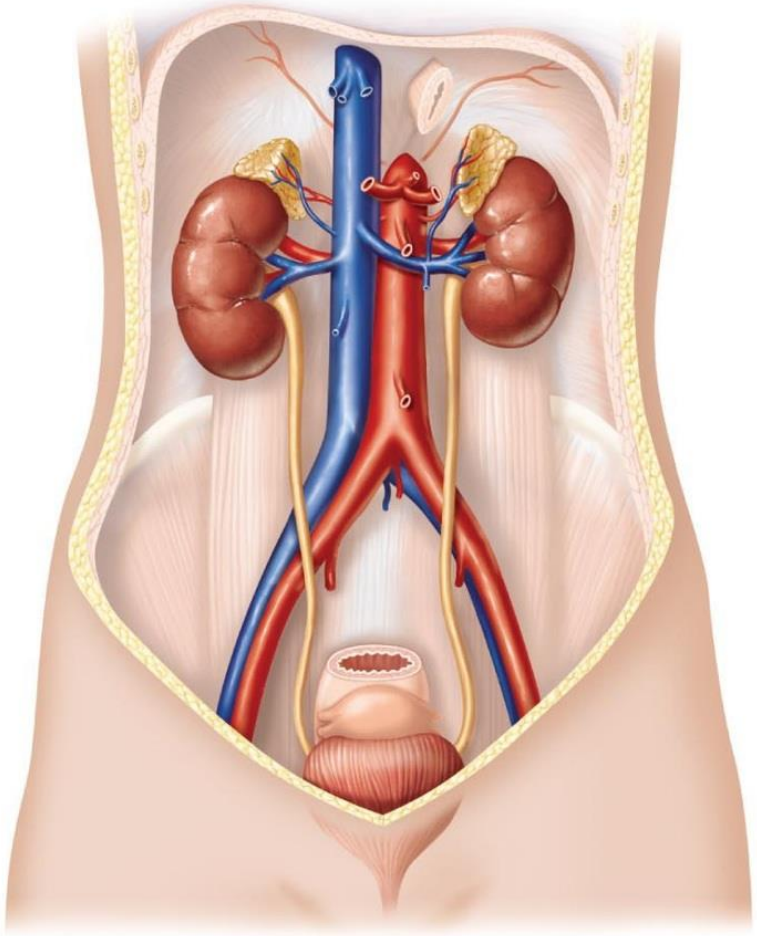
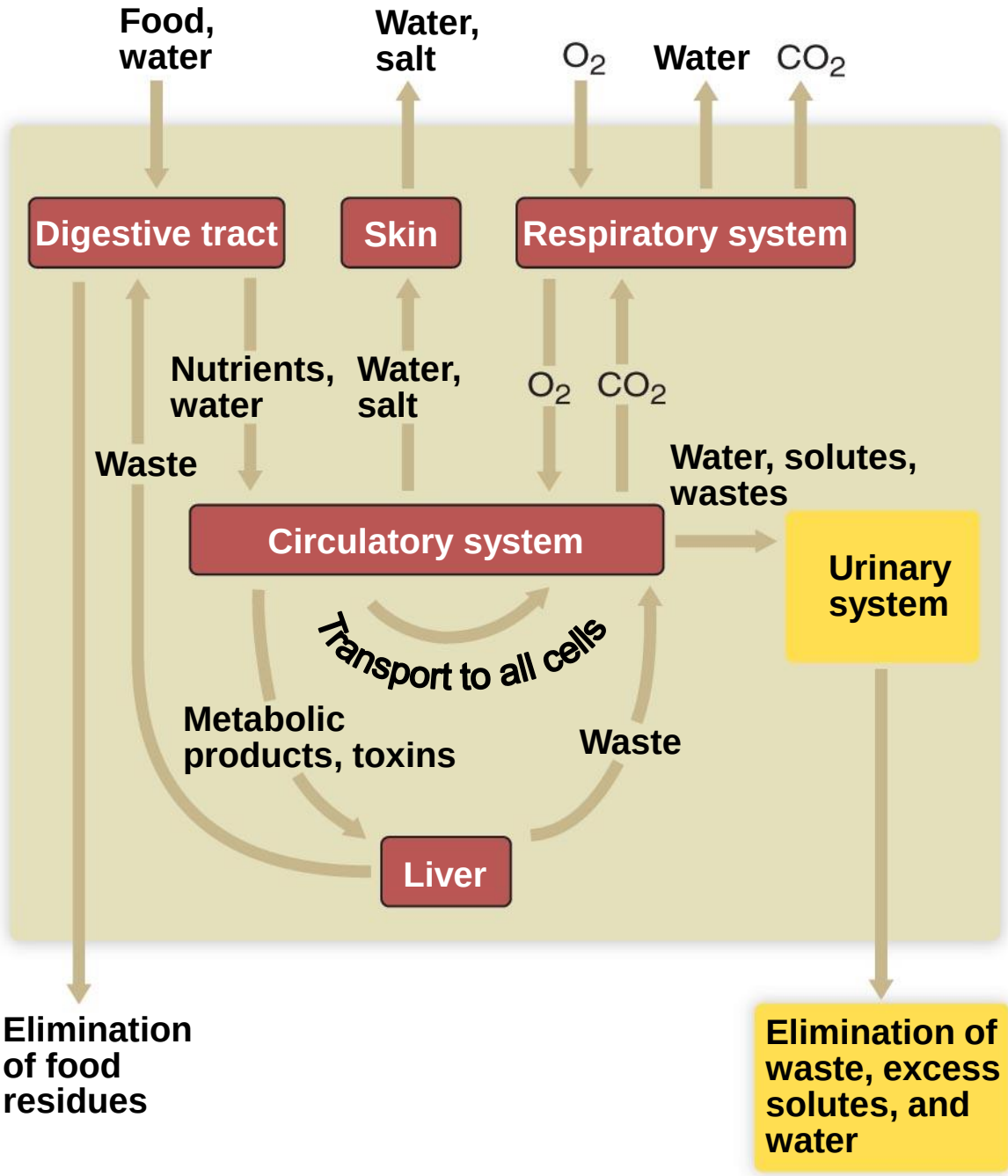
The Urinary System



Urinary System Contributes to Homeostasis

- Excretion: processes that remove wastes and excess materials from the body
  - **Digestive system**: excretes food residues and wastes produced by the liver
  - **Respiratory system (lungs)**: excrete carbon dioxide
  - **Integumentary system (skin)**: excretes water, salt
  - **Urinary system (kidneys)**: excrete nitrogenous wastes, excess solutes, and water


Food, water
Water, salt
O_2
Water
CO_2
Digestive tract
Skin
Respiratory system
Nutrients, water
Water, salt
O_2
CO_2
Waste
Water, solutes, wastes
Circulatory system
Urinary system
Transport to all cells
Metabolic products, toxins
Waste
Liver
Elimination of food residues
Elimination of waste, excess solutes, and water

Urinary System Contributes to Homeostasis

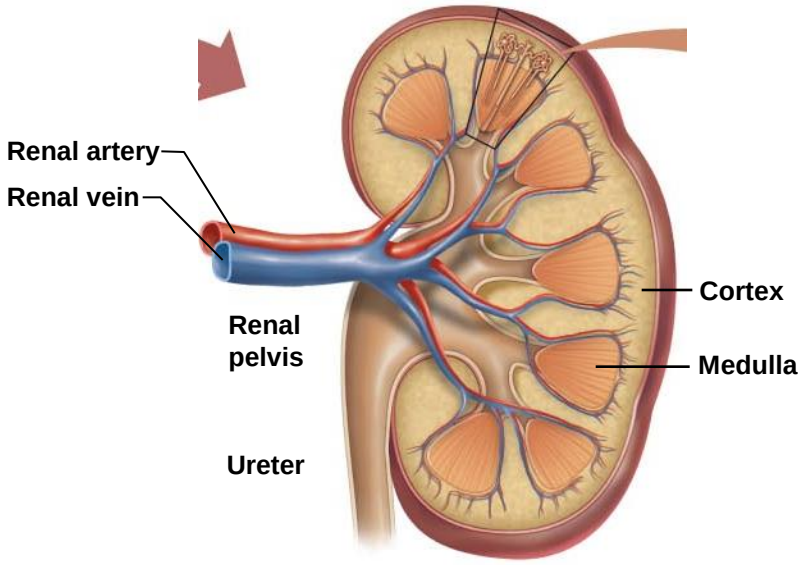
- Kidneys regulate body water levels
  - Excess water is excreted
  - Output varies from 2-1/2 liter/day to 1 liter/hour
- Kidneys regulate nitrogenous wastes and other solutes
  - Nitrogen from amino acids is made into urea in liver and transported to kidney as waste
  - Other solutes regulated by kidneys
    - Sodium, chloride, potassium, calcium, hydrogen ions, creatinine

Table 15.1 Sources of water gain and loss per day

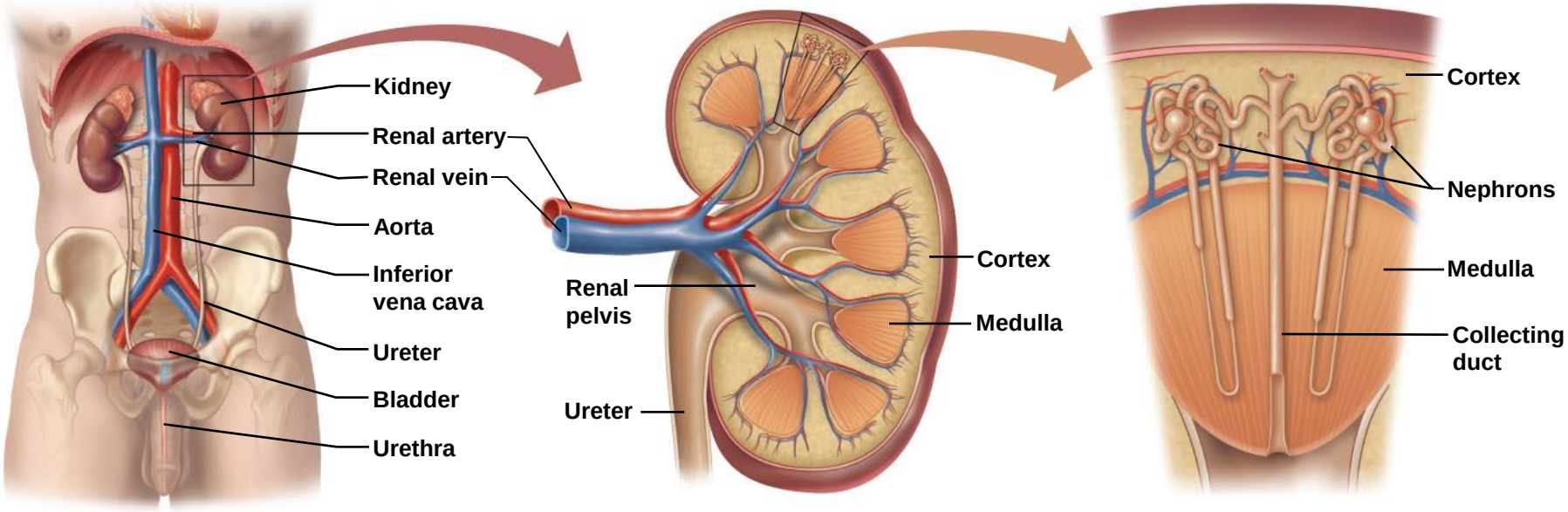
Water gain (ml/day)		Water loss (ml/day)	
Drinking fluids	1,000	Urine	1,500
Water in food	1,200	Evaporative loss (lungs)	500
Metabolic production	300	Evaporative loss (skin)	350
		Feces	150
Total	2,500	Total	2,500

Organs of the Urinary System

- Kidneys
  - Principal organ of urinary system
    - Cortex
      - outer portion of the kidney
    - Medulla
      - inner region of the kidney



b) Internal structure of the kidney.



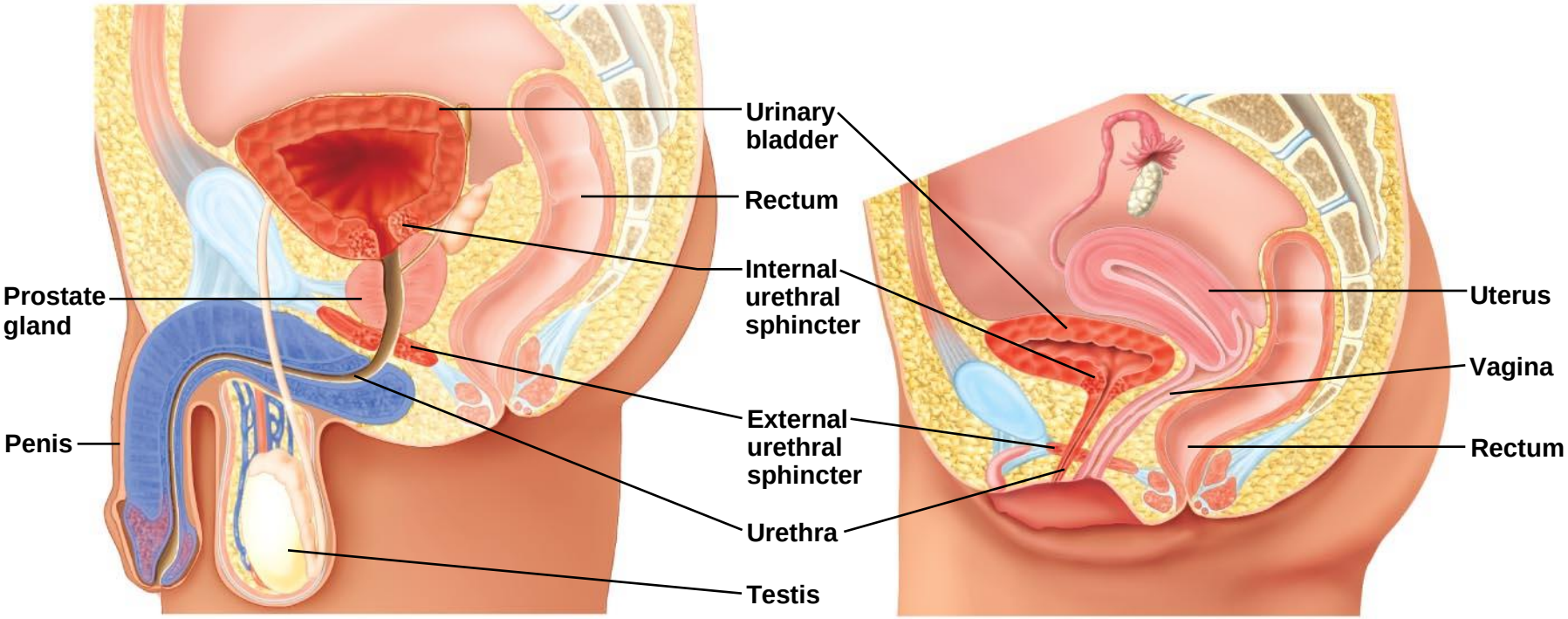
a) The components of the urinary system.

b) Internal structure of the kidney.

c) The cortex and medulla of the kidney are composed of numerous nephrons.

Organs of the Urinary System

- Ureters
  - Transport urine from kidneys to bladder
- Urinary bladder
  - Stores urine (600–1,000 ml)
- Urethra
  - Carries urine from body
  - Two sphincters control urination



a) The male.

b) The female.

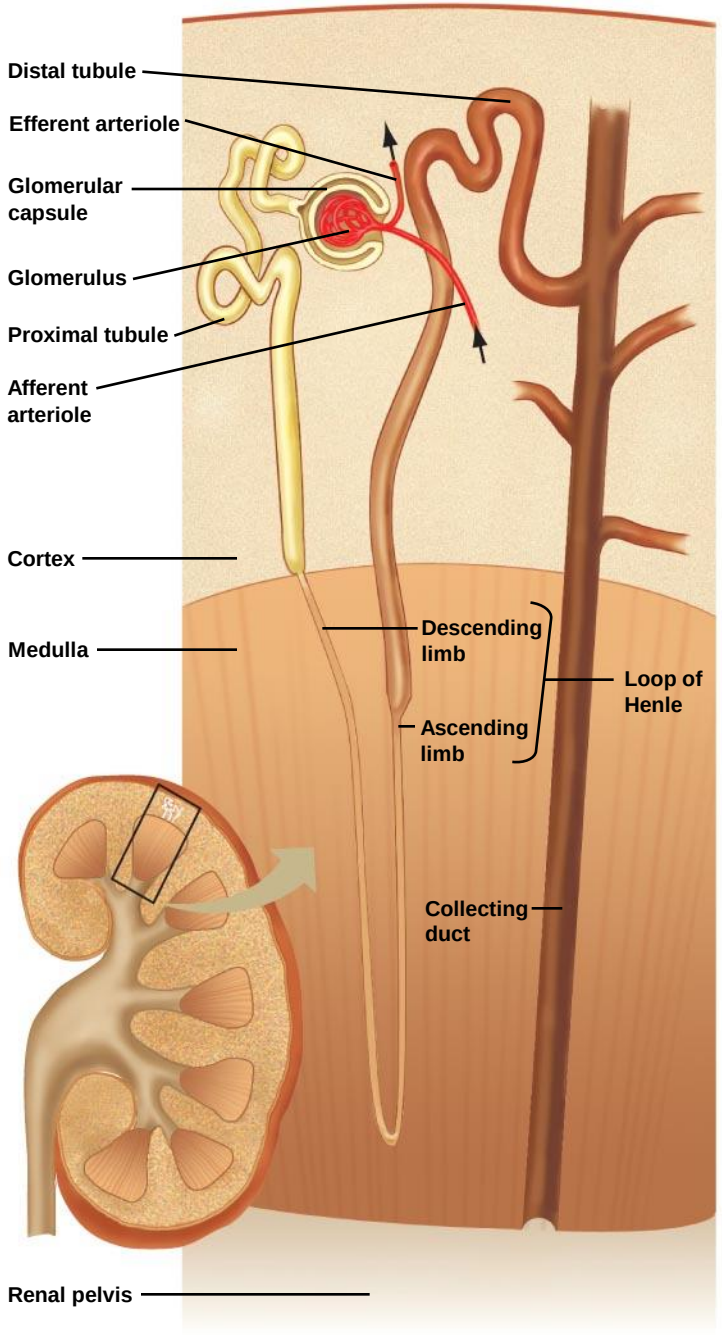
Nephrons Produce Urine

- Nephron: functional unit of the kidney
- ~1 million nephrons per kidney
- Each nephron consists of a long thin hollow tube (tubule) plus associated blood supply
- Role of nephrons
  - remove approximately 180 liters of fluid from the blood daily
  - return most of the fluid, minus the wastes that are excreted

Tubule Filters Fluid and Reabsorbs Substances

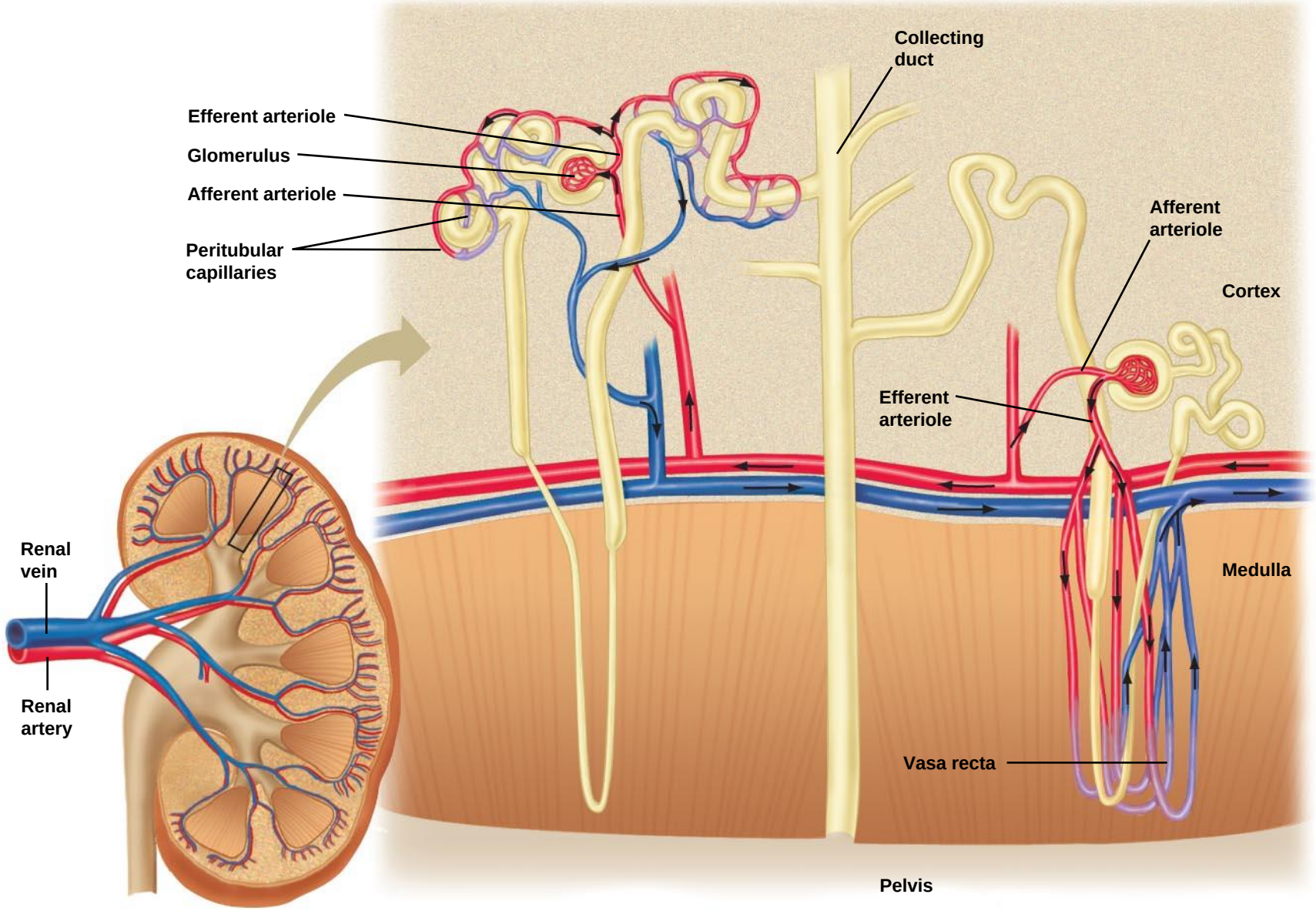
Nephron structure

- **Glomerular capsule**
  - cuplike end of nephron tubule surrounding glomerulus (network of capillaries)
  - This is where filtration occurs
- **Proximal tubule**
  - extends from glomerular capsule to renal medulla
- **Loop of Henle**
- **Distal tubule**
- **Collecting duct**
  - shared by several nephrons, empties into renal pelvis


Distal tubule
Efferent arteriole
Glomerular capsule
Glomerulus
Proximal tubule
Afferent arteriole
Cortex
Medulla
Descending limb
Loop of Henle
Ascending limb
Collecting duct
Renal pelvis

Special Blood Vessels Supply the Tubule

- Renal artery supplies the kidney
  - Arterioles
    - **Afferent**: enters the glomerular capsule
    - **Efferent**: leaves the glomerular capsule
  - Capillaries
    - **Glomerular**: network within the glomerular capsule
    - **Peritubular**: surround proximal and distal tubule
    - **Vasa recta**: parallels the loop of Henle

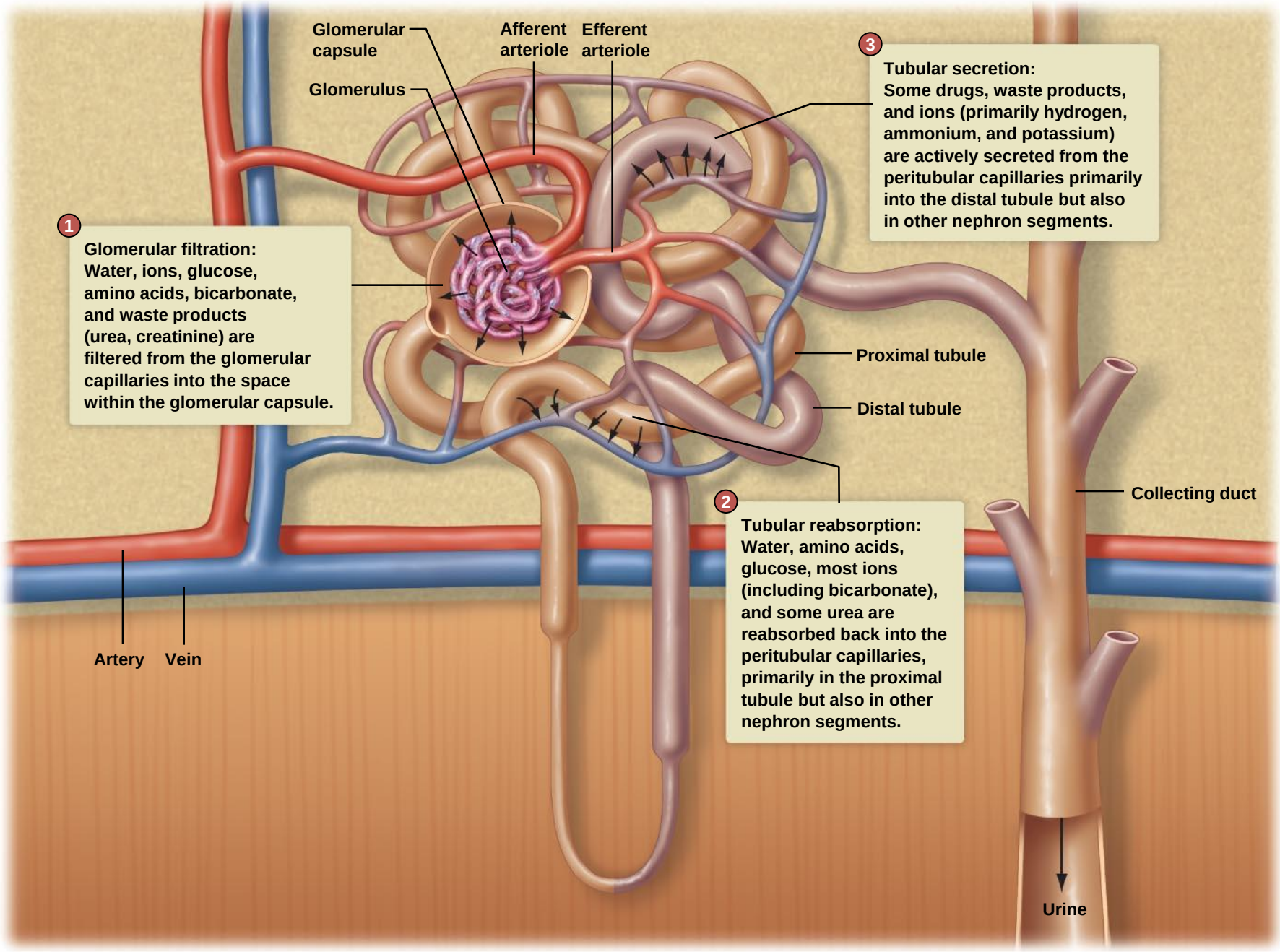


a) Main blood vessels in the kidney. The renal artery and renal vein branch many times to deliver blood to each glomerulus.

b) Post-glomerular blood vessels. The efferent arteriole of most nephrons, such as the one shown here on the left, divides to become the peritubular capillaries, which supply proximal and distal tubules in the cortex. In a few nephrons, such as the one on the right, the efferent arteriole descends into the medulla to become the vasa recta, which supply loops of Henle.

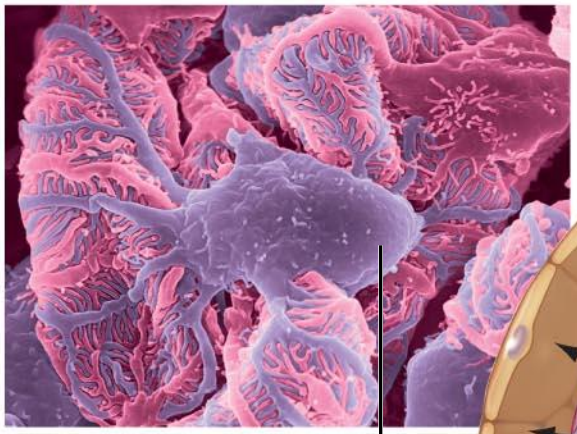
Formation of Urine: Three Basic Processes

- **Glomerular filtration**
  - movement of protein-free solution of fluid and solutes from blood into the glomerular capsule
- **Tubular reabsorption**
  - return of most of the fluid and solutes into the blood
- **Tubular secretion**
  - addition of certain solutes from the blood into the tubule


Glomerular capsule
Afferent arteriole
Efferent arteriole
Glomerulus
3
Tubular secretion:
Some drugs, waste products, and ions (primarily hydrogen, ammonium, and potassium) are actively secreted from the peritubular capillaries primarily into the distal tubule but also in other nephron segments.
1
Glomerular filtration:
Water, ions, glucose, amino acids, bicarbonate, and waste products (urea, creatinine) are filtered from the glomerular capillaries into the space within the glomerular capsule.
Proximal tubule
Distal tubule
Collecting duct
2
Tubular reabsorption:
Water, amino acids, glucose, most ions (including bicarbonate), and some urea are reabsorbed back into the peritubular capillaries, primarily in the proximal tubule but also in other nephron segments.
Artery
Vein
Urine

Glomerular Filtration Filters Fluid from Capillaries

- Filters protein-free plasma fluid from capillaries into glomerular capsule
- Large volume filtration, yet highly selective
  - Impermeable to large proteins and cells
- Filtration is driven by high blood pressure in glomerular capillaries
- Rate of filtration
  - Resting rate under local chemical control



a) The outer surface of several glomerular capillaries.

Podocyte

Glomerular capsule

Glomerular space

Glomerulus

Blood flow

Movement of glomerular filtrate

Afferent arteriole

Efferent arteriole

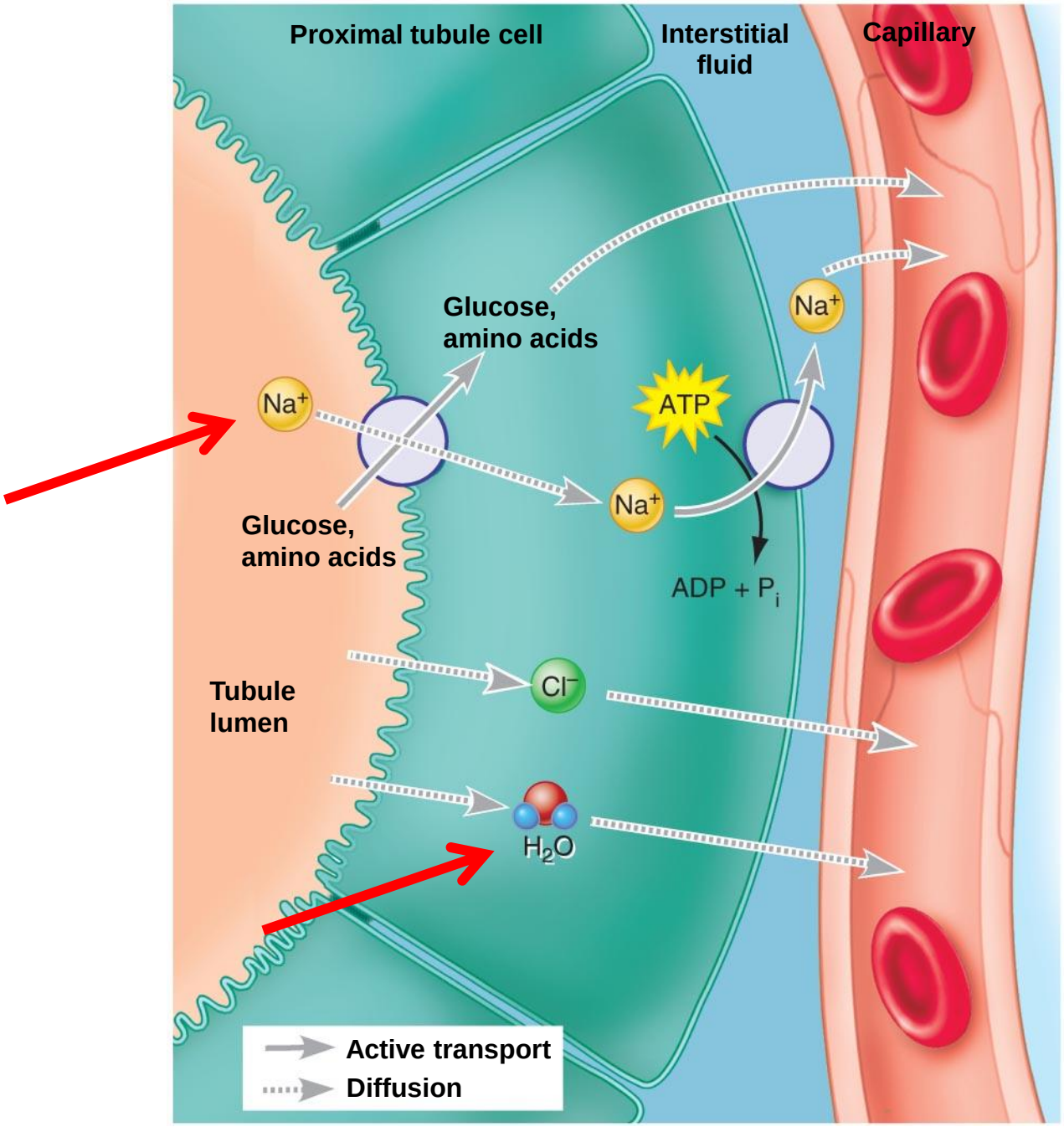
Filtrate

Proximal tubule

Capillary wall

Tubular Reabsorption Returns Filtered Water and Solutes to Blood

- 100% of filtered glucose, amino acids, and bicarbonate and 50% of urea are reabsorbed
- Most tubular reabsorption occurs in proximal tubule
- Reabsorption of sodium begins the process
  - Sodium moved by active transport from tubule cells to interstitial fluid and diffuses to capillaries
  - Movement of sodium provides energy to transport glucose and amino acids into renal tubule
  - Water reabsorbed with salts

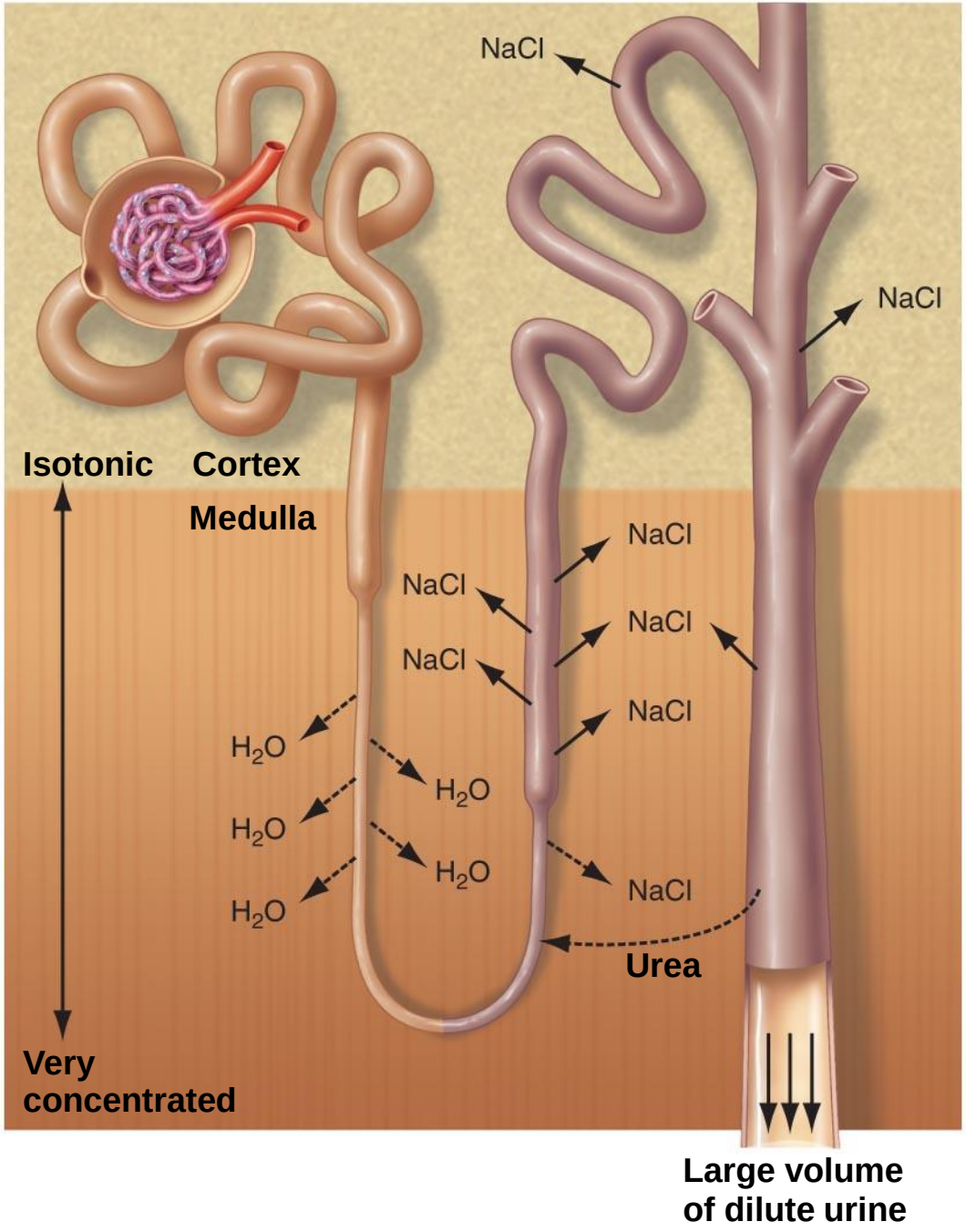

Proximal tubule cell
Interstitial fluid
Capillary
Glucose, amino acids
Na+
ATP
Na+
Na+
Glucose, amino acids
ADP + Pi
Tubule lumen
Cl−
H2O
Active transport
Diffusion

Tubular Secretion Removes Other Substances from Blood

- Involves the movement of materials from the peritubular capillaries or vasa recta to the tubule
- Purpose
  - Regulation of chemical levels in body
  - Excretion of harmful chemicals
- Substances secreted
  - Penicillin, cocaine, marijuana, pesticides, preservatives, hydrogen ions, ammonium, potassium

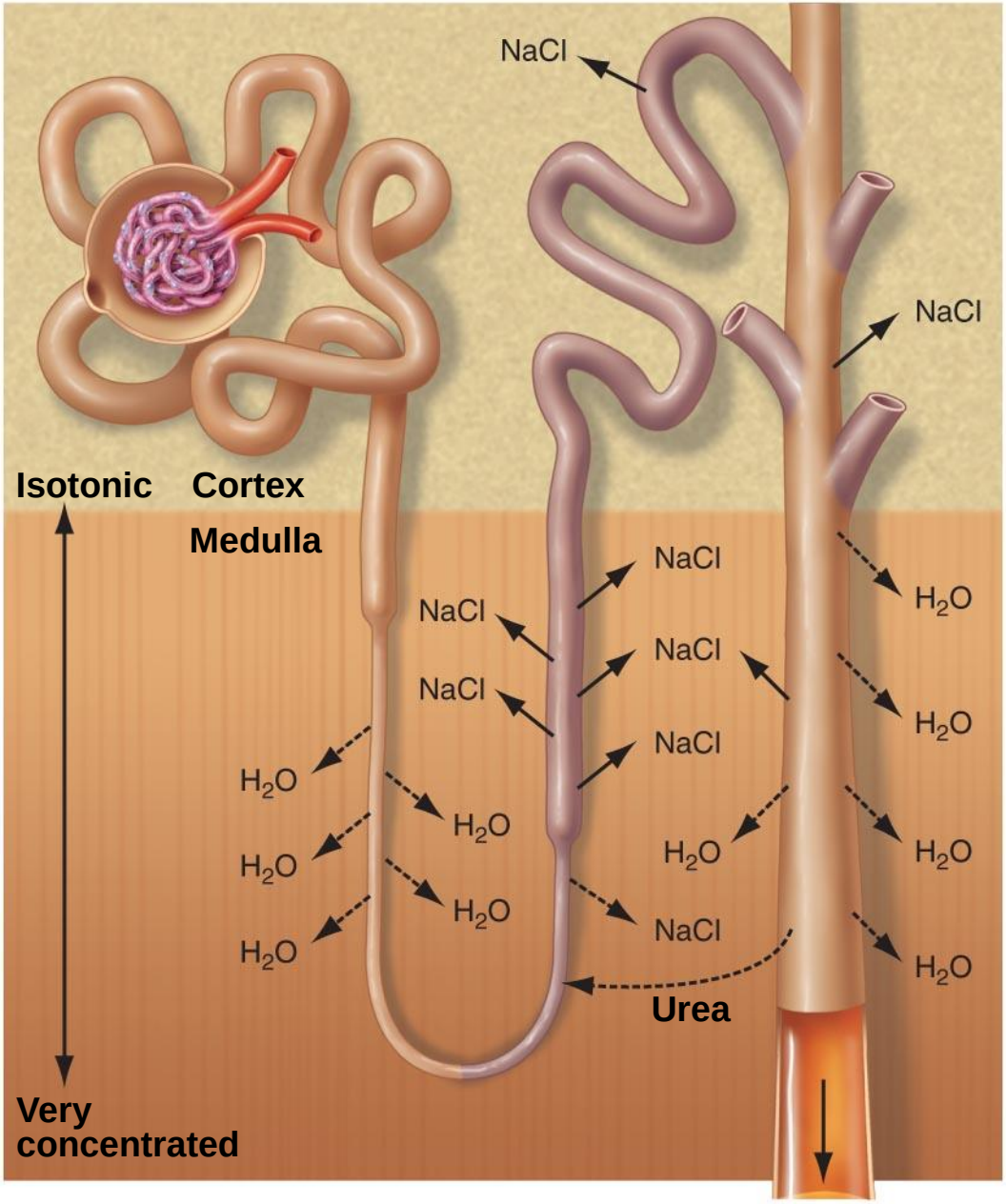
Producing Dilute Urine: Excreting Excess Water

- Kidneys respond to excess water by excreting it
- Mechanism
  - Distal tubule is impermeable to water
  - NaCl is reabsorbed without the concurrent reabsorption of water


NaCl
NaCl
Isotonic
Cortex
Medulla
NaCl
NaCl
NaCl
NaCl
H_2O
H_2O
H_2O
H_2O
H_2O
NaCl
Urea
Very concentrated
Large volume of dilute urine

Producing Concentrated Urine: Conserving Water

- Too little water can lead to lower blood volume, declining blood pressure, risk of dehydration of body cells
- Kidneys respond by conserving water and producing a more concentrated urine
- Mechanism
  - Mediated by ADH (antidiuretic hormone) from the posterior pituitary gland
  - ADH increases permeability of the collecting ducts to water and increases conservation of water


NaCl
NaCl
Isotonic
Cortex
Medulla
NaCl
NaCl
NaCl
NaCl
H_2O
H_2O
H_2O
H_2O
H_2O
H_2O
H_2O
H_2O
H_2O
NaCl
Urea
Very concentrated
Low volume of concentrated urine

Urination Depends on a Reflex

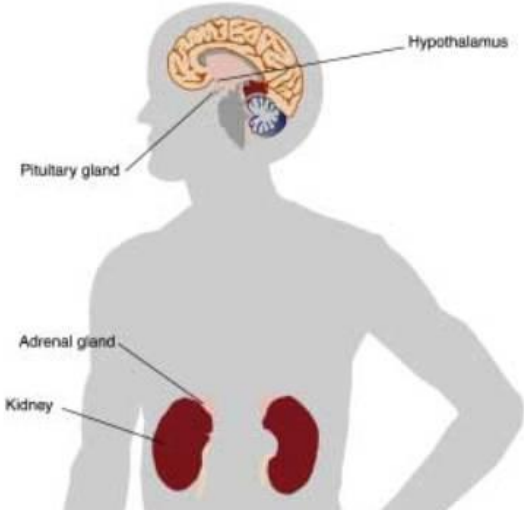
- Micturition reflex
  - Responds to stretch receptors in bladder wall
  - Internal urethral sphincter
    - Smooth muscle
  - External urethral sphincter
    - Skeletal muscle, under voluntary control
- Brain can override the micturition reflex and control the timing of urination
- Voluntary control becomes increasingly difficult as the bladder gets very full

Kidneys Maintain Homeostasis in Many Ways

- Maintain water balance
  - Adjust blood volume and blood pressure
- Aldosterone and renin help maintain salt balance in order to control blood volume
- Maintain acid-base balance and blood pH
- Regulate red blood cell production via erythropoietin (hormone)
- Activate an inactive form of vitamin D

Water Balance Determines Blood Volume and Blood Pressure

- Involves the kidneys, hypothalamus, and posterior pituitary gland



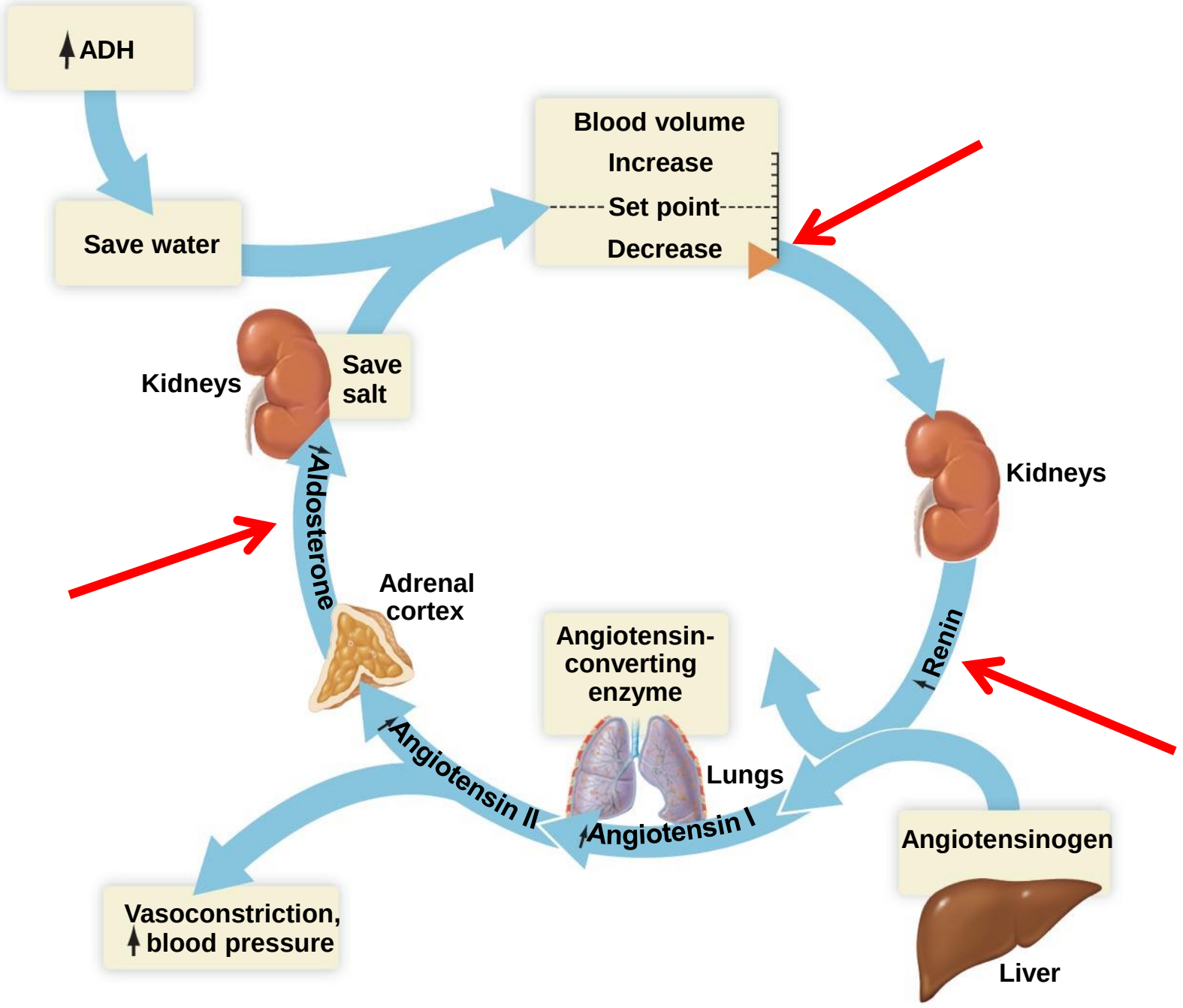
- Negative feedback loop regulates solute concentration of the blood
  - Involves increasing or reducing ADH secretion, which will modify water reabsorption of kidneys
  - Involves increasing or decreasing thirst

Water Balance Determines Blood Volume and Blood Pressure

- **Diruretic**: increases the formation and excretion of urine
  - Lasix (furosemide)
    - medication that reduces blood volume and blood pressure
  - Caffeine
    - inhibits sodium reabsorption
  - Alcohol
    - inhibits ADH release

Aldosterone & Renin Control Blood Volume

- Aldosterone release is stimulated indirectly by decreased blood volume or blood pressure
  - Decreased blood volume/blood pressure cause release of renin
  - Renin is eventually converted to angiotensin II
  - Angiotensin II stimulates adrenal cortex to release aldosterone
  - Aldosterone increases sodium reabsorption by distal tubules and collection ducts


ADH
Save water
Blood volume
Increase
Set point
Decrease
Kidneys
Save salt
Aldosterone
Adrenal cortex
Angiotensin-converting enzyme
Lungs
Angiotensin II
Angiotensin I
Renin
Kidneys
Angiotensinogen
Liver
Vasoconstriction, blood pressure

Kidneys Help Maintain Acid-Base Balance and Blood pH

- Blood pH must stay between 7.35 and 7.45
- pH regulated by kidneys, buffers, lungs
- Role of kidneys in pH maintenance
  - Reabsorption of filtered bicarbonate
  - Excretion of acid

Erythropoietin Stimulates Production of Red Blood Cells

- Decrease in amount of oxygen is detected by certain cells throughout the kidney
- Erythropoietin is secreted in response to decrease in oxygen
- Erythropoietin triggers increase in red blood cell production in the bone marrow

Kidneys Activate Vitamin D

- Exposure of skin to sunlight causes production of an inactive form of vitamin D
  - But only about 30 minutes of exposure
- Inactive form of vitamin D is transported to liver, where it is modified
- Inactive form of vitamin D is then converted to active form by kidneys

Disorders of the Urinary System

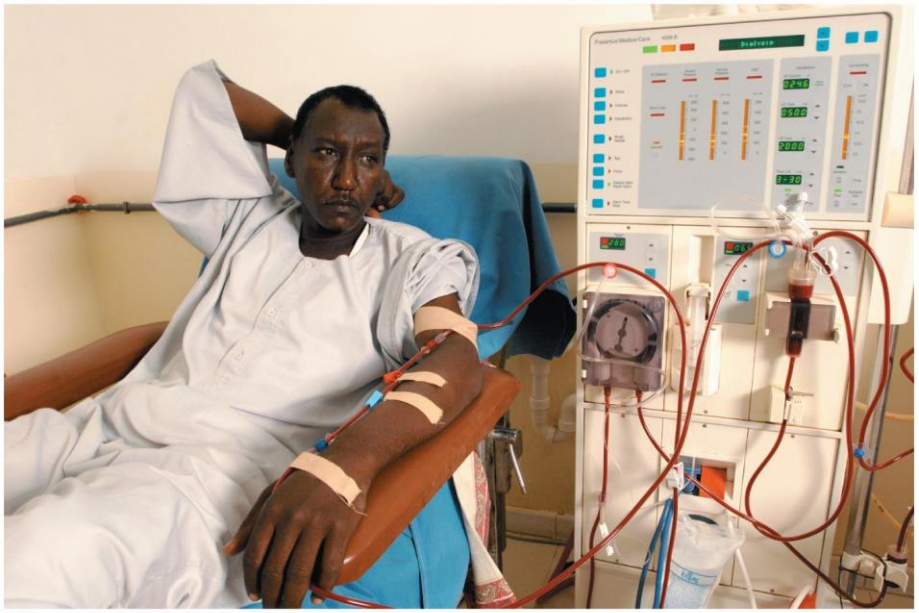
- Kidney stones
  - Crystallized minerals
  - Block urine flow
- Urinary tract infections (UTI)
  - Usually caused by bacteria
  - More common in women than men because of shorter urethra
  - If untreated, bladder infections may ascend to involve kidneys

Disorders of the Urinary System

- Acute renal failure
  - Short-term impairment, may be reversible
  - Potential causes: sustained very low blood pressure, large kidney stones within renal pelvis, infections, transfusion reactions, severe injury, toxin exposure, drug reactions
- Chronic renal failure
  - Also known as end stage renal disease (ESRD)
  - >60% reduction in functioning nephrons
  - See causes of acute renal failure above
  - 40% of people with Type I diabetes will develop renal failure

Treatment of Irreversible Kidney Failure

- Dialysis



- Kidney transplant

Dialysis Cleanses Blood Artificially

- CAPD: continuous ambulatory peritoneal dialysis
  - Can be done at home
  - Uses peritoneal cavity for waste, ion removal
  - Risk of infection
- Hemodialysis
  - Requires several visits/week to a dialysis center
  - Blood is circulated through a kidney machine

Dialysis Cleanses Blood Artificially

- Problems with dialysis
  - Dialysis cannot achieve complete homeostasis of ions and wastes
  - Dialysis does not replace renal hormones

Kidney Transplants Are a Permanent Solution to Renal Failure

- Best hope for many chronic renal failure patients
- >65,000 people on waiting list for kidneys
- Improvements in transplant protocols/processes have improved outcomes
  - Better tissue-matching techniques
  - Improved anti-rejection medications
  - National data banks