Chapter 26

Fluid, Electrolyte, and Acid Base Balance

Bi 233

Body Water Content

- Largest component of the body
  - Infants have low body fat, low bone mass, and are 73% or more water
  - Healthy males are about 60% water; healthy females are around 50%
  - This difference reflects females':
    - Higher body fat
    - Smaller amount of skeletal muscle
  - Total water content declines throughout life
    - In old age, only about 45% of body weight is water

Fluid Compartments

- Water occupies two (or three) main fluid compartments
  - Intracellular fluid (ICF) – about two thirds by volume, contained in cells
    - ~25 L
  - Extracellular fluid (ECF) – consists of two major subdivisions
    - ~15 L
    - Interstitial fluid (IF) – fluid in spaces between cells
      - 80% of ECF ~10-12 L
    - Plasma – the fluid portion of the blood
      - 20% of ECF ~3-5 L

Fluid Compartments

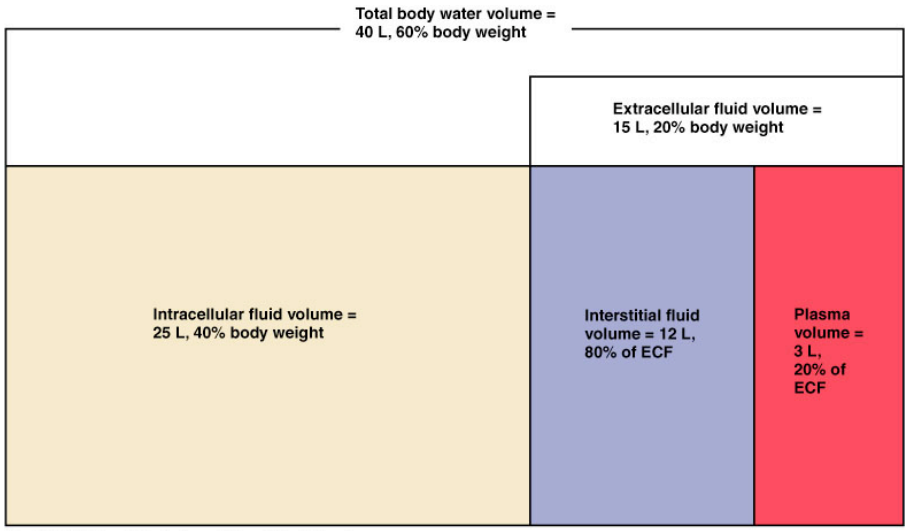


Figure 26.1

Composition of Body Fluids

- Water is the universal solvent
- Solutes are broadly classified into:
  - Electrolytes – ionic (cations or anions)
    - Inorganic salts, all acids and bases, and some proteins
    - Yield two or more solute particles when dissolved in solution
      - $NaCl \Rightarrow Na^{+} + Cl^{-}$
      - $CaCl_2 \Rightarrow Ca^{++} + 2Cl^{-}$
  - Nonelectrolytes – covalent
    - Glucose, lipids, creatinine, and urea
- Electrolytes have greater osmotic power than nonelectrolytes
- Water moves according to osmotic gradients

Extracellular and Intracellular Fluids

- Each fluid compartment of the body has a distinctive pattern of electrolytes
- Extracellular fluids are similar (except for the high protein content of plasma)
  - Na^{+} primary cation
    - Also Ca^{2+}
  - Cl^{-} primary anion
    - Also HCO_3^{-}
    - Plasma has many more protein and sodium anions but fewer chloride ions than interstitial fluid
    - More proteins in intracellular than extracellular fluid

Extracellular and Intracellular Fluids

- Intracellular fluids have low sodium and chloride
  - Potassium primary cation
    - Also magnesium Mg^{2+}
  - Phosphate primary anion
    - Also hydrogen phosphate
      - HPO_4^-
- Sodium and potassium concentrations in extra- and intracellular fluids are nearly opposites
  - Due to cellular ATP-dependent sodium-potassium pumps

Extracellular and Intracellular Fluids

- Proteins, phospholipids, cholesterol, and neutral fats account for:
  - 90% of the mass of solutes in plasma
  - 60% of the mass of solutes in interstitial fluid
  - 97% of the mass of solutes in the intracellular compartment

Electrolyte Composition of Body Fluids

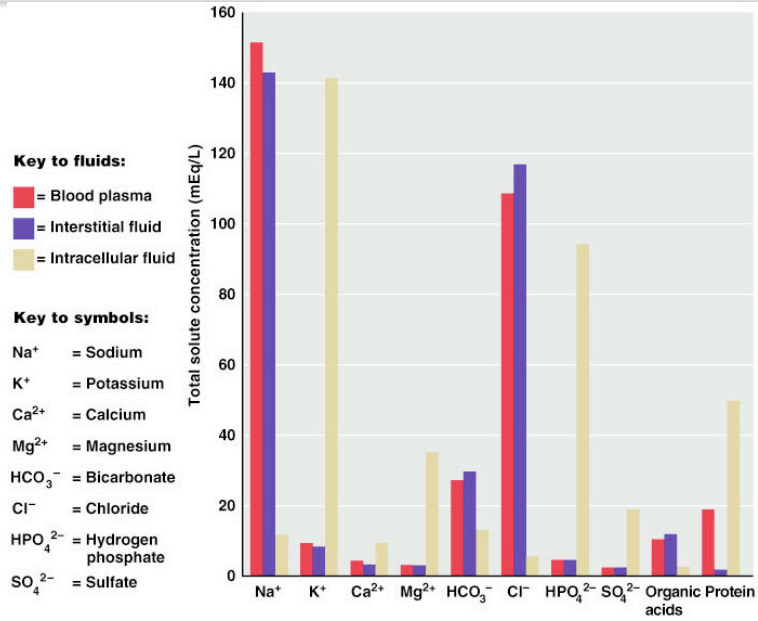
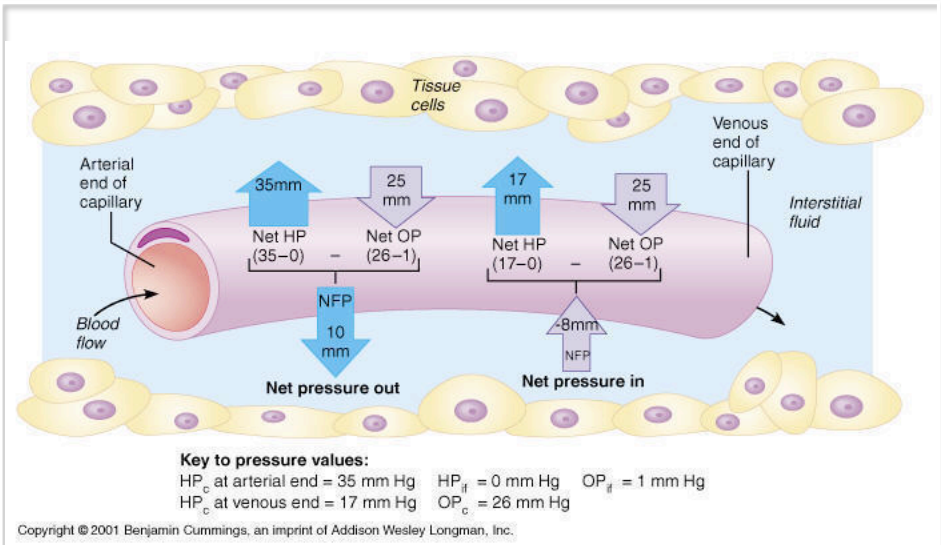


Figure 26.2

Fluid Movement Among Compartments

- Fluid exchange between compartments is continuous
  - Regulated by osmotic and hydrostatic pressures
    - Any change in solute concentration leads to net water movement
      - ECF greater impact than ICF
  - Movement between plasma and interstitial fluid (within ECF) solutes move in both directions
    - Dependent upon four pressures
      - Capillary hydrostatic pressure
      - Capillary osmotic pressure
      - Interstitial fluid hydrostatic pressure
      - Interstitial fluid osmotic pressure



Extracellular and Intracellular Fluids

- Ion fluxes are restricted and move selectively by active transport
  - Nutrients, respiratory gases, and wastes move unidirectionally
  - Two-way osmotic water movement
    - Dependent on Na^+ movement out of cell and K^+ into the cell
      - Also aldosterone and ADH secretion
    - Low Na^+ concentration in interstitial fluid (low osmotic pressure), water may leave the cell but then return resulting in water intoxication

Continuous Mixing of Body Fluids

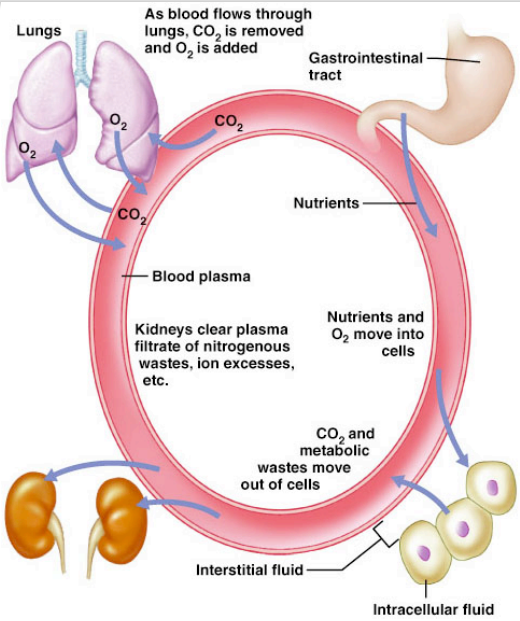


Figure 26.3

Water Balance and ECF Osmolality

- To remain properly hydrated, water intake must equal water output
- Water intake sources
  - Ingested fluid (60%) and solid food (30%)
  - Metabolic water or water of oxidation (10%)

Water Balance and ECF Osmolality

- Water output
  - Urine (60%) and feces (4%)
  - Insensible losses (28%), sweat (8%)
- Increases in plasma osmolality trigger thirst and release of antidiuretic hormone (ADH)

Water Intake and Output

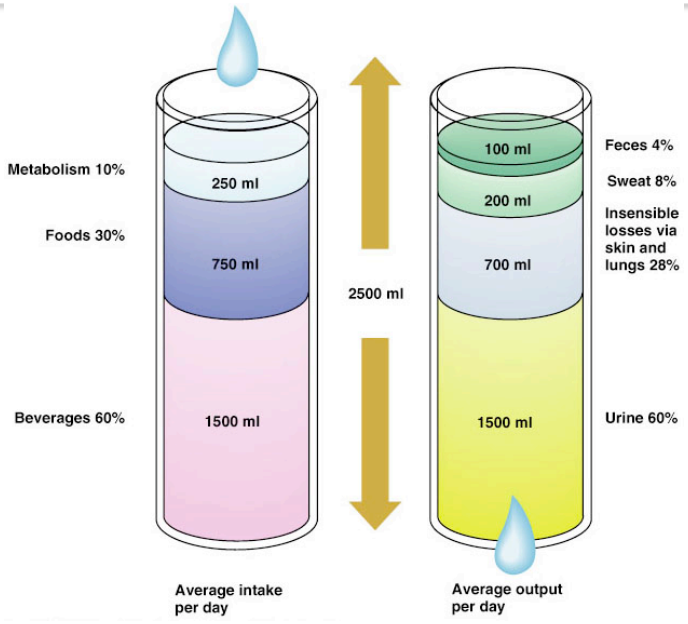


Figure 26.4

Regulation of Water Intake

- The hypothalamic thirst center is stimulated:
  - By a decline in plasma volume of 10%–15%
  - By increases in plasma osmolality of 1–2%
    - ⇓ fluid in interstitium and plasma cells - ⇓ saliva - dry mouth and throat/stimulation of osmoreceptors and crenation of supraoptic nuclei - thirst

Regulation of Water Intake

- Thirst is quenched as soon as we begin to drink water
- Feedback signals that inhibit the thirst centers include:
  - Moistening of the mucosa of the mouth and throat
  - Activation of stomach and intestinal stretch receptors

Regulation of Water Intake: Thirst Mechanism

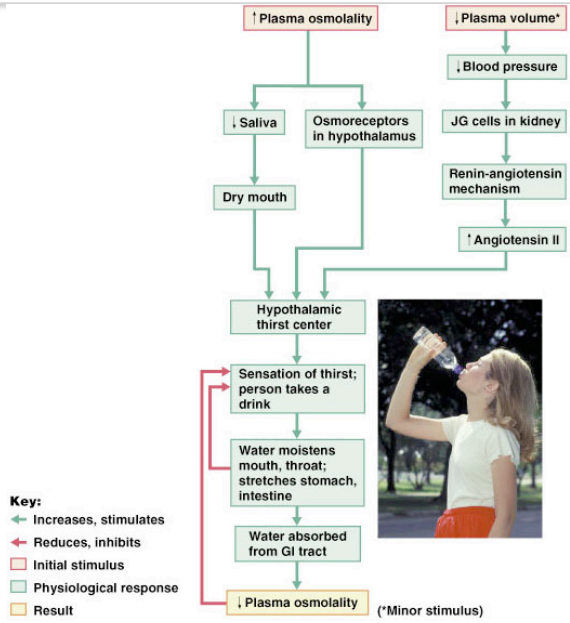


Figure 26.5

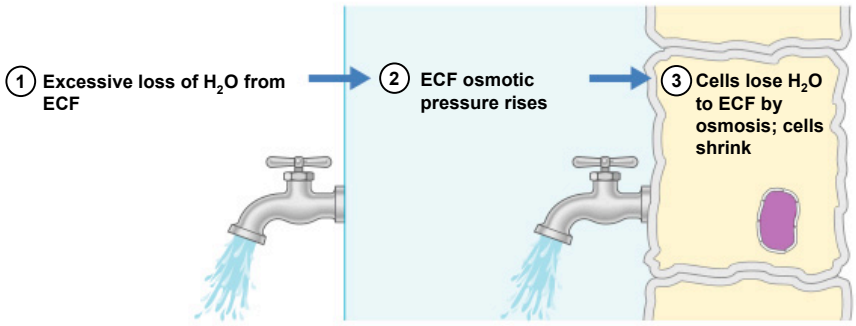
Regulation of Water Output

- Obligatory water losses include:
  - Insensible water losses from lungs and skin (28%)
  - Water that accompanies undigested food residues in feces (4%), urine (60%), sweating (8%)
- Obligatory water loss reflects the fact that:
  - Kidneys excrete 900-1200 mOsm of solutes to maintain blood homeostasis
  - Urine solutes must be flushed out of the body in water
    - ~1500ml
- Fluids may also be lost due to vomiting, diarrhea, extensive skin burns, increased blood pressure, or diet

Disorders of Water Balance: Dehydration

- Water loss exceeds water intake
  - Body is in negative fluid balance
  - Causes include:
    - hemorrhage, severe burns, prolonged vomiting or diarrhea, profuse sweating, water deprivation, and diuretic abuse
  - Signs and symptoms:
    - Cottonmouth, thirst, dry flushed skin, and oliguria
      - Treat with salt pills
- Prolonged dehydration may lead to weight loss, fever, and mental confusion
- Other consequences include hypovolemic shock and loss of electrolytes

Disorders of Water Balance: Dehydration



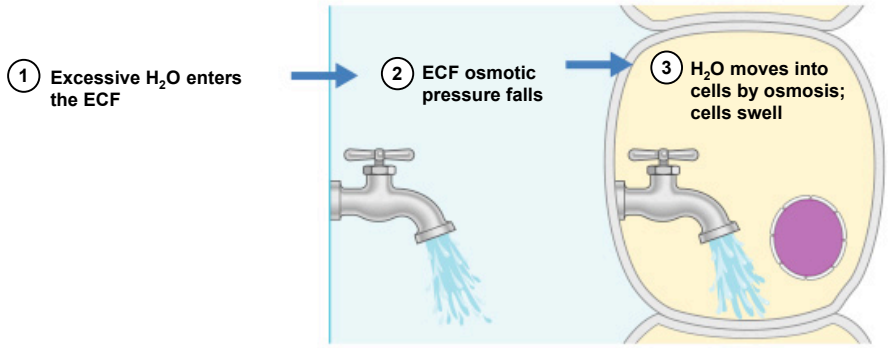
(a) Mechanism of dehydration

Figure 26.7a

Disorders: Hypotonic Hydration

- Hypotonic hydration
  - Can lead to dilutional hyponatremia, or water intoxication
- ECF is diluted – sodium content is normal but excess water is present
  - Or sodium is low and water is otherwise normal
- Causes:
  - Renal insufficiency or an extraordinary amount of water ingested quickly
- Symptoms:
  - Muscle weakness, headaches, hypotension, tachycardia, circulatory shock
  - Severe: mental confusion, stupor, coma

Disorders: Hypotonic Hydration



(b) Mechanism of hypotonic hydration

Figure 26.7b

Disorders of Water Balance: Edema

- Atypical accumulation of fluid in the interstitial space
  - Leading to tissue swelling
    - Requires 30% increase to be detectable
- Symptoms:
  - Increased fluid in interstitial space
  - Impaired tissue function due to increased distance between capillaries and cells
    - Diminishes perfusion

Disorders of Water Balance: Edema

- Causes:
  - Anything that increases flow of fluids out of the bloodstream or hinders their return
    - Factors that accelerate fluid loss include:
      - Increased capillary permeability as in allergic/inflammatory responses
      - Increased intra-capillary pressure (hydrostatic)
        - Due to increased arterial dilation, blockage of veins, increased venous pressure
      - Increased interstitial fluid colloid osmotic pressure due to blocked lymphatics
        - Extra proteins in interstitial space and reduction in plasma

Edema

- Hindered fluid return
  - Usually reflects an imbalance in colloid osmotic pressures
  - May result in low blood volume/pressure
- Hypoproteinemia – low levels of plasma proteins
  - Forces fluids out of capillary beds at the arterial ends
  - Fluids fail to return at the venous ends
  - Results from protein malnutrition, liver disease, or glomerulonephritis

Electrolyte Balance

- Electrolytes are salts, acids, and bases
  - But electrolyte balance usually refers only to salt balance
- Salts are important for:
  - Provision of essential minerals
  - Control of osmotic movement between compartments
  - Maintain acid-base balance
  - Controlling fluid movements
- Salts enter the body by ingestion and are lost via perspiration, feces, and urine

Sodium in Fluid and Electrolyte Balance

- Sodium holds a central position in fluid and electrolyte balance
- Sodium salts:
  - Account for 90-95% of all solutes in the ECF
  - Contribute 280 mOsm of the total 300 mOsm ECF solute concentration
- Single most abundant cation in the ECF
- Along with potassium, critical for nerve impulse transmission
- Primary cation exerting significant osmotic pressure
  - Effects all three compartments
- As sodium bicarbonate, central to pH buffering

Regulation of Sodium Balance: Aldosterone

- Sodium reabsorption
  - 65% of sodium in filtrate is reabsorbed in the proximal tubules
  - 25% is reclaimed in the loops of Henle
- When aldosterone levels are high
  - All remaining Na^+ is actively reabsorbed
- Water follows sodium
  - If tubule permeability has been increased with ADH

Regulation of Sodium: Atrial Natriuretic Peptide

- Atrial cells detect increased blood pressure
  - Detected as stretching
  - Release ANP
  - ANP travels to the kidney to trigger sodium excretion
  - Inhibits release of ADH, aldosterone, angiotensin, and renin

Mechanisms and Consequences of ANP Release

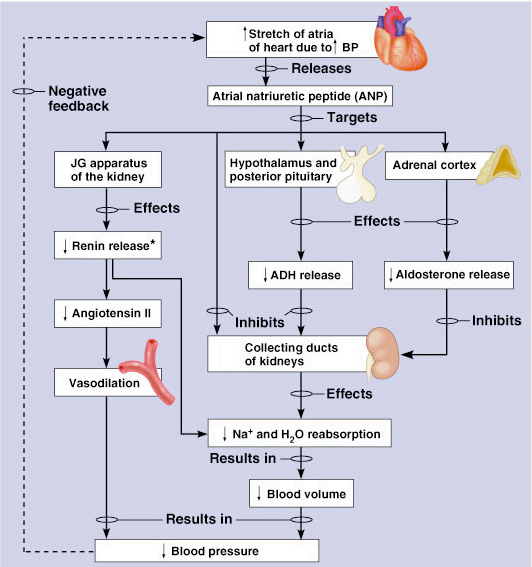


Figure 26.10

Regulation of Sodium: ADH

- If sodium concentration is low
  - Hypotonic solution
  - ADH release is inhibited
  - Dilute urine production increases
    - ADH dictates at the DCT and collecting ducts whether urine becomes dilute or concentrated

Cardiovascular System Baroreceptors

- Baroreceptors
  - Alert the brain of increases in blood volume (hence increased blood pressure)
    - In heart, aorta, carotid arteries
      - Send message to hypothalamus
        - Sympathetic nervous system impulses to the kidneys decline
        - Afferent arterioles dilate
        - Glomerular filtration rate rises
        - Sodium and water output increase

Typical Sodium Levels

- Normal
  - 135 - 145 mEq/L
- Abnormal
  - Hyponatremia < 135 mEq/L
    - Due to increased
      - water intake
      - ADH secretion
  - Hypernatremia > 145 mEq/L
    - Diabetes insipidus
      - Increased water loss in urine

Maintenance of Blood Pressure Homeostasis

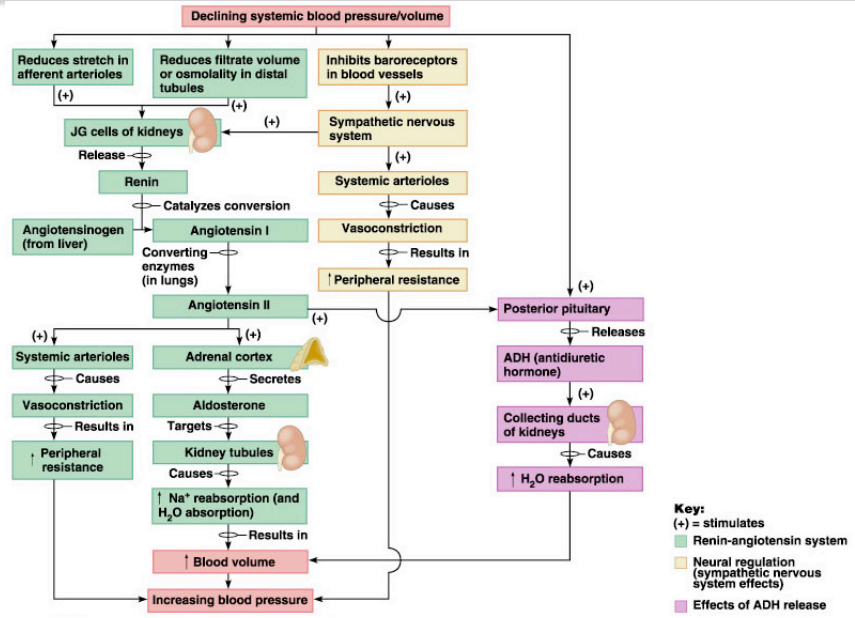


Figure 26.9

Regulation of Potassium Balance

- Primary intercellular cation
  - Helps maintain fluid volume in cells and control pH
    - Through exchange with Na^+ or H^+
- High extracellular K^+ leads to acidosis
  - Results in high H^+ concentration inside cells
- Low extracellular K^+ leads to alkalosis
  - K^+ has moved into cells
    - Therefore H^+ has been pumped out

Regulation of Potassium Balance

- Relative ICF-ECF potassium ion concentration affects a cell's resting membrane potential
  - Excessive ECF potassium decreases membrane potential
  - Too little K^+ causes hyperpolarization and nonresponsiveness

Regulation of Potassium Balance

- Hyperkalemia and hypokalemia can:
  - Disrupt electrical conduction in the heart
  - Lead to sudden death
- Hydrogen ions shift in and out of cells
  - Leads to corresponding shifts in potassium in the opposite direction
  - Interferes with activity of excitable cells

Influence of Aldosterone

- Aldosterone stimulates potassium ion secretion by principal cells
  - In cortical collecting ducts
    - For each Na^+ reabsorbed, a K^+ is secreted
- Increased K^+ in the ECF around the adrenal cortex causes:
  - Release of aldosterone
  - Potassium secretion
- Potassium controls its own ECF concentration
  - Via feedback regulation of aldosterone release

Typical Potassium Levels

- Normal
  - 3 - 5 mEq/L
- Abnormal
  - Hypokalemia < 3 mEq/L
    - Due to diarrhea
  - Hyperkalemia > 5mEq/L
    - From severe burns or renal failure