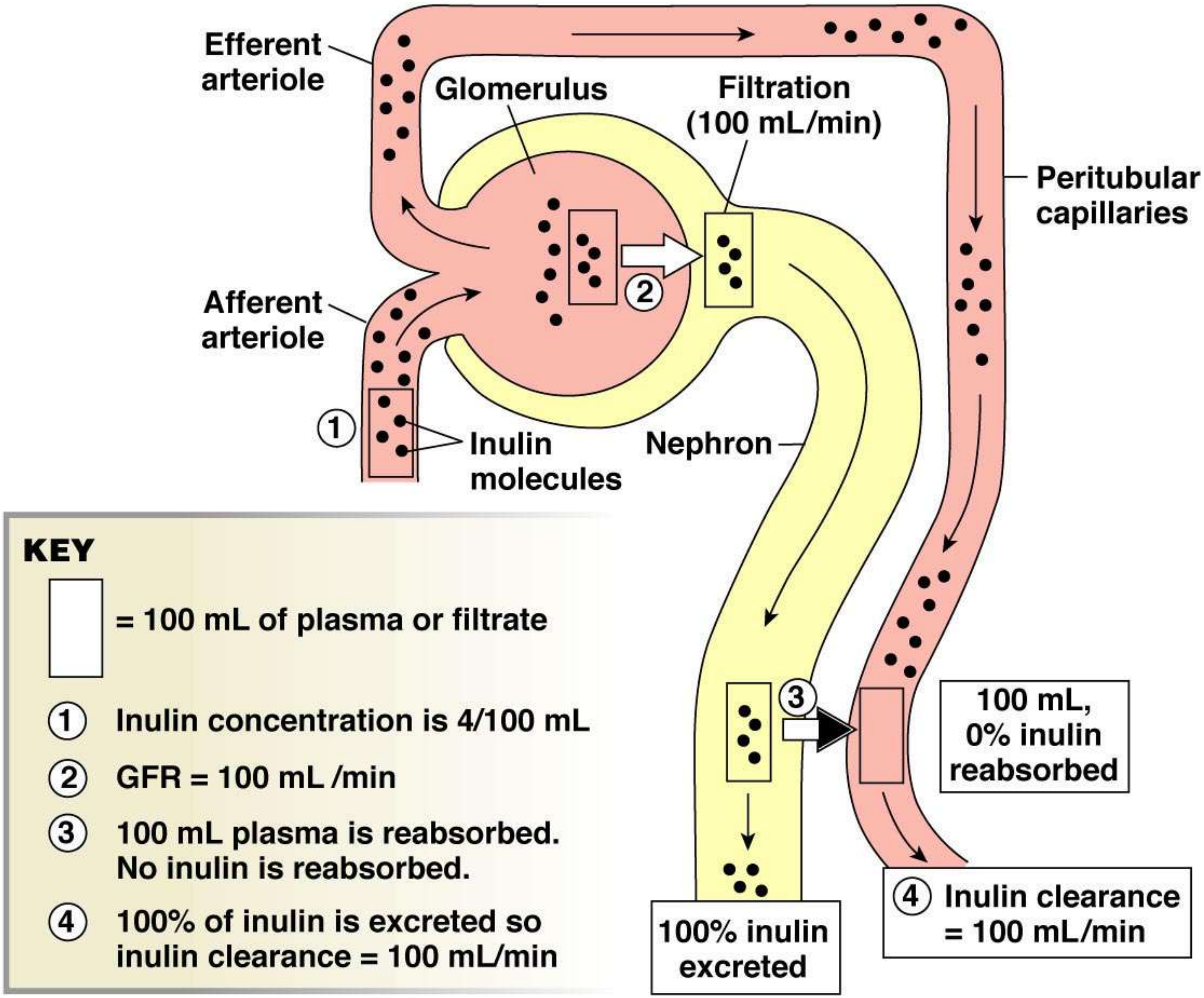

Efferent arteriole
Glomerulus
Filtration (100 mL/min)
Peritubular capillaries
Afferent arteriole
2
1
Inulin molecules
Nephron
KEY
= 100 mL of plasma or filtrate
1 Inulin concentration is 4/100 mL
2 GFR = 100 mL /min
3 100 mL plasma is reabsorbed. No inulin is reabsorbed.
4 100% of inulin is excreted so inulin clearance = 100 mL/min
3
100 mL, 0% inulin reabsorbed
100% inulin excreted
4 Inulin clearance = 100 mL/min

Figure 19-16

TABLE 19-2 Renal Handling of Solutes

For any molecule X that is freely filtered at the glomerulus:

If filtration rate is greater than excretion rate,	there is net reabsorption of X.
If excretion rate is greater than filtration rate,	there is net secretion of X.
If filtration and excretion rate are the same,	X passes through the nephron without net reabsorption or secretion.
If the clearance of X is less than inulin clearance,	there is net reabsorption of X.
If the clearance of X is equal to inulin clearance,	X is neither reabsorbed nor secreted.
If the clearance of X is greater than inulin clearance,	there is net secretion of X.

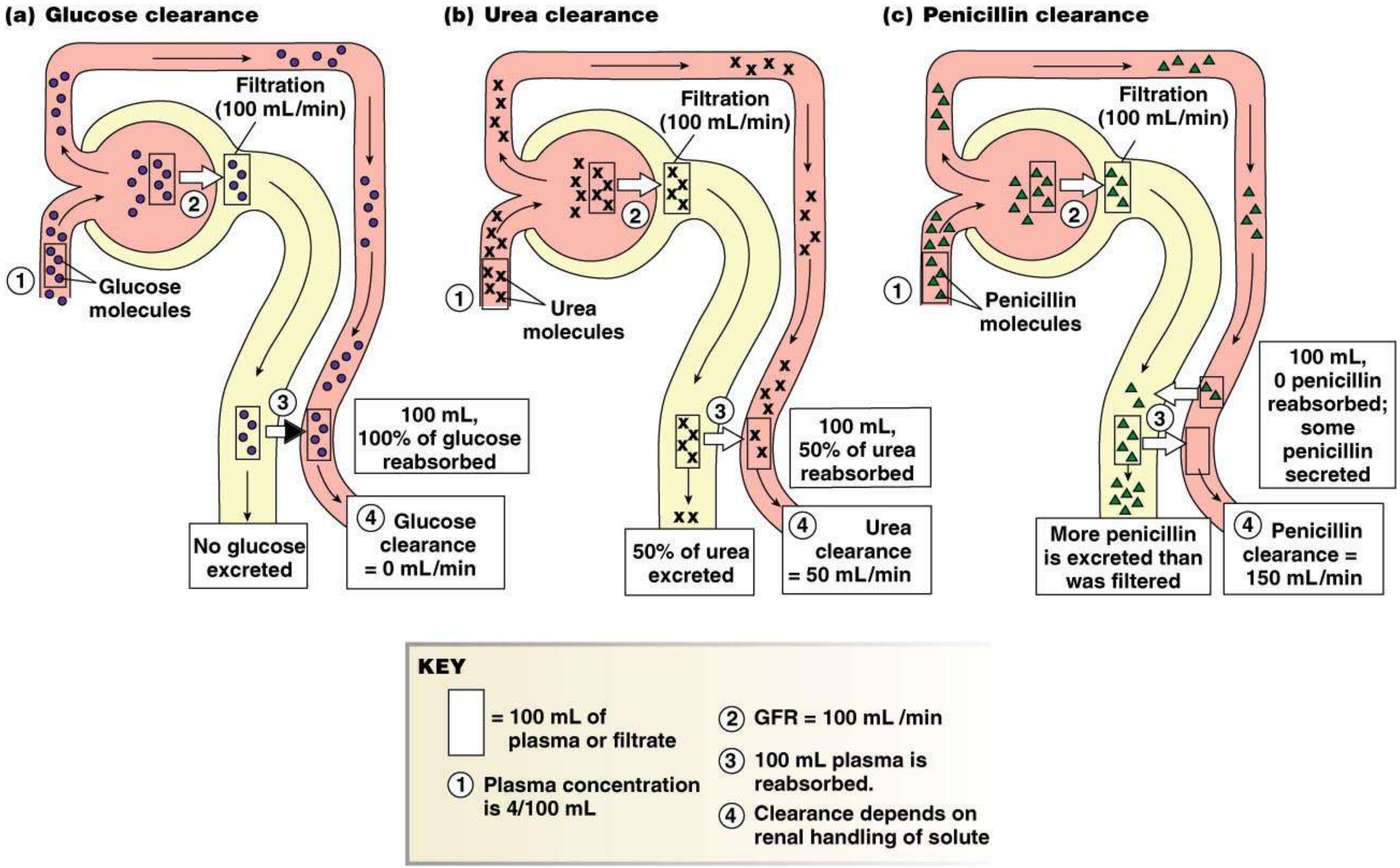


Figure 19-17 - Overview

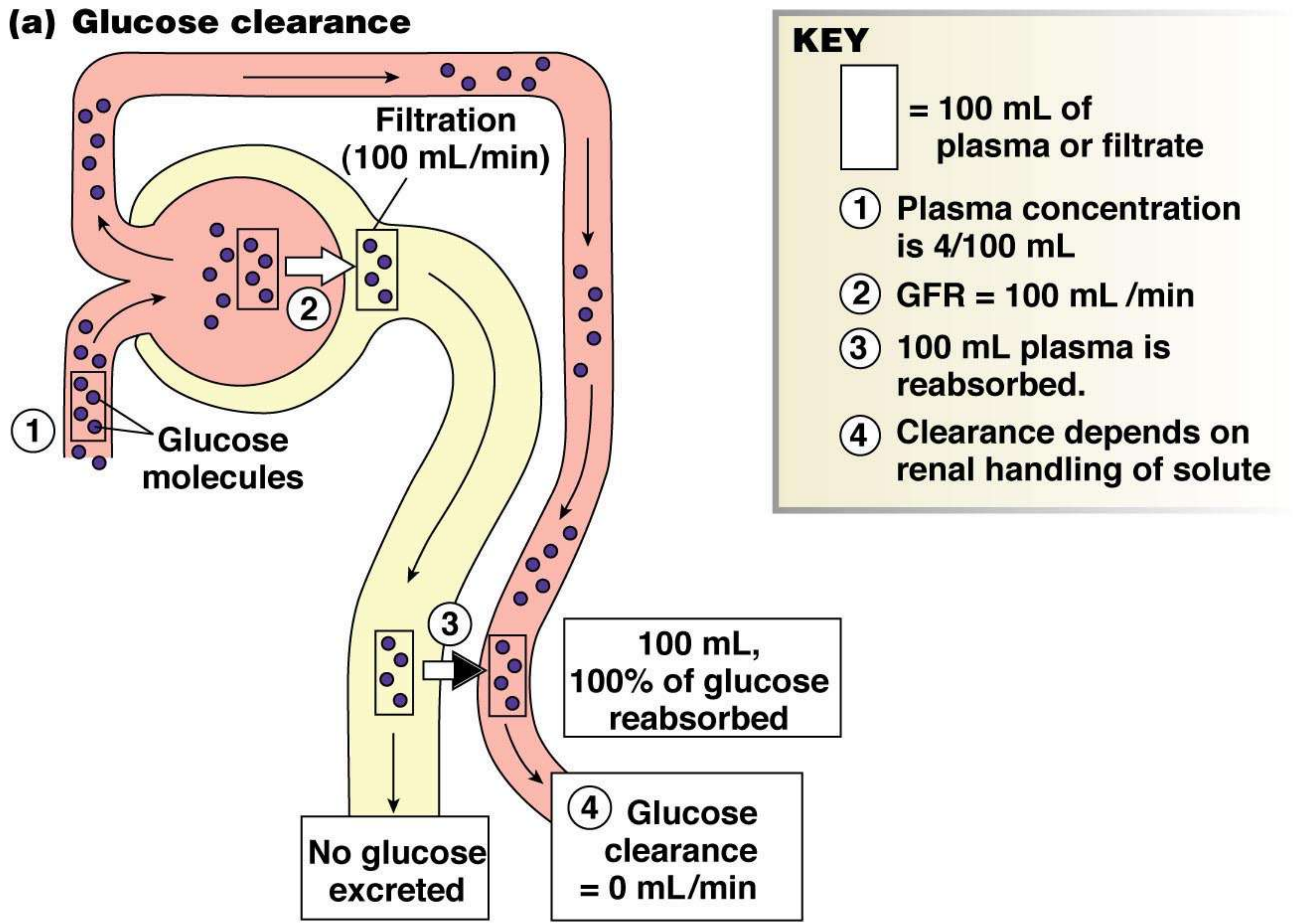


Figure 19-17a

(b) Urea clearance

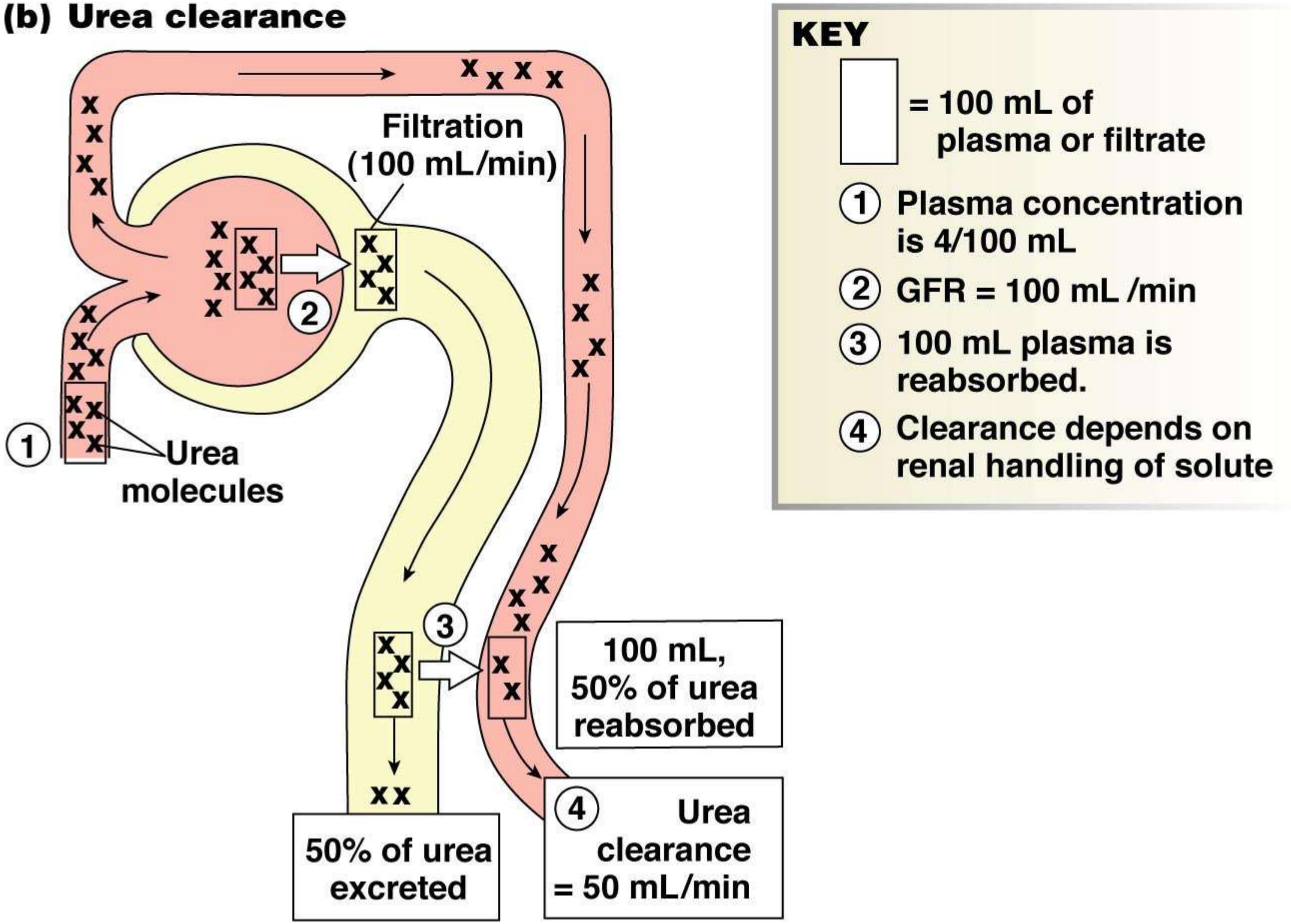


Figure 19-17b

(c) Penicillin clearance

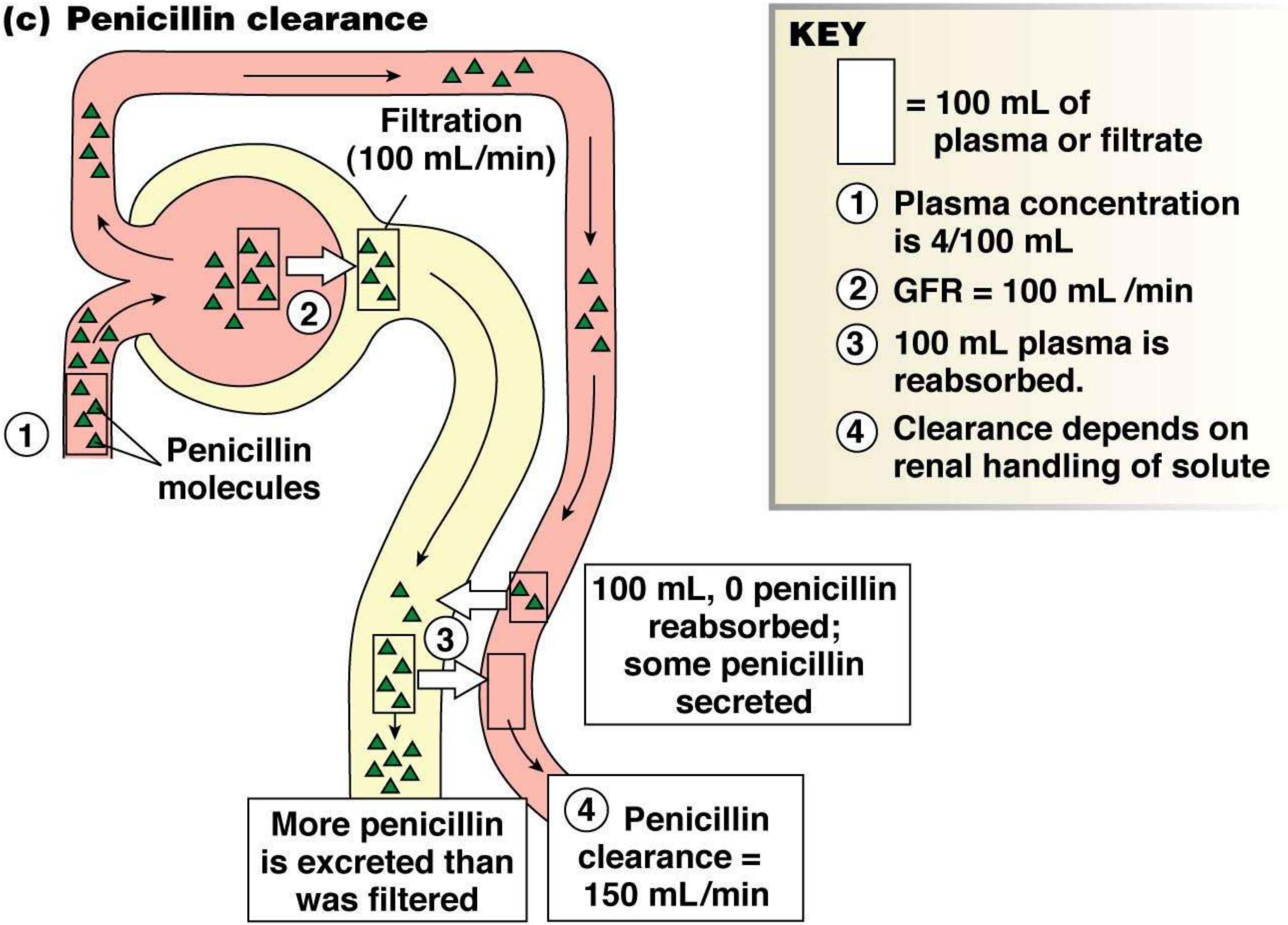


Figure 19-17c

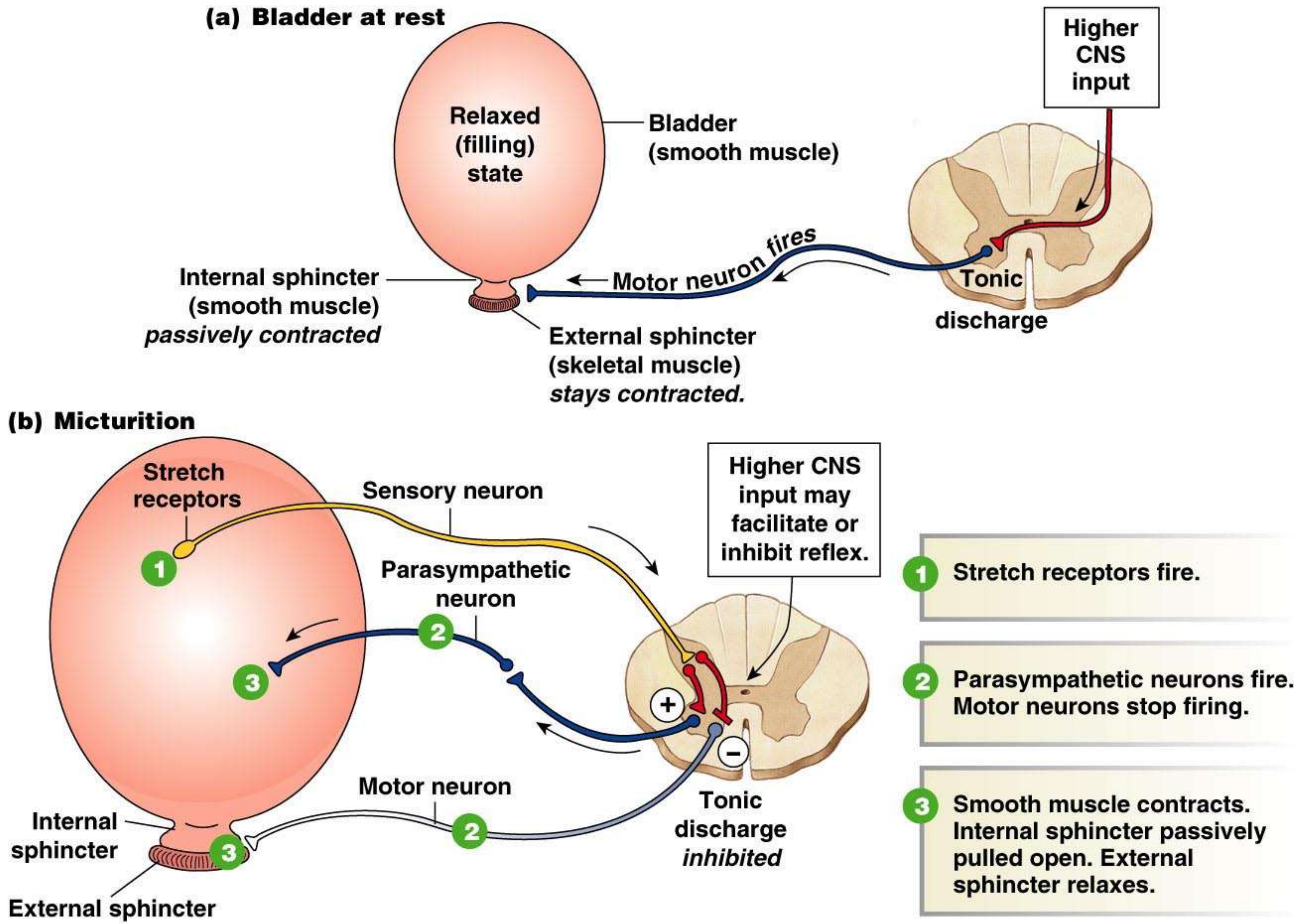


Figure 19-18 Overview

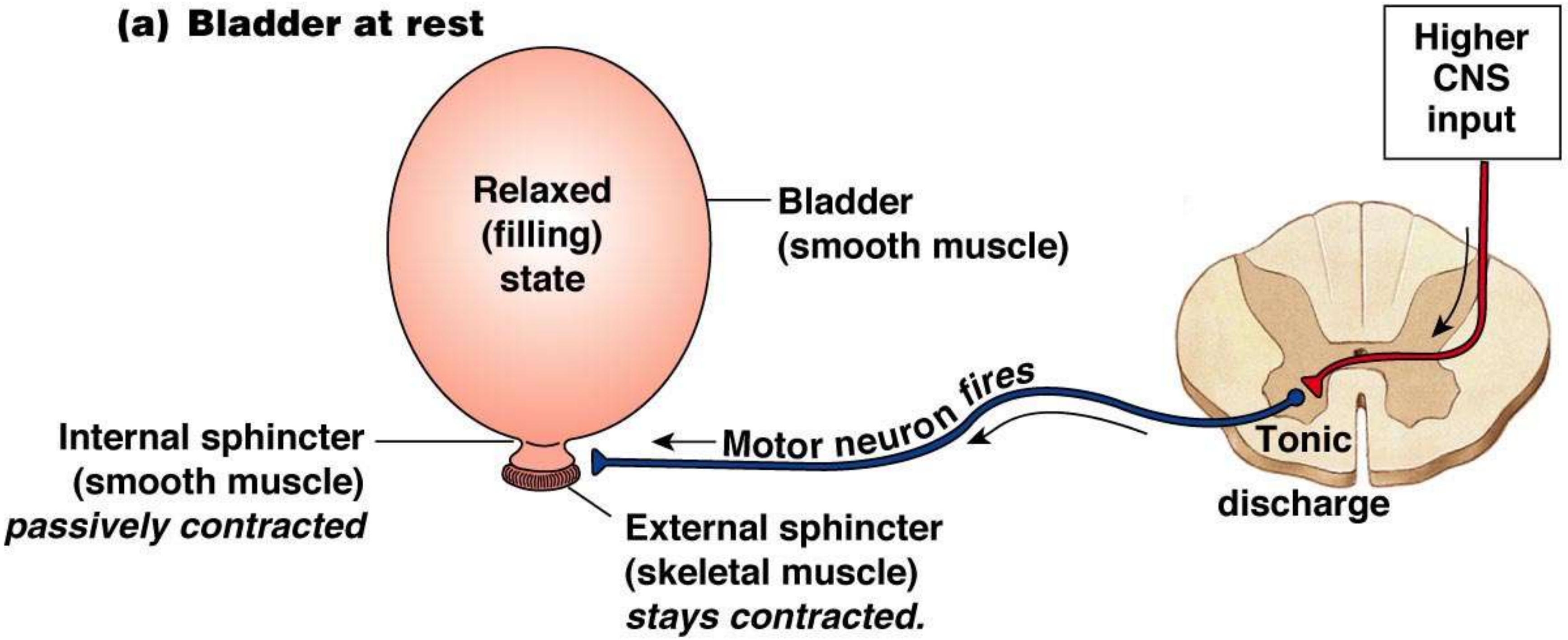


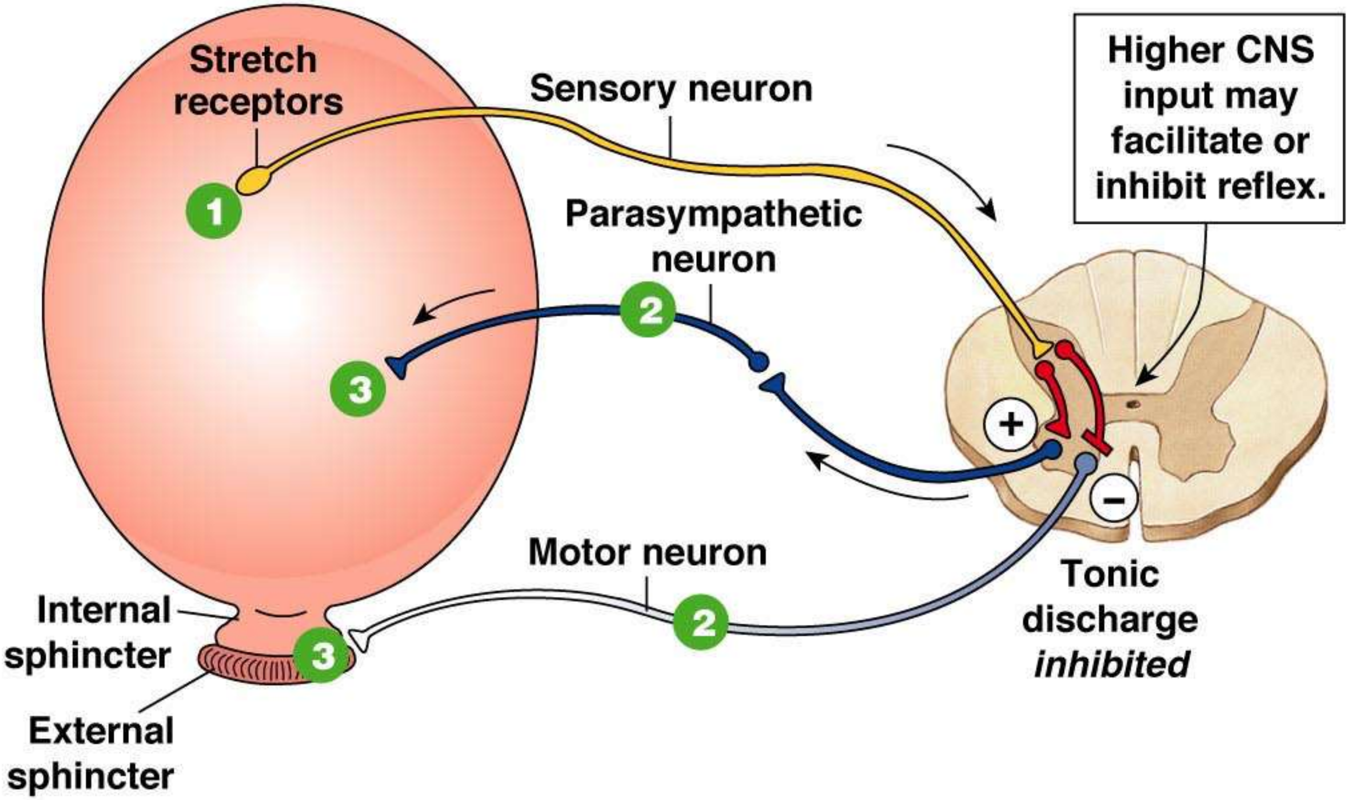
Figure 19-18a

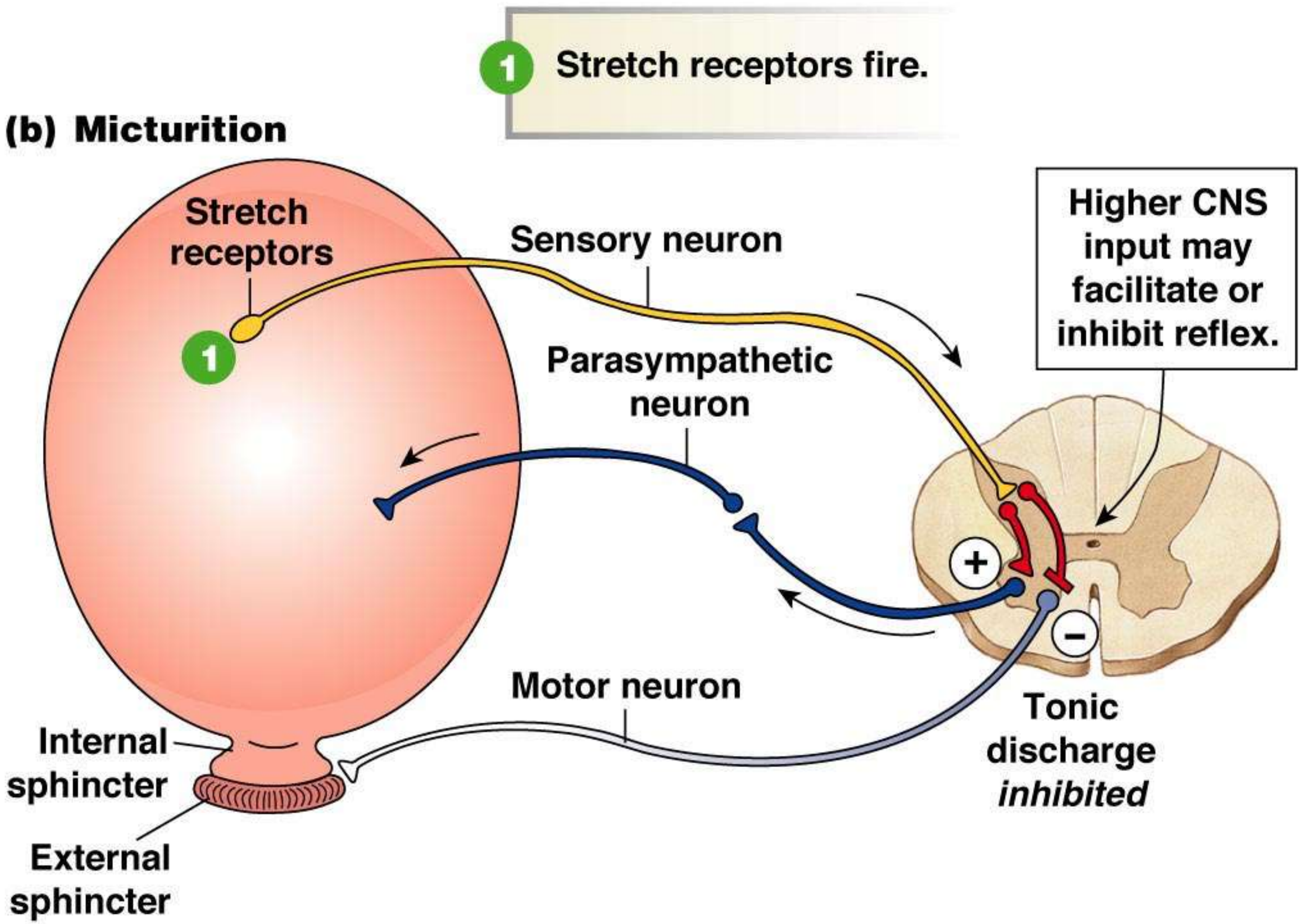
1 Stretch receptors fire.

2 Parasympathetic neurons fire. Motor neurons stop firing.

3 Smooth muscle contracts. Internal sphincter passively pulled open. External sphincter relaxes.

(b) Micturition




1 Stretch receptors fire.
(b) Micturition
Stretch receptors
1
Sensory neuron
Higher CNS input may facilitate or inhibit reflex.
Parasympathetic neuron
+
−
Motor neuron
Tonic discharge *inhibited*
Internal sphincter
External sphincter

2 Parasympathetic neurons fire.
Motor neurons stop firing.

(b) Micturition

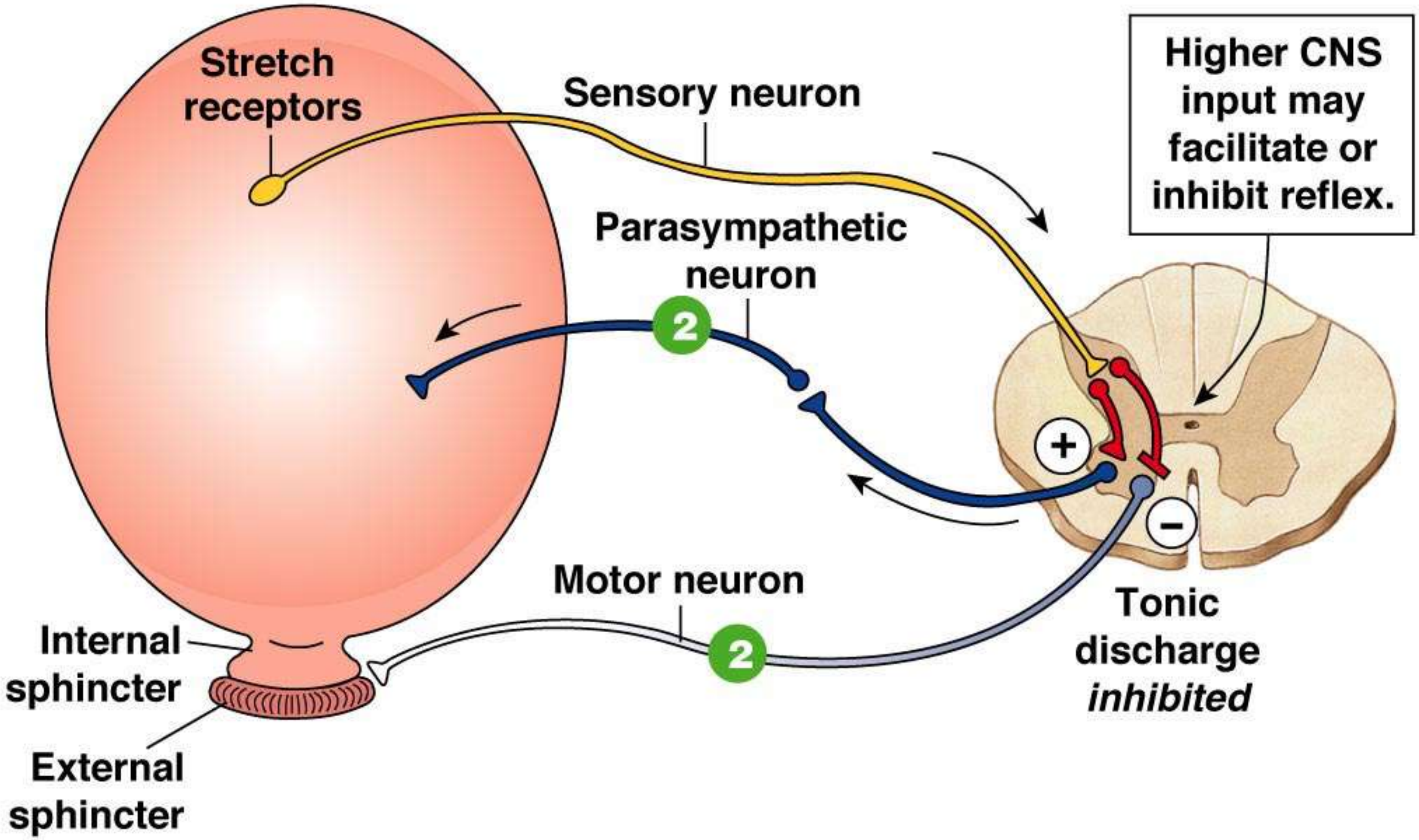


Figure 19-18b, step 2

3 Smooth muscle contracts. Internal sphincter passively pulled open. External sphincter relaxes.

(b) Micturition

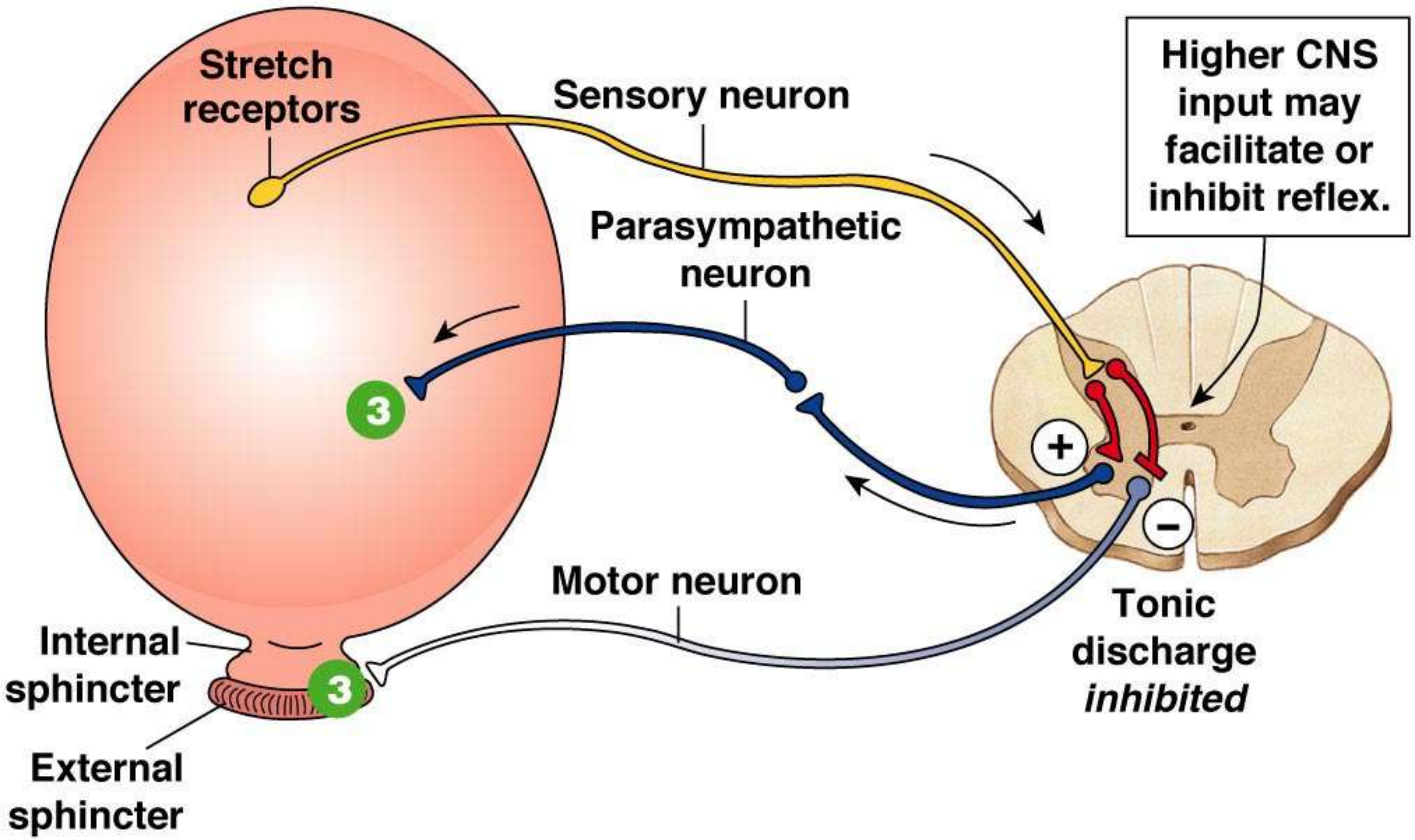


Figure 19-18b, step 3