Urinary System: Renal Physiology for Medical Students, L10

Chapter 29 : Renal Regulation of Potassium, Calcium, Phosphate,
and Magnesium; Integration of Renal Mechanisms for Control of Blood Volume and Extracellular Fluid Volume

Reference: Guyton & Hall, Jordanian first edition
Chapter29

Dr. Ebaa M. Alzayadneh, PhD.

Email: e.zayadneh@ju.edu.jo

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Objectives

- Identify the mechanisms by which the kidney regulates Potassium, Calcium, Phosphate homeostasis
- Identify renal tubular mechanisms of potassium reabsorption and secretion
- Understand factors affecting homeostasis of potassium
- Understand examples of integration of renal mechanisms for control of blood volume and extracellular fluid volume

Question

- A 26-year-old woman recently adopted a healthier diet to eat more fruits and vegetables. As a result, her potassium intake increased from 80 to 160 mmol/day. Which of the following conditions would you expect to find 2 weeks after she increased her potassium intake, compared with before the increase?

	Potassium Excretion Rate	Sodium Excretion Rate	Plasma Aldosterone Concentration	Plasma Potassium Concentration
A)	↔	↔	↑	Large increase (>1 mmol/l)
B)	↔	↓	↑	Small increase (<1 mmol/l)
C)	↑ 2×	↔	↑	Small increase (<1 mmol/l)
D)	↑ 2×	↑	↓	Large increase (>1 mmol/l)
E)	↑ 2×	↑	↔	Large increase (>1 mmol/l)

Normal potassium intake, distribution, and output from the body.

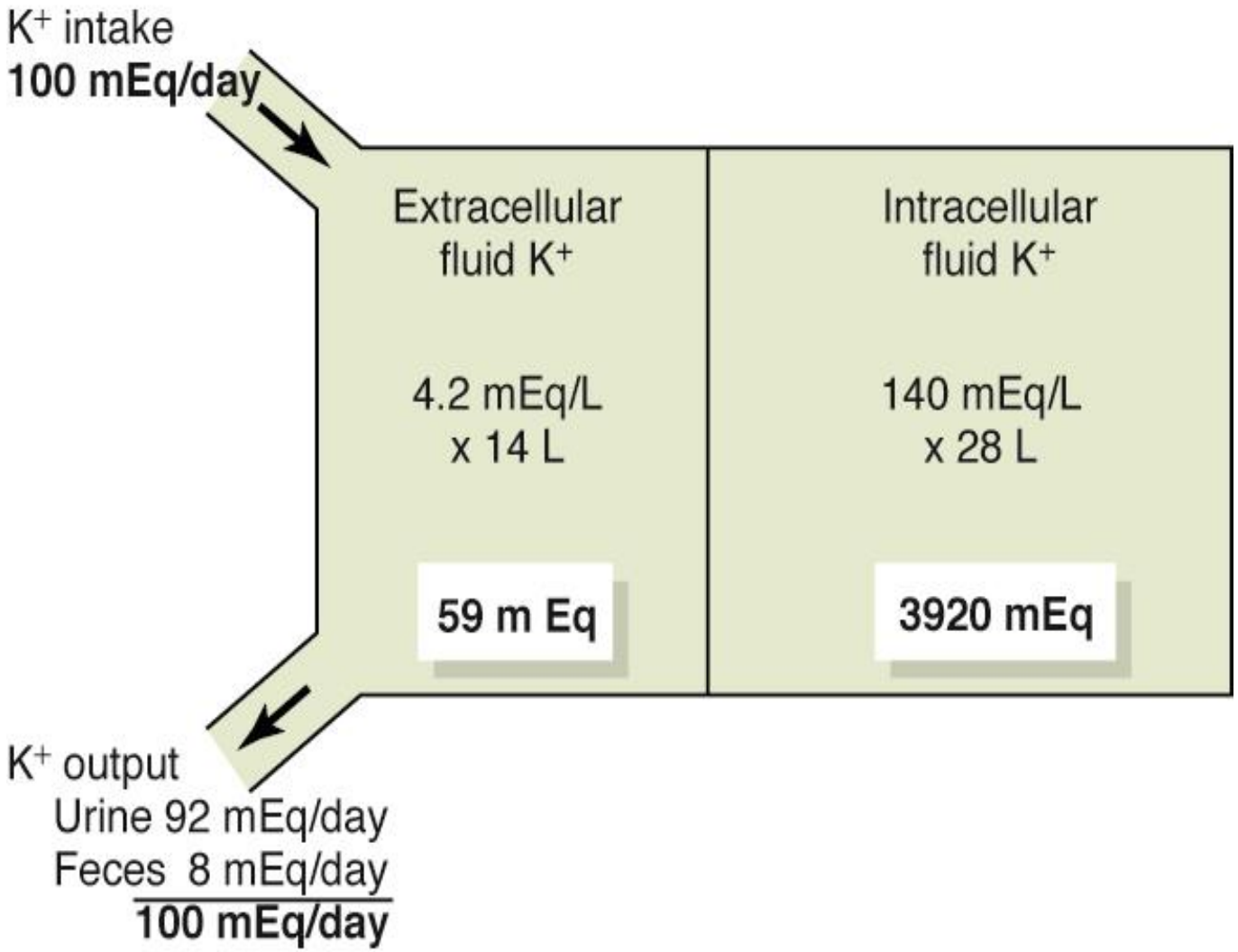


Figure 29-1

Clinical Perspective

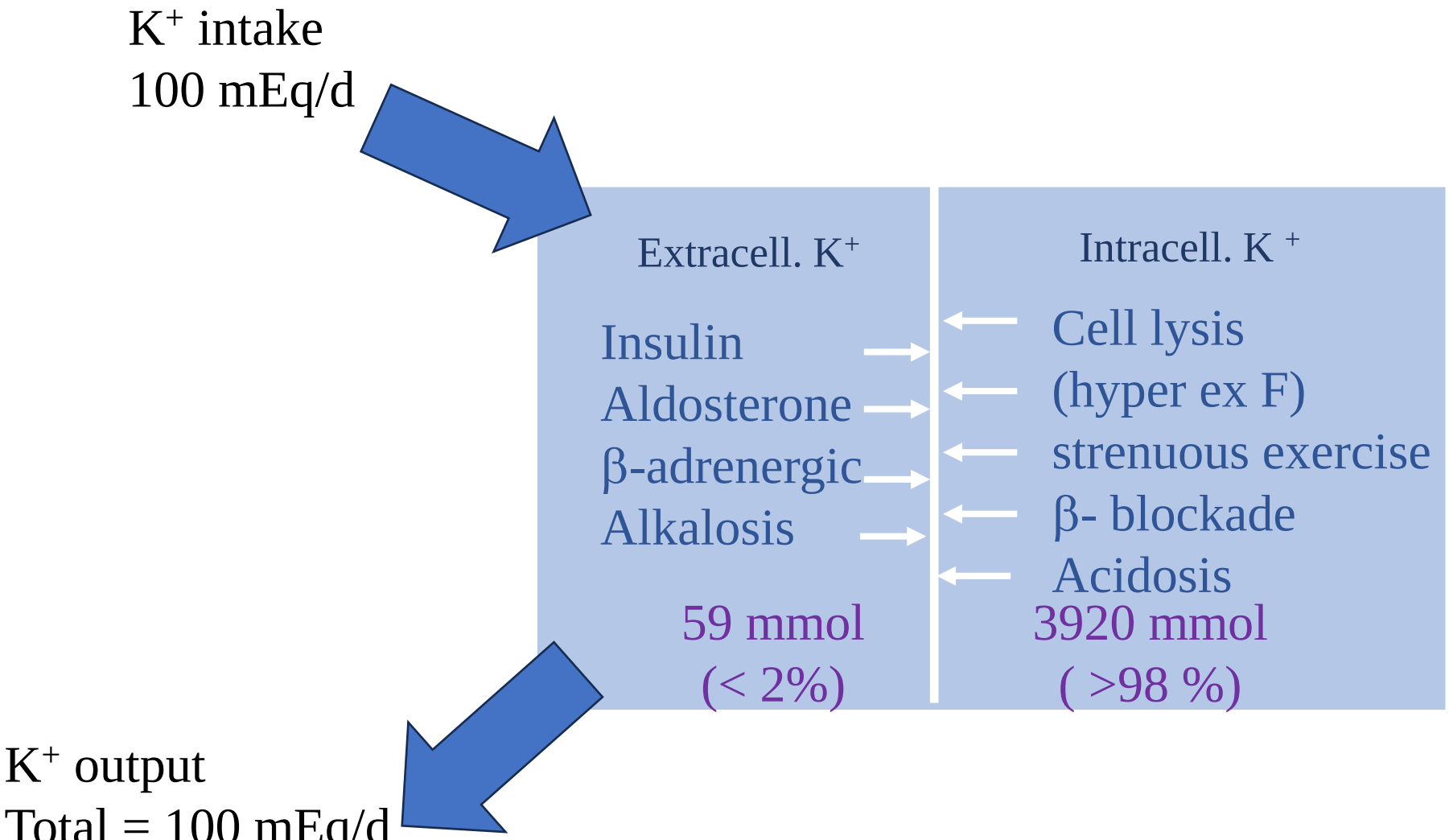
Effects of severe hyperkalemia

- Partial depolarization of cell membranes
- Cardiac toxicity
  ventricular fibrillation or asystole

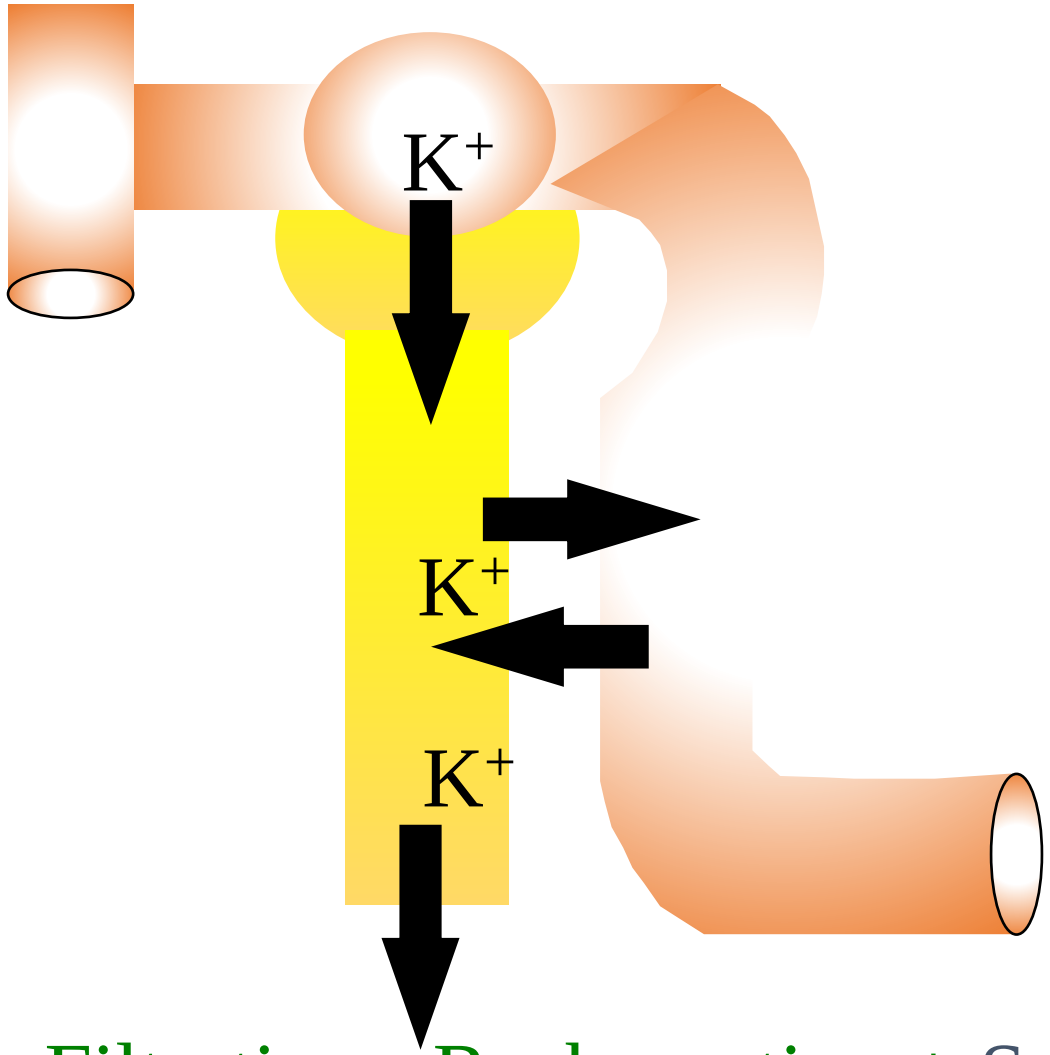
Effects of severe hypokalemia

- Hyperpolarization of cell membranes
- Fatigue, muscle weakness
- hypoventilation
- delayed ventricular repolarization

Potassium Regulation: Internal and External



Control of Potassium Excretion



Excretion = Filtration - Reabsorption + Secretion

Renal tubular sites of potassium reabsorption and secretion.

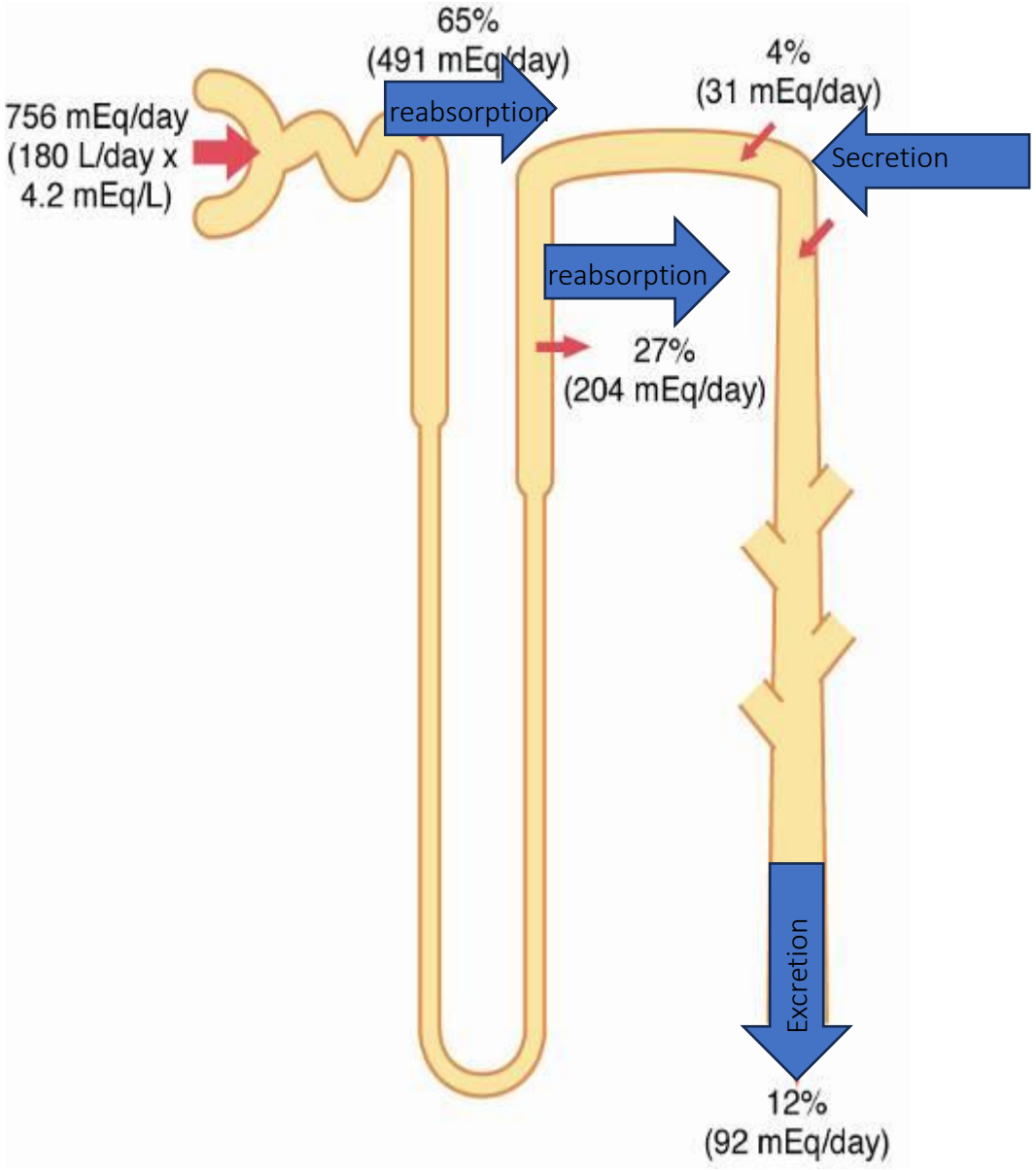
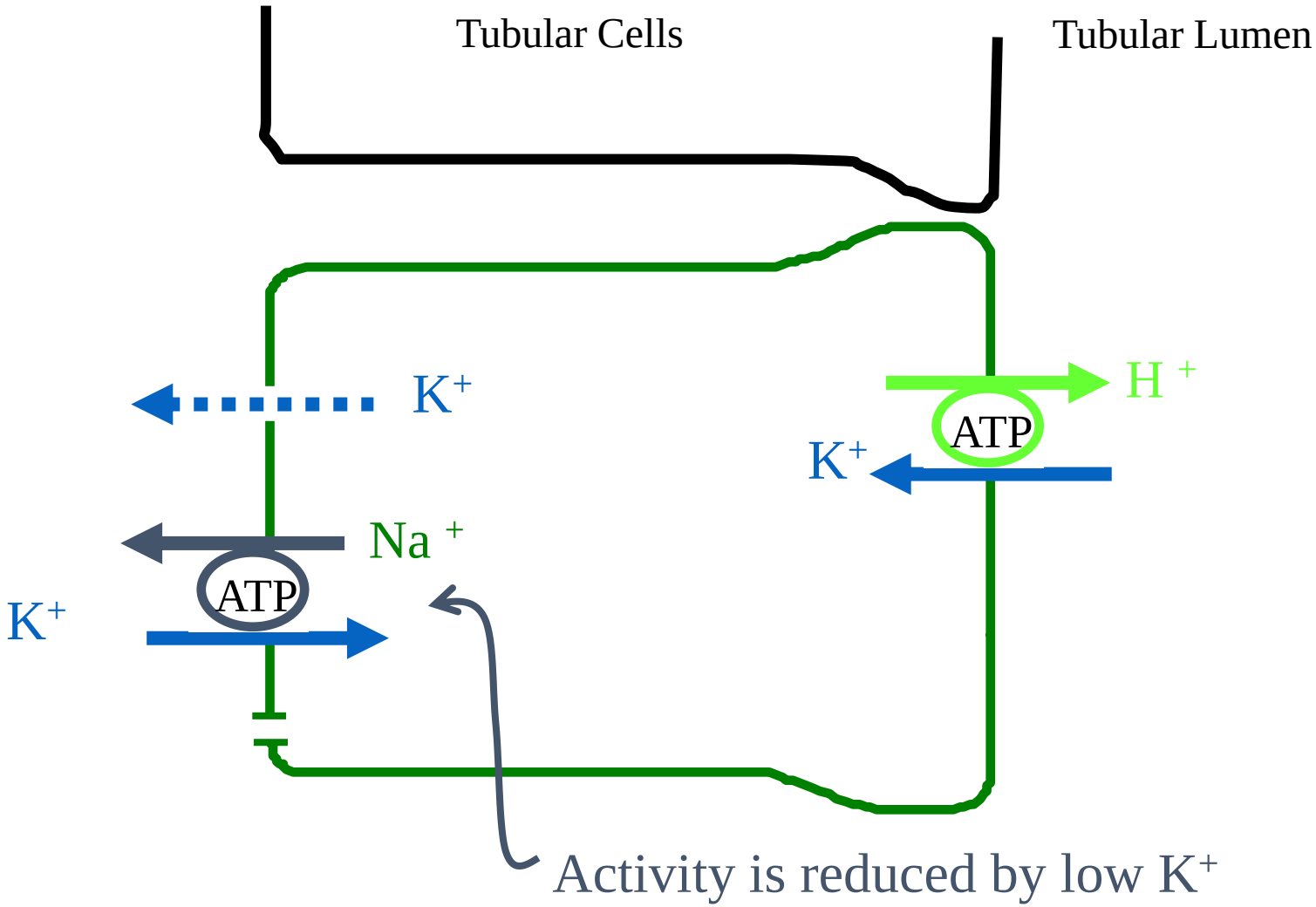


Figure 29-2

Late Distal and Cortical Collecting Tubules

Intercalated Cells –Reabsorb K^+



Potassium Secretion by Principal Cells

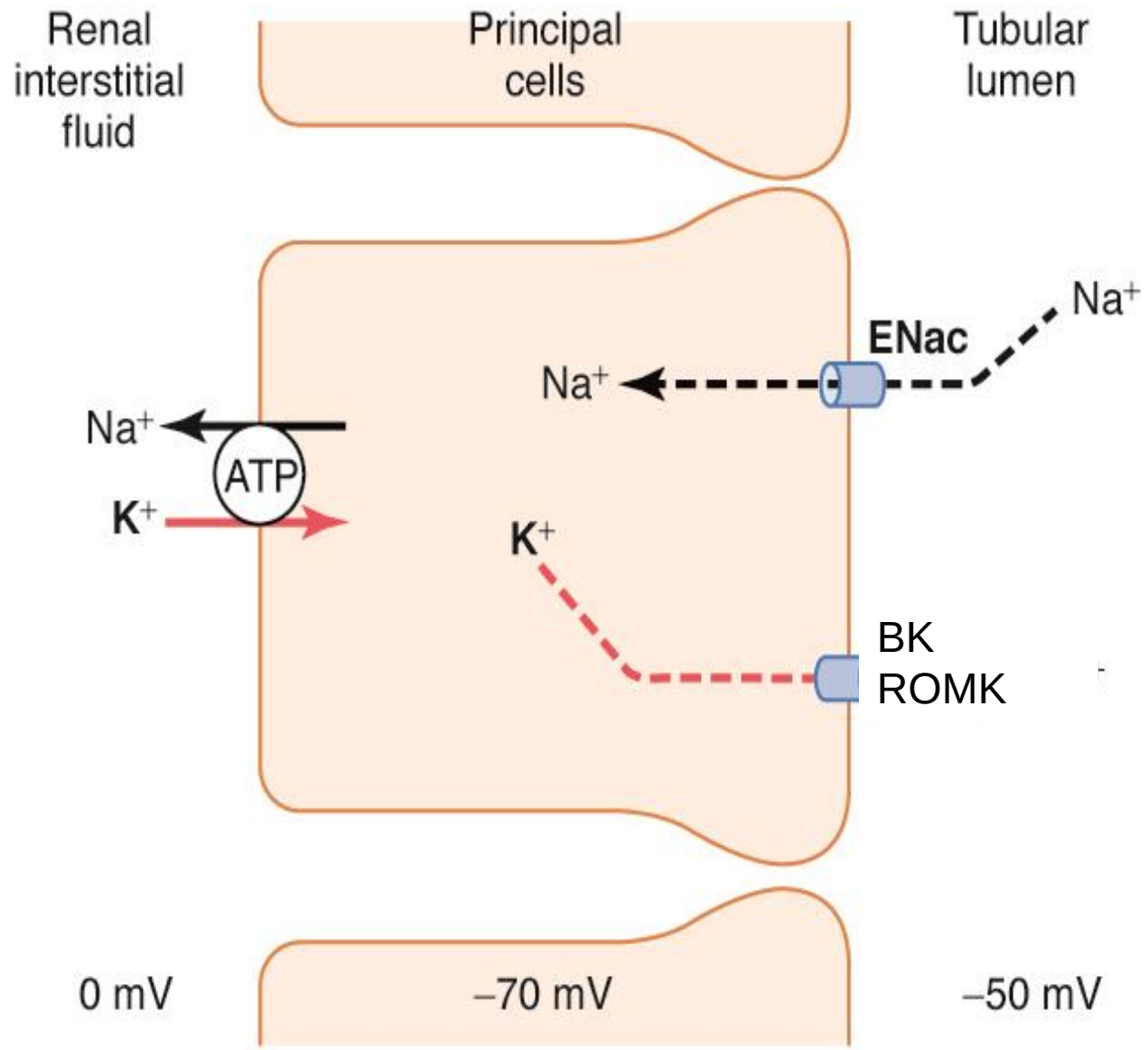
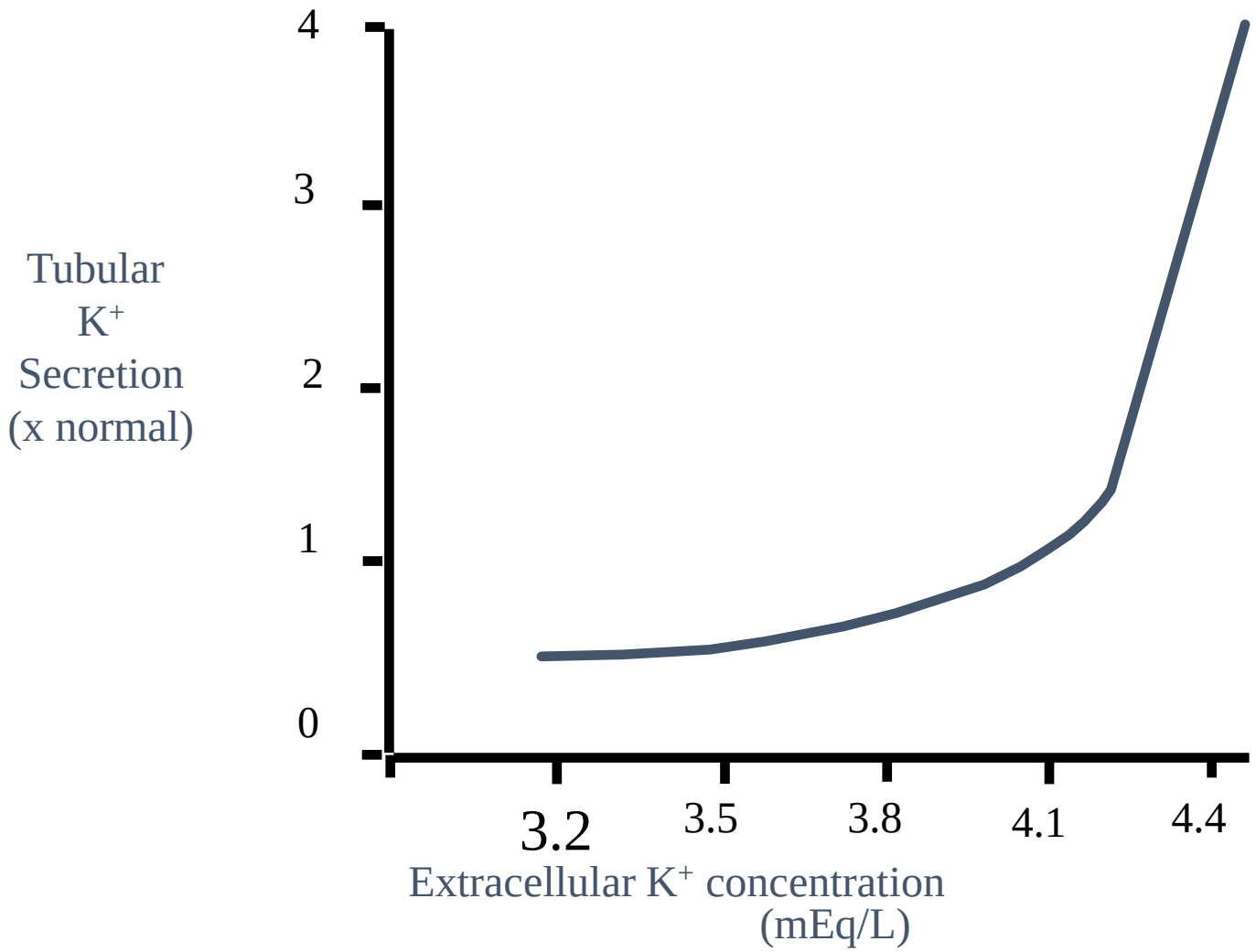


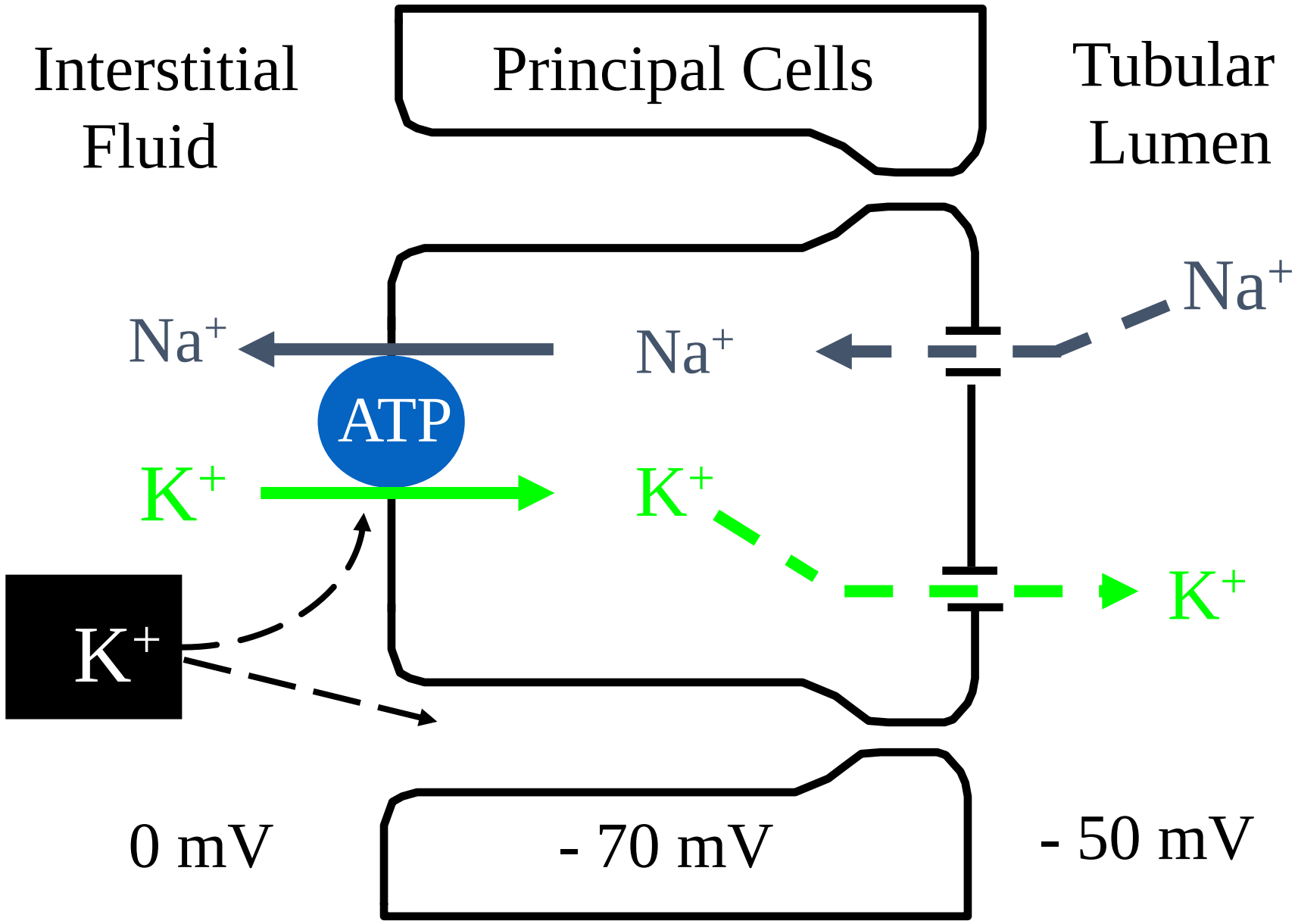
Figure 29-3

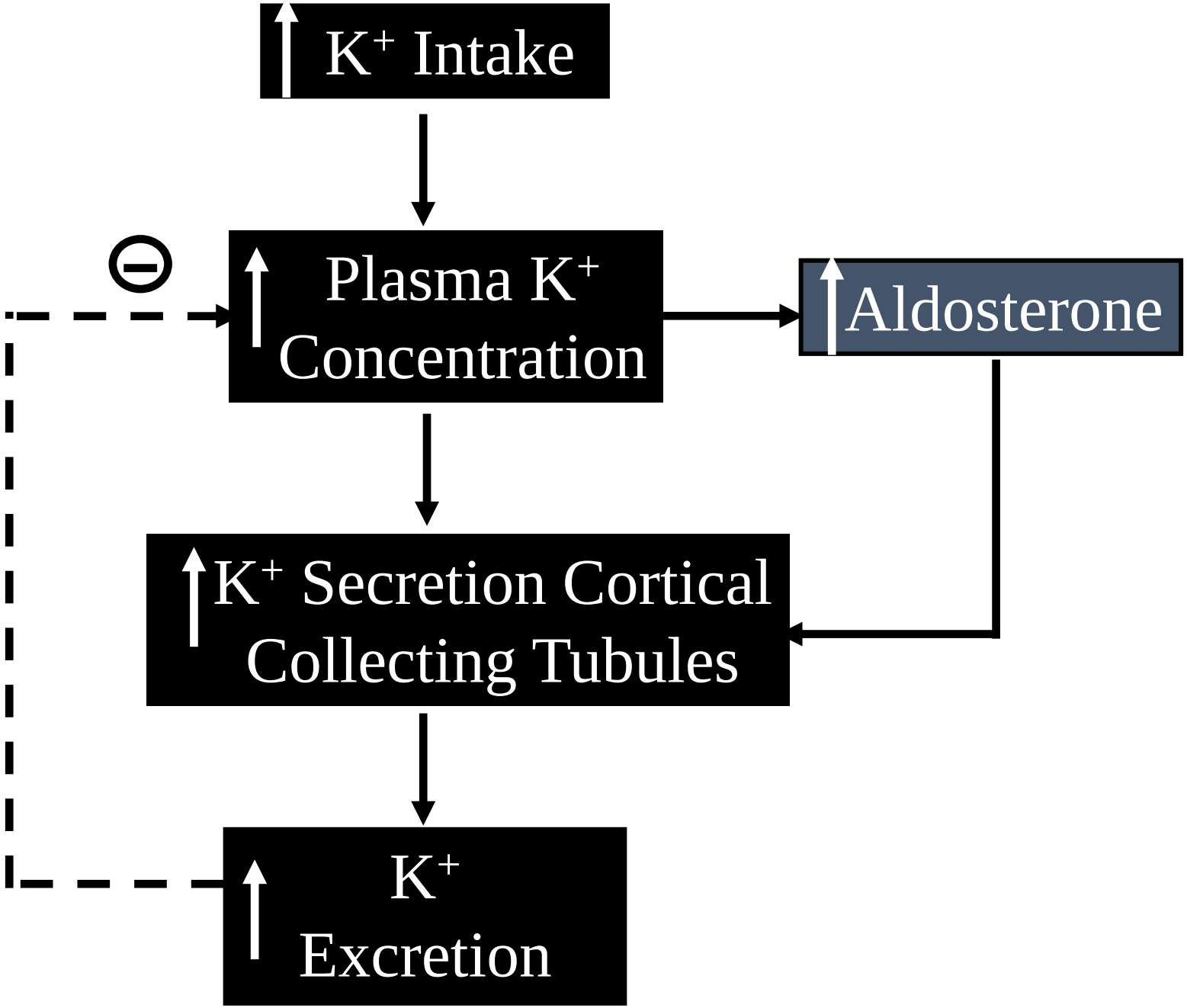
Control of Cortical Collecting Tubule (Principal Cells) K^+ Secretion

- Extracellular K^+ concentration : increases K^+ secretion
- Aldosterone : increases K^+ secretion
- Sodium (volume) delivery : increases K^+ secretion
- Acid - base status:
  - acidosis : decreases K^+ secretion
  - alkalosis : increases K^+ secretion

Effect of Extracellular K^+ on Excretion of K^+




Interstitial Fluid
Principal Cells
Tubular Lumen
Na+
Na+
Na+
ATP
K+
K+
K+
K+
0 mV
- 70 mV
- 50 mV


K+ Intake
Plasma K+ Concentration
Aldosterone
K+ Secretion Cortical Collecting Tubules
K+ Excretion

Increased serum K^+ stimulates aldosterone secretion

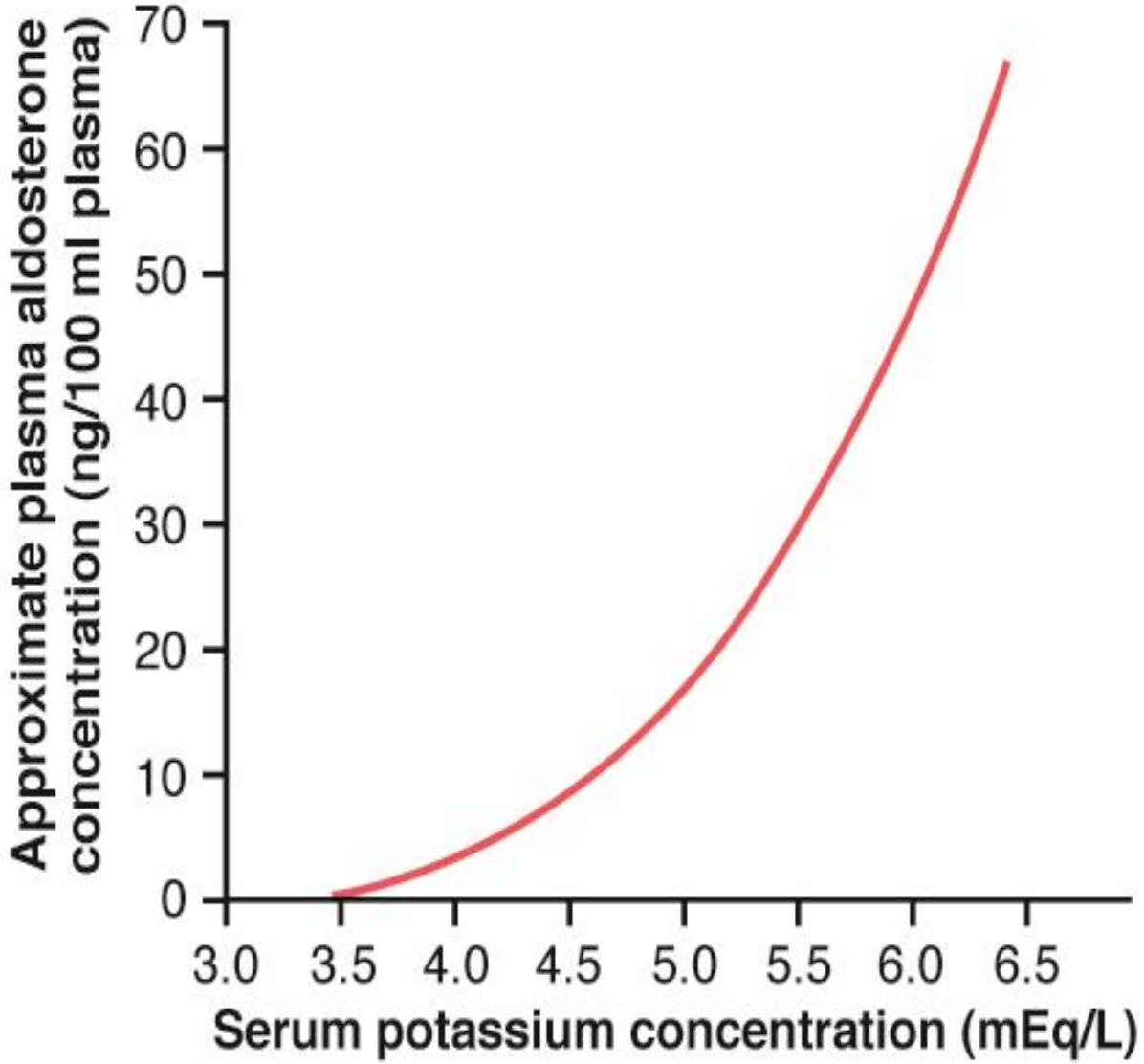
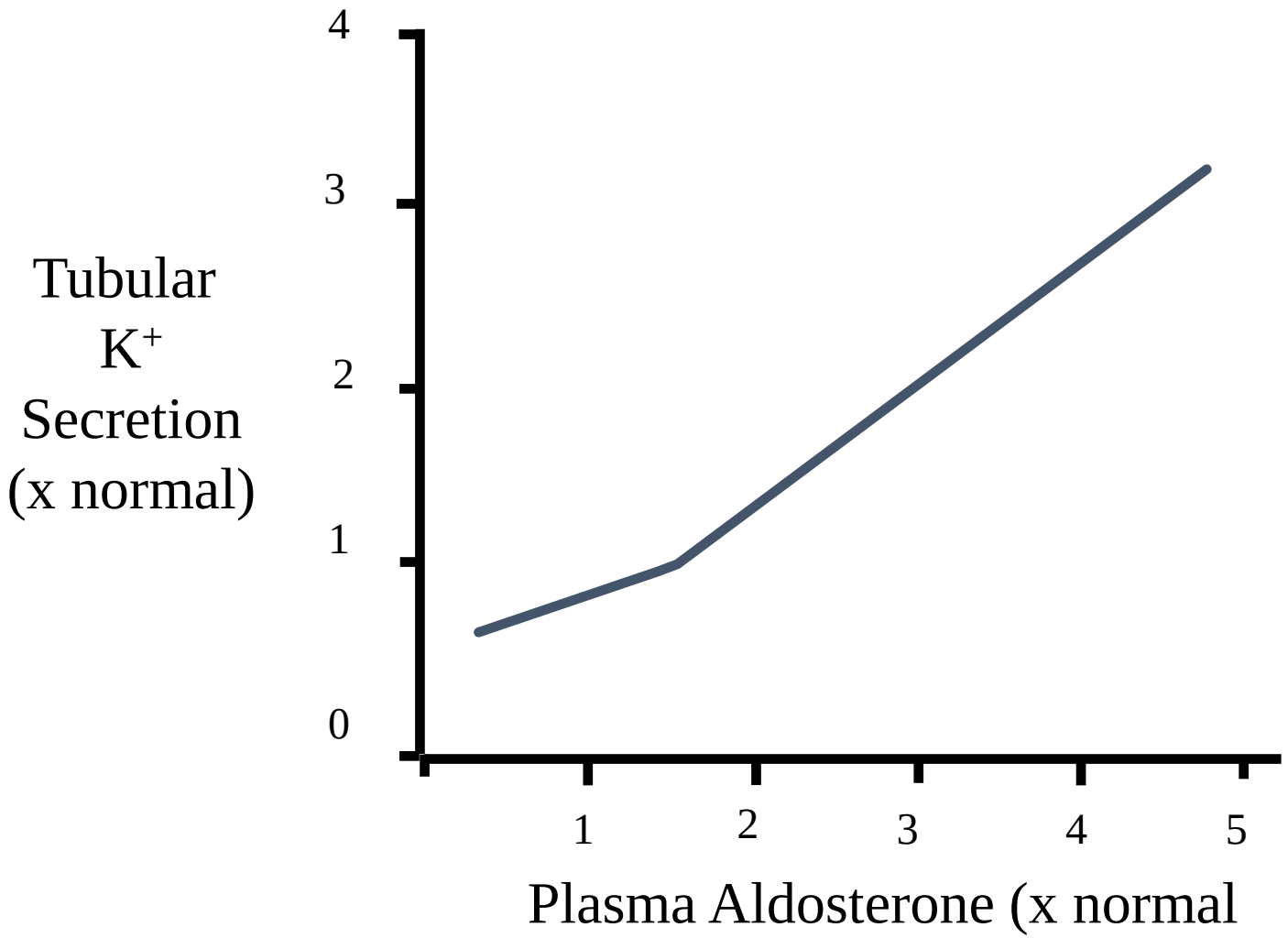
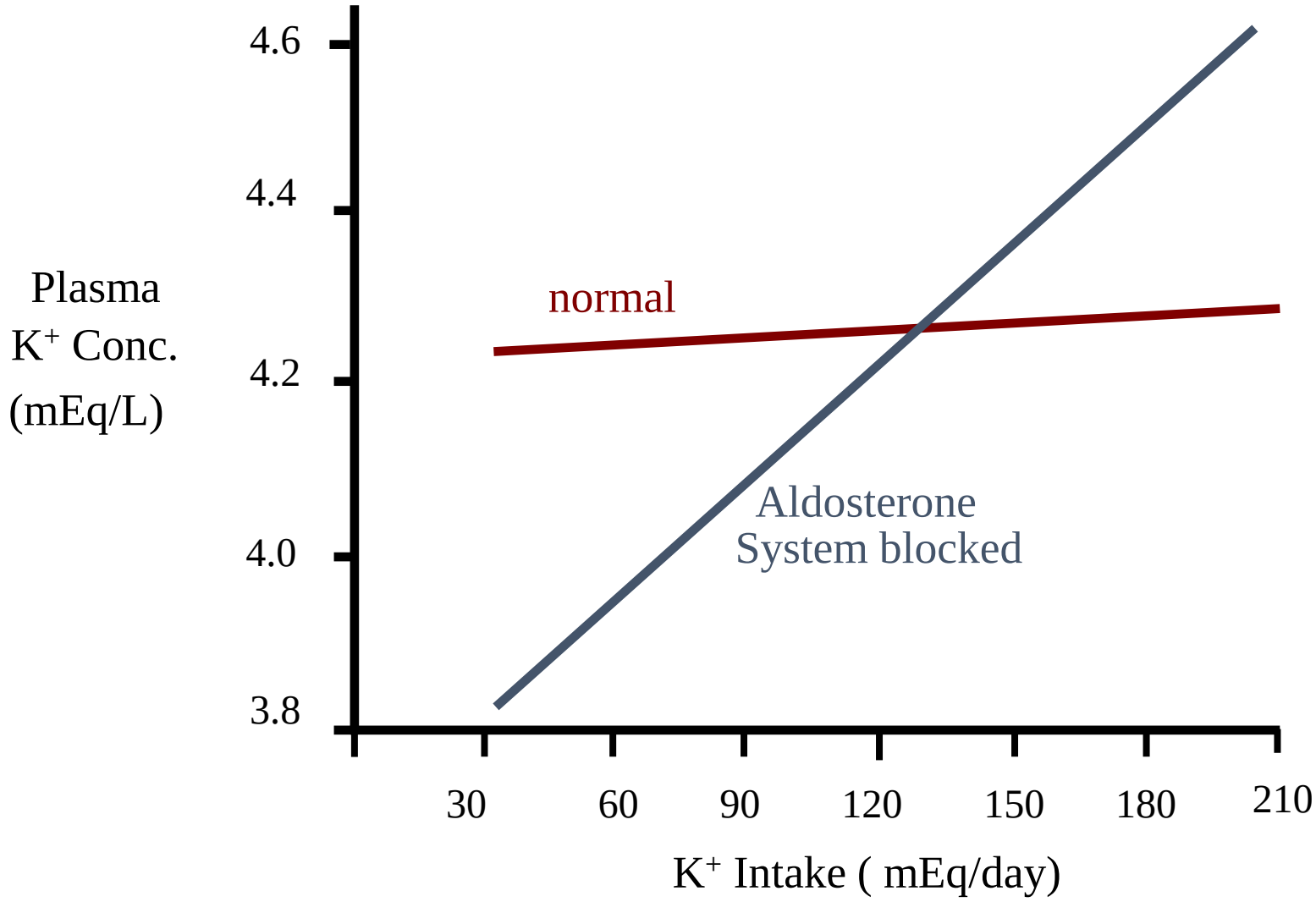


Figure 29-5

Effect of Aldosterone on K^+ Excretion



K^+ After Blocking Aldosterone System



Effect of collecting tubule flow rate on K^+ secretion

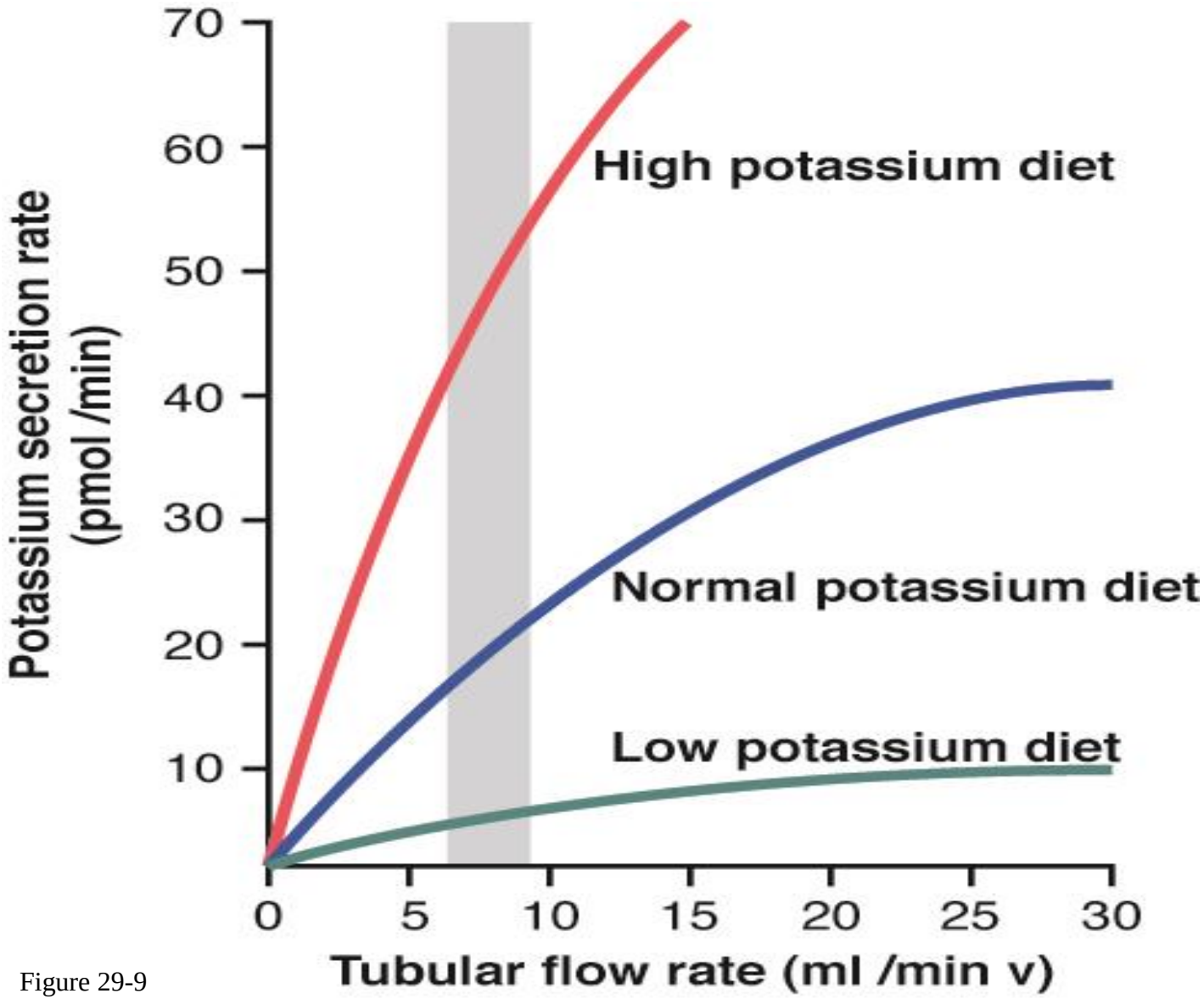
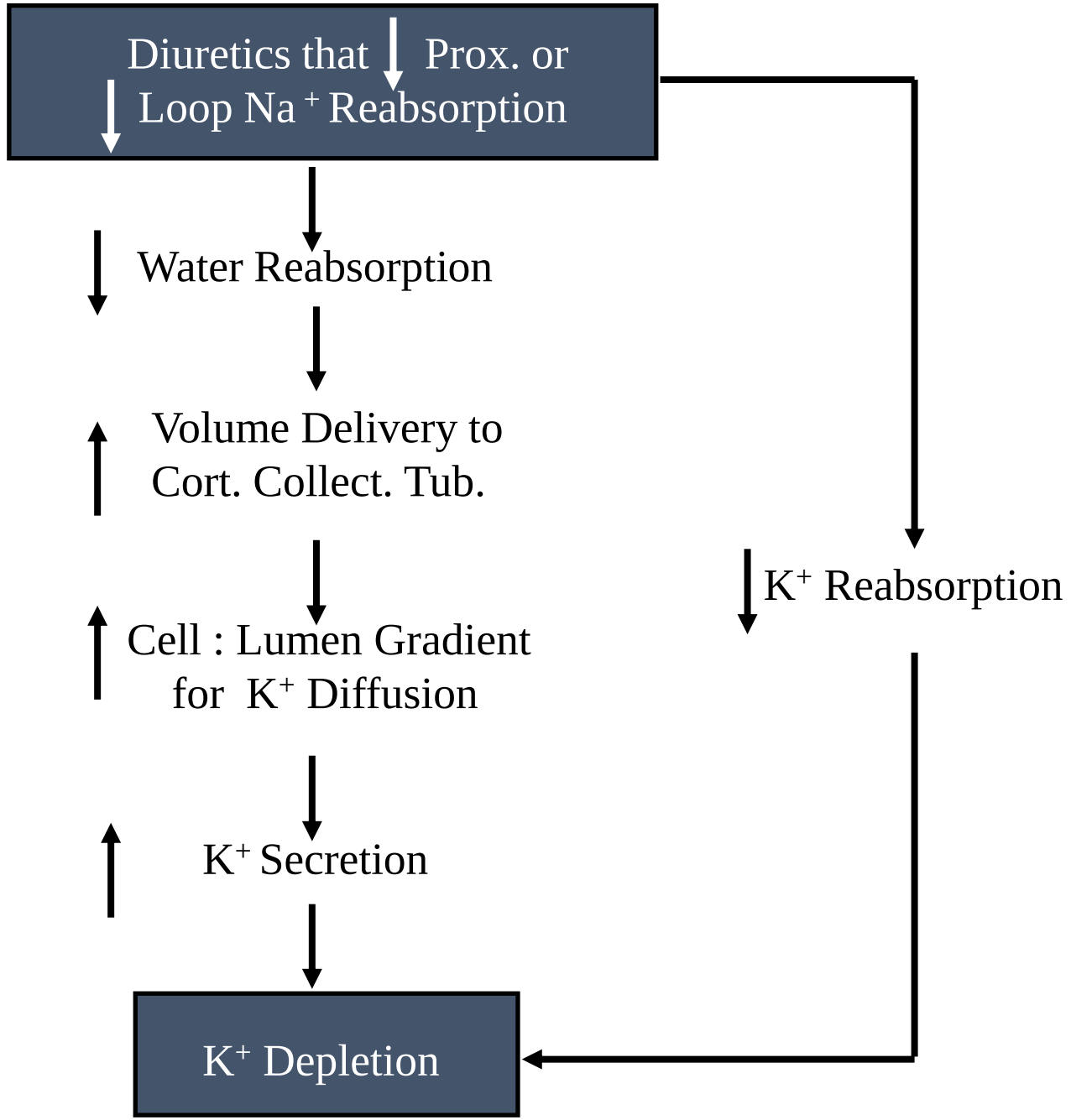
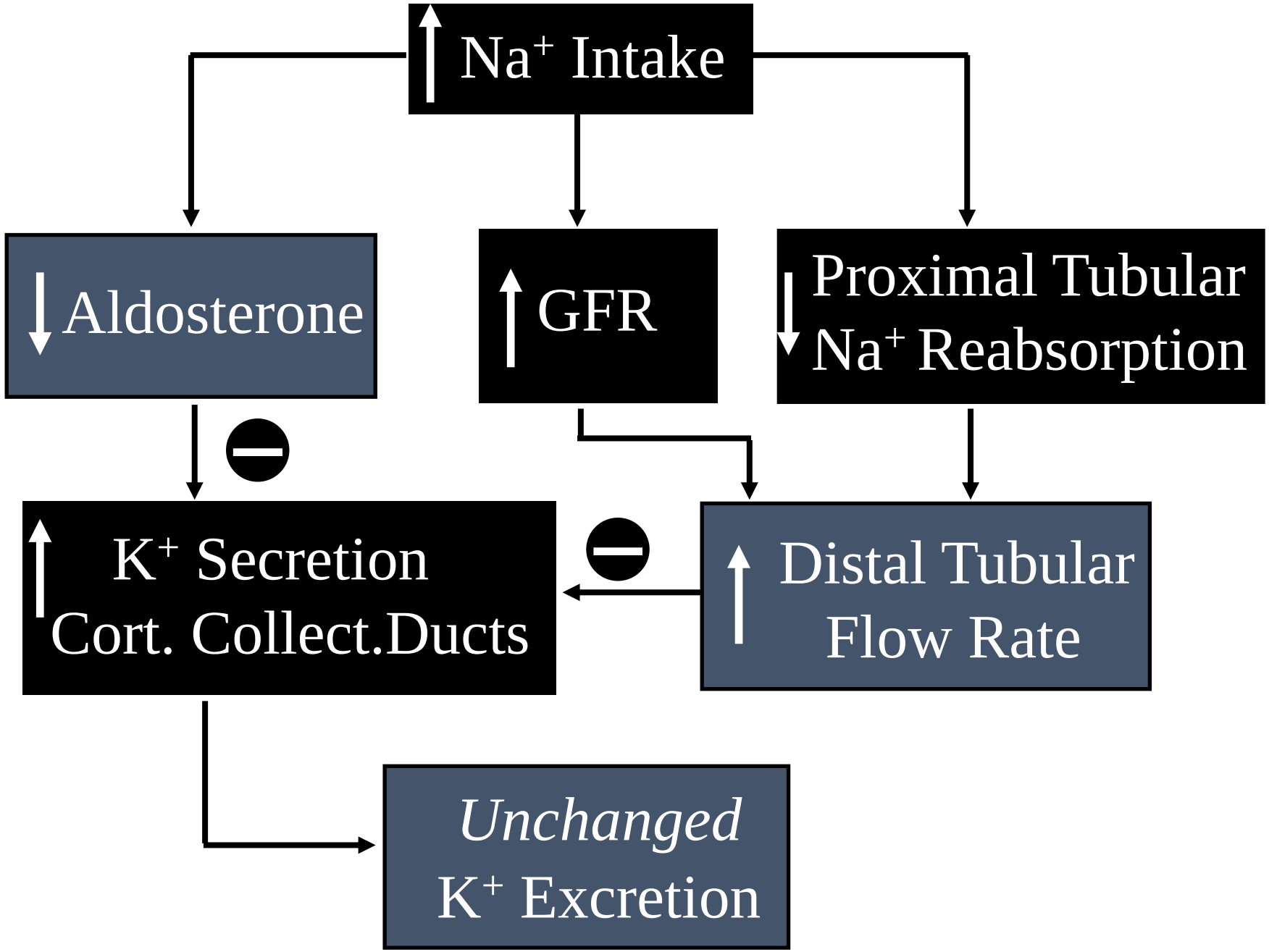


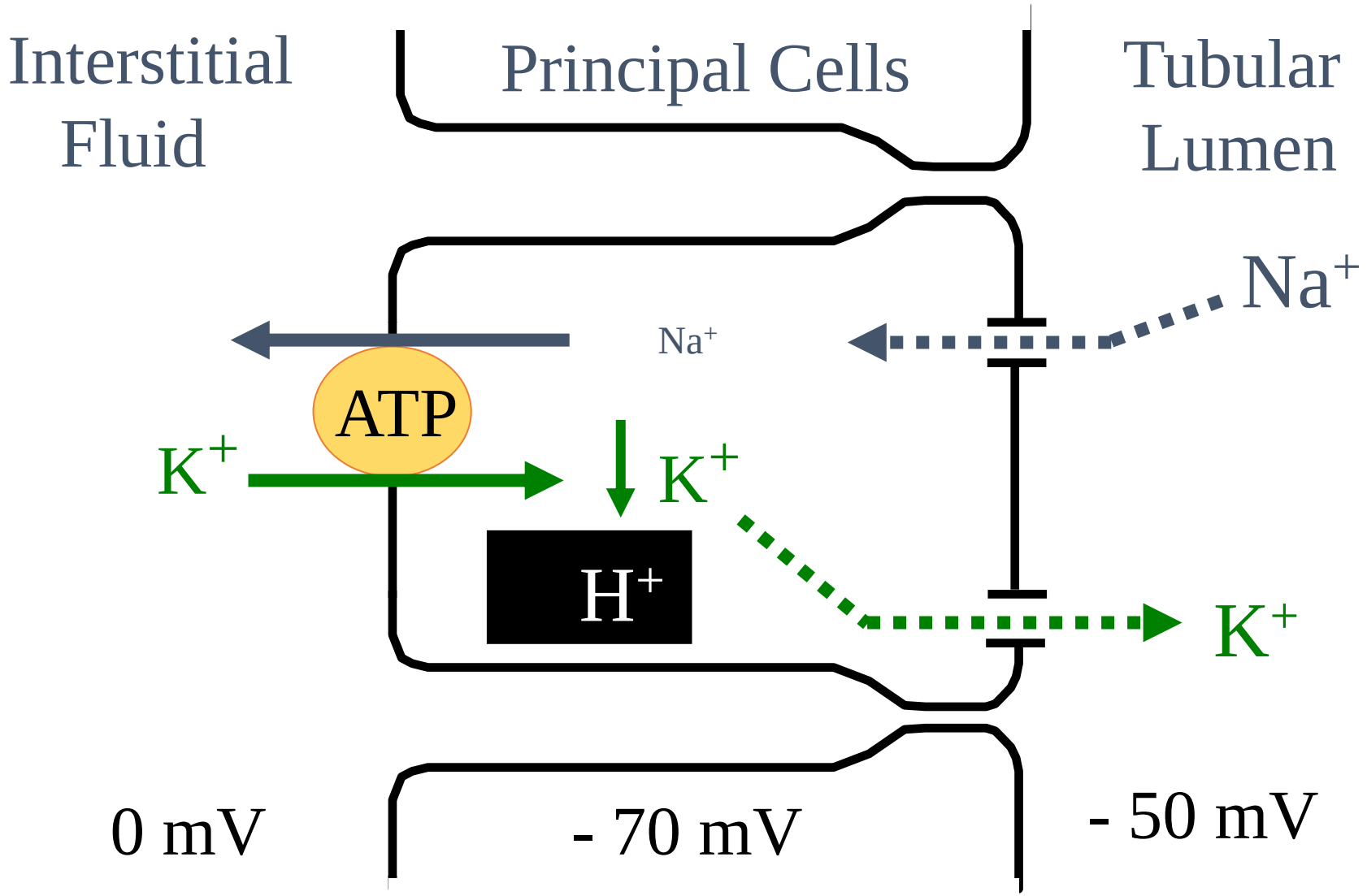
Figure 29-9

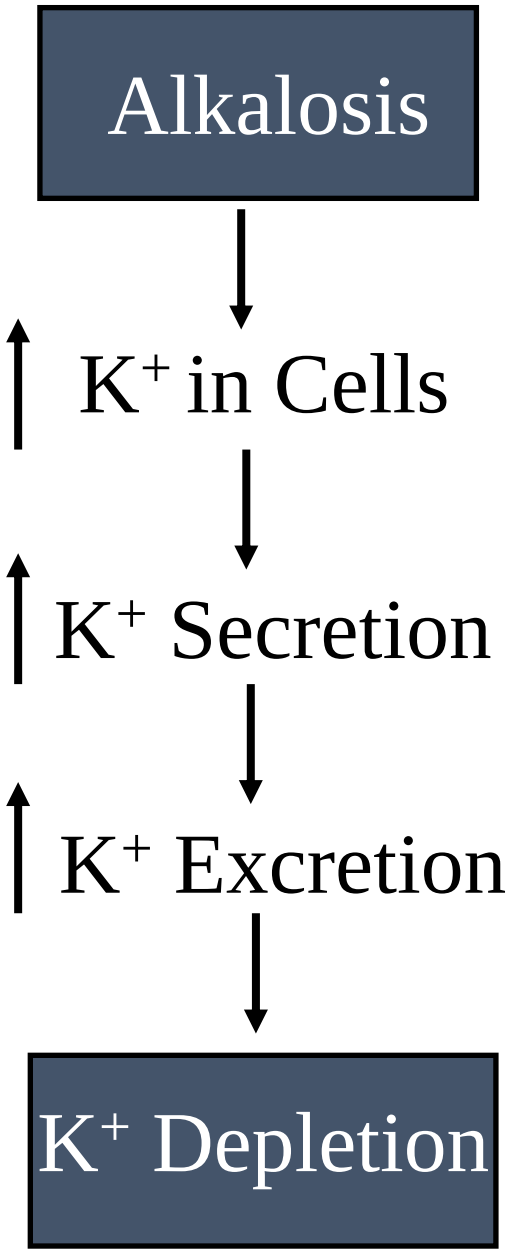
Clinical Perspective




↑ Na+ Intake
↓ Aldosterone
↑ GFR
↓ Proximal Tubular Na+ Reabsorption
⊖
⊖
↑ K+ Secretion Cort. Collect.Ducts
↑ Distal Tubular Flow Rate
Unchanged K+ Excretion

Acidosis Decreases Cell K^+




Alkalosis
K^+ in Cells
K^+ Secretion
K^+ Excretion
K^+ Depletion

Clinical Perspective

Causes of Hyperkalemia

- Renal failure
- Decreased distal nephron flow (heart failure, severe volume depletion, NSAID, etc)
- Decreased aldosterone or decreased effect of aldosterone
  - adrenal insufficiency
  - K^+ sparing diuretics (spironolactone, eplerenone)
- Metabolic acidosis (hyperkalemia is mild)
- Diabetes (kidney disease, acidosis, ↓ insulin)

Clinical Perspective

Causes of Hypokalemia

- Very low intake of K^+
- GI loss of K^+ - diarrhea
- Metabolic alkalosis
- Excess insulin
- Increased distal tubular flow /
  - salt wasting nephropathies
  - osmotic diuretcs
  - loop diuretics
- Excess aldosterone or other mineralocorticoids

Question

- Which of the following would cause the most serious hypokalemia?
  A) A decrease in potassium intake from 150 mEq/day to 60 mEq/day

B) An increase in sodium intake from 100 to 200 mEq/day

C) Excessive aldosterone secretion plus high sodium intake

D) Excessive aldosterone secretion plus low sodium intake

E) A patient with Addison's disease

F) Treatment with a beta-adrenergic blocker

G) Treatment with spironolactone

Compensatory responses to decreased plasma ionized calcium

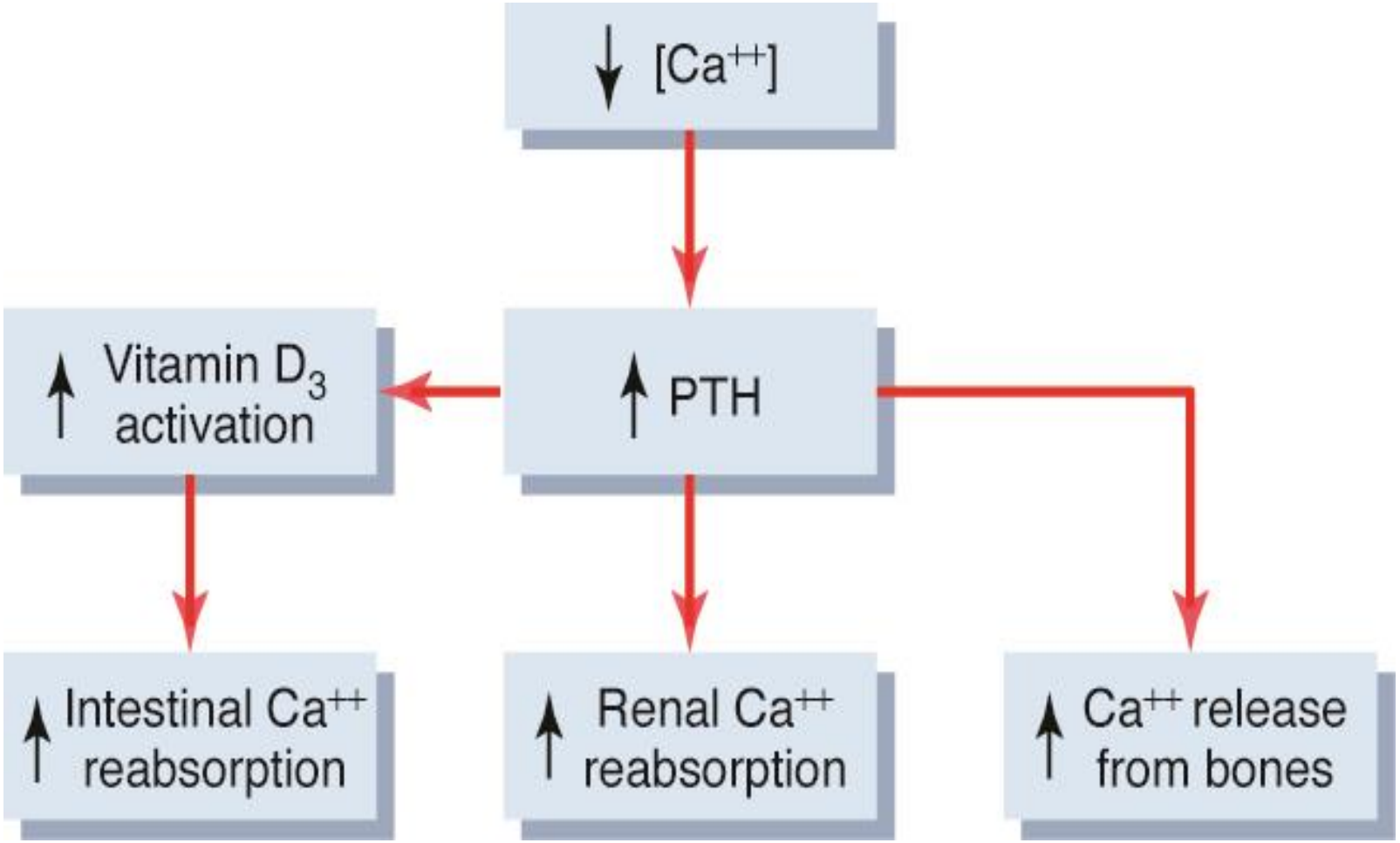


Figure 29-11

Proximal tubular calcium reabsorption

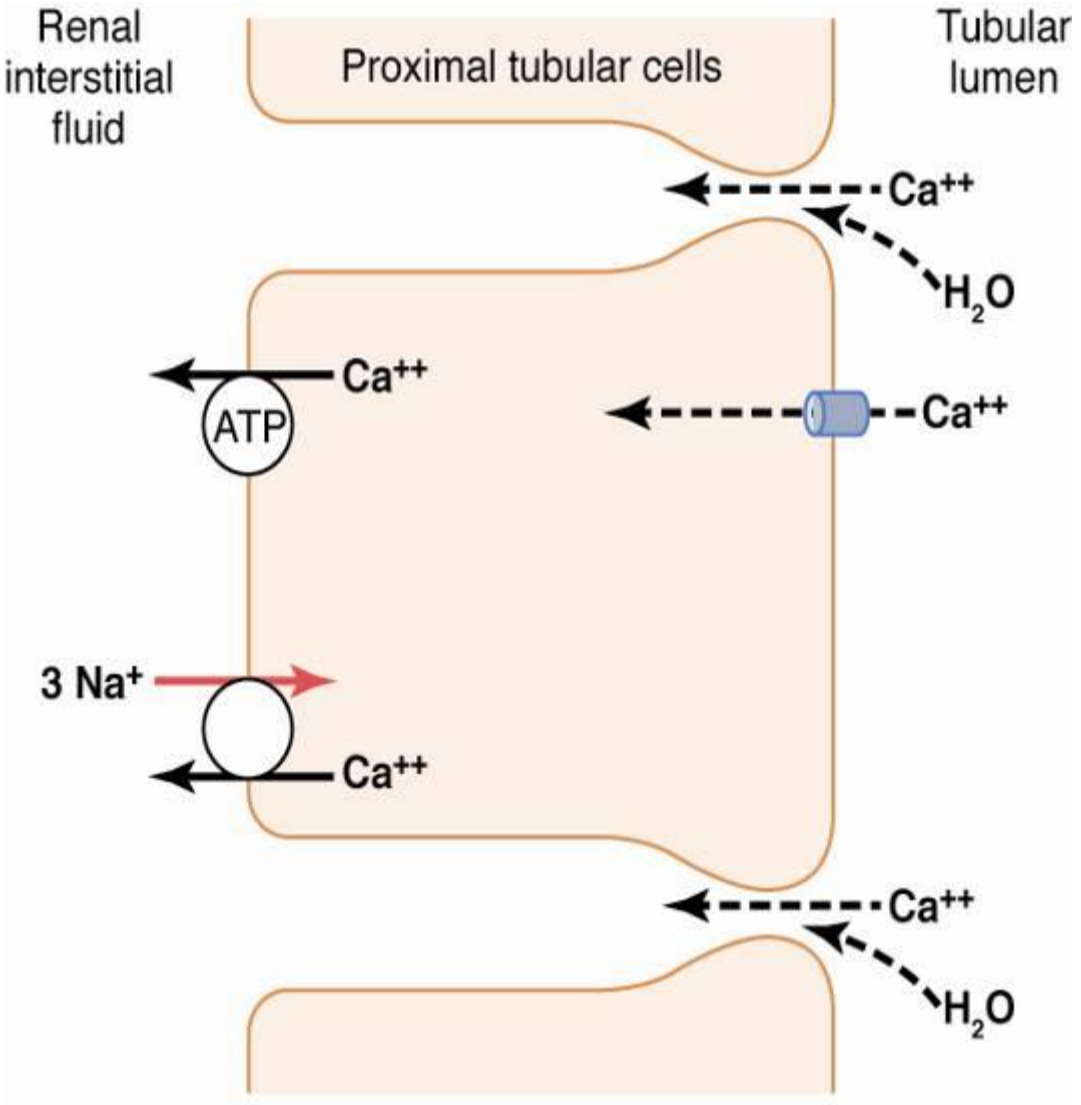


Figure 29-12

Integration of Renal Mechanisms for Regulation of Body Fluids

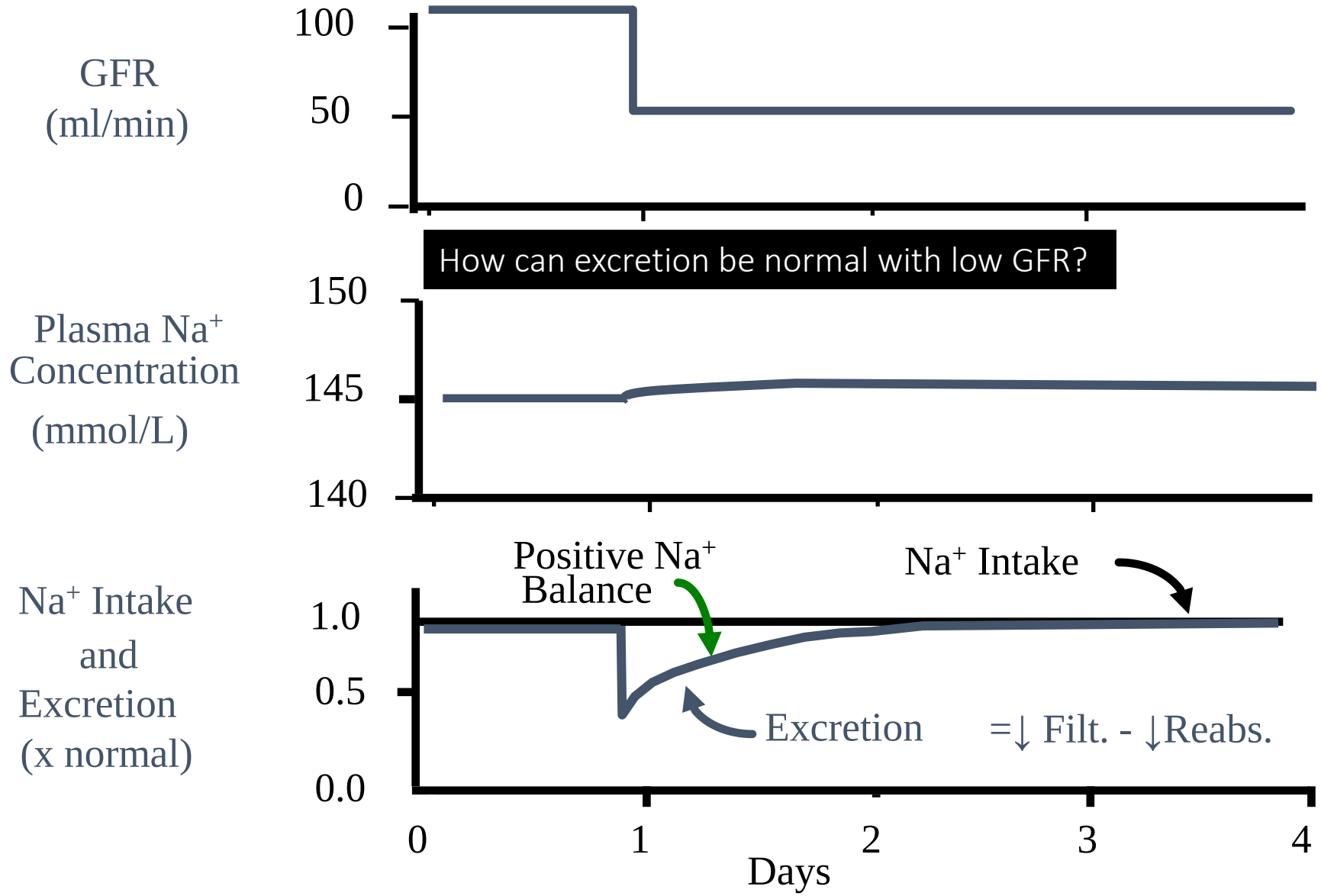
Excretion = Filtration - Reabsorption + Secretion

If there is a steady - state :

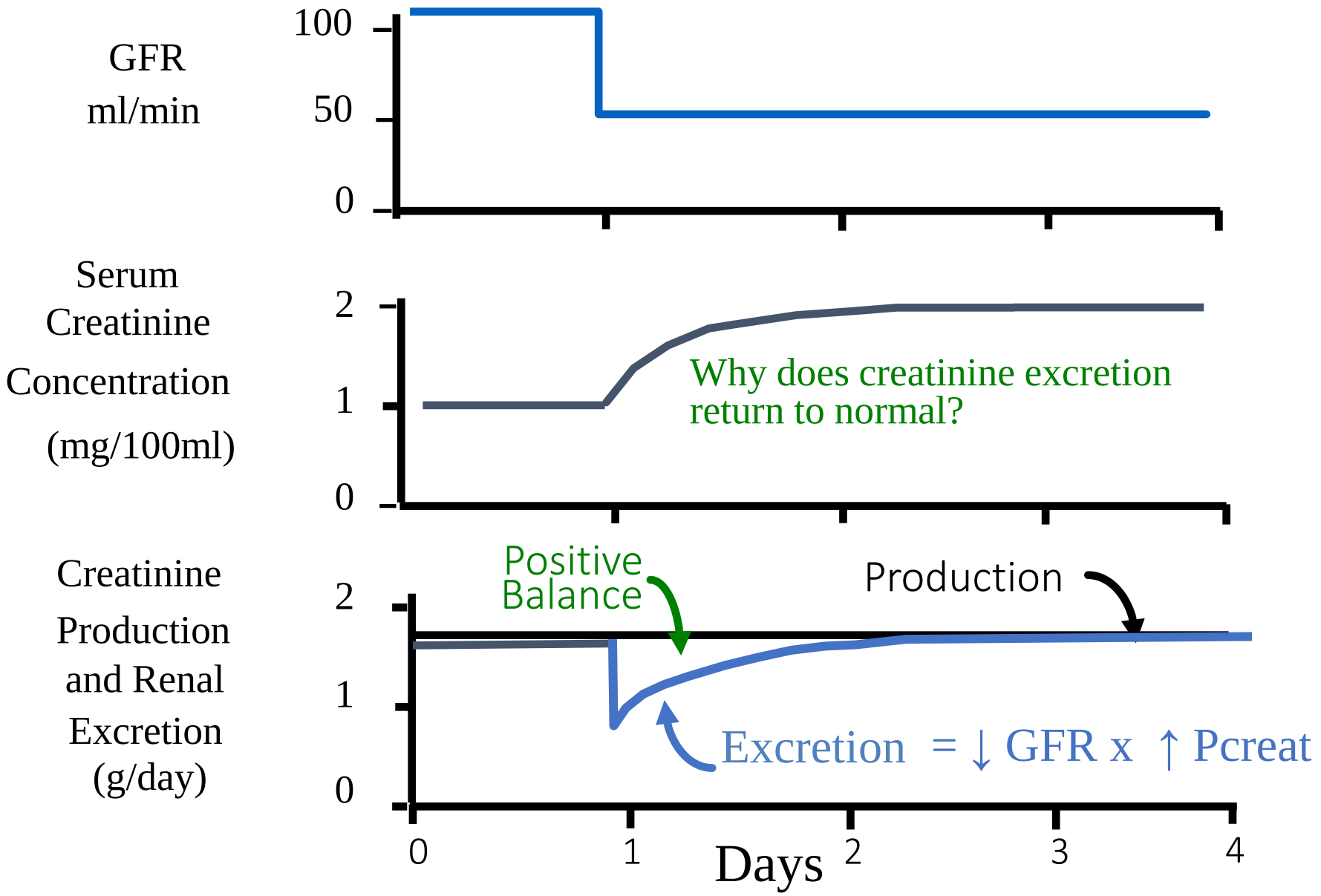
Fluid Excretion = Fluid Intake

Electrolyte Excretion = Electrolyte intake

Effect of Decreased GFR on Sodium



Effect of Decreased GFR on Creatinine



Plasma concentrations of solutes in chronic renal failure

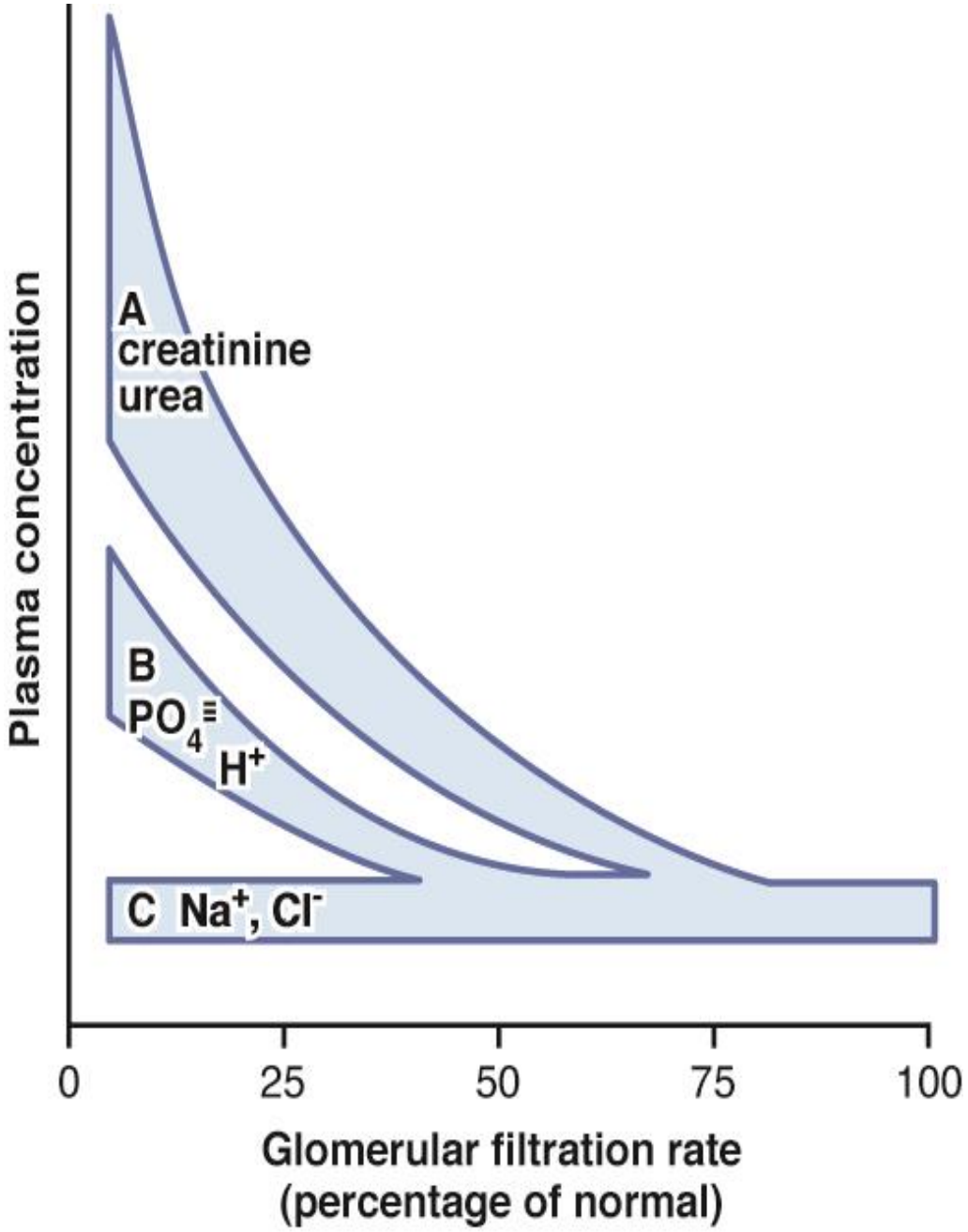
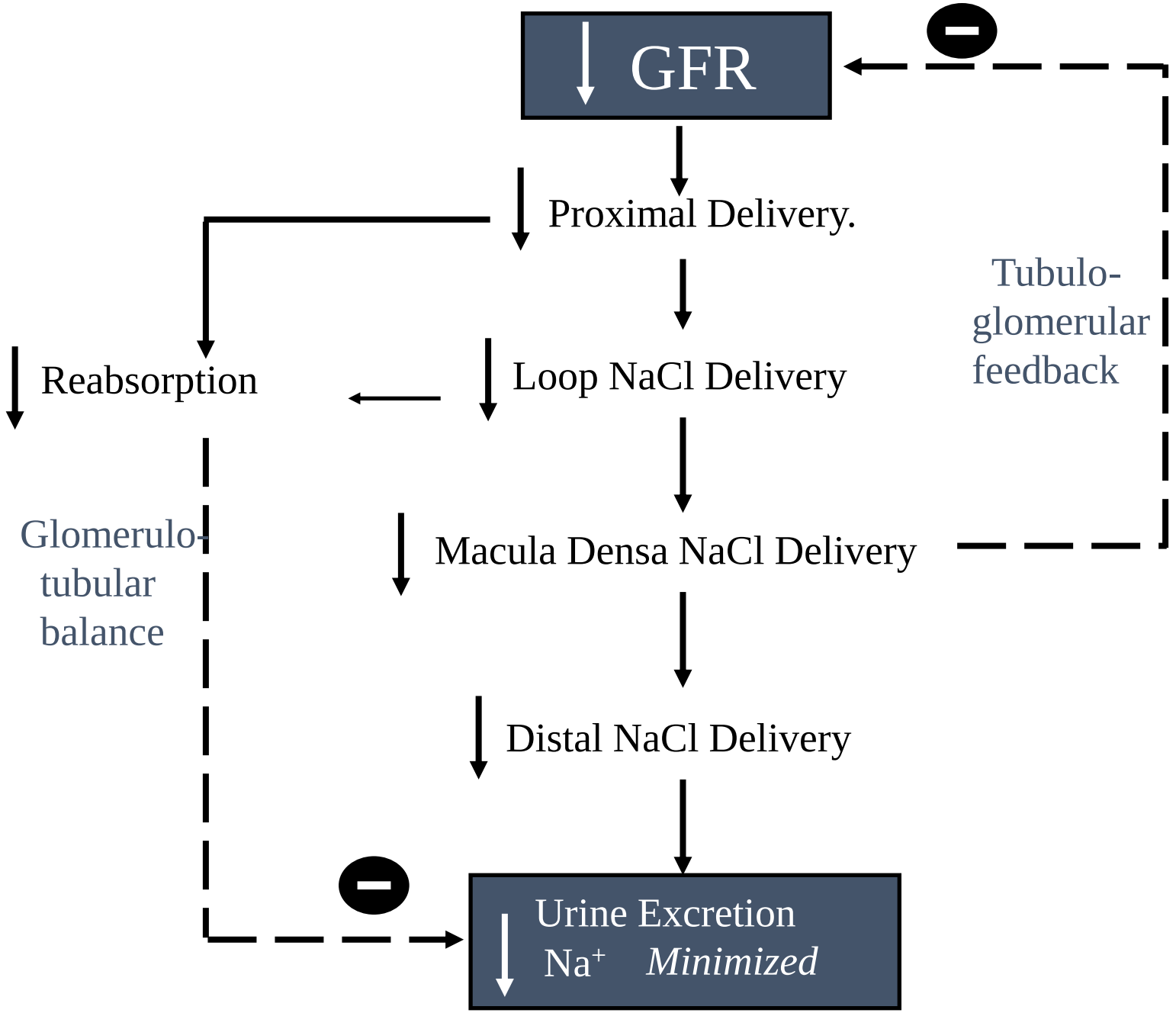


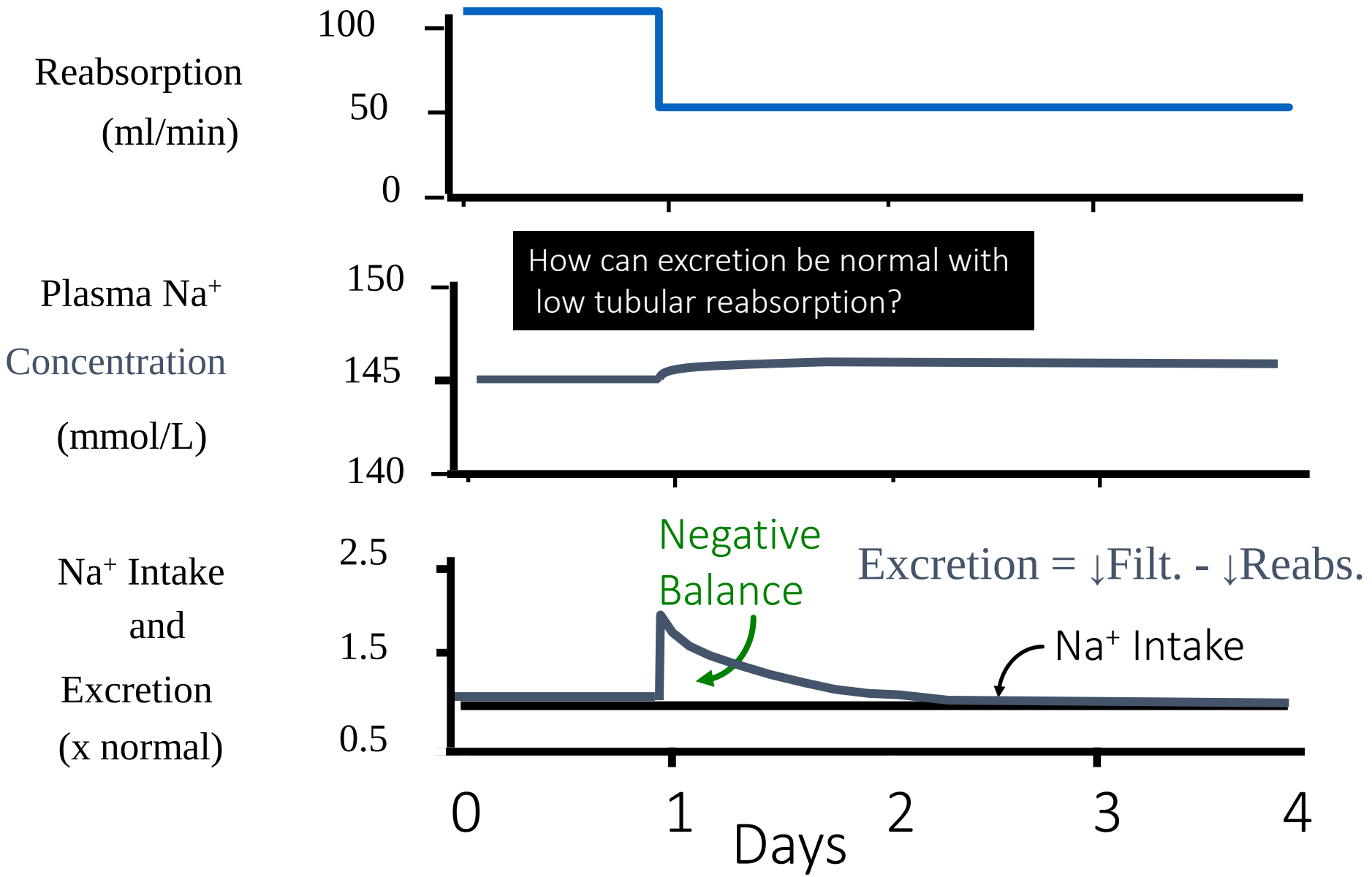
Figure 31-5

Hierarchy of Responses to Disturbances of Body Fluid Regulation

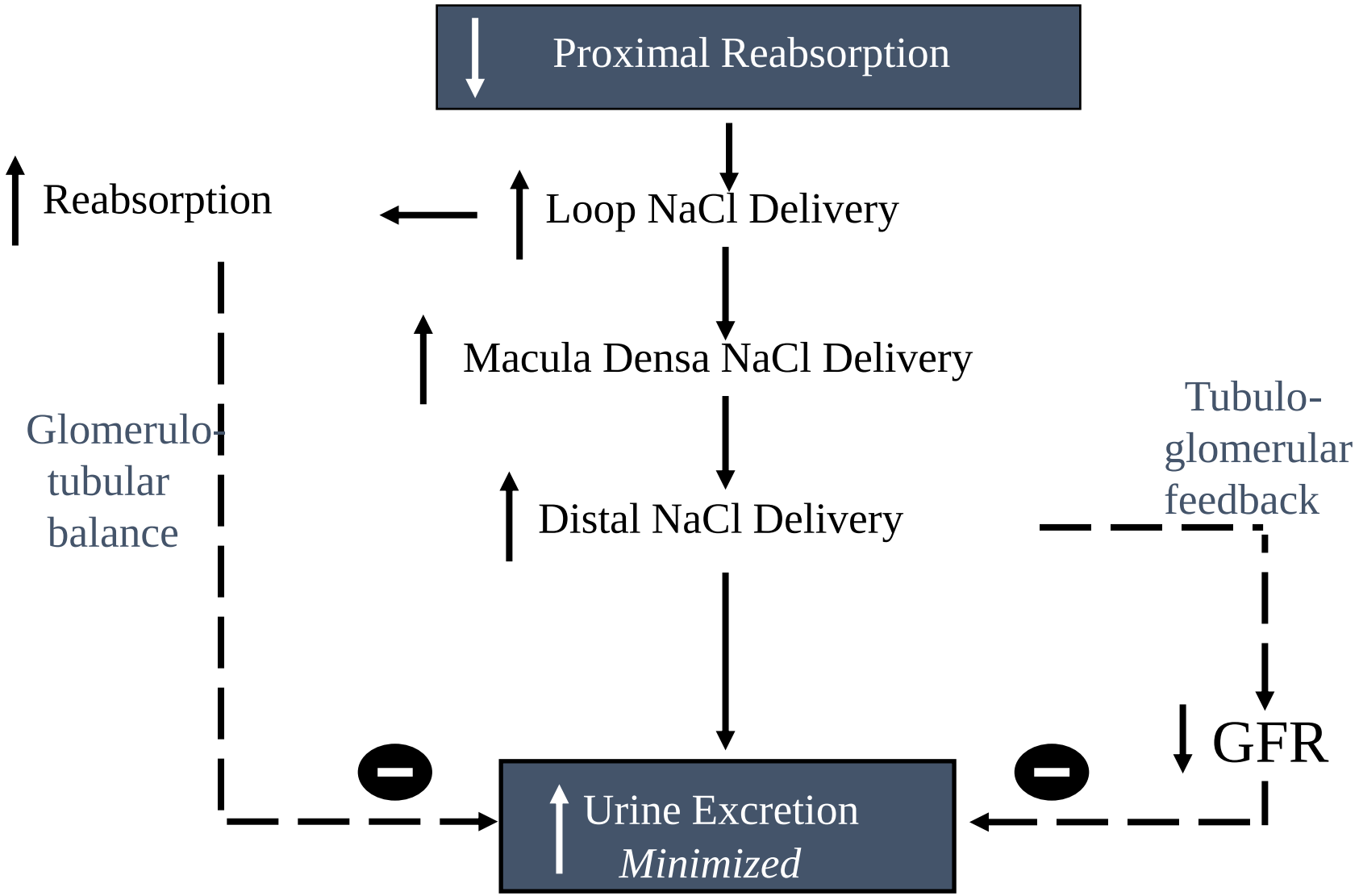
1. Local renal mechanisms
   - changes in GFR
   - changes in tubular reabsorption
   - changes in tubular secretion
2. Systemic mechanisms (which can affect the whole body)
   - changes in hormones
   - changes in sympathetic activity
   - changes in blood pressure
   - changes in blood composition


GFR
Proximal Delivery.
Reabsorption
Loop NaCl Delivery
Tubulo-glomerular feedback
Glomerulo-tubular balance
Macula Densa NaCl Delivery
Distal NaCl Delivery
Urine Excretion
Na+ Minimized

Effect of Decreased Reabsorption on Sodium Balance



Maintenance of Sodium Balance After Decreased Proximal Reabsorption



Hierarchy of Responses to Disturbances of Body Fluid Regulation

In steady-state, Intake = Output

1. Local renal responses
   - changes in GFR
   - changes in tubular reabsorption
   - changes in tubular secretion

2. Systemic mechanisms (which can affect the whole body)
   - changes in hormones
   - changes in sympathetic activity
   - changes in blood pressure
   - changes in blood composition

Sodium excretion and extracellular fluid volume during diuretic administration.

Compensations that Permit Na^+ balance:

- ↓ blood pressure
- ↑ renin, angiotensin II
- ↑ aldosterone

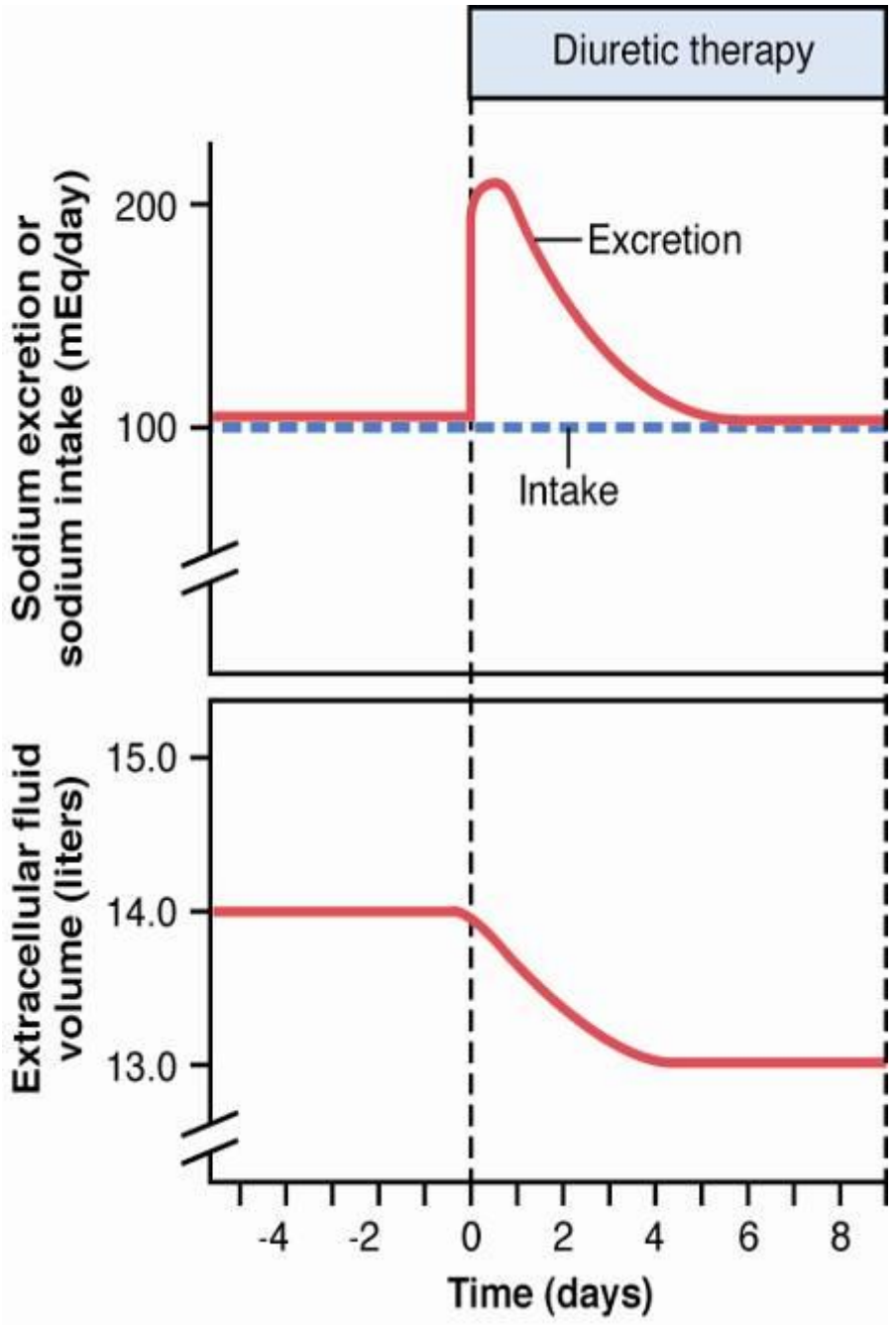
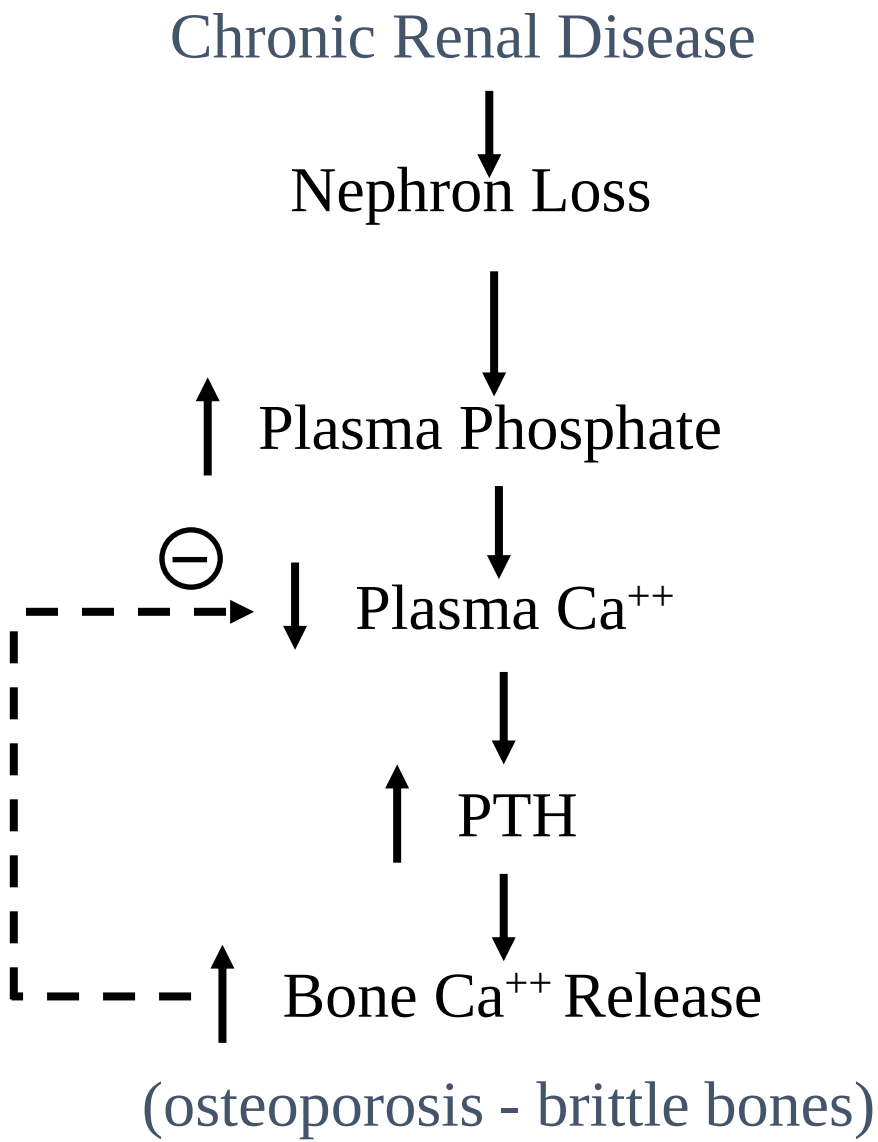


Figure 31-1

Hormonal Response to Chronic Renal Disease - PTH



Hierarchy of Responses to Disturbances of Body Fluid Regulation

In steady-state, Intake = Output

1. Local renal responses
   - changes in GFR
   - changes in tubular reabsorption
   - changes in tubular secretion
2. Systemic mechanisms (which can affect the whole body)
   - changes in hormones
   - changes in sympathetic activity
   - changes in blood pressure
   - changes in blood composition

Renal-Body Fluid Feedback- Increased Fluid (Na^+) Intake

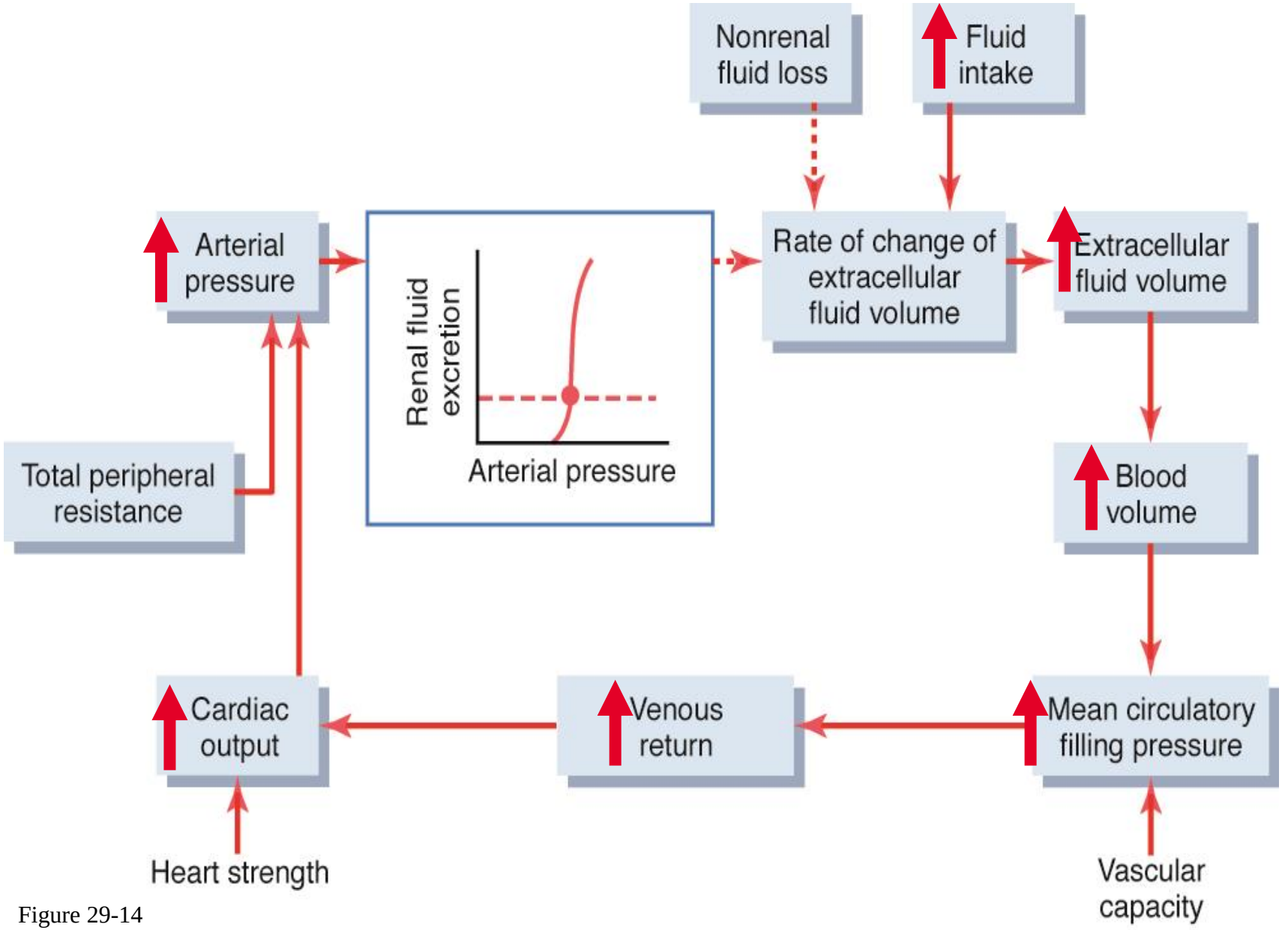


Figure 29-14

Integrated Responses to High Na^+ Intake

Excretion Na^+ = Filtration Na^+ - Reabsorption Na^+

1. Small increase in GFR
2. Decreased Na^+ Reabsorption is caused by:
    - small increase in blood pressure
    - increased peritubular capillary pressure
    - decreased angiotensin II
    - decreased aldosterone
    - Increased natriuretic hormones (e.g. ANP)

Net effect = increased Na^+ excretion