# Fluids and electrolytes

## Body Water Content

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

## Fluid Compartments

- Water occupies two main fluid compartments
- Intracellular fluid (ICF) – about two thirds by volume, contained in cells
- Extracellular fluid (ECF) – consists of two major subdivisions
  - Plasma – the fluid portion of the blood
  - Interstitial fluid (IF) – fluid in spaces between cells
- Other ECF – lymph, cerebrospinal fluid, eye humors, synovial fluid, serous fluid, and gastrointestinal secretions

## Fluid Compartments

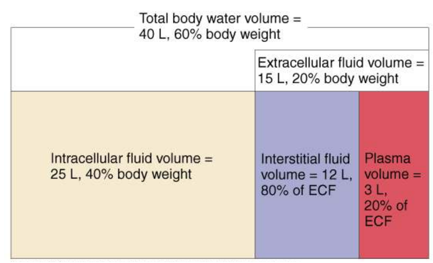



Figure 25.1

## Composition of Body Fluids

- Water is the universal solvent
- Solutes are broadly classified into:
  - Electrolytes – inorganic salts, all acids and bases, and some proteins
  - Nonelectrolytes – examples include glucose, lipids, creatinine, and urea
- Electrolytes have greater osmotic power than nonelectrolytes
- Water moves according to osmotic gradients

## Electrolyte Concentration

- Expressed in milliequivalents per liter (mEq/L), a measure of the number of electrical charges in one liter of solution
- mEq/L = (concentration of ion in [mg/L]/the atomic weight of ion) × number of electrical charges on one ion
- For single charged ions, 1 mEq = 1 mOsm
- For bivalent ions, 1 mEq = 1/2 mOsm

## 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)
  - Sodium is the chief cation
  - Chloride is the major anion
- Intracellular fluids have low sodium and chloride
  - Potassium is the chief cation
  - Phosphate is the chief anion

## Extracellular and Intracellular Fluids

- Sodium and potassium concentrations in extra- and intracellular fluids are nearly opposites
- This reflects the activity of cellular ATP-dependent sodium-potassium pumps
- Electrolytes determine the chemical and physical reactions of fluids

## 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

## Extracellular and Intracellular Fluids

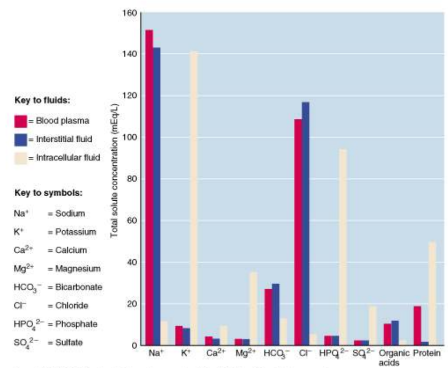



Figure 25.2

## Fluid Movement Among Compartments

- Compartmental exchange is regulated by osmotic and hydrostatic pressures
- Net leakage of fluid from the blood is picked up by lymphatic vessels and returned to the bloodstream
- Exchanges between interstitial and intracellular fluids are complex due to the selective permeability of the cellular membranes
- Two-way water flow is substantial

## Extracellular and Intracellular Fluids

- Ion fluxes are restricted and move selectively by active transport
- Nutrients, respiratory gases, and wastes move unidirectionally
- Plasma is the only fluid that circulates throughout the body and links external and internal environments
- Osmolalities of all body fluids are equal; changes in solute concentrations are quickly followed by osmotic changes

## Extracellular and Intracellular Fluids

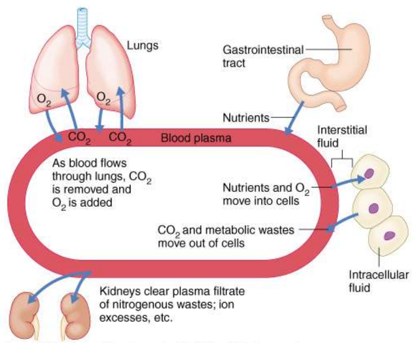



Figure 25.3

## Water Balance

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

## Water Balance

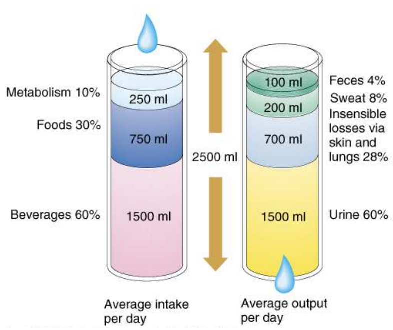



Figure 25.4

## Regulation of Water Intake

- The hypothalamic thirst center is stimulated by:
  - Decreases in plasma volume of 10%
  - Increases in plasma osmolality of 1–2%
- Thirst is quenched as soon as we begin to drink water
- Feedback signals that inhibit the thirst centers include:
  - Damping of mucosa of the mouth
  - Moistening of the throat
  - Activation of stomach and intestinal stretch receptors

## Regulation of Water Intake

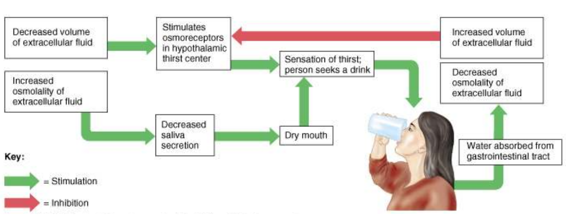



Figure 25.5

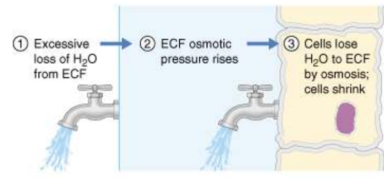
## Regulation of Water Output

- Obligatory water losses include:
  - Insensible water losses from lungs and skin
  - Water that accompanies undigested food residues in feces
- Obligatory water loss reflects the facts that:
  - Kidneys excrete 900–1200 mOsm of solutes to maintain blood homeostasis
  - Urine solutes must be flushed out of the body in water

## Disorders of Water Balance: Dehydration

- Water loss exceeds water intake and the 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
- 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 25.6a

## Disorders of Water Balance: Hypotonic Hydration

- Renal insufficiency or an extraordinary amount of water ingested quickly can lead to cellular overhydration, or water intoxication
- ECF is diluted – sodium content is normal but excess water is present
- The resulting hyponatremia promotes net osmosis into tissue cells, causing swelling
- These events must be quickly reversed to prevent severe metabolic disturbances, particularly in neurons

## Disorders of Water Balance: Hypotonic Hydration


(b) Mechanism of hypotonic hydration (water intoxication)

Figure 25.6b

## Disorders of Water Balance: Edema

- Atypical accumulation of fluid in the interstitial space, leading to tissue swelling
- Caused by anything that increases flow of fluids out of the bloodstream or hinders their return
- Factors that accelerate fluid loss include:
  - Increased blood pressure, capillary permeability
  - Incompetent venous valves, localized blood vessel blockage
  - Congestive heart failure, hypertension, high blood volume

## Edema

- Hindered fluid return usually reflects an imbalance in colloid osmotic pressures
- 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

## Edema

- Blocked (or surgically removed) lymph vessels:
  - Cause leaked proteins to accumulate in interstitial fluid
  - Exert increasing colloid osmotic pressure, which draws fluid from the blood
- Interstitial fluid accumulation results in low blood pressure and severely impaired circulation

## Electrolyte Balance

- Electrolytes are salts, acids, and bases, but electrolyte balance usually refers only to salt balance
- Salts are important for:
  - Neuromuscular excitability
  - Secretory activity
  - Membrane permeability
  - 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
- Sodium is the single most abundant cation in the ECF
- Sodium is the only cation exerting significant osmotic pressure

## Sodium in Fluid and Electrolyte Balance

- The role of sodium in controlling ECF volume and water distribution in the body is a result of:
  - Sodium being the only cation to exert significant osmotic pressure
  - Sodium ions leaking into cells and being pumped out against their electrochemical gradient
- Sodium concentration in the ECF normally remains stable

## Sodium in Fluid and Electrolyte Balance

- Changes in plasma sodium levels affect:
  - Plasma volume, blood pressure
  - ICF and interstitial fluid volumes
- Renal acid-base control mechanisms are coupled to sodium ion transport

## 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 Balance: Aldosterone

- The renin-angiotensin mechanism triggers the release of aldosterone
- This is mediated by the juxtaglomerular apparatus, which releases renin in response to:
  - Sympathetic nervous system stimulation
  - Decreased filtrate osmolality
  - Decreased stretch (due to decreased blood pressure)
- Renin catalyzes the production of angiotensin II, which prompts aldosterone release

## Regulation of Sodium Balance: Aldosterone

- Adrenal cortical cells are directly stimulated to release aldosterone by elevated $K^+$ levels in the ECF
- Aldosterone brings about its effects (diminished urine output and increased blood volume) slowly

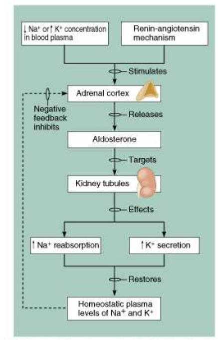



Figure 25.7

## Cardiovascular System Baroreceptors

- Baroreceptors alert the brain of increases in blood volume (hence increased blood pressure)
  - Sympathetic nervous system impulses to the kidneys decline
  - Afferent arterioles dilate
  - Glomerular filtration rate rises
  - Sodium and water output increase

## Cardiovascular System Baroreceptors

- This phenomenon, called pressure diuresis, decreases blood pressure
- Drops in systemic blood pressure lead to opposite actions and systemic blood pressure increases
- Since sodium ion concentration determines fluid volume, baroreceptors can be viewed as "sodium receptors"

## Influence and Regulation of ADH

- Water reabsorption in collecting ducts is proportional to ADH release
- Low ADH levels produce dilute urine and reduced volume of body fluids
- High ADH levels produce concentrated urine
- Hypothalamic osmoreceptors trigger or inhibit ADH release
- Factors that specifically trigger ADH release include prolonged fever; excessive sweating, vomiting, or diarrhea; severe blood loss; and traumatic burns

## Influence and Regulation of ADH

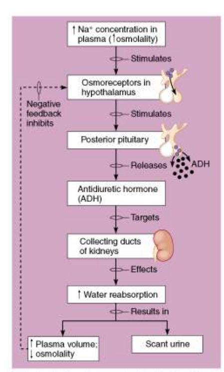



Figure 25.8

## Maintenance of Blood Pressure Homeostasis

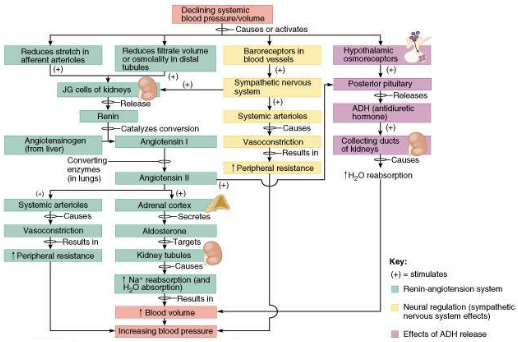



Figure 25.9

## Atrial Natriuretic Peptide (ANP)

- Reduces blood pressure and blood volume by inhibiting:
  - Events that promote vasoconstriction
  - $Na^+$ and water retention
- Is released in the heart atria as a response to stretch (elevated blood pressure)
- Has potent diuretic and natriuretic effects
- Promotes excretion of sodium and water
- Inhibits angiotensin II production

## Atrial Natriuretic Peptide (ANP)

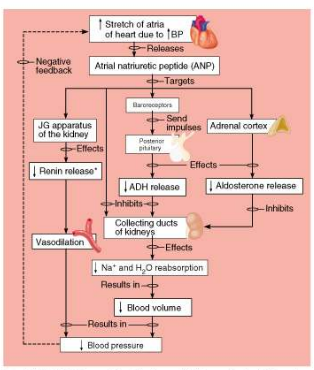



Figure 25.10