Urinary System:
Renal Physiology for Medical Students, L4-8

Urine Formation by the Kidneys:
II. Tubular Reabsorption and Secretion

Reference: Guyton & Hall, Jordanian first edition Chapter27

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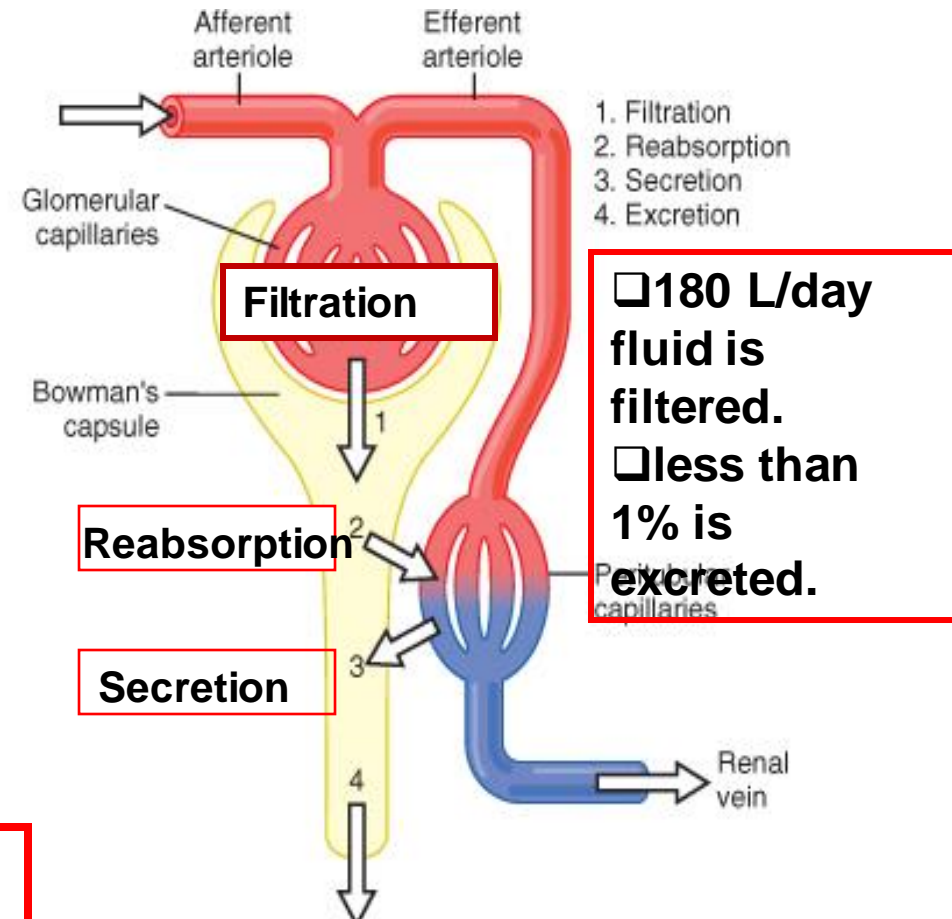
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2023

Objectives

- Describe the mechanisms of renal reabsorption and secretion in the nephron for different substances.

- Identify the functions of the different parts of the nephron tubules and describe the transport mechanisms occurring in each part.

- Describe the changes in concentrations of different substances in the renal tubules and the underlying causes of these changes.

- Understand how inulin can be used to estimate water reabsorption in each segment of the nephron.

The functional unit of the kidney

Basic Mechanisms
of Urine Formation

- Ultrafiltration
- Reabsorption
- Secretion
- Excretion

Afferent arteriole

Efferent arteriole

1. Filtration
2. Reabsorption
3. Secretion
4. Excretion

Glomerular capillaries

Filtration

❑180 L/day fluid is filtered.
❑less than 1% is excreted.

Bowman's capsule

Reabsorption

Secretion

Peritubular capillaries

Renal vein

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Urinary excretion (1-2 L/day)

Excretion= Filtration-Reabsorption+ Secretion

Audio-Visual Aid 🎧 ▶

 Please watch this animation Demonstarting:

- [Reabsorption and Secretion animation - YouTube](#)

Reabsorption and Secretion animation

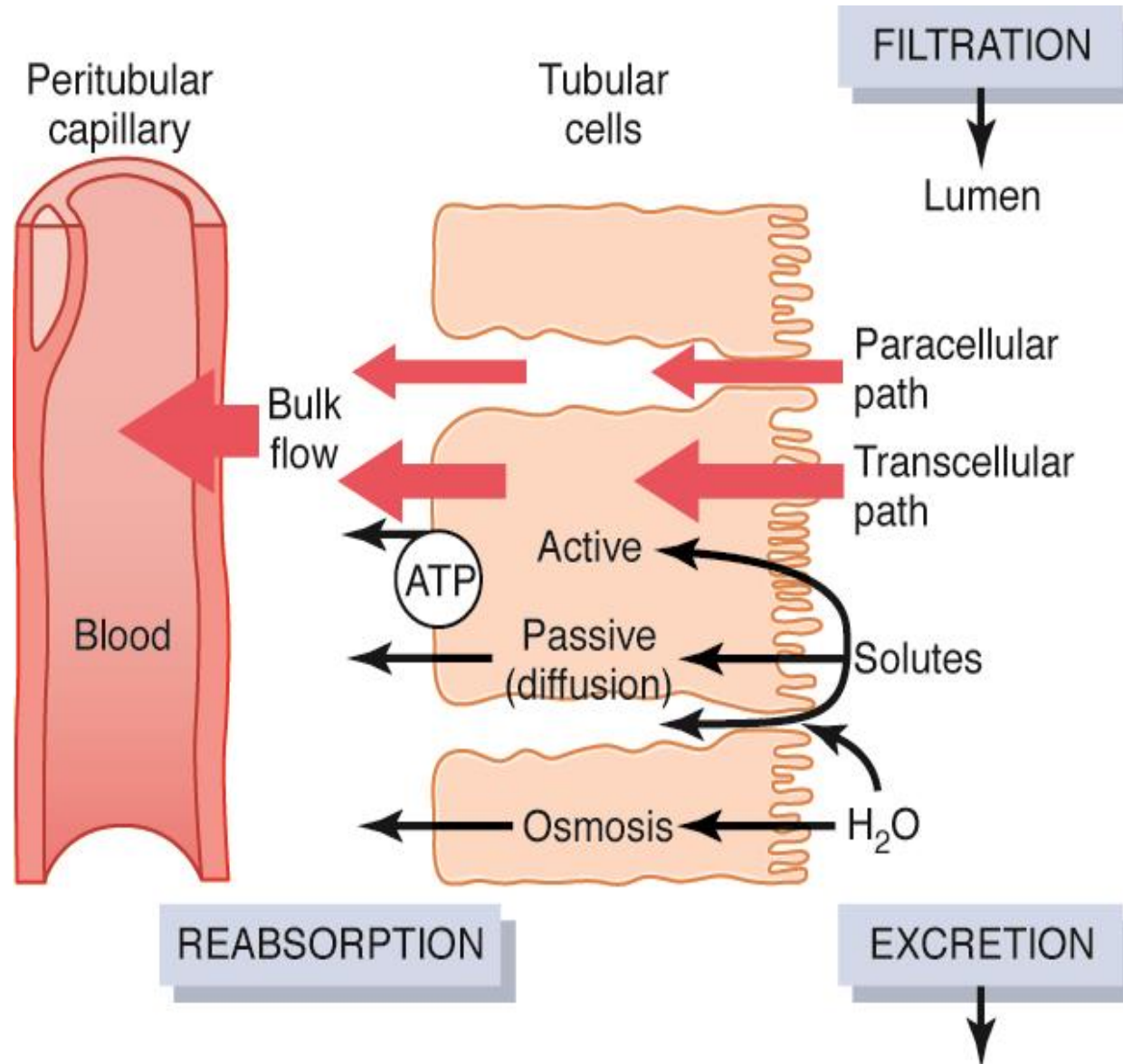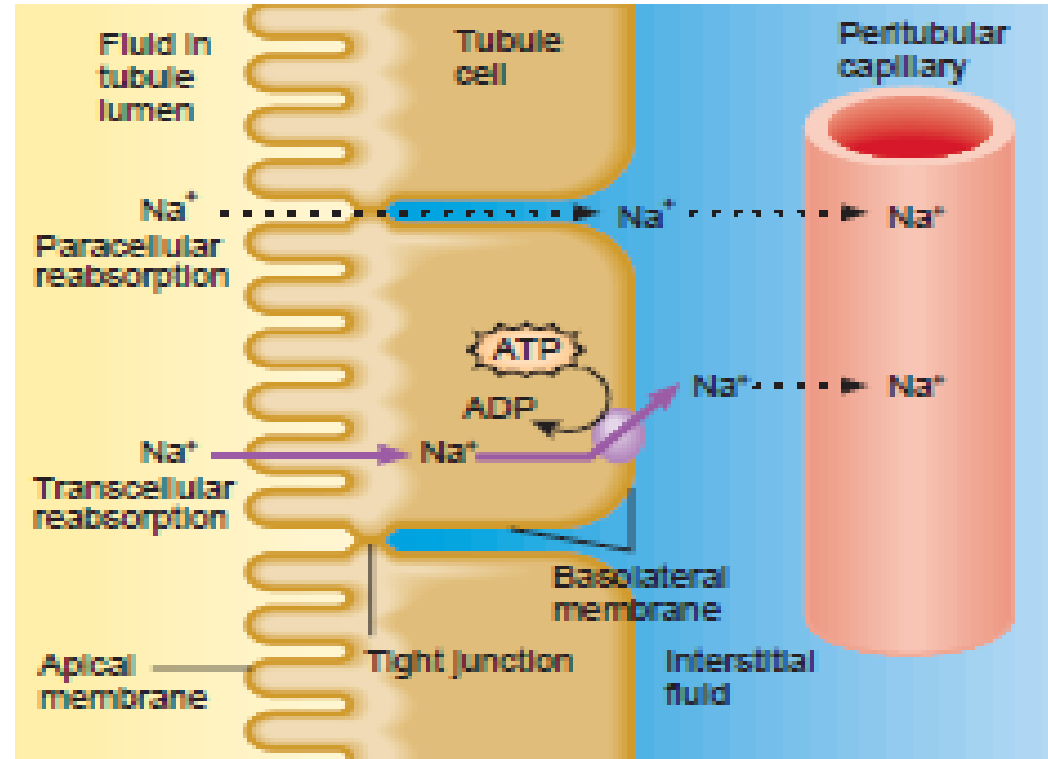medical amboss
2.18K subscribers   Subscribe   👍 21   👎   ➔ Share   ...

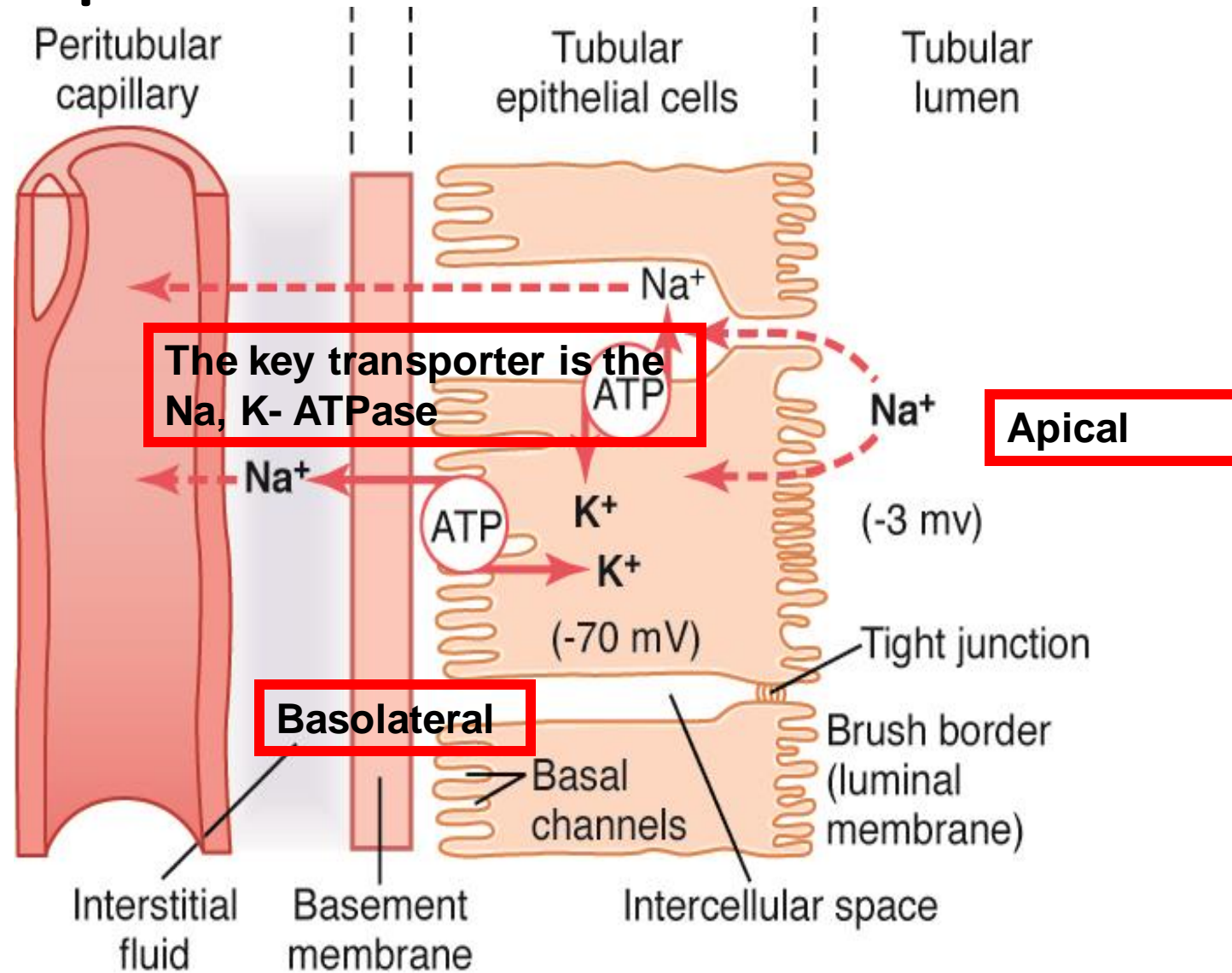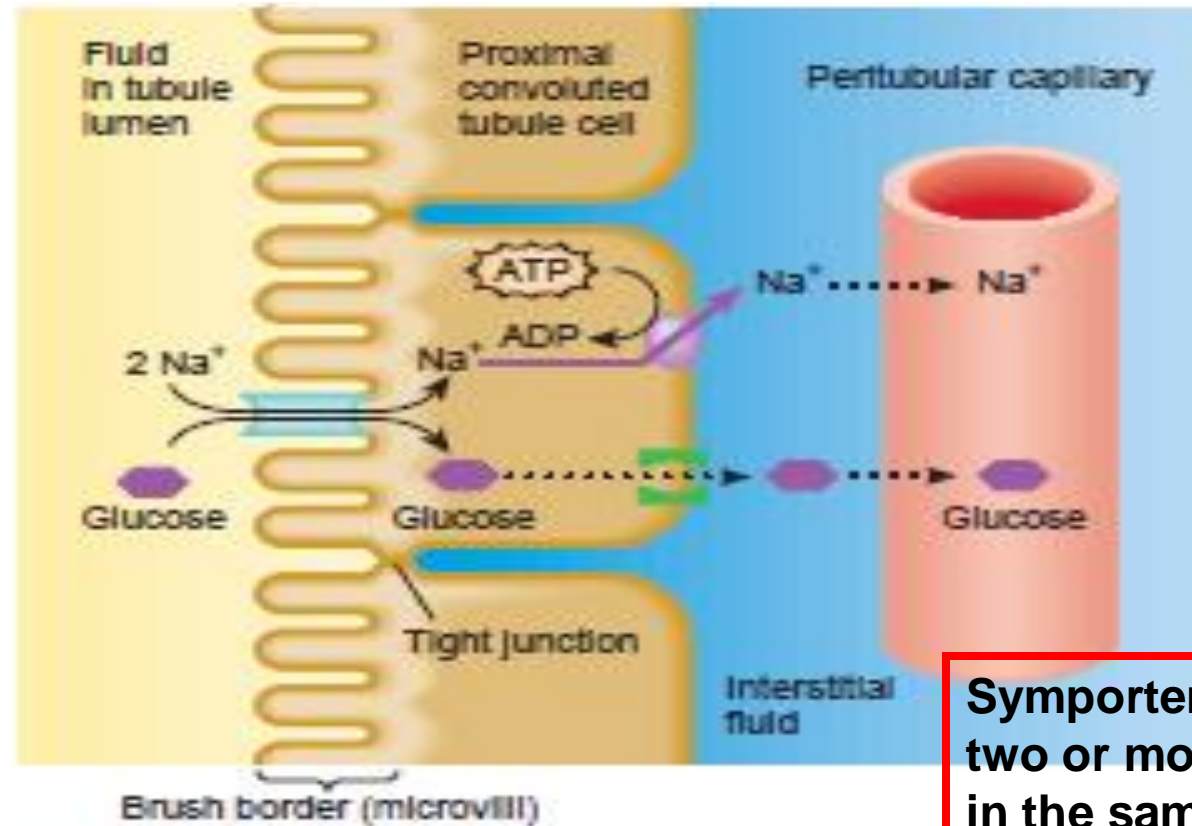# Reabsorption of Water and Solutes

Reabsorption of Water and Solutes

Active Transport

Proximal tubule reabsorption
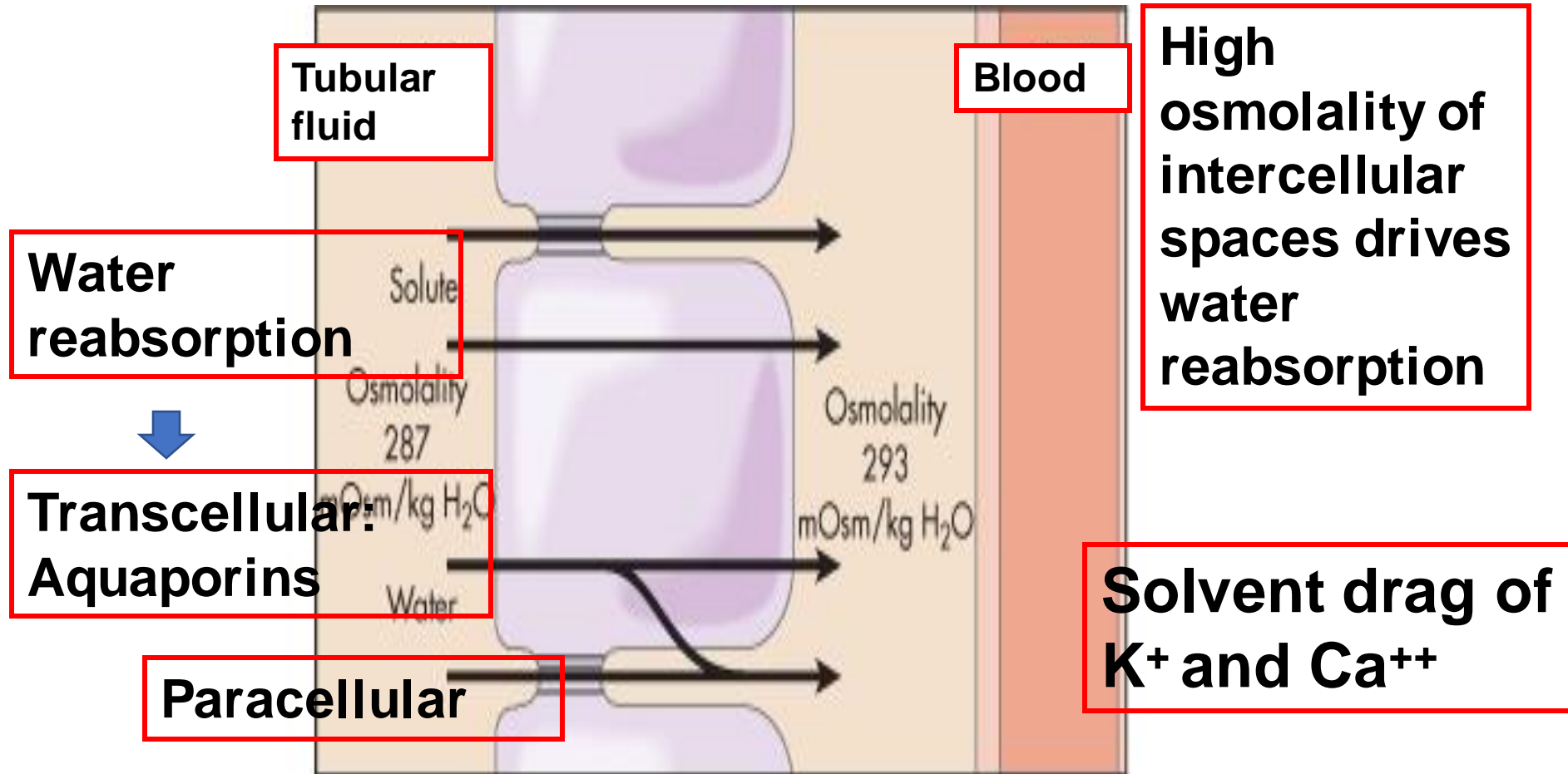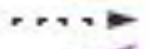
Tubular fluid

Blood

High osmolality of intercellular spaces drives water reabsorption

Water reabsorption

Transcellular: Aquaporins

Paracellular

Solvent drag of K$^+$ and Ca^{++}

Solute

Osmolality 287 mOsm/kg H$_2$O

Water

Osmolality 293 mOsm/kg H$_2$O

Glucose: Proximal Tubules

Fluid in tubule lumen | Proximal convoluted tubule cell | Peritubular capillary

ATP
ADP
2 Na⁺
Na⁺
Na⁺ ⋯⋯▸ Na⁺
Glucose | Glucose | Glucose
Tight junction
Interstitial fluid
Brush border (microvilli)

Key:
- Na⁺-glucose symporter
- Glucose facilitated diffusion transporter
- Diffusion
- Sodium-potassium pump

Symporter= transports two or more substances in the same direction

Glucose is transported via secondary active transport (facilitated diffusion)

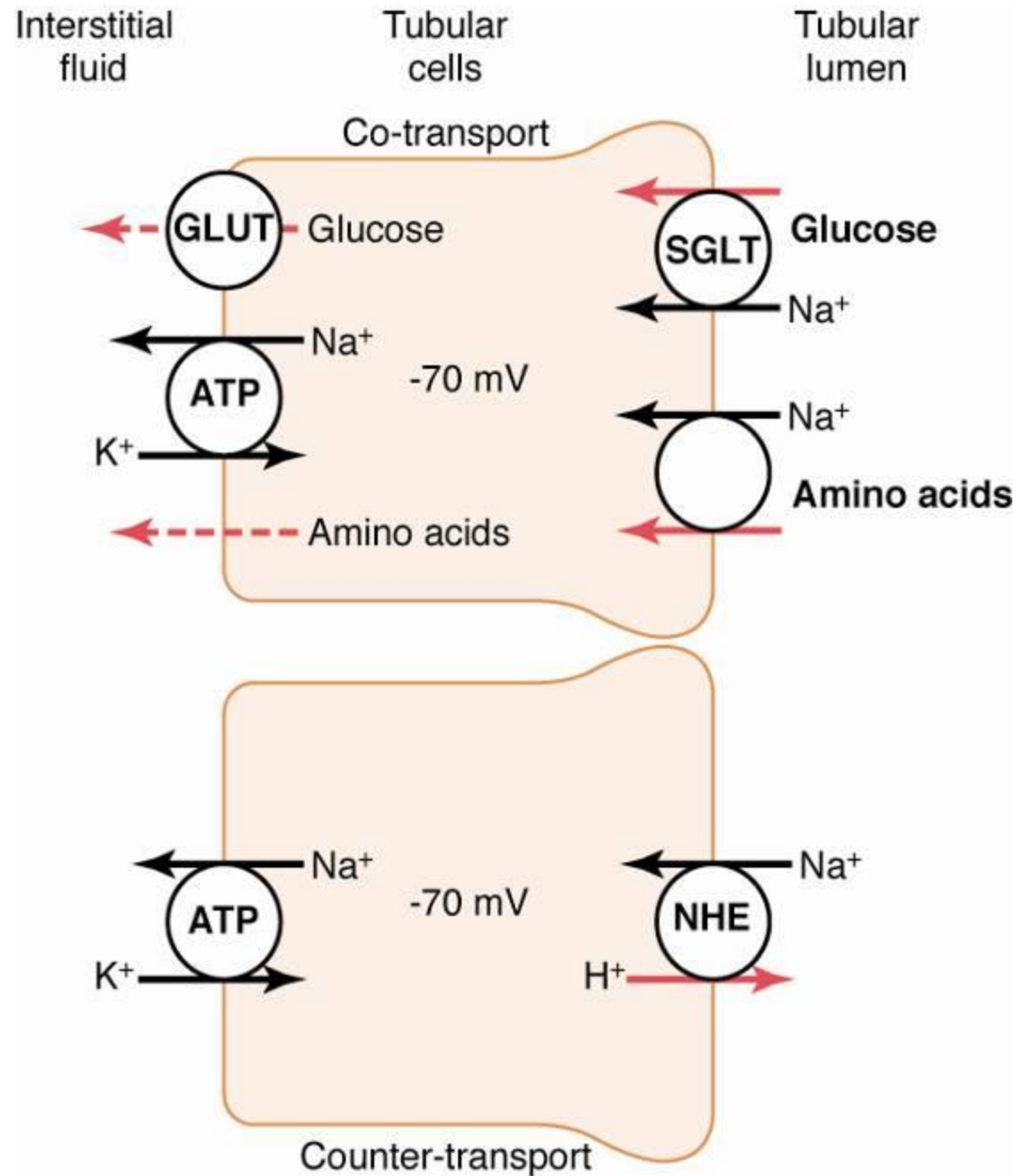Mechanisms of secondary active transport in Proximal Convoluted Tubules.

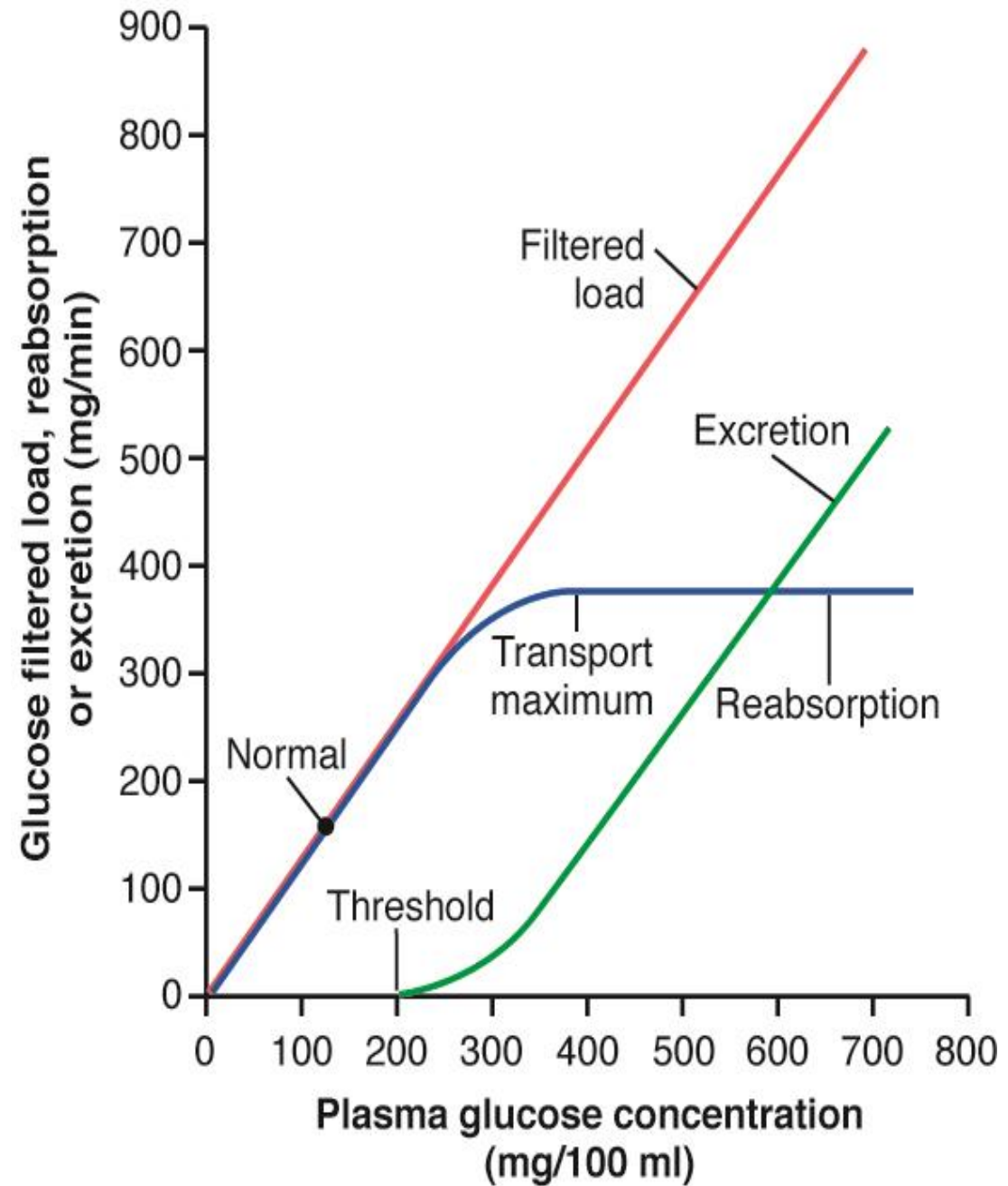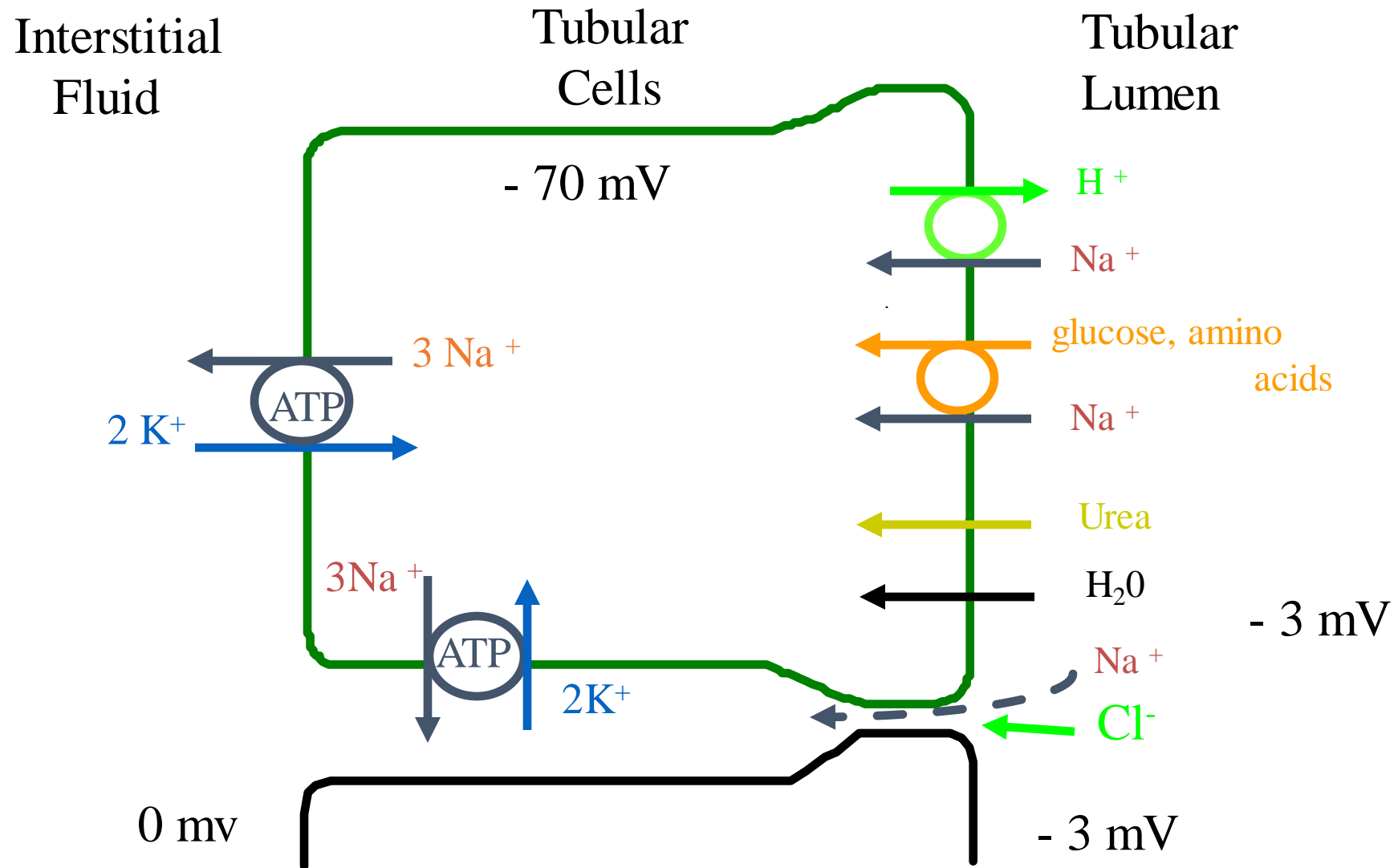Figure 27-3

Glucose Transport Maximum

Figure 27-4

Proximal Convoluted Cells

Mechanisms of water, chloride, and urea reabsorption coupled with sodium reabsorption
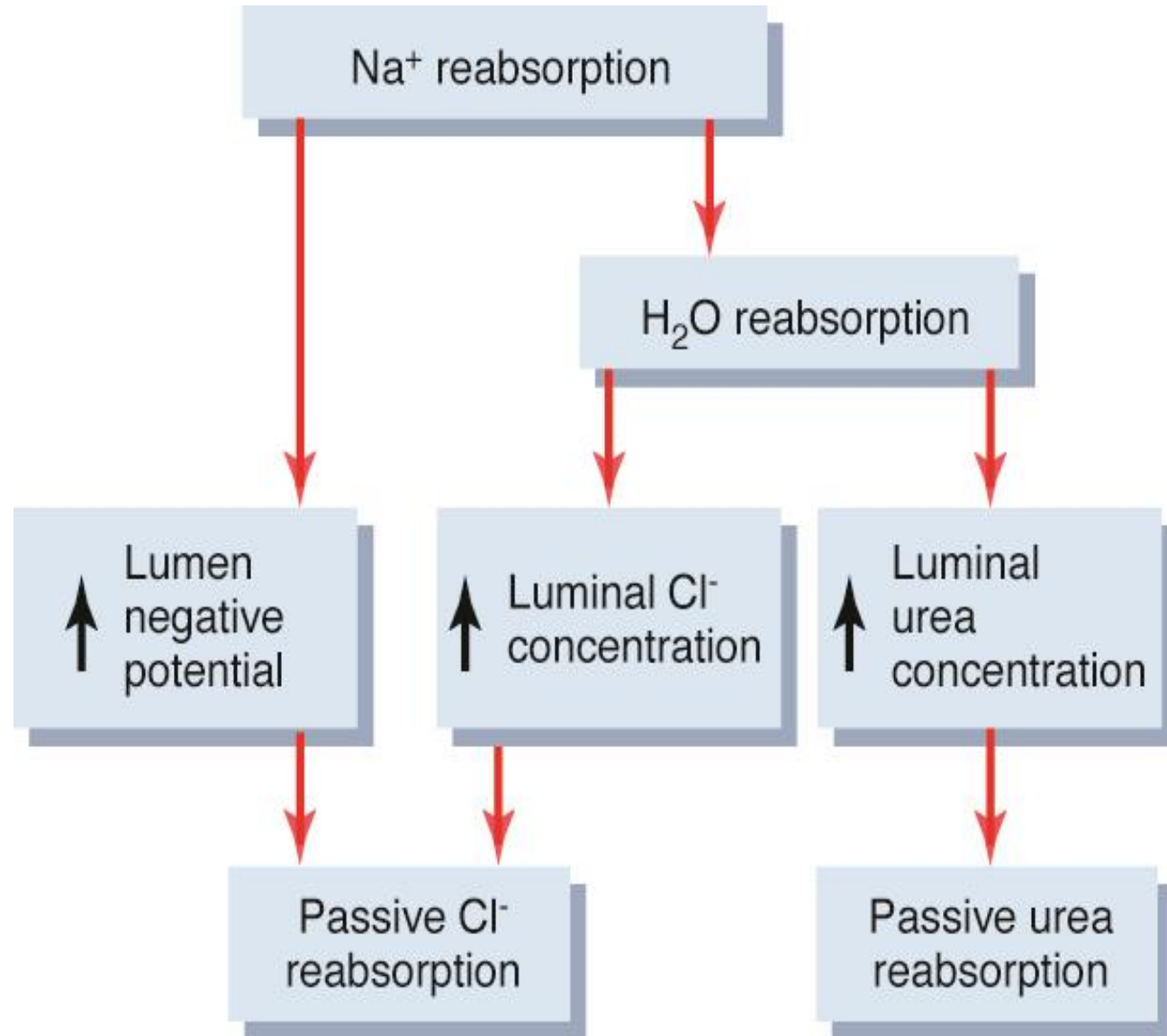
Figure 27-5

Proximal Tubules

- The proximal tubules reabsorbs about 67% of filtered water, Na^+, Cl^-, K^+, HCO_3^-.

- The proximal tubules reabsorbs almost all glucose and amino acids filtered by the glomeruli.

- The key transporter element is the Na, K- ATP ase in the basolateral membrane.

65%

Proximal tubule

Na^+, Cl^-, HCO_3^-, K^+, H_2O, glucose, amino acids

Isosmotic

H^+, organic acids, bases

: Guyton & Hall: Textbook of Medical Physiology 11e - www.studentconsult.
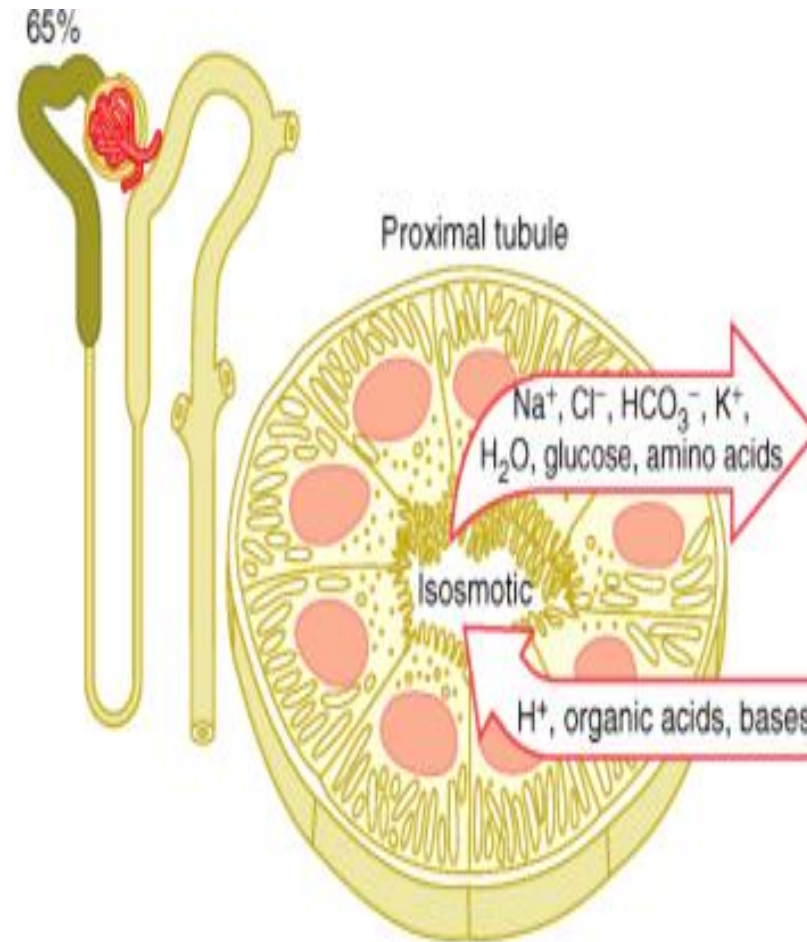
Changes in concentration in proximal tubule

Concentrations of solutes in different parts of the tubule depend on relative reabsorption of the solutes compared to water

Figure 27-7

Loop of Henle

Peritubular capillary

Thin descending loop of Henle

H_2O

H_2O

Thin Descending
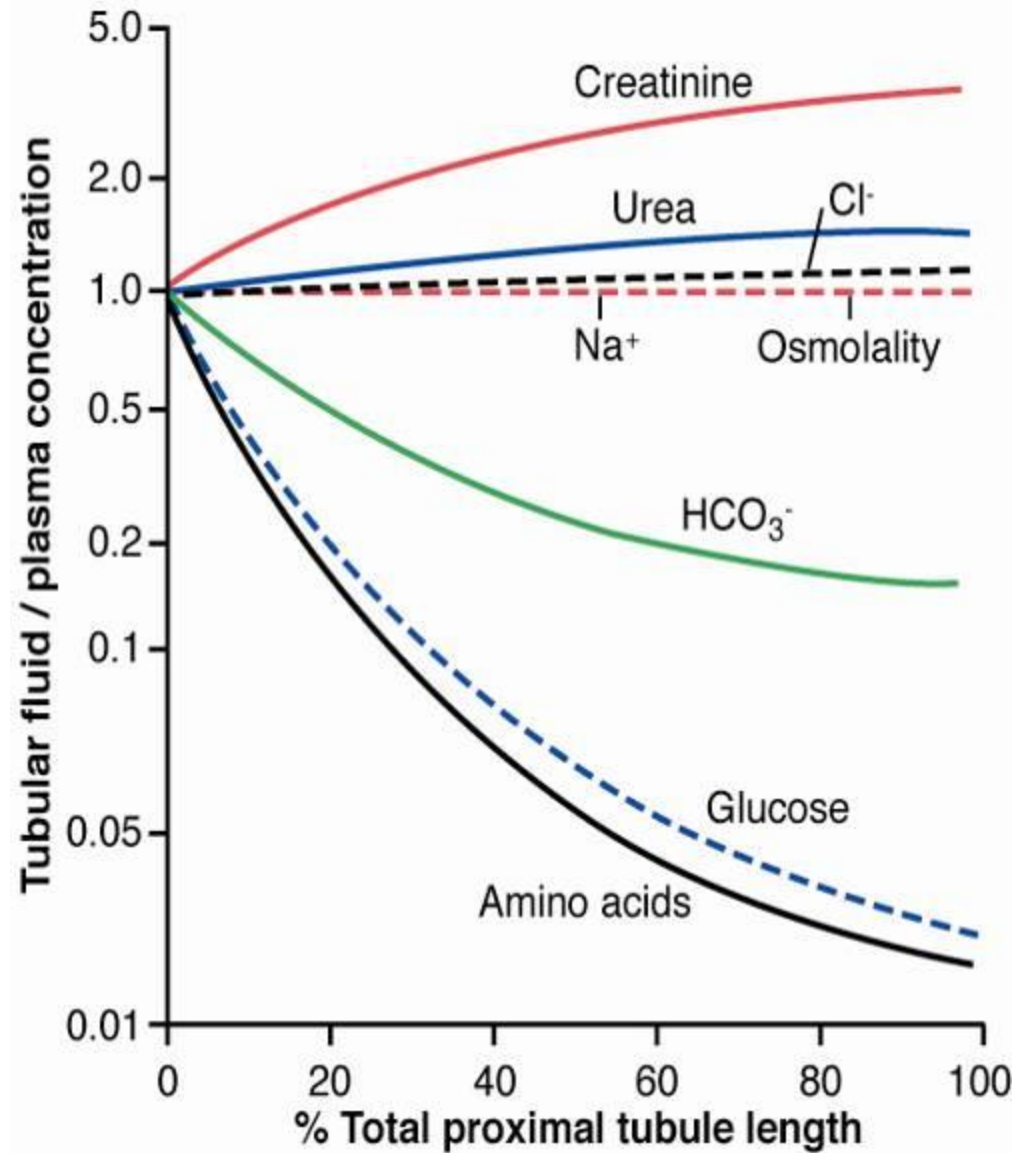- **15% of H_2O reabsorbed.**

Thin Ascending
- **Passive reabsorption of Na+, K+, Cl-.**
- **Impermeable to H_2O.**

25%

Thick ascending loop of Henle

Peritubular capillary

Na^+Cl^-

Na^+, Cl^-, K^+, Ca^{++}, HCO_3^-, Mg^{++}

Hypo-osmotic

H^+

Thick Ascending
25% of Na+, K+, Cl- HCO_3^-, Ca^{++}, Mg^{++} **reabsorbed.**
- **Impermeable to H_2O.**
- **Called = Diluting segment.**
- **Secretion of H^+**

Guyton & Hall: Textbook of Medical Physiology 11e - www.studer
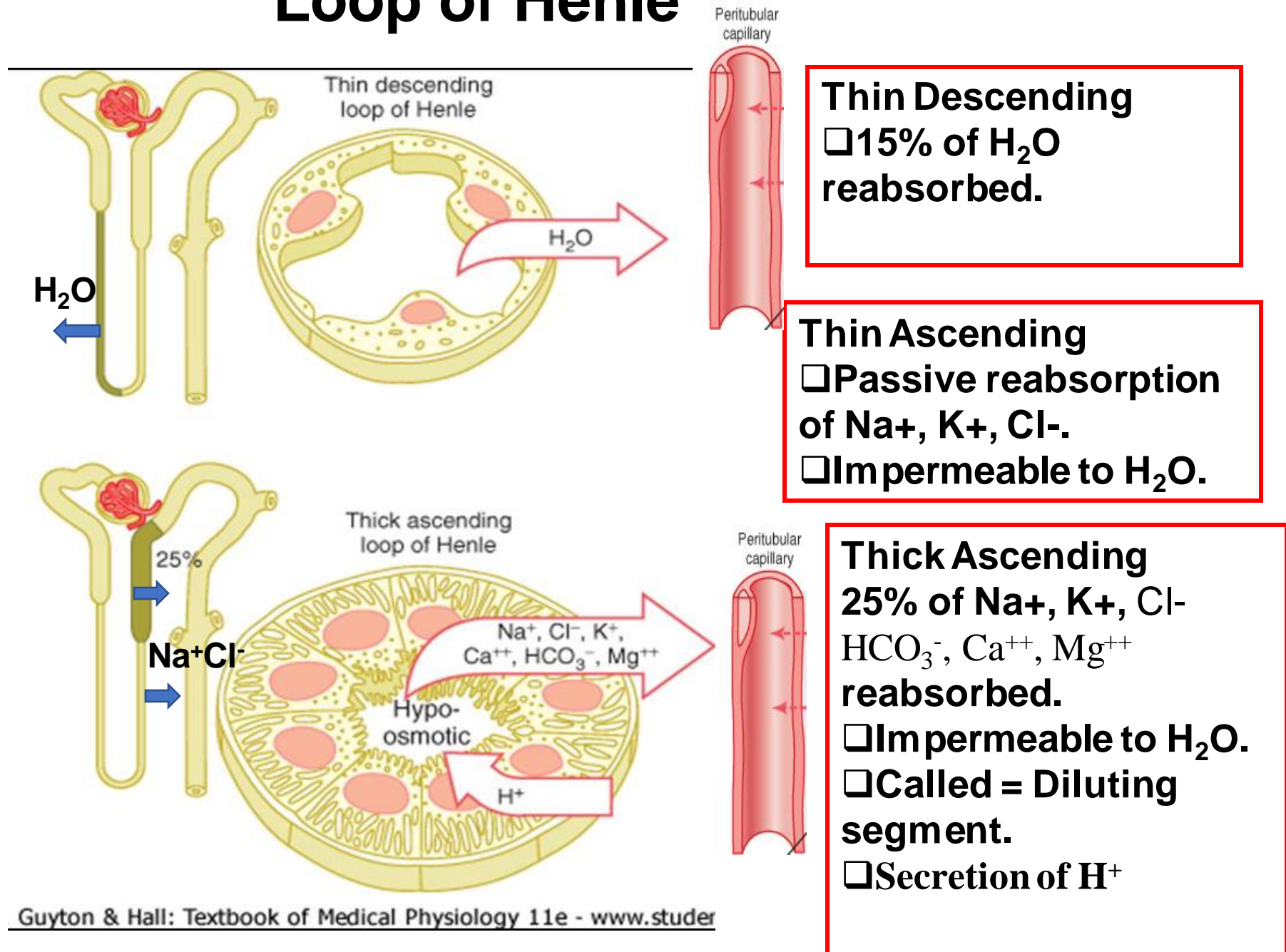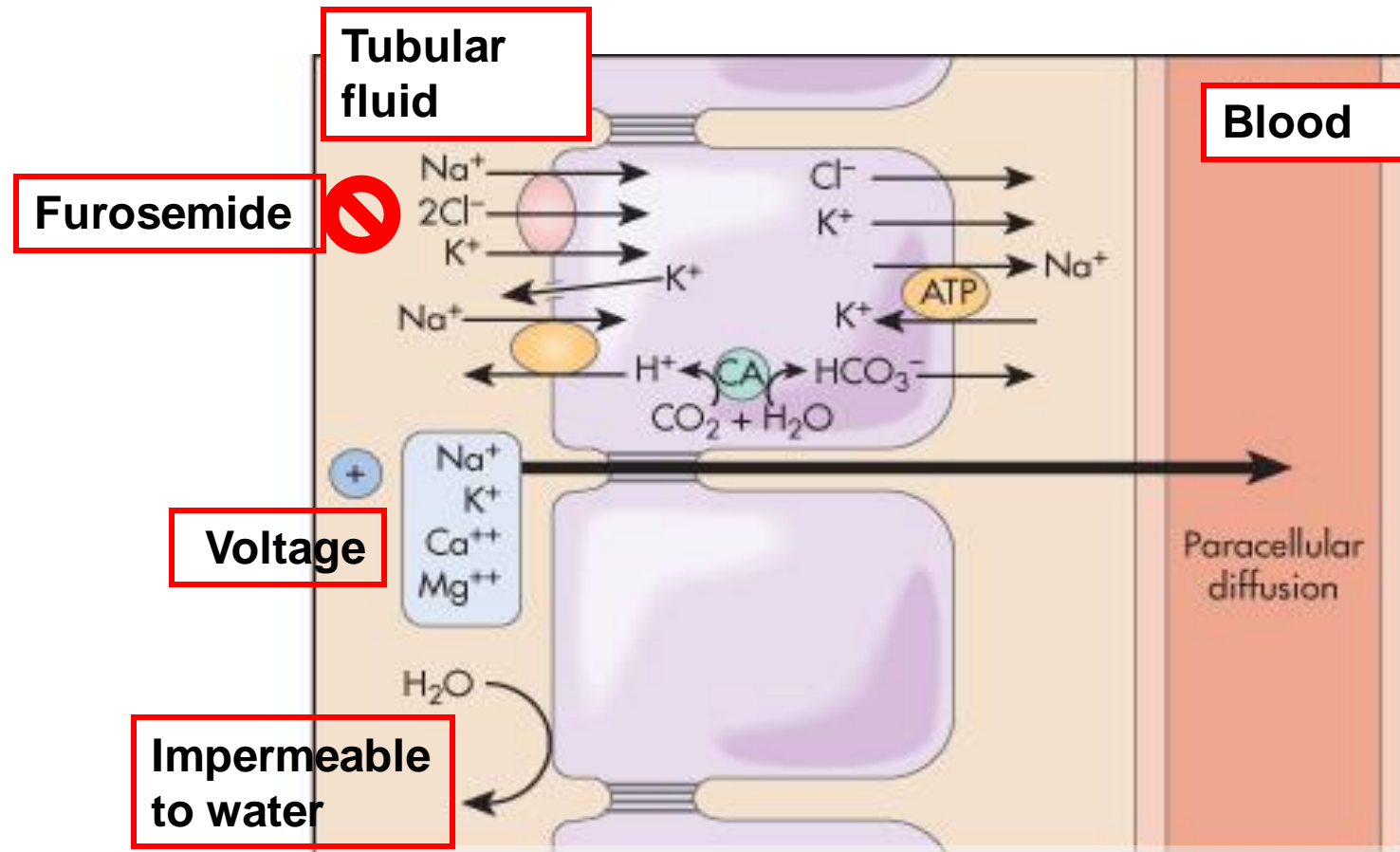
Loop of Henle

- Water reabsorption occurs exclusively in the **thin descending** limb of Henle via AQP1 water channels.(**Aquaporins**)

- Reabsorption of **NaCl** occurs in both thin and thick **ascending** limb of Henle.

- In thin ascending limb NaCl is reabsorbed passively. However, in thick ascending limb NaCl is reabsorbed through Na^+-K^+ ATPase in basolateral membrane ans .

- Ascending limb is impermeable to water.

- Reabsorption of Ca^{++} and $HCO3^-$ occurs also in Loop of Henle.

Thick ascending limb of Henle

Tubular fluid

Furosemide

Blood

Voltage

Impermeable to water

of NaCl Reabsorption:
- 50% is Transcellular
- 50% is Paracellular

Na^+
$2Cl^-$
K^+

Cl^-
K^+

K^+

Na^+

Na^+

ATP

K^+

H^+ CA HCO_3^-
$CO_2 + H_2O$

Na^+
K^+
Ca^{++}
Mg^{++}

Paracellular diffusion

H_2O

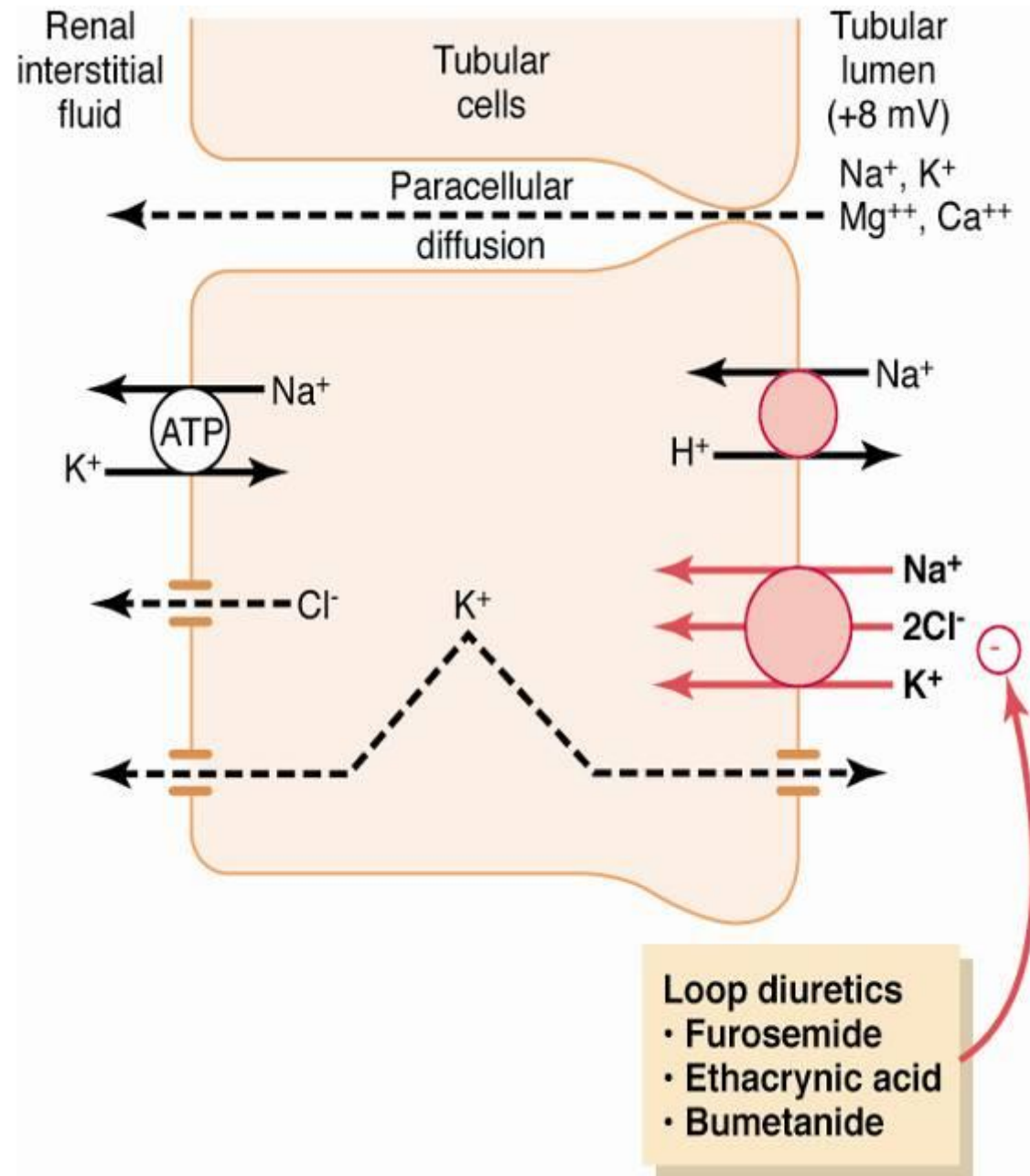Sodium chloride and potassium transport in thick ascending loop of Henle
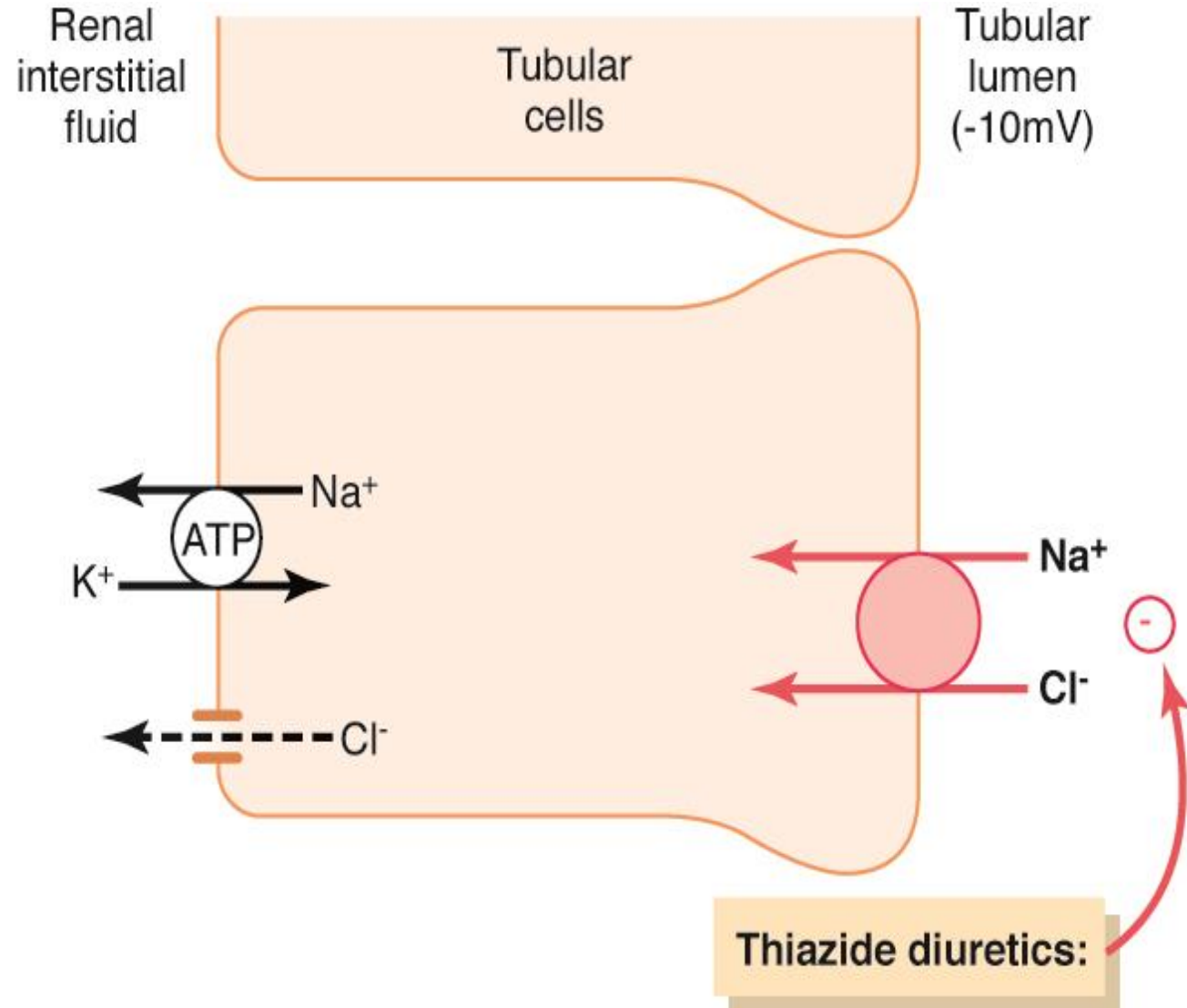
Figure 27-9
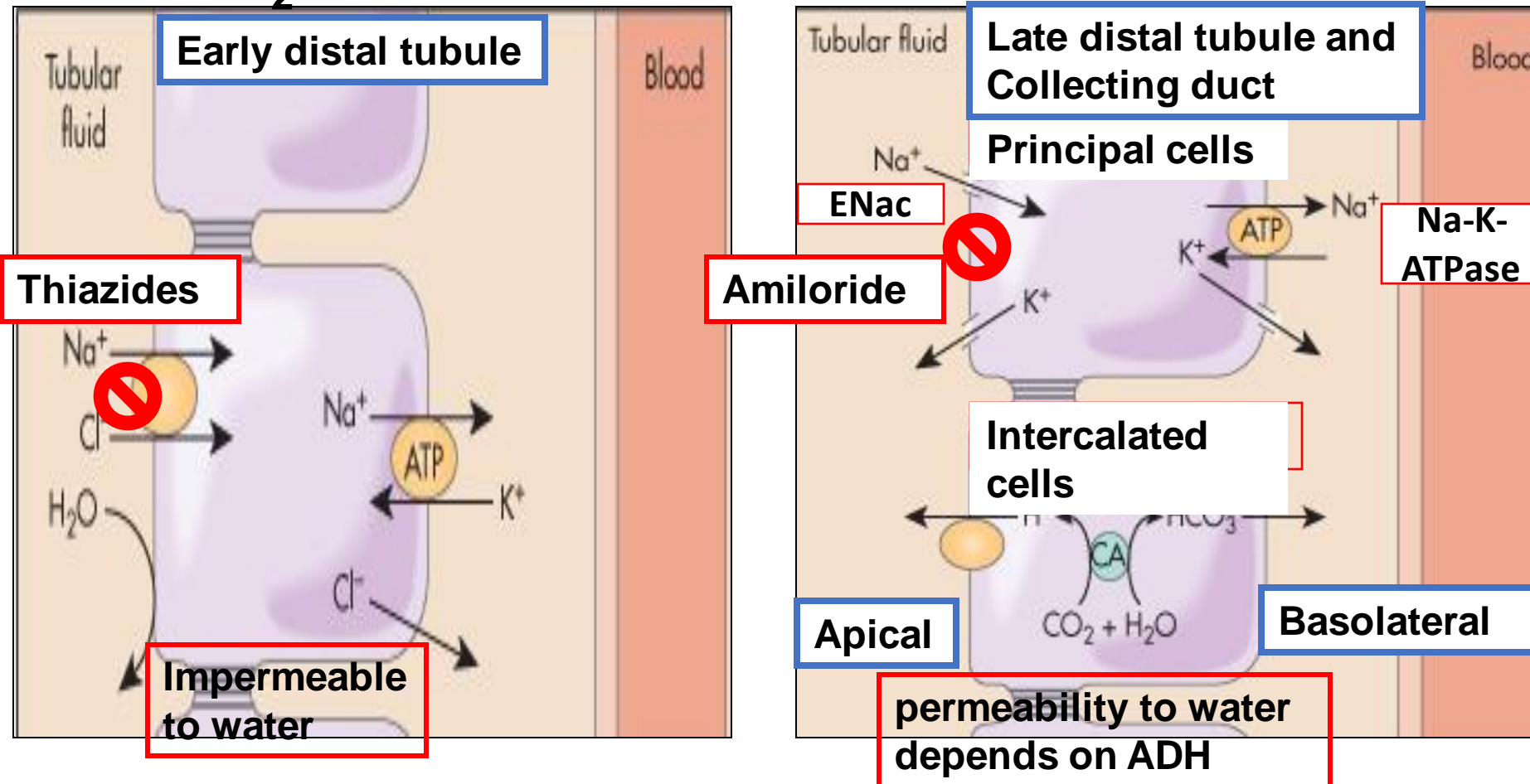
Early Distal Tubule

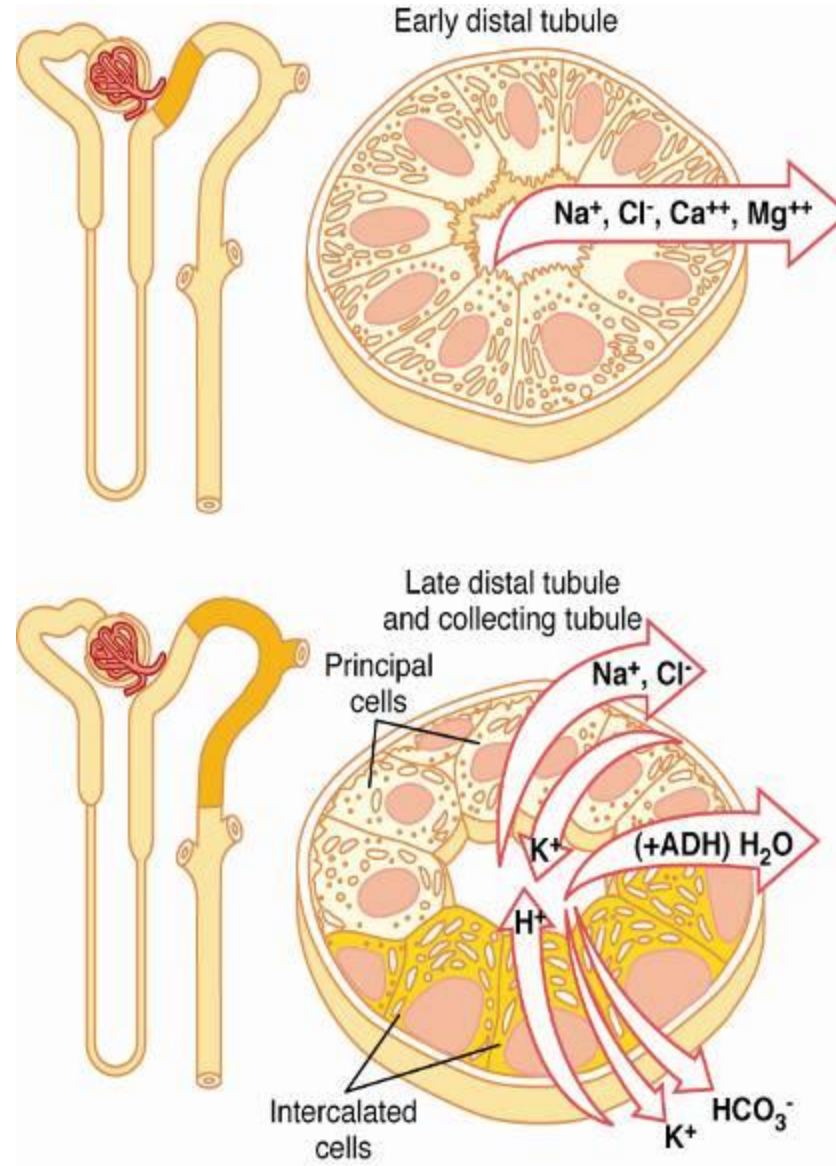
Figure 27-10

Early Distal Tubule

- Functionally similar to thick ascending loop
- Not permeable to water (called diluting segment)
- Active reabsorption of Na^+, Cl^-, K^+, Mg^{++}
- Contains macula densa

Distal tubule and collecting duct

❑ **Reabsorbs 7% NaCl, secrets K+ and H+ and reabsorbs 8-17% H_2O**

Early distal tubule

Tubular fluid

Blood

Thiazides

Na+

Cl-

Na+

ATP

K+

H_2O

Cl-

Impermeable to water

Late distal tubule and Collecting duct

Tubular fluid

Blood

Principal cells

Na+

ENac

Amiloride

ATP → Na+

K+

Na-K-ATPase

K+

Intercalated cells

H+   CA HCO_3

Apical

$CO_2 + H_2O$

Basolateral

permeability to water depends on ADH

Early and Late Distal Tubules and Collecting Tubules.

~ 5% of filtered load NaCl reabsorbed
- <u>not</u> permeable to H_2O
- not very permeable to urea

- permeablility to H_2O depends on ADH
- not very permeable to urea

Figure 27-11

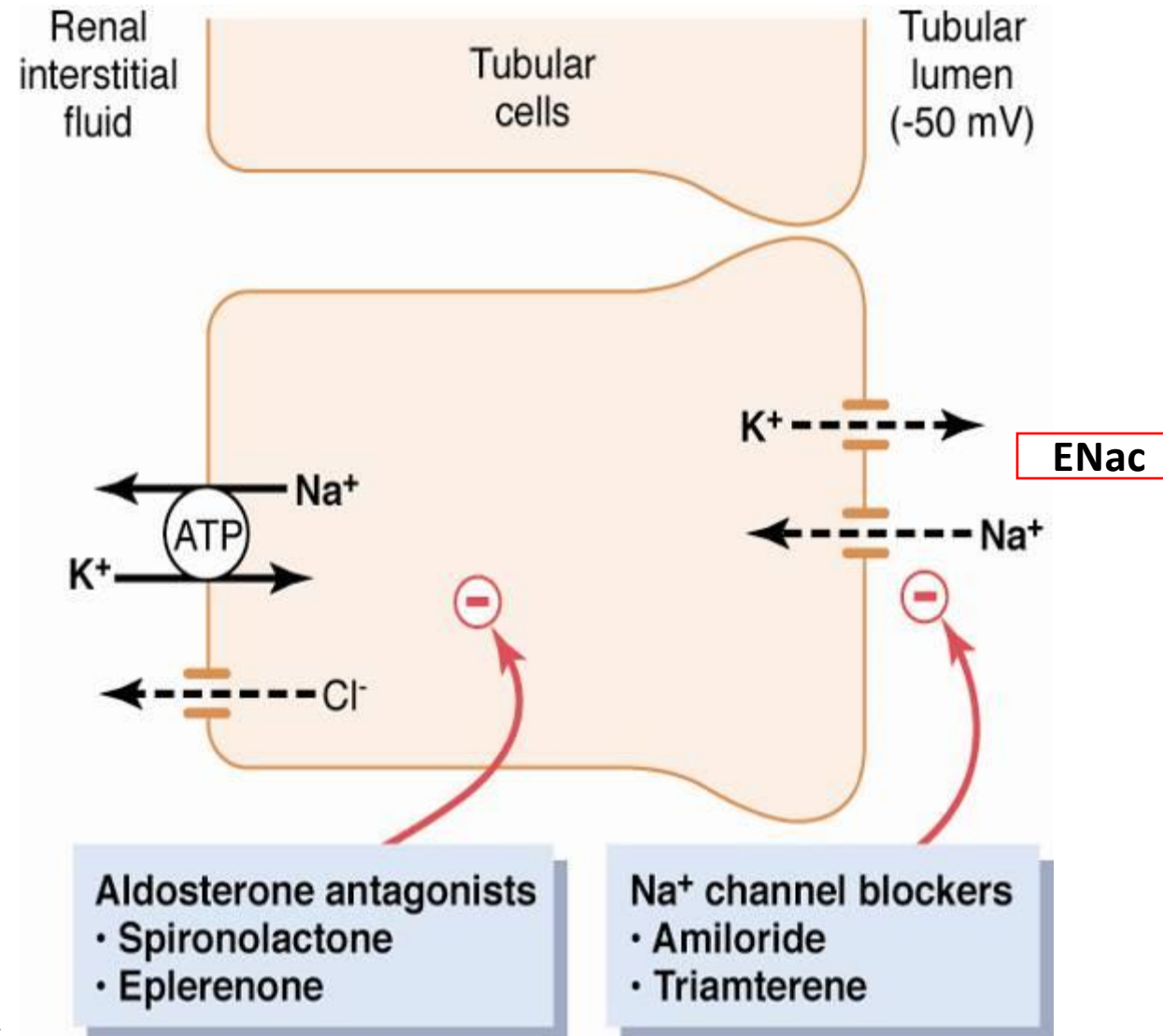# Late Distal and Cortical Collecting Tubules Principal Cells – Secrete K⁺
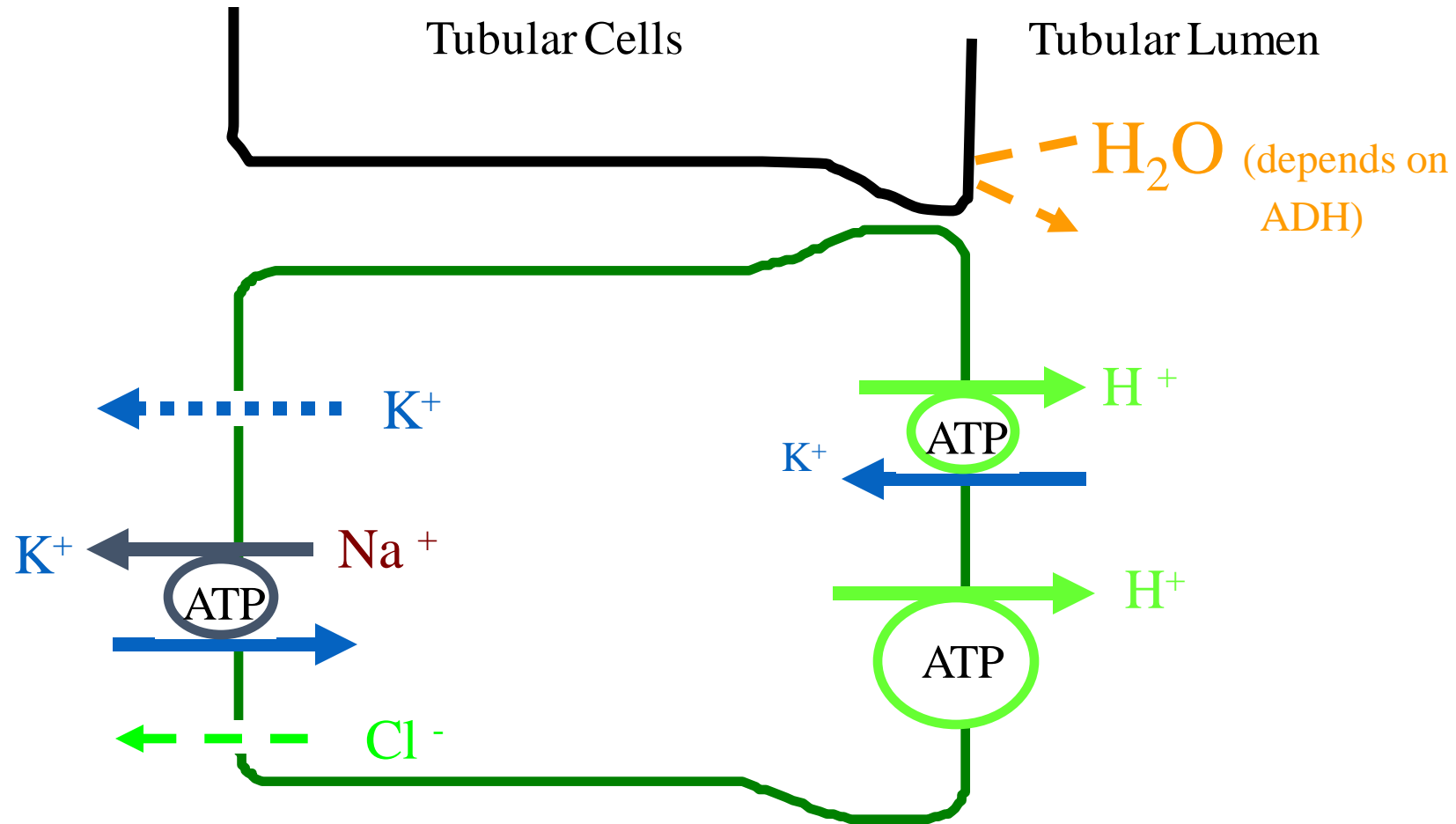

Figure 27-12

Late Distal and Cortical Collecting Tubules Intercalated Cells –Secrete H⁺

Tubular Cells

Tubular Lumen

H_2O (depends on ADH)

K^+

H^+

ATP

K^+

K^+

Na^+

ATP

H^+

ATP

Cl^-

Transport characteristics of medullary collecting ducts

Medullary collecting duct

Na$^+$, Cl$^-$

(+ADH) H$_2$O

Urea

H$^+$

HCO$_3^-$
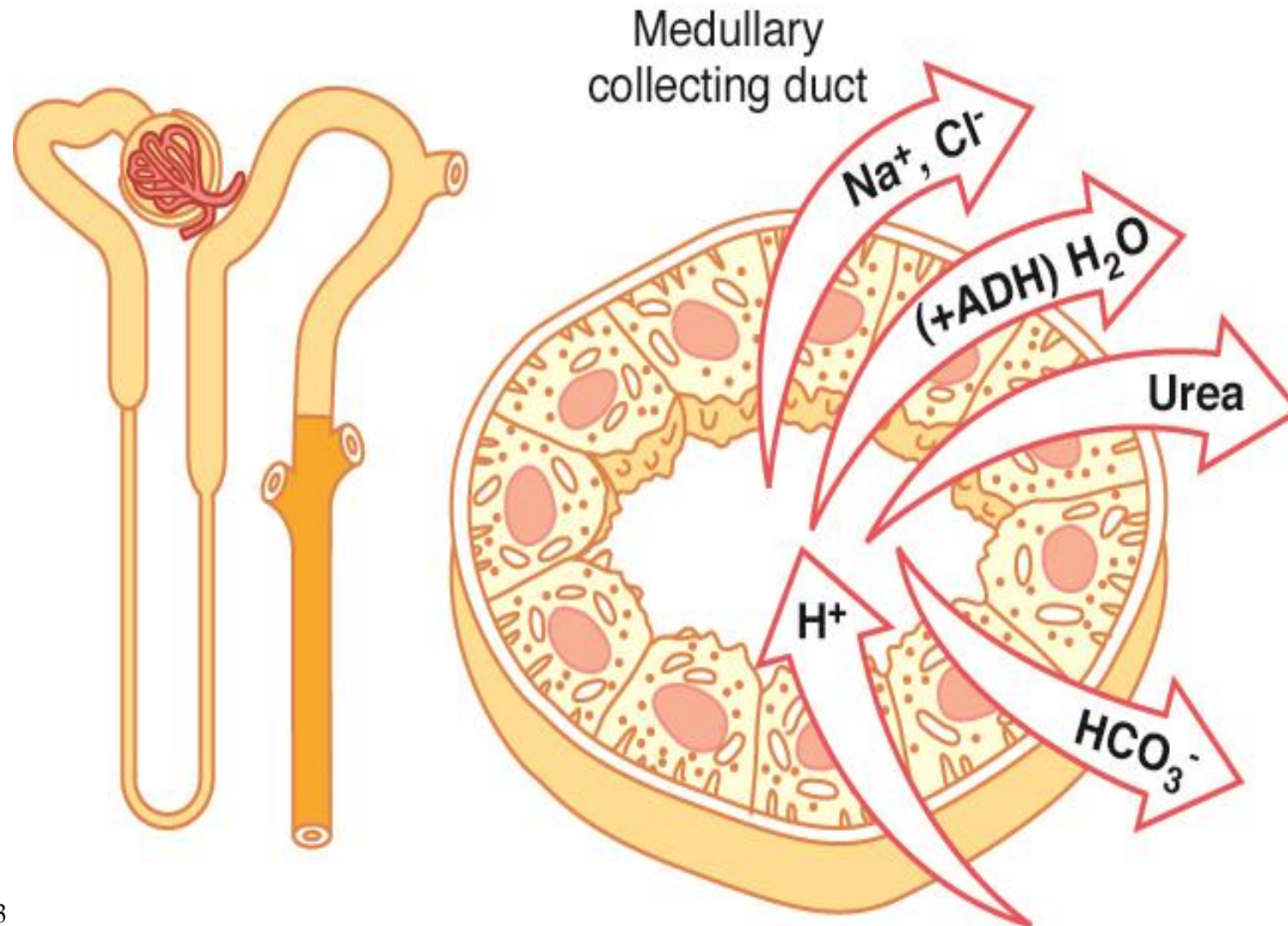
Figure 27-13

Normal Renal Tubular Na$^+$ Reabsorption
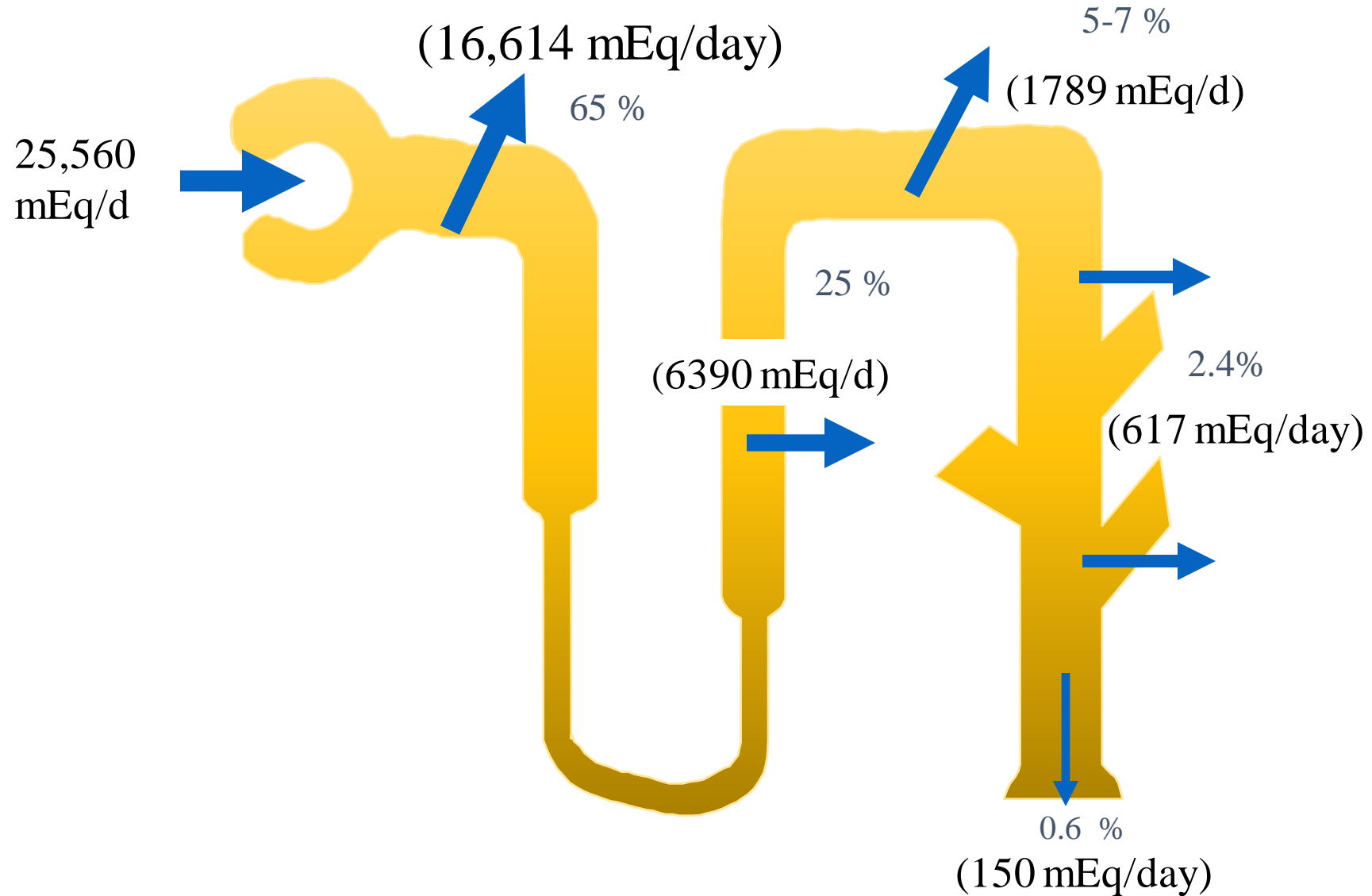
25,560 mEq/d

(16,614 mEq/day)

65 %

5-7 %

(1789 mEq/d)

25 %

(6390 mEq/d)

2.4%

(617 mEq/day)

0.6 %

(150 mEq/day)

Concentrations of solutes in different parts of the tubule depend on relative reabsorption of the solutes compared to water

• If water is reabsorbed to a greater extent than the solute, the solute will become more concentrated in the tubule (e.g. creatinine, inulin)

• If water is reabsorbed to a lesser extent than the solute, the solute will become less concentrated in the tubule (e.g. glucose, amino acids)

Changes in concentrations of substances in the renal tubules

Concentrations of solutes in different parts of the tubule depend on relative reabsorption of the solutes compared to water
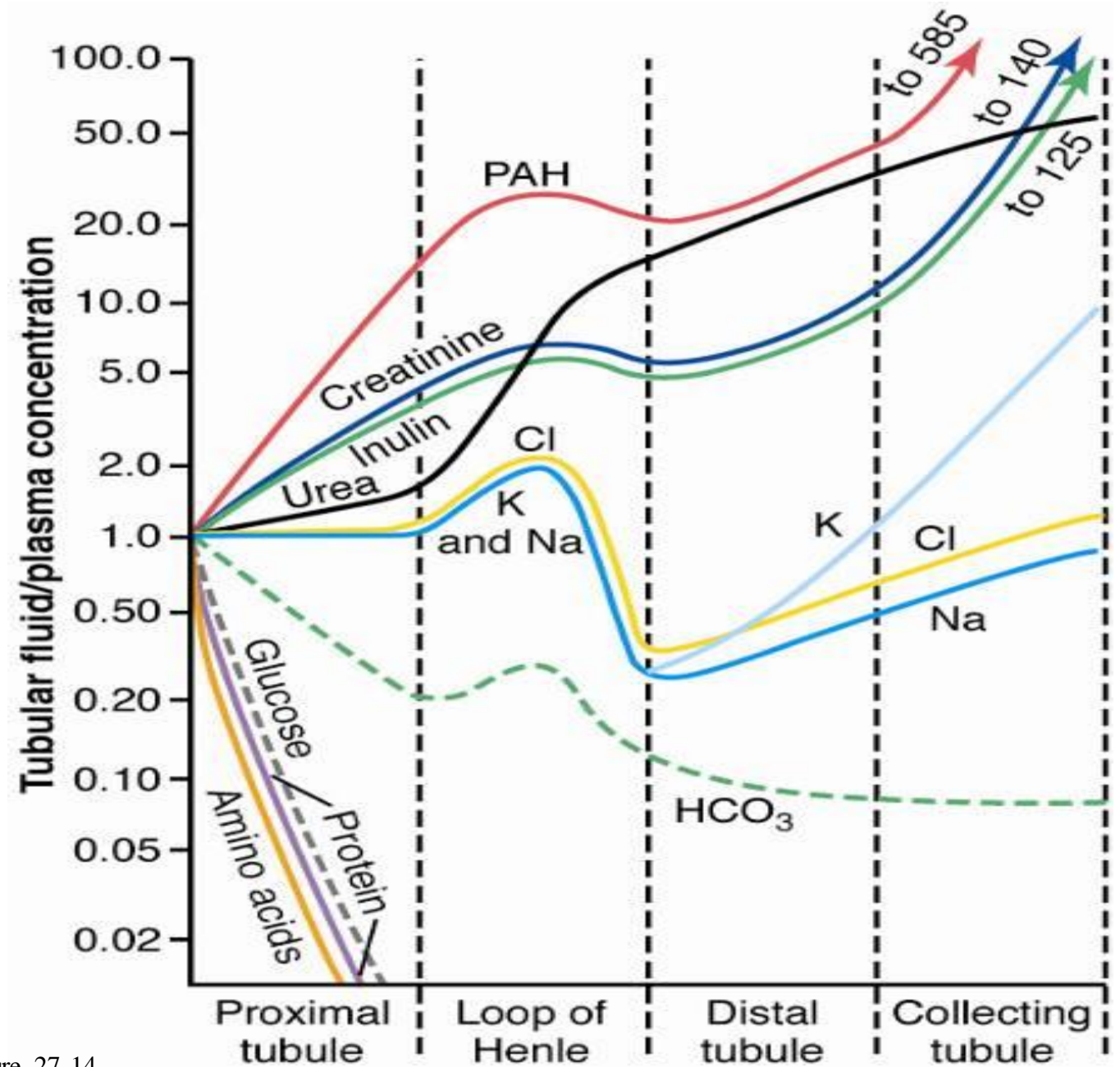

Figure 27-14

The figure below shows the concentrations of inulin at different points along the tubule, expressed as the tubular fluid/plasma (TF/P_{inulin}) concentration of inulin. If inulin is not reabsorbed by the tubule, what is the percentage of the filtered water that has been reabsorbed or remains at each point ? What percentage of the filtered water has been reabsorbed up to that point?

$A =$ 1/3 (33.33 %) remains
66.67 % reabsorbed

$B =$ 1/8 (12.5 %) remains
87.5 % reabsorbed

$C =$ 1/50 (2.0 %) remains
98.0 % reabsorbed
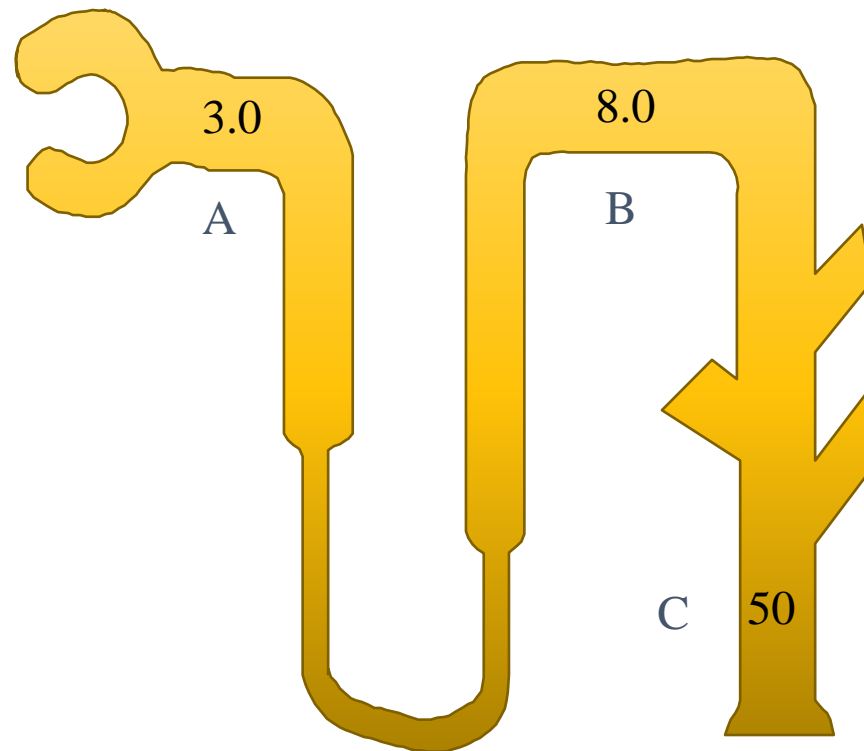
Regulation of Tubular Reabsorption

- Glomerulotubular Balance
- Peritubular Physical Forces
- Hormones

    - aldosterone
    - angiotensin II
    - antidiuretic hormone (ADH)
    - natriuretic hormones (ANF)
    - parathyroid hormone

- Sympathetic Nervous System
- Arterial Pressure (pressure natriuresis)
- Osmotic factors

Glomerulotubular Balance
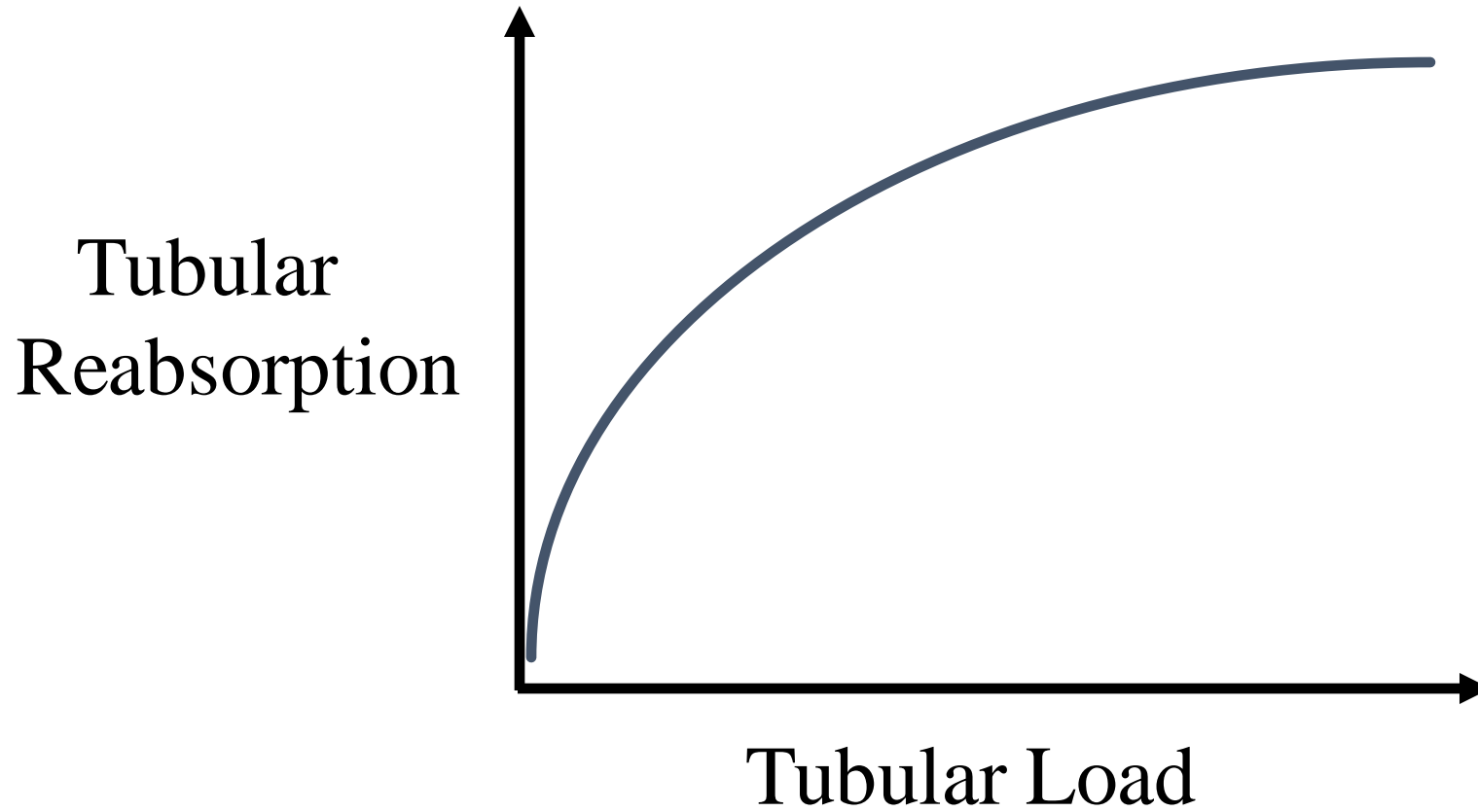
Importance of Glomerulotubular Balance in Minimizing Changes in Urine Volume

GFR	Reabsorption	% Reabsorption	Urine Volume
no glomerulotubular balance			
125	124	99.2	1.0
150	124	82.7	26.0
"perfect" glomerulotubular balance			
150	148.8	99.2	1.2

Peritubular capillary reabsorption
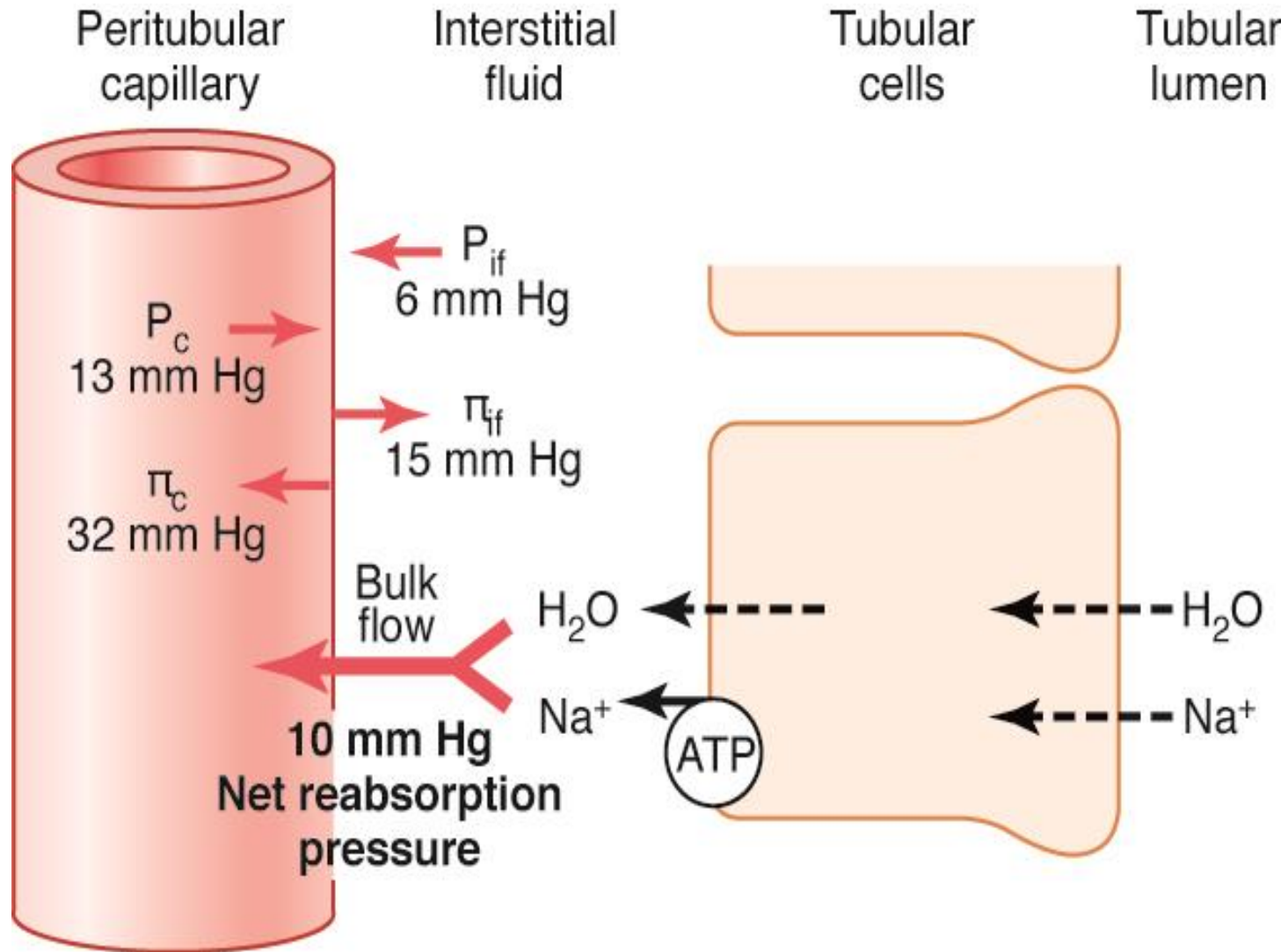
Figure 27-15

Calculation of Tubular Reabsorption

(when Excret s < Filt s)

Reabsorption = Filtration -Excretion

Filt s = GFR x Ps

(Ps = Plasma conc of s)

Excret s = Us x V

Us = Urine conc of s

V = urine flow rate
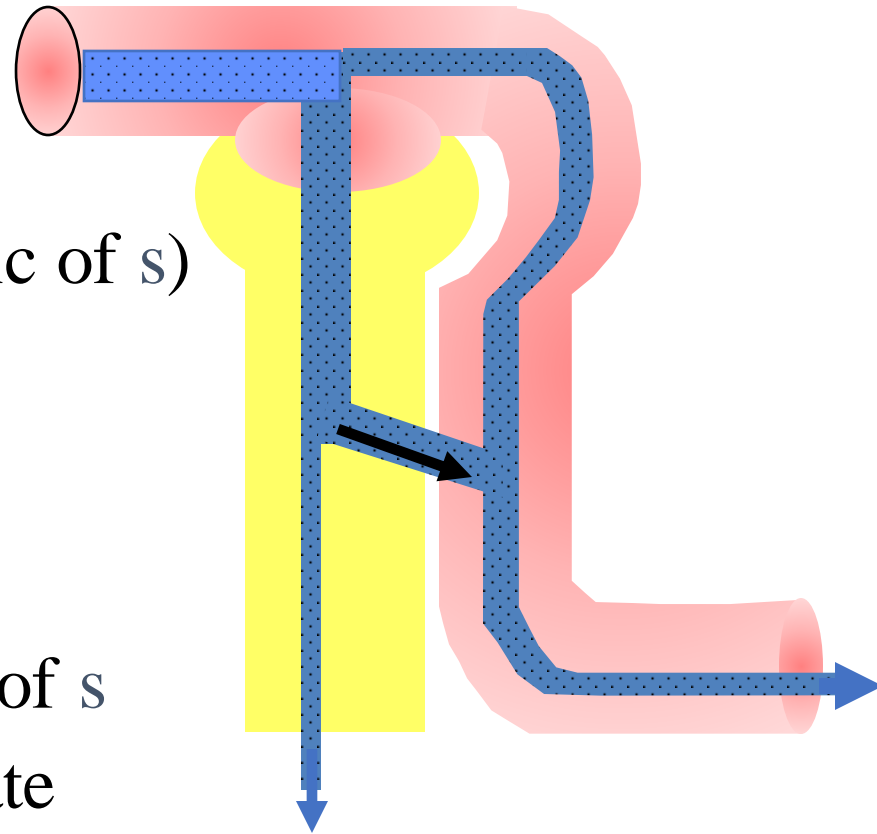
Calculation of Tubular Secretion

(when Excret s > Filt s)

Secretion = Excretion - Filtration

Filt s = GFR x Ps
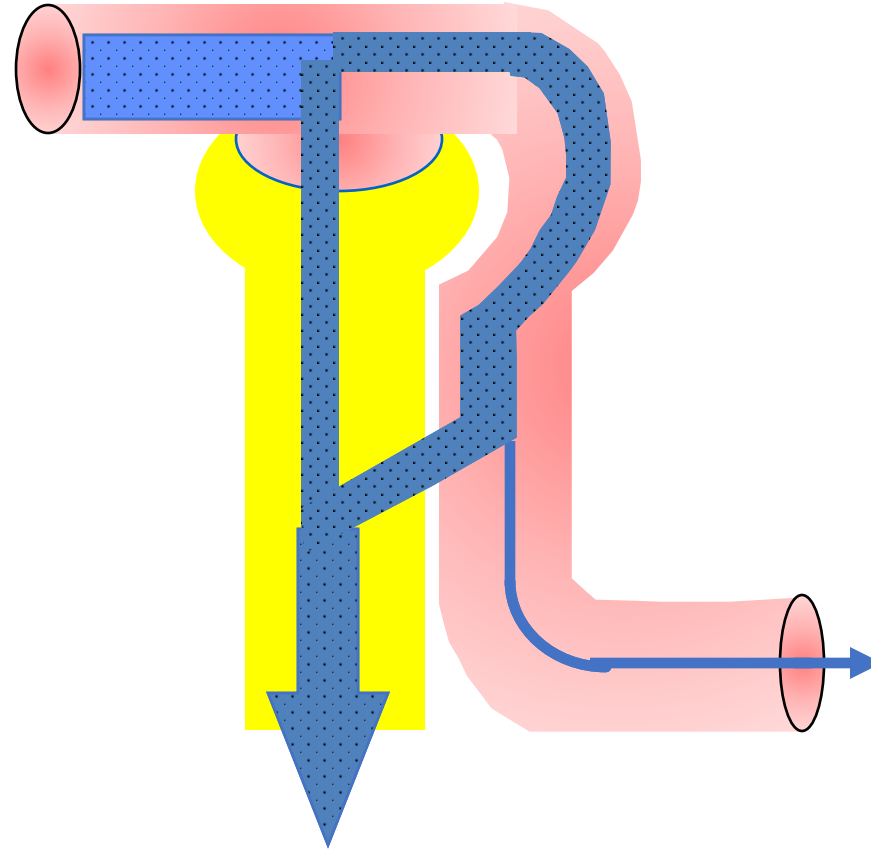
Excret s = Us x V

Example: Given the following data, calculate the rate of Na$^+$ filtration, excretion, reabsorption, and secretion

GFR = 100 ml/min (0.1 L/min)

P$_{Na}$ = 140 mEq/L

urine flow = 1 ml/min (.001 L/min)

urine Na conc = 100 mEq/L

Filtration Na = GFR x P$_{Na}$

$$= 0.1 \text{ L/min x } 140 \text{ mEq/L} = 14 \text{ mEq/min}$$

Excretion Na = Urine flow rate x Urine Na conc

$$= .001 \text{ L/min x } 100 \text{ mEq/L}$$

$$= 0.1 \text{ mEq/min}$$

Example: Given the following data, calculate the rate of Na^+ filtration, excretion, reabsorption, and secretion

GFR = 100 ml/min;
P_{Na} = 140 mEq/L
urine flow = 1 ml/min;
urine Na conc = 100 mEq/L

Filtration Na = 0.1 L/min x 140 mEq/L = 14 mEq/min
Excretion Na = .001 L/min x 100 mEq/L = 0.1 mEq/min
Reabsorption Na = Filtration Na - Excretion Na

Reabs Na = 14.0 - 0.1 = 13.9 mEq/min

Secretion Na = There is no net secretion of Na since
Excret Na < Filt Na

Transport Maximum

Some substances have a maximum rate of tubular transport
due to saturation of carriers, limited ATP, etc

• Transport Maximum: Once the transport maximum is
reached for all nephrons, further increases in tubular
load are not reabsorbed and are excreted.

• Threshold is the tubular load at which transport maximum is
exceeded in some nephrons. This is not exactly the same
as the transport maximum of the whole kidney because
some nephrons have lower transport max's than others.
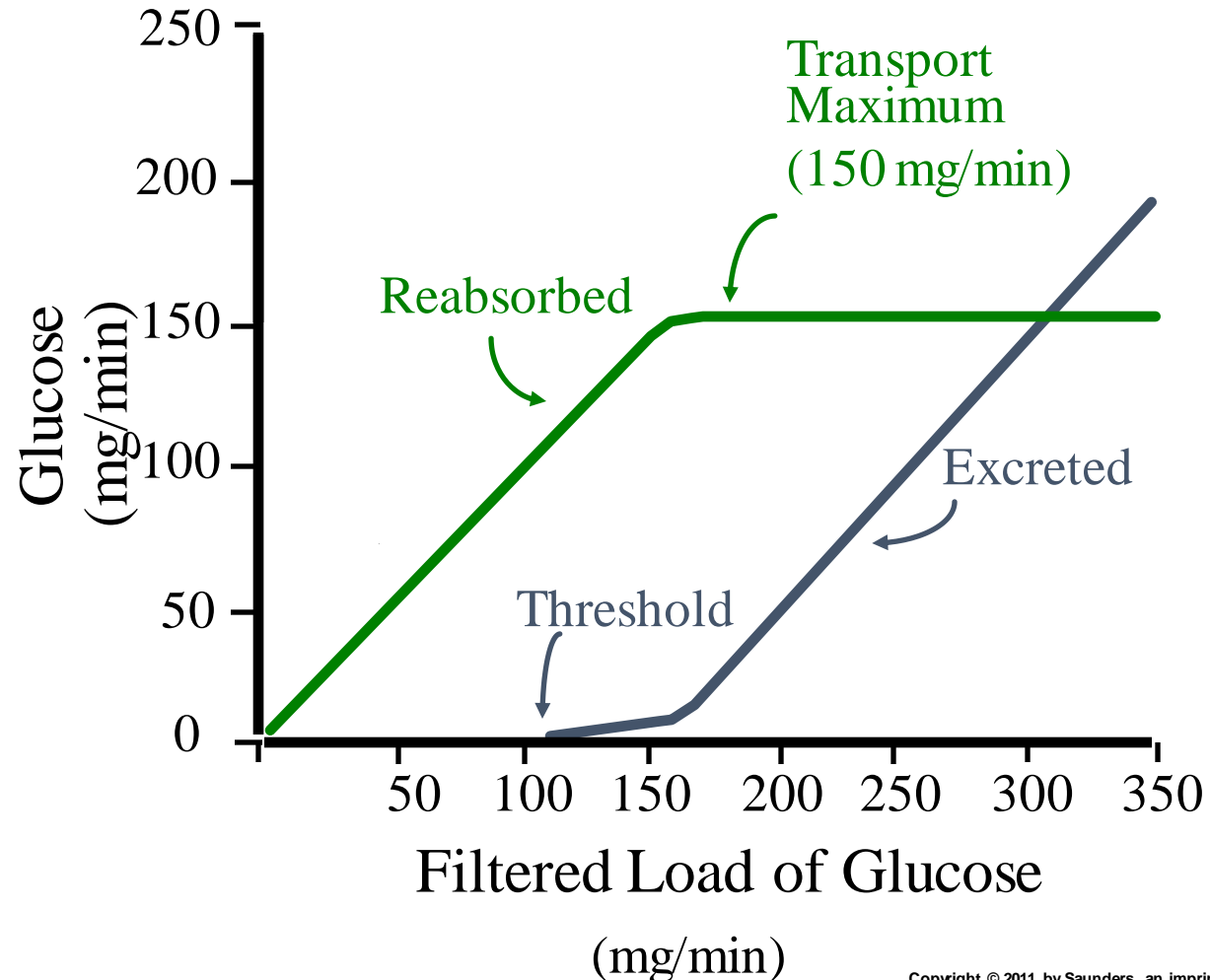
• Examples: glucose, amino acids, phosphate, sulphate

Does Na+ have Transport Maximum?

A uninephrectomized patient with uncontrolled diabetes has a GFR of 90 ml/min, a plasma glucose of 200 mg% (2mg/ml), and a transport max (Tm) shown in the figure. What is the glucose excretion for this patient?

1. 0 mg/min
2. 30 mg/min
3. 60 mg/min
4. 90 mg/min
5. 120 mg/min

Answer: Filt $_{Glu}$ =   (GFR x P$_{Glu}$) = (90 x 2) = 180 mg/min
                    Reabs $_{Glu}$ =   T$_{max}$ = 150 mg/min
                    Excret $_{Glu}$ =   30 mg/min

GFR = 90 ml/min
P$_{Glu}$ = 2 mg/ml
T$_{max}$ = 150 mg/min

a. 0 mg/min
b. 30 mg/min
c. 60 mg/min
d. 90 mg/min
e. 120 mg/min

Transport
Maximum
(150 mg/min)

Reabsorbed

Glucose
(mg/min)

250

200

150

100

50

0

Excreted

Threshold

50   100 150 200 250 300 350
Filtered Load of Glucose
(mg/min)
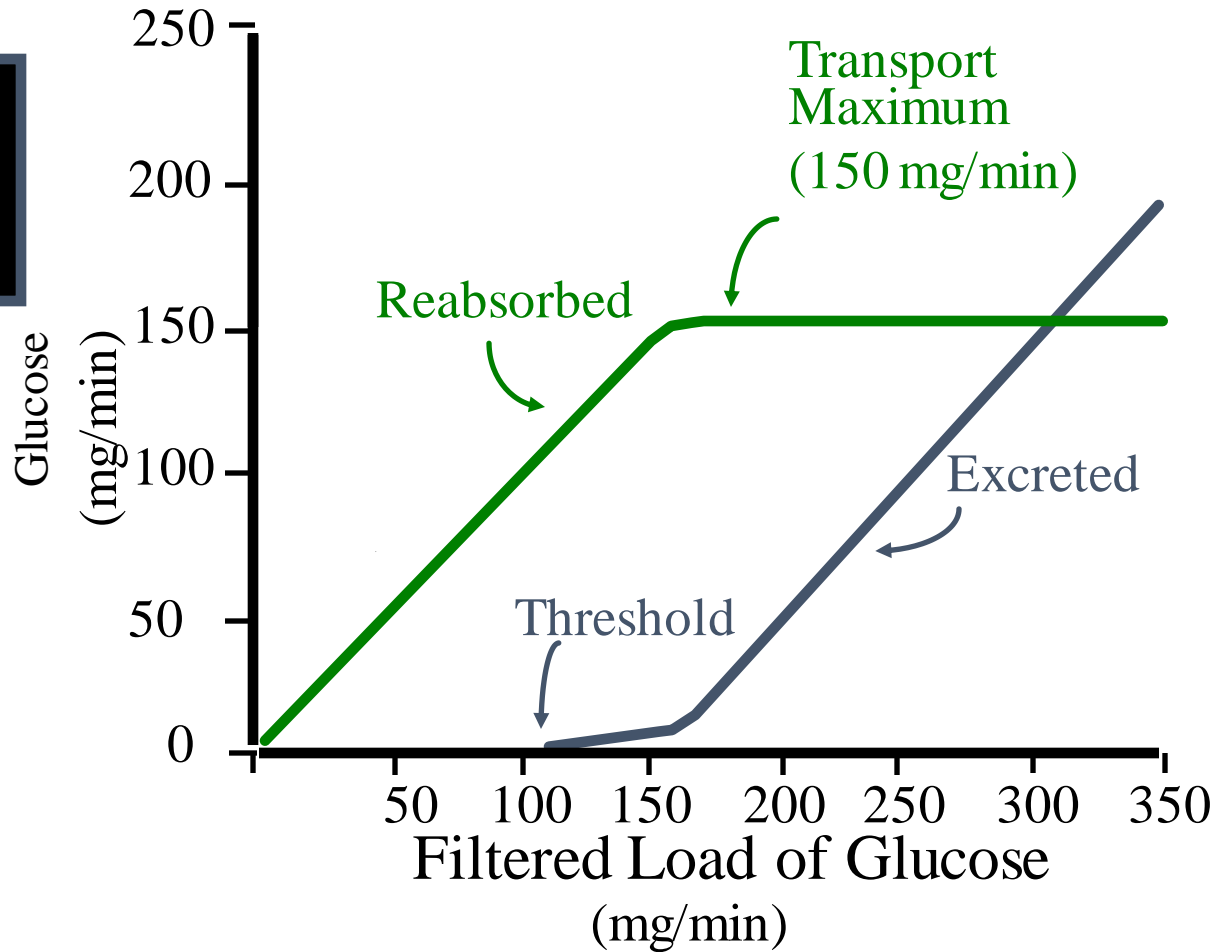
Peritubular Capillary Reabsorption

$Reabs = Net\ Reabs\ Pressure\ (NRP)\ \ x\ \ K_f$

$= \ (10\ mmHg)\ x\ (12.4\ ml/min/mmHg)$

$Reabs = 124\ ml/min$

Determinants of Renal Reabsorption

$\uparrow K_f$ ⟶ $\uparrow$ Reabsorption

$\uparrow Pc$ ⟶ $\downarrow$ Reabsorption

$\uparrow \Pi c$ ⟶ $\uparrow$ Reabsorption
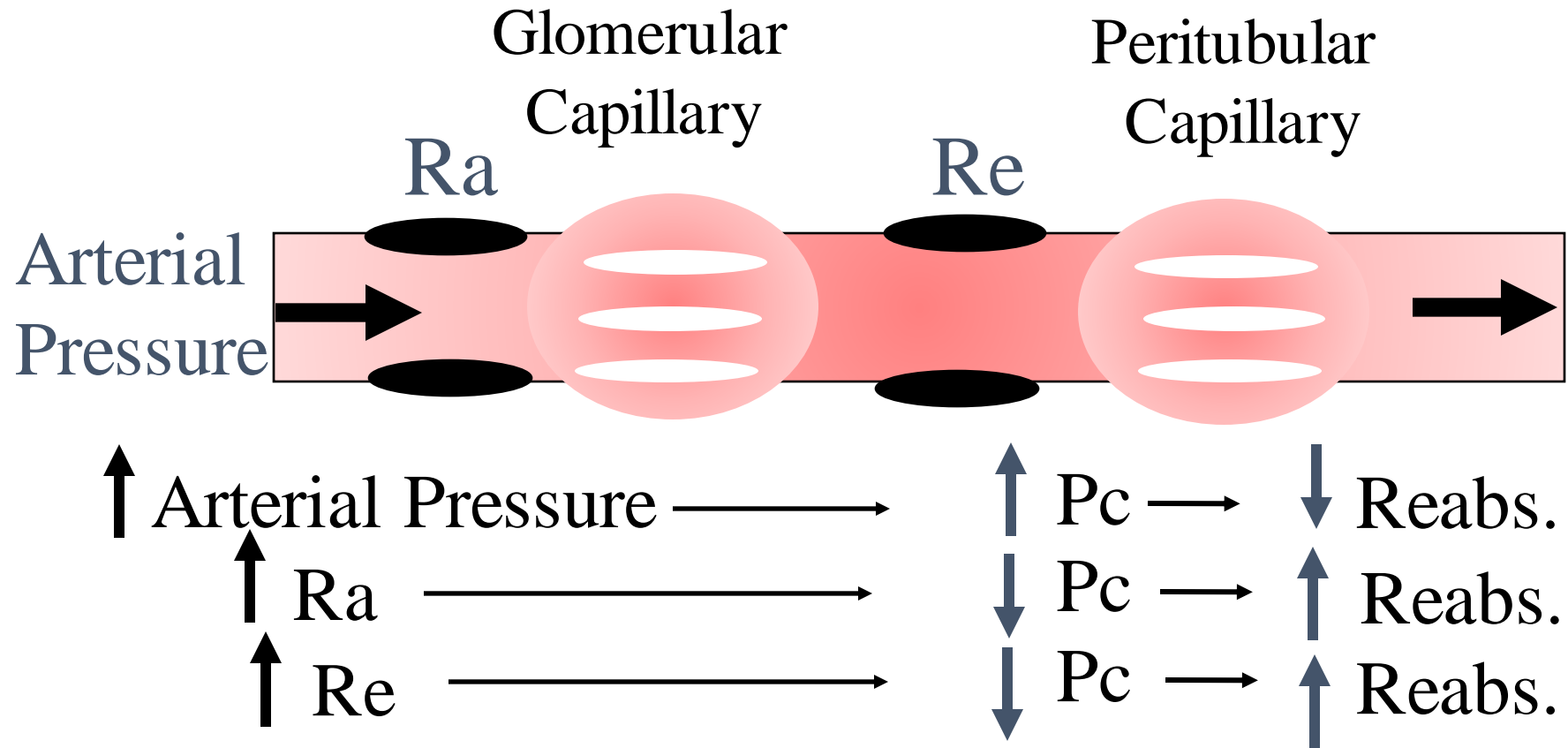
Determinants of Renal Reabsorption

$\uparrow \Pi c \longrightarrow \uparrow$ Reabsorption

$\uparrow$ Plasm. Prot. $\longrightarrow \uparrow \Pi a \longrightarrow \uparrow \Pi c$

$\uparrow$ Filt. Fract. $\longrightarrow \uparrow \Pi c$

Remember

Filt. Fract. = GFR / RPF

Summary:
Determinants of Renal Reabsorption

$\uparrow K_f$ $\longrightarrow$ $\uparrow$ Reabsorption

$\uparrow Pc$ $\longrightarrow$ $\downarrow$ Reabsorption

$\downarrow Ra$ $\longrightarrow$ $\uparrow Pc$ ($\downarrow$ Reabs)

     $\downarrow Re$ $\longrightarrow$ $\uparrow Pc$ ($\downarrow$ Reabs)

     $\uparrow$ Art. Press $\longrightarrow$ $\uparrow Pc$ ($\downarrow$ Reabs)

$\uparrow \Pi c$ $\longrightarrow$ $\uparrow$ Reabsorption

     $\uparrow \Pi a$ $\longrightarrow$ $\uparrow \Pi c$

     $\uparrow$ Filt. Fract. $\longrightarrow$ $\uparrow \Pi c$
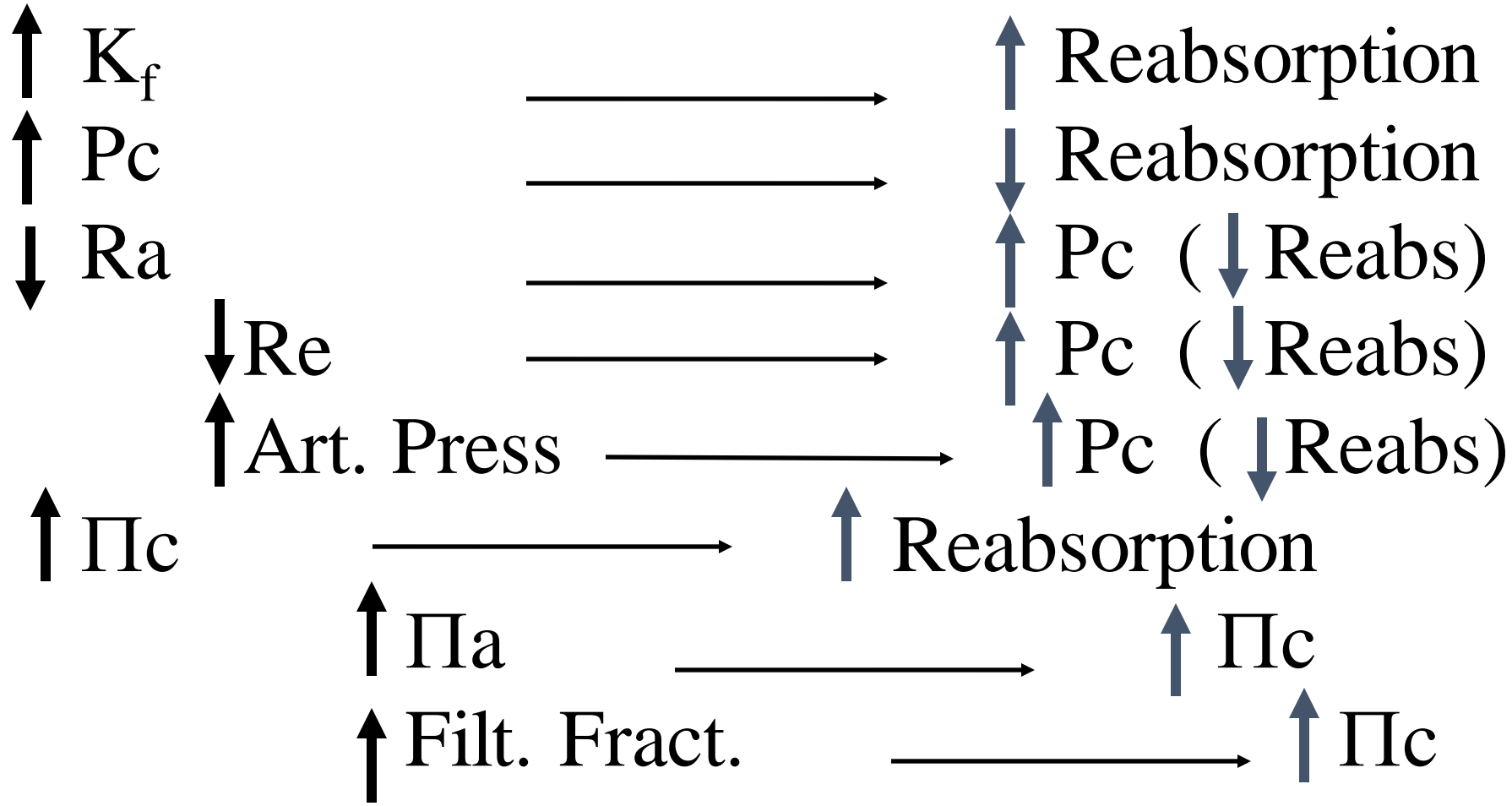
Effect of increased hydrostatic pressure or decreased colloid osmotic pressure in peritubular capillaries to reduce reabsorption
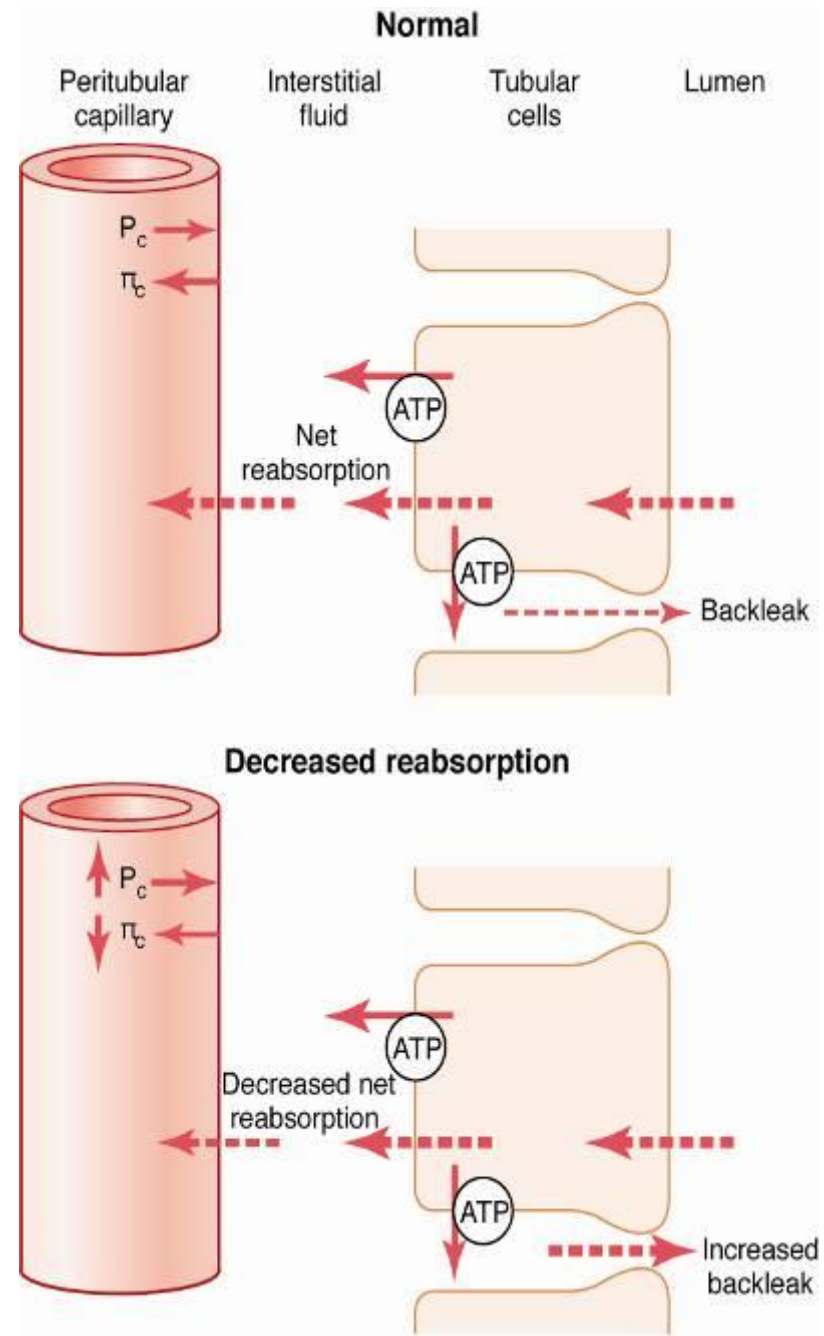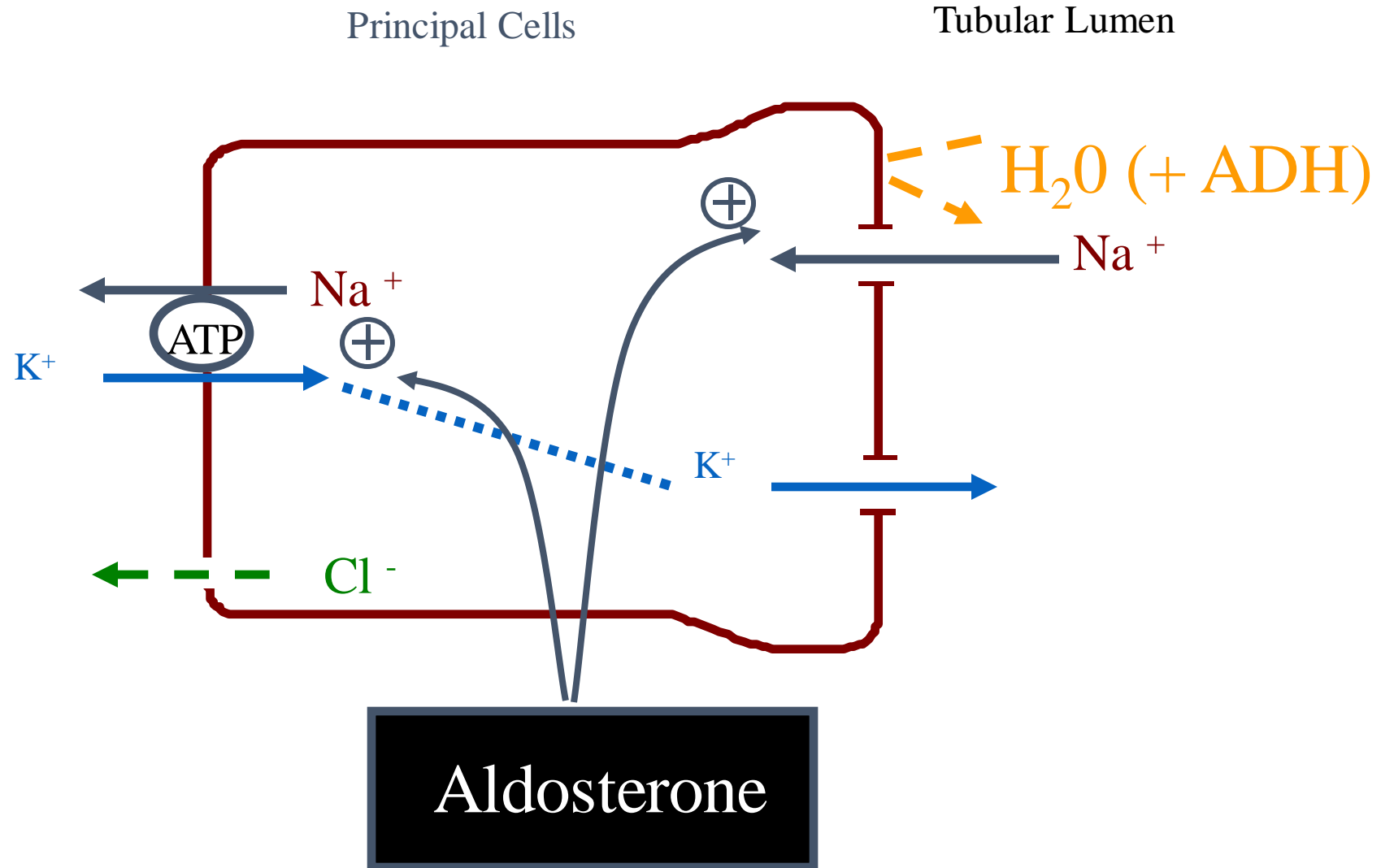

Figure 27-16

Aldosterone actions on late distal, cortical and medullary collecting tubules

- Increases Na^+ reabsorption - principal cells

- Increases K^+ secretion - principal cells

- Increases H^+ secretion - intercalated cells

Late Distal, Cortical and Medullary Collecting Tubules

Principal Cells

Tubular Lumen

H_2O (+ ADH)

Na^+

Na^+

ATP

K^+

K^+

Cl^-

Aldosterone

Clinical Perspective
Abnormal Aldosterone Production

- Excess aldosterone (Primary aldosteronism Conn's syndrome) - Na^+ retention, hypokalemia, alkalosis, hypertension

- Aldosterone deficiency - Addison's disease Na^+ wasting, hyperkalemia, hypotension

Control of Aldosterone Secretion

Factors that increase aldosterone secretion
- Angiotensin II
- Increased K^+
- adrenocorticotrophic hormone (ACTH)
    (permissive role)

Factors that decrease aldosterone secretion
- Atrial natriuretic factor (ANF)
- Increased Na^+ concentration (osmolality)

Angiotensin II Increases Na$^+$ and Water Reabsorption

- Stimulates aldosterone secretion

- Directly increases Na$^+$ reabsorption
  (proximal, loop, distal, collecting tubules)

- Constricts efferent arterioles
  - decreases peritubular capillary
    hydrostatic pressure
  - increases filtration fraction, which increases
    peritubular colloid osmotic pressure)
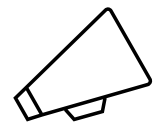
Audio-Visual Aid Renin Angiotensin Aldosterone System - YouTube

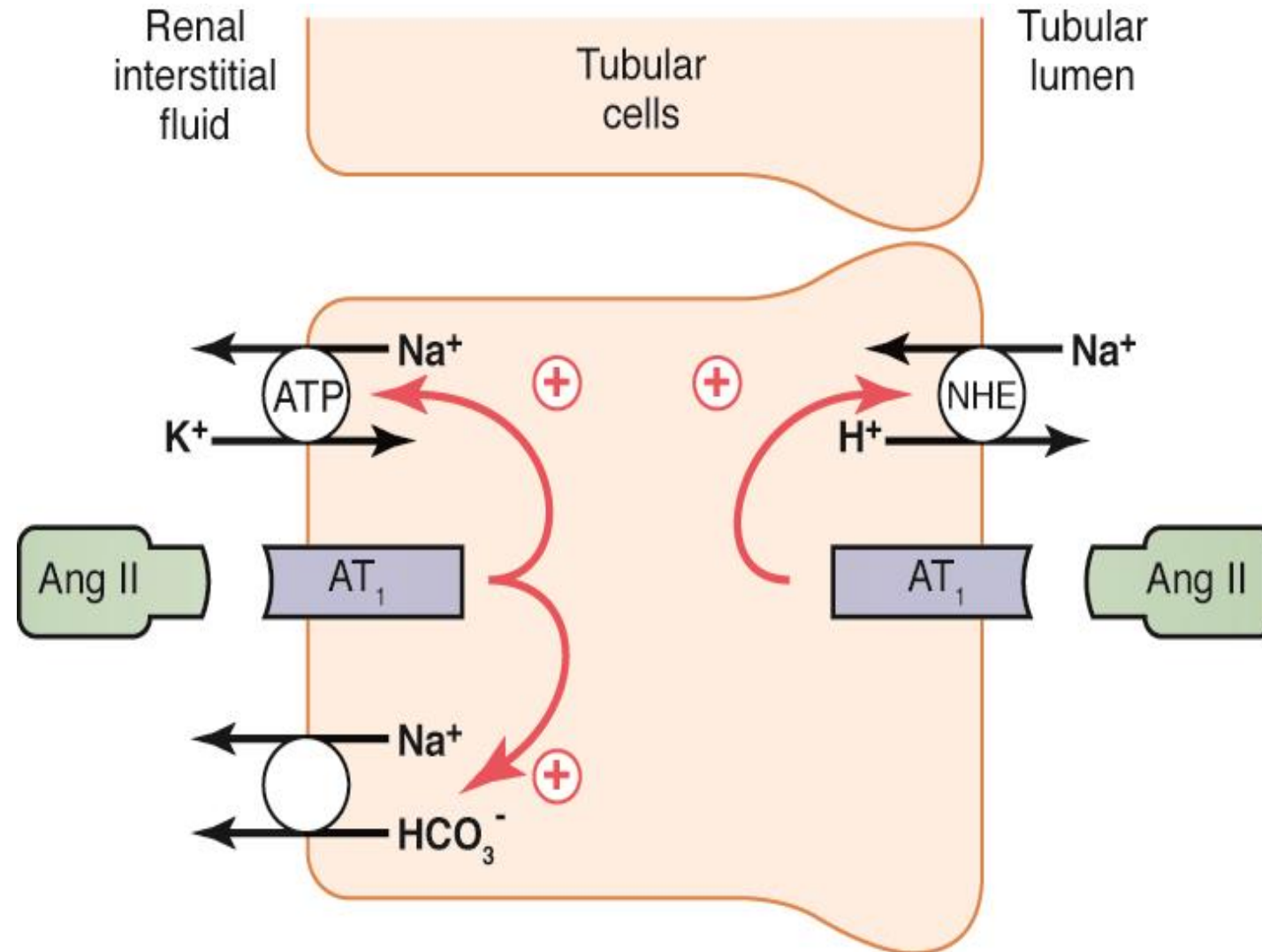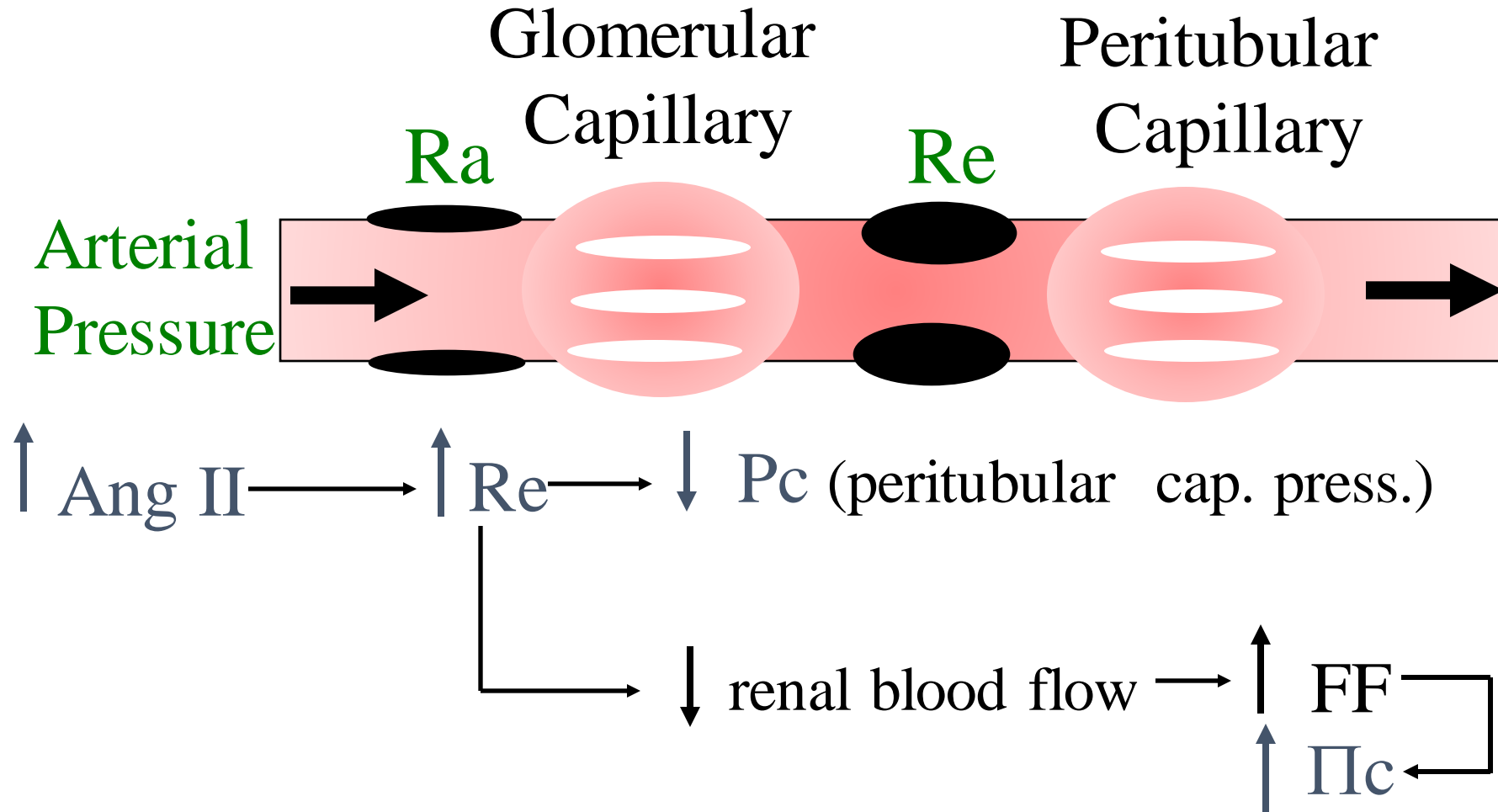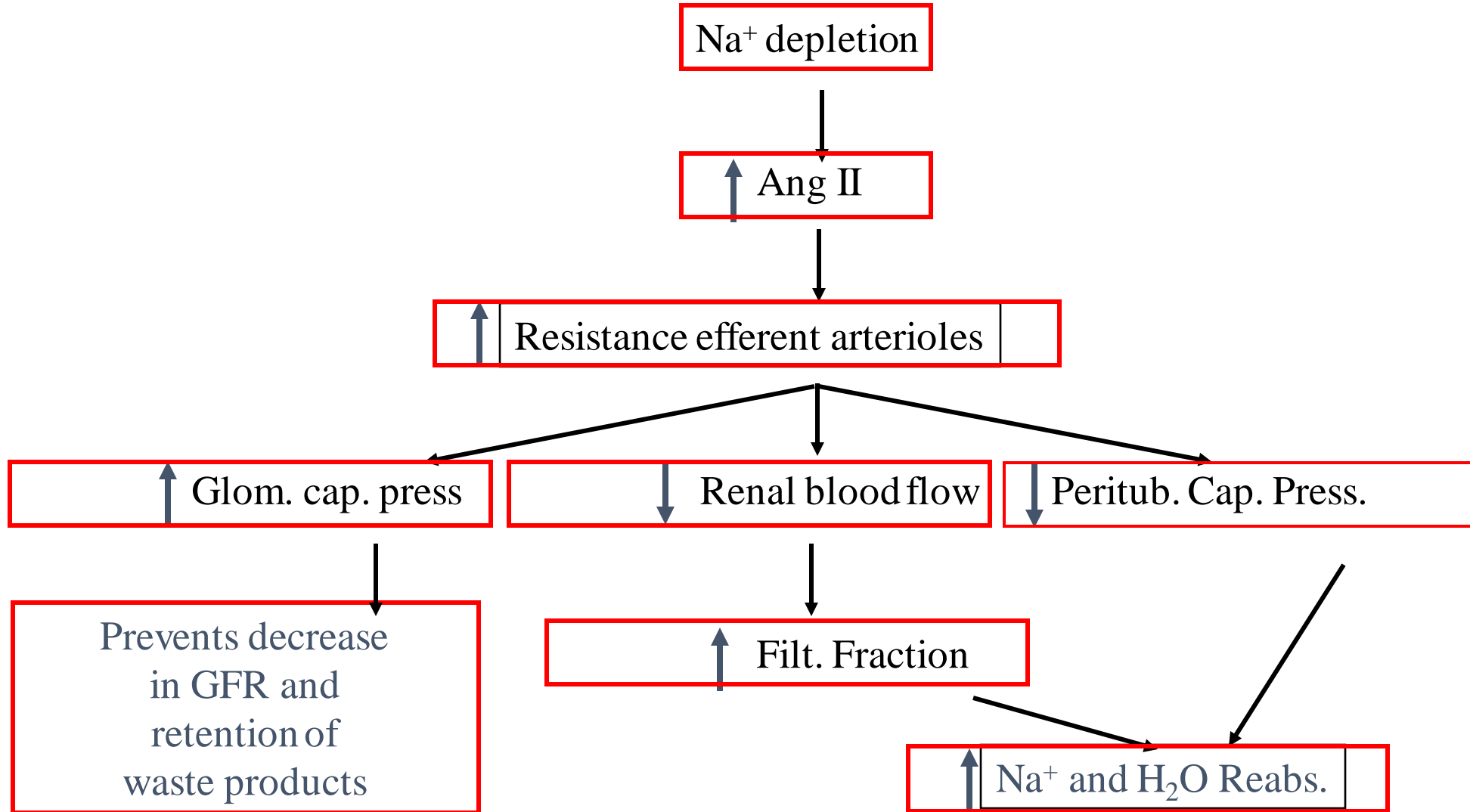# Angiotensin II increases renal tubular sodium reabsorption

Figure 27-17

Effect of Angiotensin II on Peritubular Capillary Dynamics

Ang II constriction of efferent arterioles causes Na$^+$ and water retention and maintains excretion of waste products

Na$^+$ depletion

↑ Ang II

↑ Resistance efferent arterioles

↑ Glom. cap. press

↓ Renal blood flow

↓ Peritub. Cap. Press.

Prevents decrease in GFR and retention of waste products

↑ Filt. Fraction

↑ Na$^+$ and H$_2$O Reabs.

Angiotensin II blockade decreases Na$^+$ reabsorption and blood pressure

- ACE inhibitors (captopril, benazipril, ramipril)
- Ang II antagonists (losartan, candesartin, irbesartan)
- Renin inhibitors (aliskirin)
  - decrease aldosterone
  - directly inhibit Na$^+$ reabsorption
  - decrease efferent arteriolar resistance

Natriuresis and Diuresis + ↓ Blood Pressure

Antidiuretic Hormone (ADH)

- Secreted by posterior pituitary

- Increases H_2O permeability and reabsorption in distal and collecting tubules
- Allows differential control of H_2O and solute excretion
- Important controller of extracellular fluid osmolarity

ADH synthesis in
the magnocellular
neurons of hypothalamus,
release by the posterior
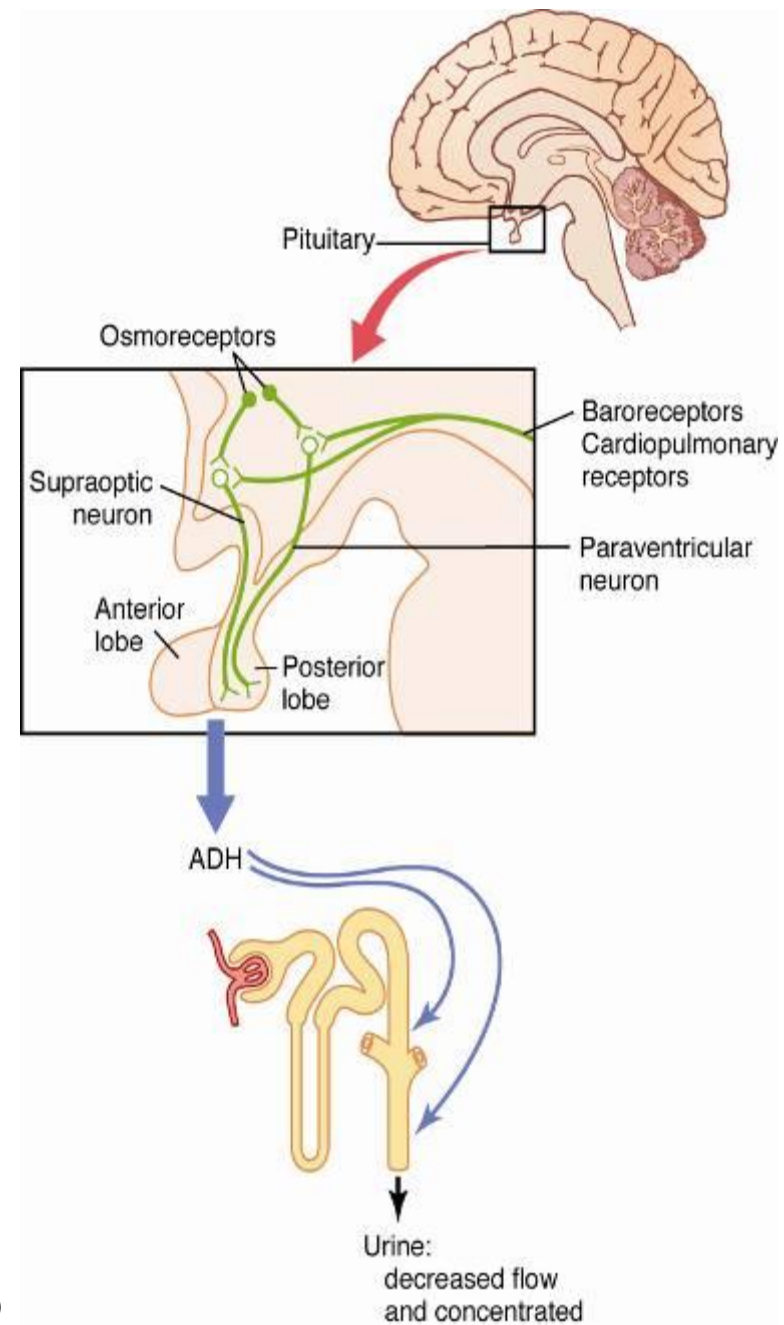pituitary, and action
on the kidneys

Pituitary

Osmoreceptors

Baroreceptors
Cardiopulmonary
receptors

Supraoptic
neuron

Paraventricular
neuron

Anterior
lobe

Posterior
lobe

ADH

Urine:
decreased flow
and concentrated

Figure 28-10

Mechanism of action of ADH in distal and collecting tubules
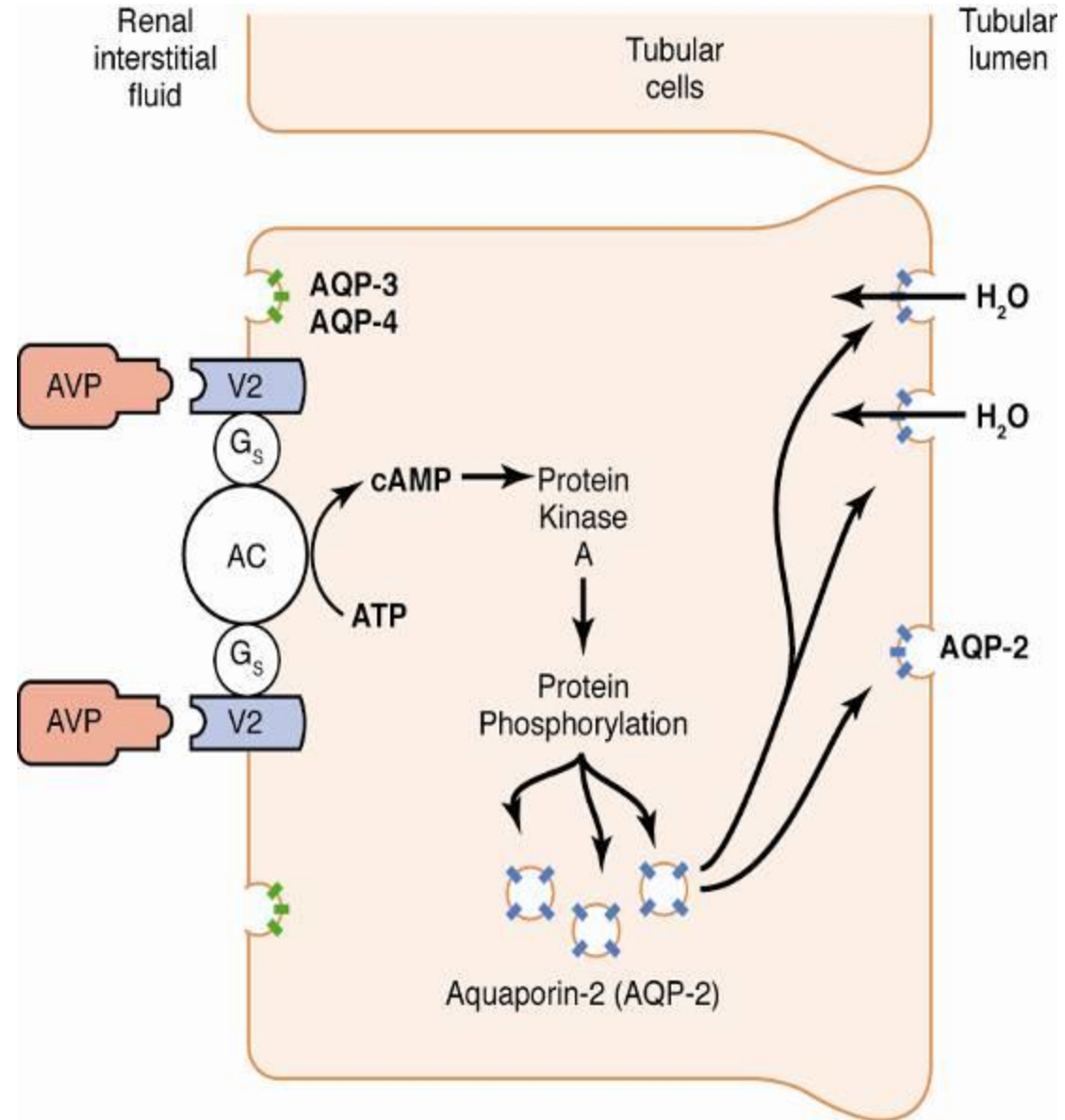
Figure 28-18

Feedback Control of Extracellular Fluid Osmolarity by ADH

Extracell. Osm

(osmoreceptors-hypothalamus

ADH secretion

(posterior pituitary)

Tubular H_2O permeability

(distal, collecting)

H_2O Reabsorption

(distal, collecting)

H_2O Excretion
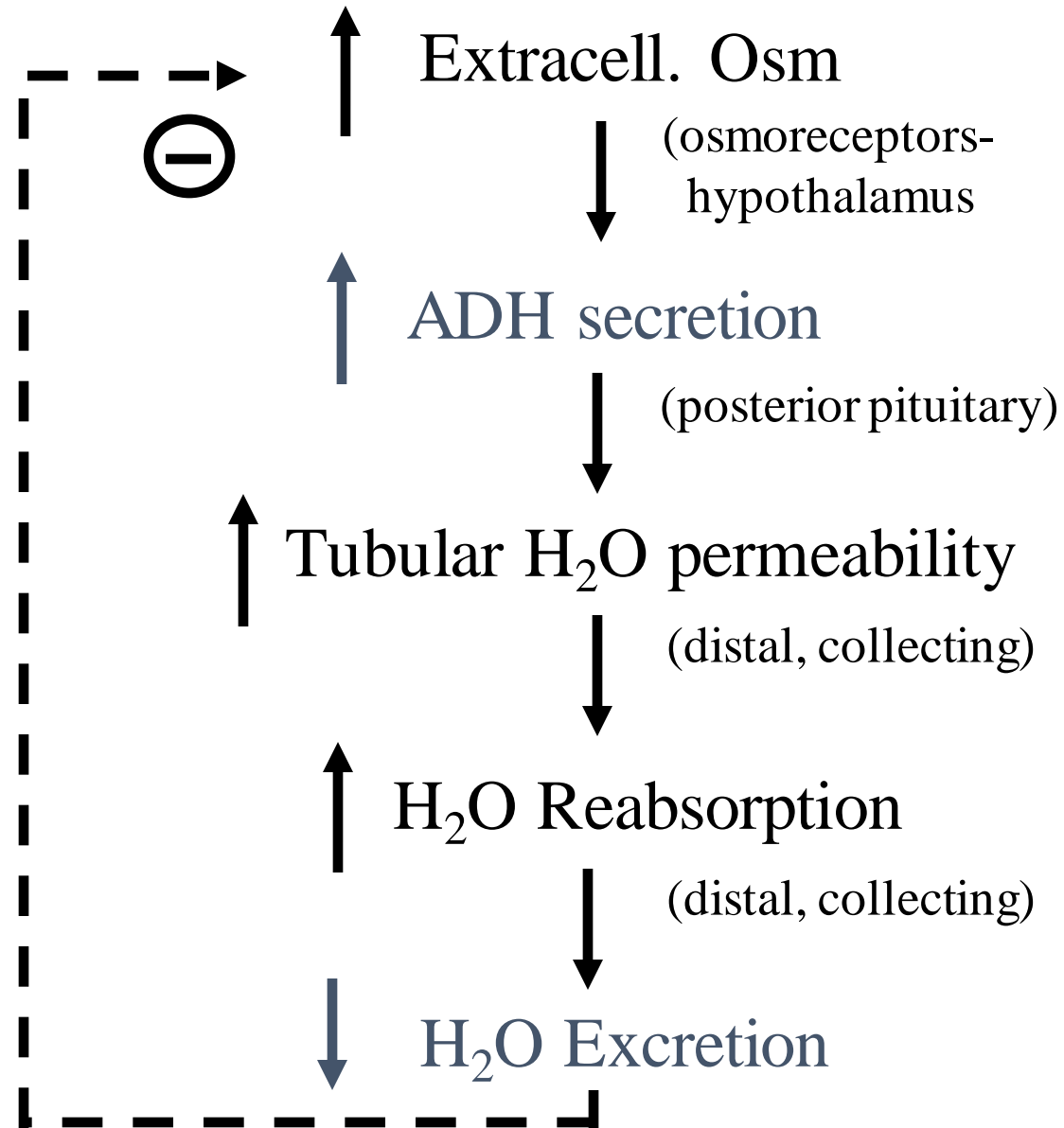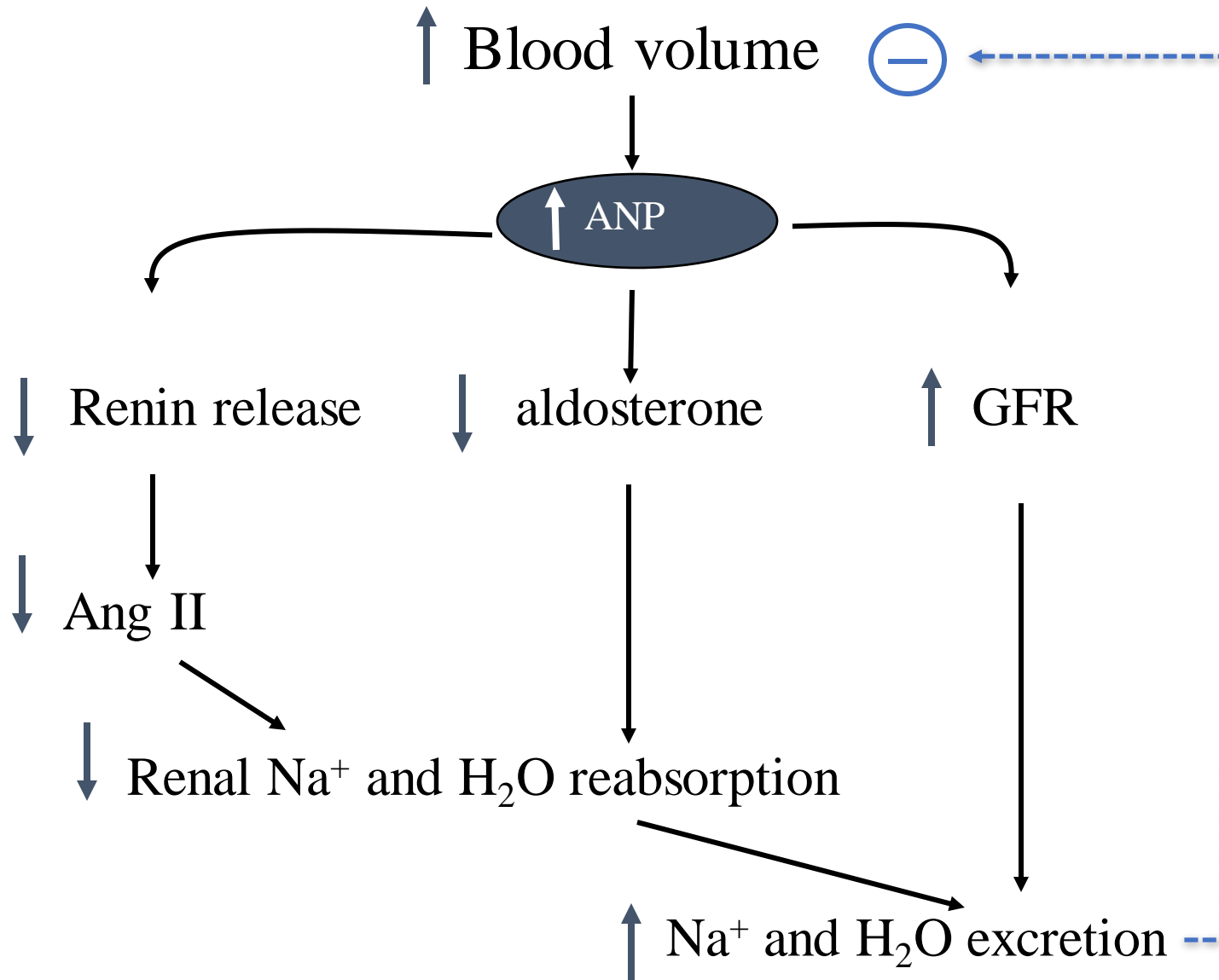
Clinical Perspective
Abnormalities of ADH

- Inappropriate ADH syndrome (excess ADH)
  - decreased plasma osmolarity, hyponatremia

- "Central" Diabetes insipidus (insufficient ADH)
  - increased plasma osmolarity, hypernatremia, excess thirst

Atrial natriuretic peptide increases Na^+ excretion

- Secreted by cardiac atria in response to stretch (increased blood volume)
- Directly inhibits Na^+ reabsorption
- Inhibits renin release and aldosterone formation
- Increases GFR
- Helps to minimize blood volume expansion

Atrial Natriuretic Peptide (ANP)

↑ Blood volume ⊖

↓

↑ ANP

↓ Renin release ↓ aldosterone ↑ GFR

↓ Ang II

↓ Renal Na$^+$ and H$_2$O reabsorption

↑ Na$^+$ and H$_2$O excretion

Parathyroid hormone increases renal Ca^{++} reabsorption

- Released by parathyroids in response to decreased extracellular Ca^{++}

- Increases Ca^{++} reabsorption by kidneys

- Increases Ca^{++} reabsorption by gut

- Decreases phosphate reabsorption

- Helps to increase extracellular Ca^{++}

(see chapter 29)
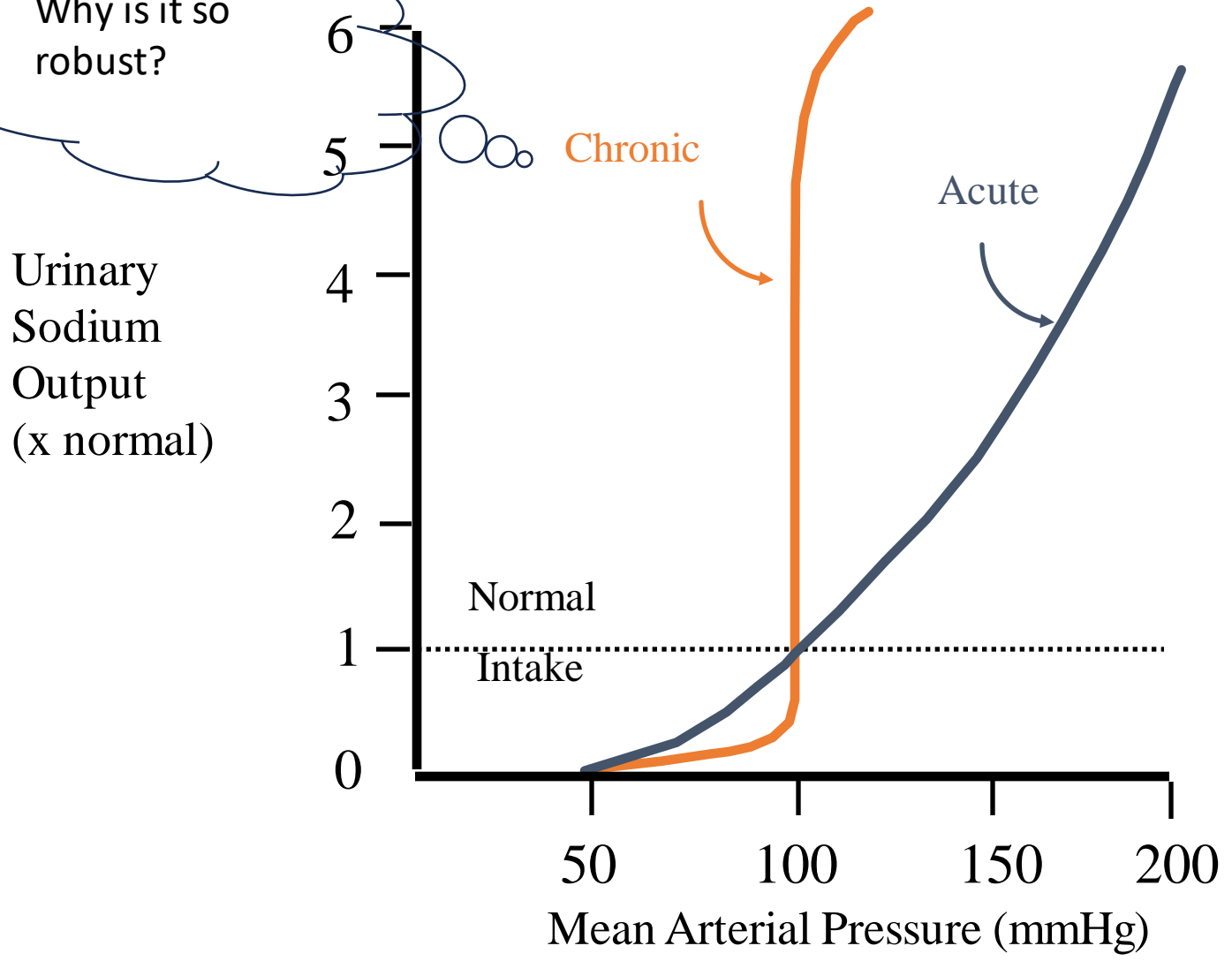
Control of Ca^{++} by Parathyroid Hormone
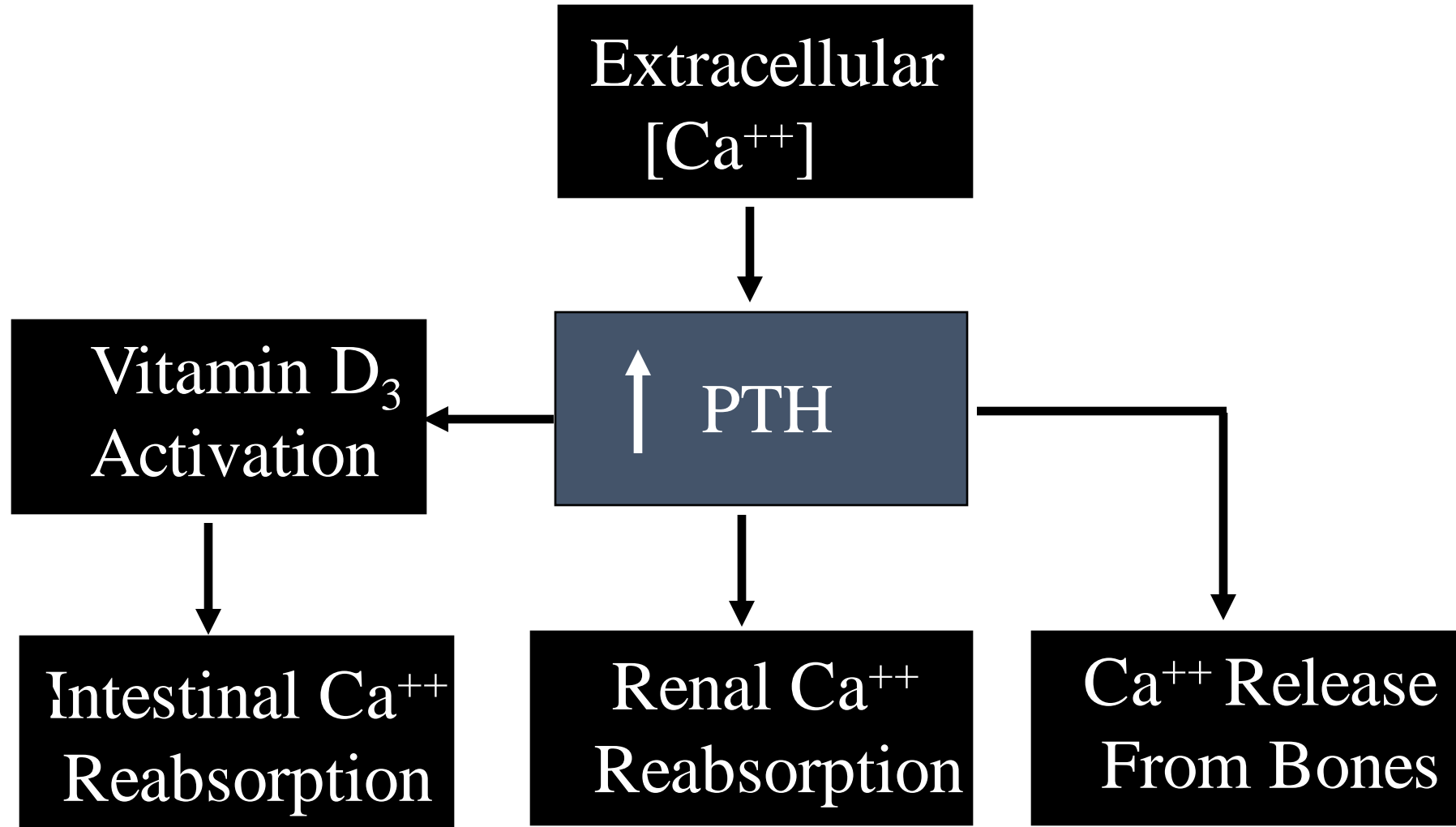
Sympathetic nervous system increases Na$^+$ reabsorption

- Directly stimulates Na$^+$ reabsorption
- Stimulates renin release
- Decreases GFR and renal blood flow (only a high levels of sympathetic stimulation)

Increased Arterial Pressure Decreases Na$^+$ Reabsorption (Pressure Natriuresis)

- Increased peritubular capillary hydrostatic pressure

- Decreased renin and aldosterone

- Increased release of intrarenal natriuretic factors
    - prostaglandins
   - EDRF

Osmotic Effects on Reabsorption

- Water is reabsorbed only by osmosis
- Increasing the amount of unreabsorbed solutes in the tubules decreases water reabsorption

i.e. diabetes mellitus : unreabsorbed glucose in tubules causes diuresis and water loss

i.e. osmotic diuretics (mannitol)

Assessing Kidney Function

- Plasma concentration of waste products
    (e.g. BUN, creatinine)
- Urine specific gravity, urine concentrating ability;
- Urinalysis test reagent strips (protein, glucose, etc)
- Biopsy
- Albumin excretion (microalbuminuria)
- Isotope renal scans
- Imaging methods (e.g. MRI, PET, arteriograms,
    iv pyelography, ultrasound etc)
- Clearance methods (e.g. 24-hr creatinine clearance)
- etc
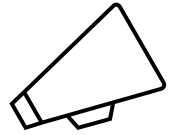
Link To Recording of Clearance and GFR Calculation

https://fisjo-my.sharepoint.com/:v:/g/personal/e_zayadneh_ju_edu_jo/EVfxrMv5fDZHgWF5wU3y3x0BW4Y-3tEaRCkc6iRxRnZ7rQ?e=LosKcU

Clearance

- "Clearance" describes the rate at which substances are removed (cleared) from the plasma.

- Renal clearance of a substance is the volume of plasma <u>completely</u> cleared of a substance per min by the kidneys.

Clearance Technique

Renal clearance (C_s) of a substance is the volume of plasma completely cleared of a substance per min.

$$C_s \text{ x } P_s = U_s \text{ x } V$$

$$C_s = \frac{U_s \text{ x } V}{P_s} = \frac{\text{urine excretion rate}}{\text{Plasma conc. s}}$$

Where : C_s = clearance of substance S

P_s = plasma conc. of substance S

U_s = urine conc. of substance S

V = urine flow rate

Clearances of Different Substances

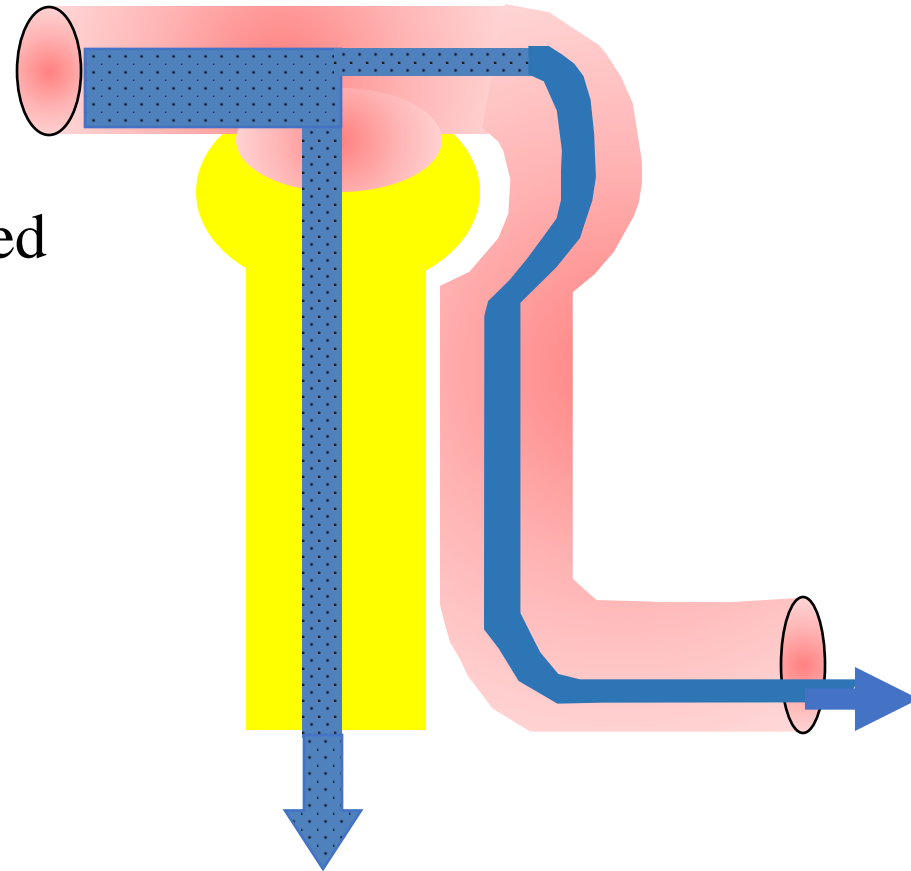| Substance	Clearance (ml/min)
glucose	0
albumin	0
sodium	0.9
urea	70
inulin	125
creatinine	140
PAH	600

Use of Clearance to Measure GFR

For a substance that is freely filtered, but not reabsorbed or secreted (inulin, ^{125}I-iothalamate, creatinine), renal clearance is equal to GFR

amount filtered = amount excreted

$$GFR \times P_{in} = U_{in} \times V$$

$$GFR = \frac{U_{in} \times V}{P_{in}}$$

Calculate the GFR from the following data:

$P_{inulin} = 1.0$ mg / 100ml

$U_{inulin} = 125$ mg/100 ml

Urine flow rate = 1.0 ml/min

$$GFR = C_{inulin} = \frac{U_{in} \times V}{P_{in}}$$

$$GFR = \frac{125 \times 1.0}{1.0} = 125 \text{ ml/min}$$

Theoretically, if a substance is completely cleared from
the plasma, its clearance rate would equal renal plasma flow

Cx = renal plasma flow
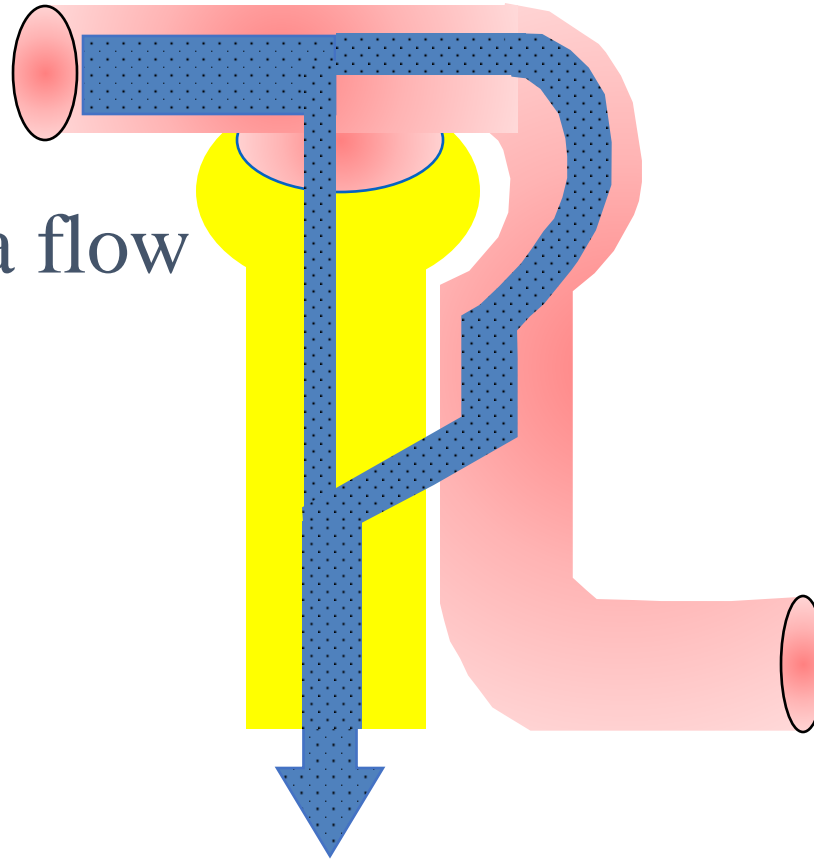
Paraminohippuric acid (PAH) is freely filtered and secreted
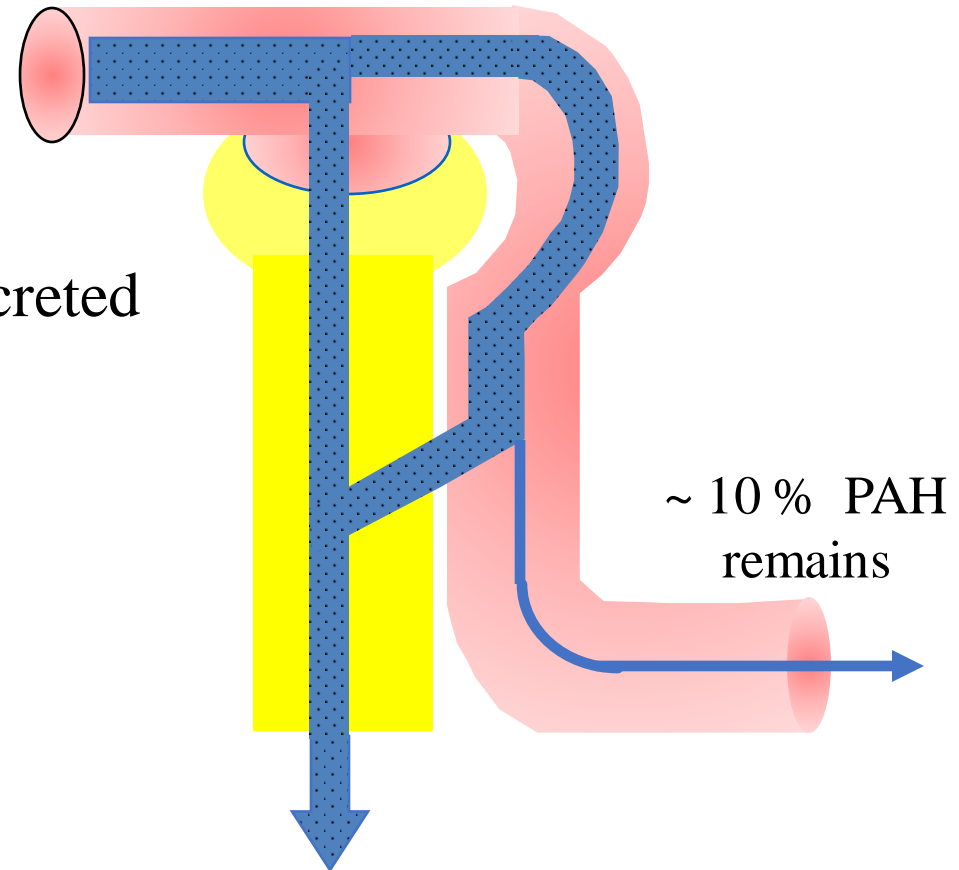and is almost completely cleared from the renal plasma

1. amount enter kidney =
   $$RPF \times P_{PAH}$$

2. amount entered $\cong$ amount excreted

3. $ERPF \times P_{pah} = U_{PAH} \times V$

   $$= \frac{U_{PAH} \times V}{P_{PAH}}$$

   ERPF = Clearance PAH

~ 10 % PAH
remains

ERPF=estimated renal plasma flow

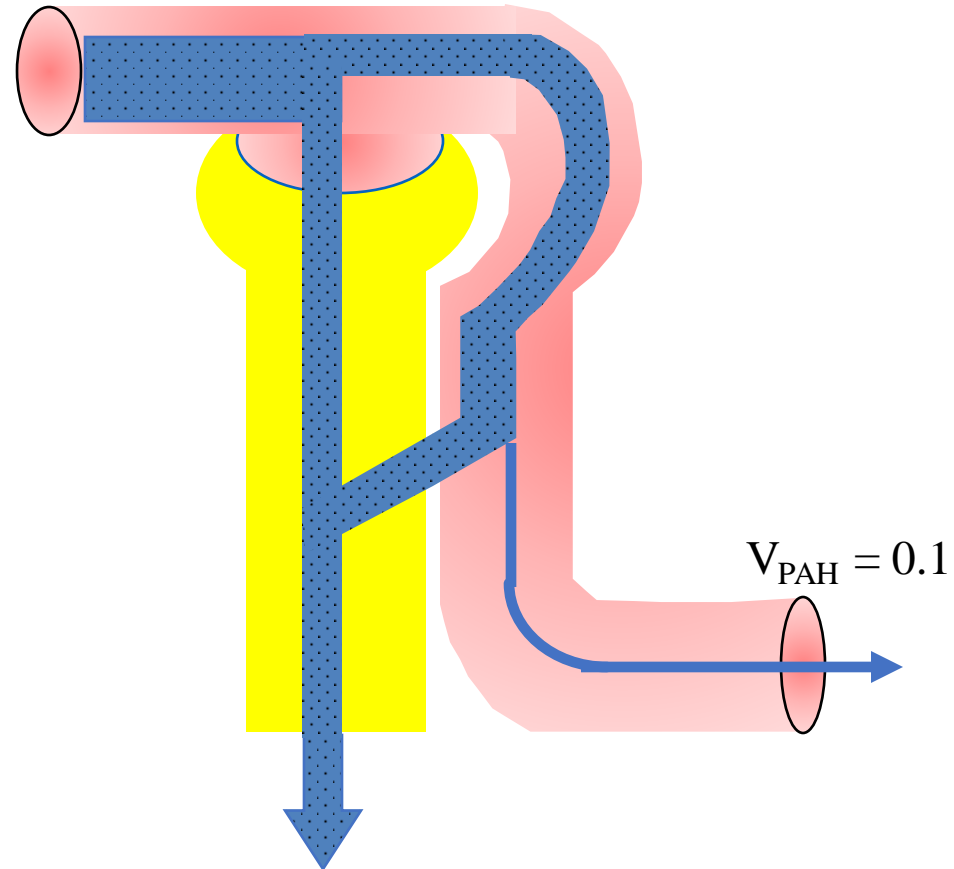**To calculate <u>actual</u> RPF ,**
one must correct for incomplete extraction of PAH

$$A_{PAH} = 1.0$$

$$E_{PAH} = \frac{A_{PAH} - V_{PAH}}{A_{PAH}}$$

$$= \frac{1.0 - 0.1}{1.0} = 0.9$$

normally, $E_{PAH} = 0.9$
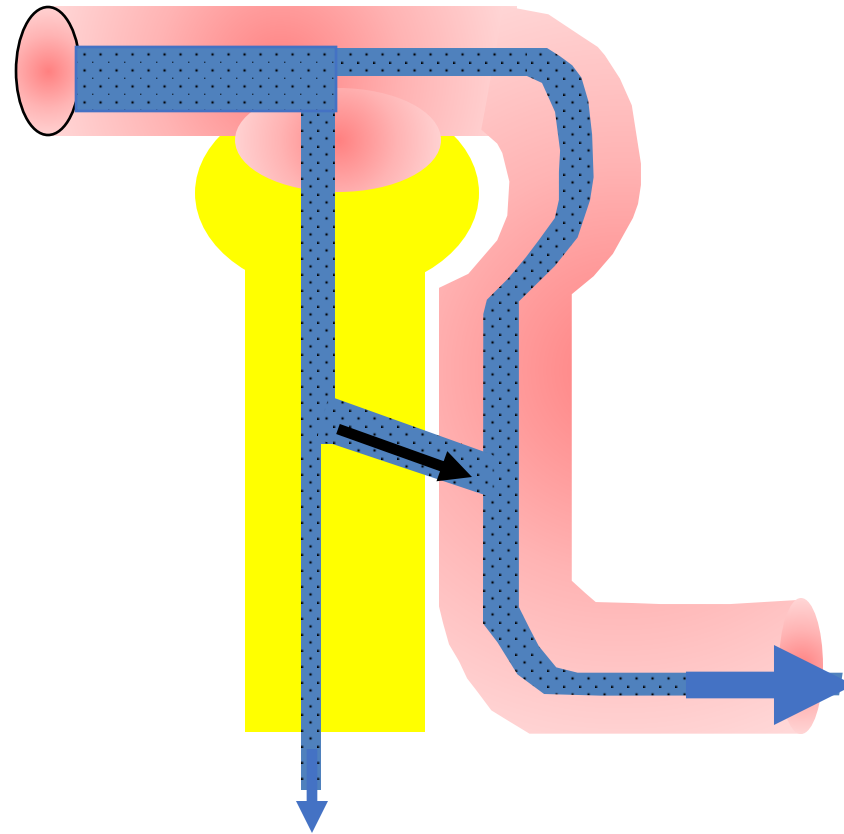
i.e PAH is 90 % extracted

$$RPF = \frac{ERPF}{E_{PAH}}$$

$$V_{PAH} = 0.1$$

Calculation of Tubular Reabsorption

Reabsorption = Filtration -Excretion

Filt s = GFR x Ps

Excret s = Us x V

Calculation of Tubular Secretion

Secretion = Excretion - Filtration

$$\text{Filt}_s = \text{GFR} \times P_s$$
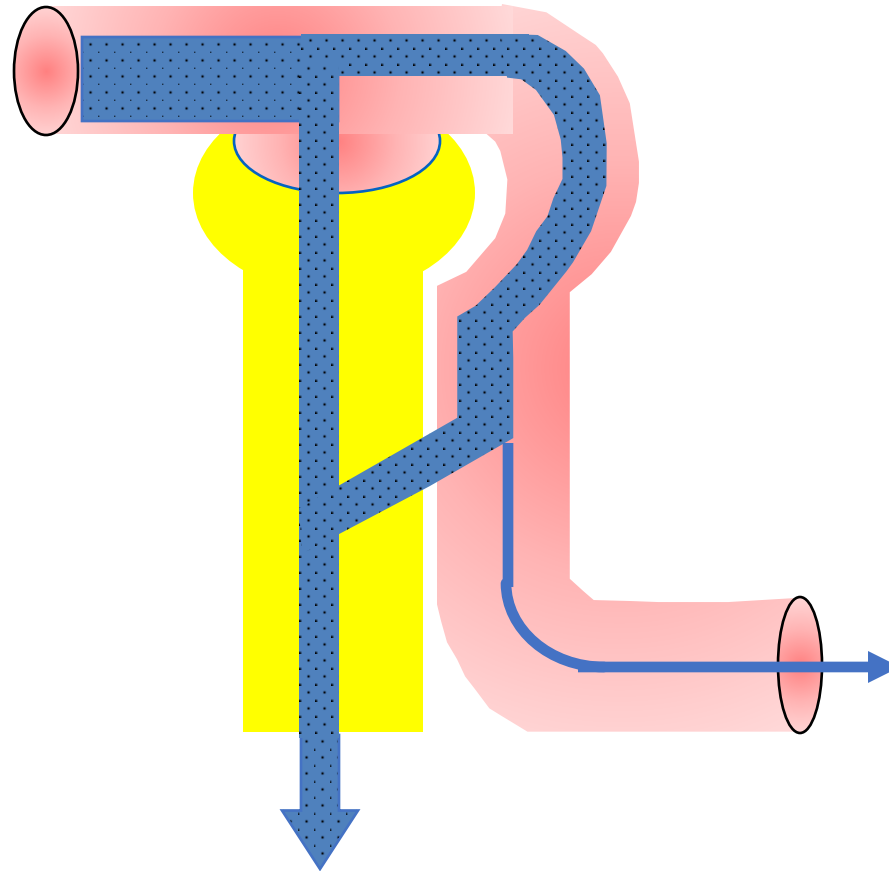
$$\text{Excret}_s = U_s \times V$$

Question

The maximum possible clearance rate of a substance that is completely cleared from the plasma by the kidneys would be equal to

1. glomerular filtration rate
2. the filtered load of the substance
3. urine excretion rate of the substance
4. renal plasma flow
5. none of the above

Use of Clearance to Estimate Renal Plasma Flow

Theoretically, if a substance is completely cleared from
the plasma, its clearance rate would equal renal plasma flow

Cx = renal plasma flow
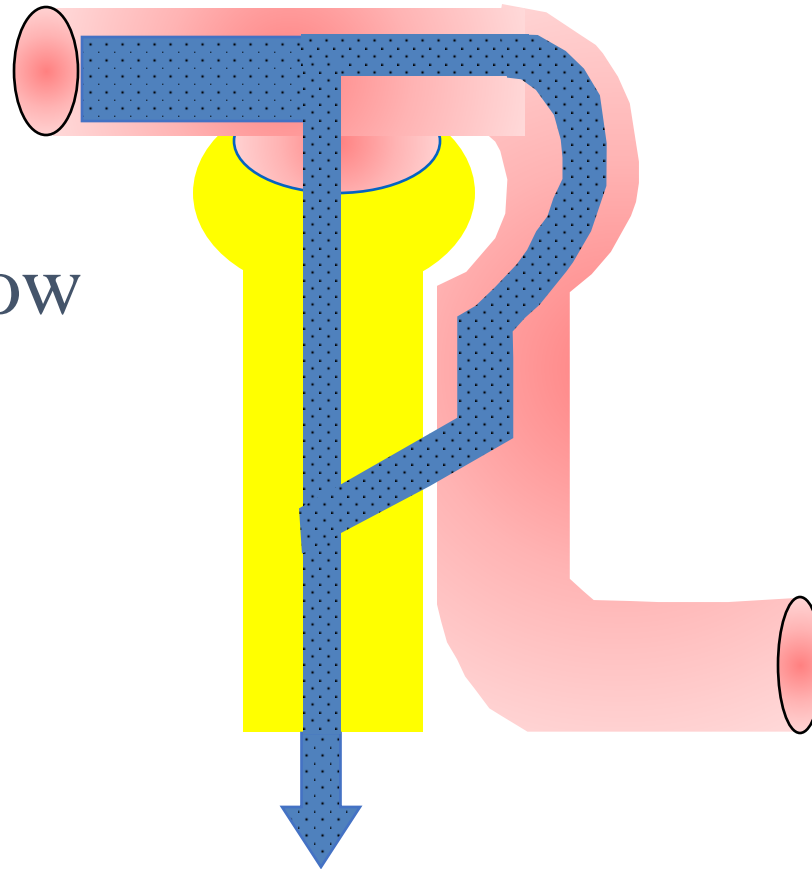
Clearances of Different Substances

Substance	Clearance (ml/min
inulin	125
PAH	600
glucose	0
sodium	0.9
urea	70

Clearance of inulin (C_{in}) = GFR

if Cx < Cin : indicates reabsorption of x

if Cx > Cin : indicates secretion of x

Clearance creatinine (C_{creat}) ~ 140 (used to estimate GFR)

Clearance of PAH (C_{pah}) ~ effective renal plasma flow

Effect of reducing GFR by 50 % on serum creatinine concentration and creatinine excretion rate
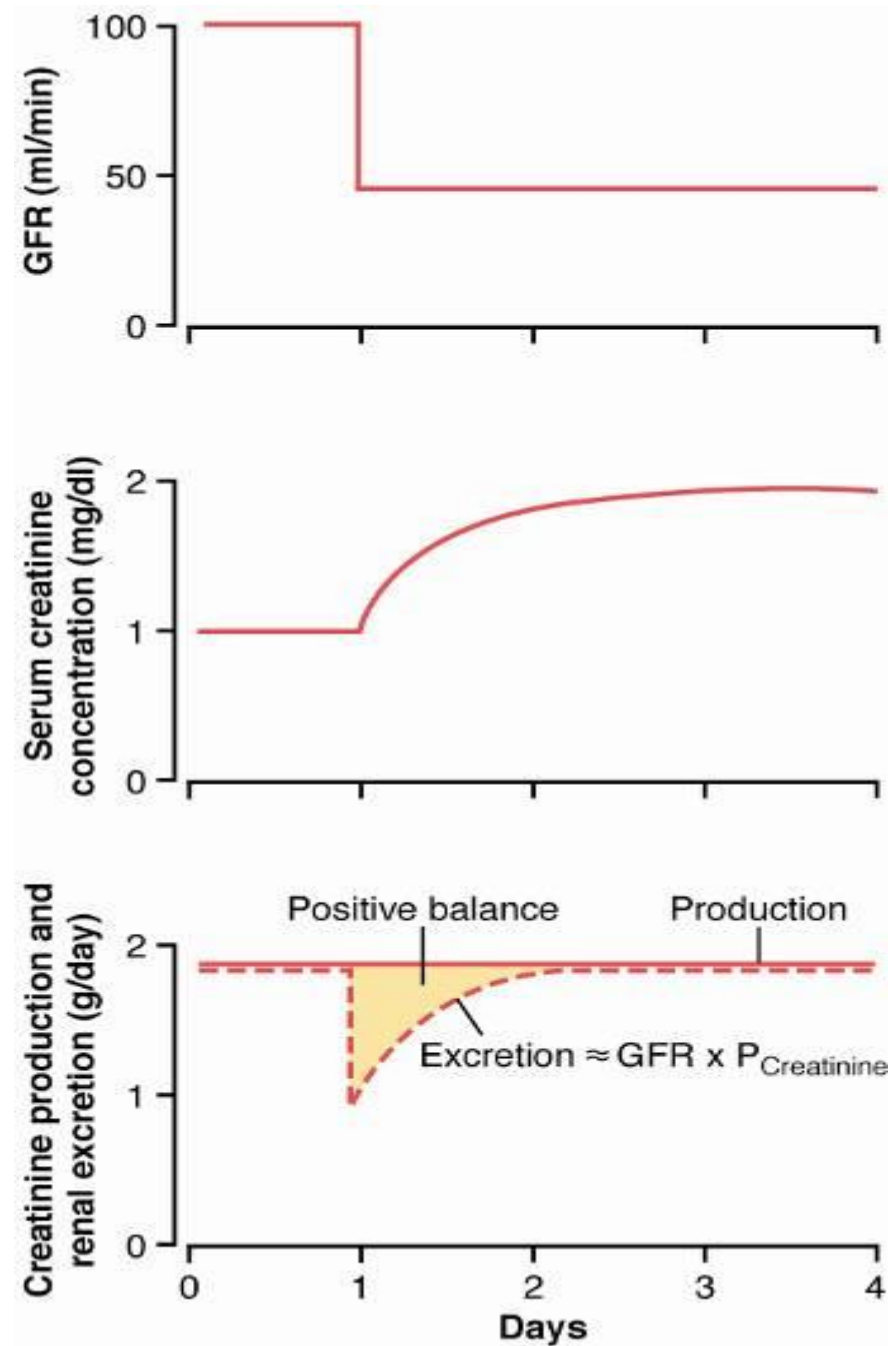

Figure 27-20

True or False?

Reduction of GFR by 50 % will increase serum creatinine to double while, creatinine excretion rate will remain the same as normal in steady state conditions

✓

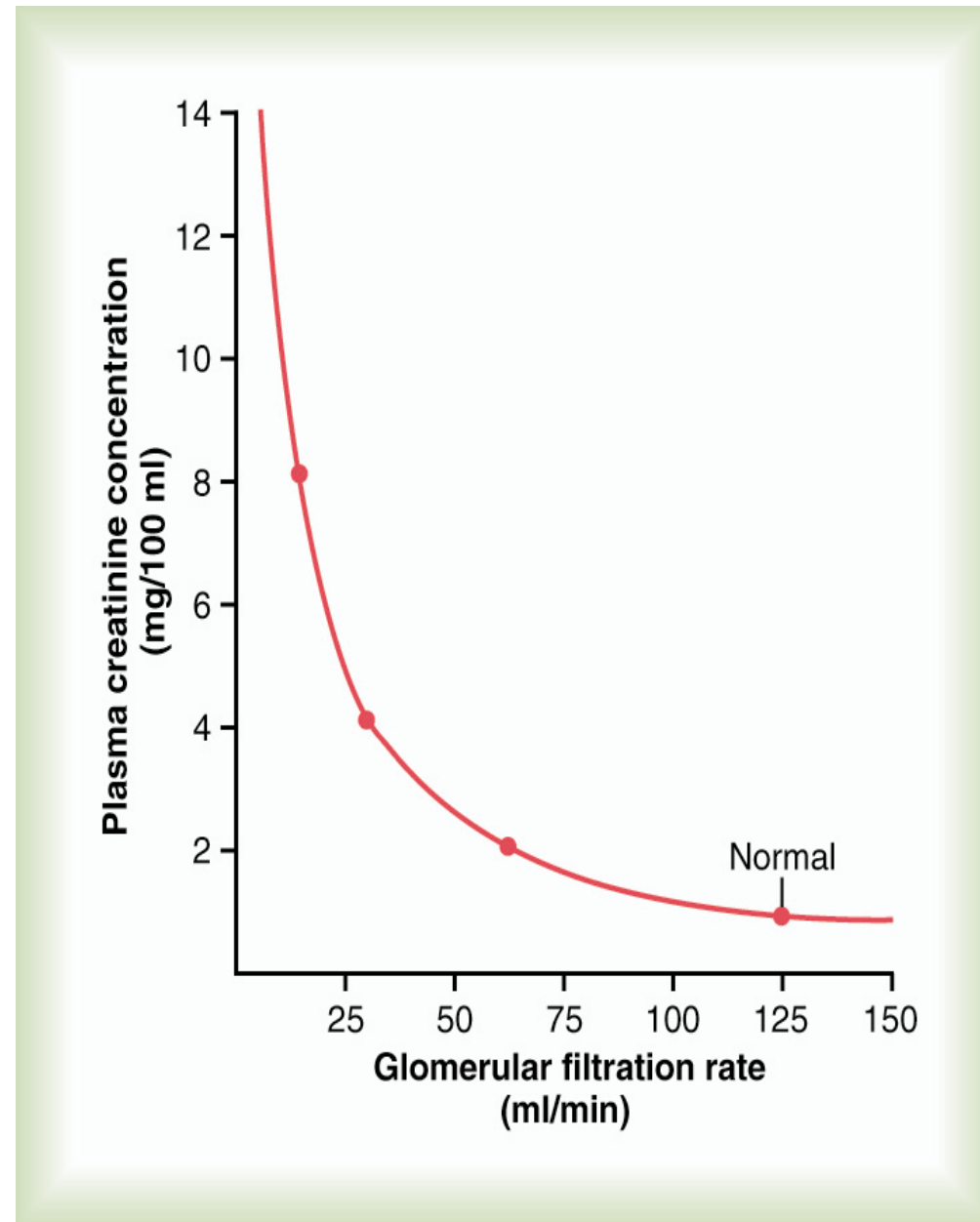**Plasma creatinine can be used to estimate changes in GFR**

Figure 27-21

Clinical Perspective

Clinical GFR estimation equations using GFR

Online calculator:

eGFR Calculator | National Kidney Foundation

Model	Equation
Creatinine model	$36.76 + 1.91 \times Wt - 0.47 \times SCr$
Weight model	$16.25 + 1.67 \times Wt$
Cockcroft function[a]	$\dfrac{(130 + 0.09 \times Age) \times Wt \times (1 + 0.11 \times Sex)}{SCr}$
Jelliffe function[a]	$\dfrac{(2530 + 126 \times Age) \times BSA \times (1 + 0.13 \times Sex)}{SCr}$
Léger model	$\dfrac{(56.7 \times Wt + 0.142 \times Hght^2)}{SCr}$
Schwartz regression	$\dfrac{0.55 \times Hght}{SCr \times 0.01131} \times (BSA/1.73)$ if female $\left(1.5 \times Age + \dfrac{0.5 \times Hght}{SCr \times 0.01131}\right) \times (BSA/1.73)$ if male

Coefficients derived from modelling data set, except for Schwarz and Léger equations where the original coefficients are used. Wt: weight (kg); Age: age (years); Sex: 1 if male, 0 if female; SCr: serum creatinine (μmol l^{-1}); BSA: body surface area (m^2); Hght: height (cm). [a]Coefficients re-estimated from current data set using nonlinear mixed effects modelling.

Clinical Perspective

Chronic kidney disease evaluation by GFR

Stage	Description	GFR (mL/min)
1	Kidney damage (protein in the urine) with normal or elevated GFR	90 or more
2	Kidney damage with mildly decreased GFR	60–89
3	Kidney damage with moderately decreased GFR	30–59
4	Kidney damage with severely decreased GFR	15–29
5	Kidney failure: end-stage renal disease (ESRD). Patients who have Stage 5 disease require dialysis or transplantation to survive.	Less than 15