Fluids, Electrolytes and Acid-Base Balance

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Objectives

- Define normal ranges of electrolytes
- Compare/contrast intracellular, extracellular, and intravascular volumes
- Outline methods of determining fluid and acid/base balance
- Describe the clinical manifestations of various electrolyte imbalances.

Normal Plasma Ranges of Electrolytes

- Cations
  - Sodium
  - Potassium
  - Calcium
  - Magnesium
- Anions
  - Chloride
  - Bicarbonate
  - Phosphate
  - Sulfate
  - Organic Acids (Lactate)
  - Total Protein

- Concentration
  - 135-145 mEq/L
  - 3.5-5.0 mEq/L
  - 8.0-10.5 mEq/L
  - 1.5-2.5 mEq/L

  - 95-105 mEq/L
  - 24-30 mEq/L
  - 2.5-4.5 mEq/L
  - 1.0 mEq/L
  - 2.0 mEq/L
  - 6.0-8.4 mEq/L

Normal Ranges of Electrolytes

- Sodium (Na^+)
  - Range 135 - 145 mEq/L in serum
  - Total body volume estimated at 40 mEq/kg
  - 1/3 fixed to bone, 2/3 extracellular and available for trans-membrane exchange
  - Normal daily requirement 1-2 mEq/kg/day
  - Chief extracellular cation

Normal Ranges of Electrolytes

- Potassium (K^+)
  - Range 3.5 - 5.0 mEq/L in serum
  - Total body volume estimated at 50 mEq/kg
  - 98% intracellular
    - concentration of 150 mEq/L
    - extracellular concentration of 70 mEq/L
  - Normal daily requirement 0.5 – 0.8 mEq/kg/day
  - Chief intracellular cation

Normal Ranges of Electrolytes

- Intracellular v Extracellular
  - Electrolyte composition is different
    - Intracellular - K^+, Mg^+, PO_4^-, SO_4^-, and proteins
    - Extracellular - Na^+, Ca^+, Mg^+, Cl^-, HCO_3^- and lactate
  - Compositions of ions are maintained
    - selective permeability of cell membranes
    - active ion pumps
  - Movement of water is passive
    - colloid osmotic gradients intravascular v interstitial spaces (extracellularly)
    - osmolar gradients intracellularly v extracellularly

Fluid Balance

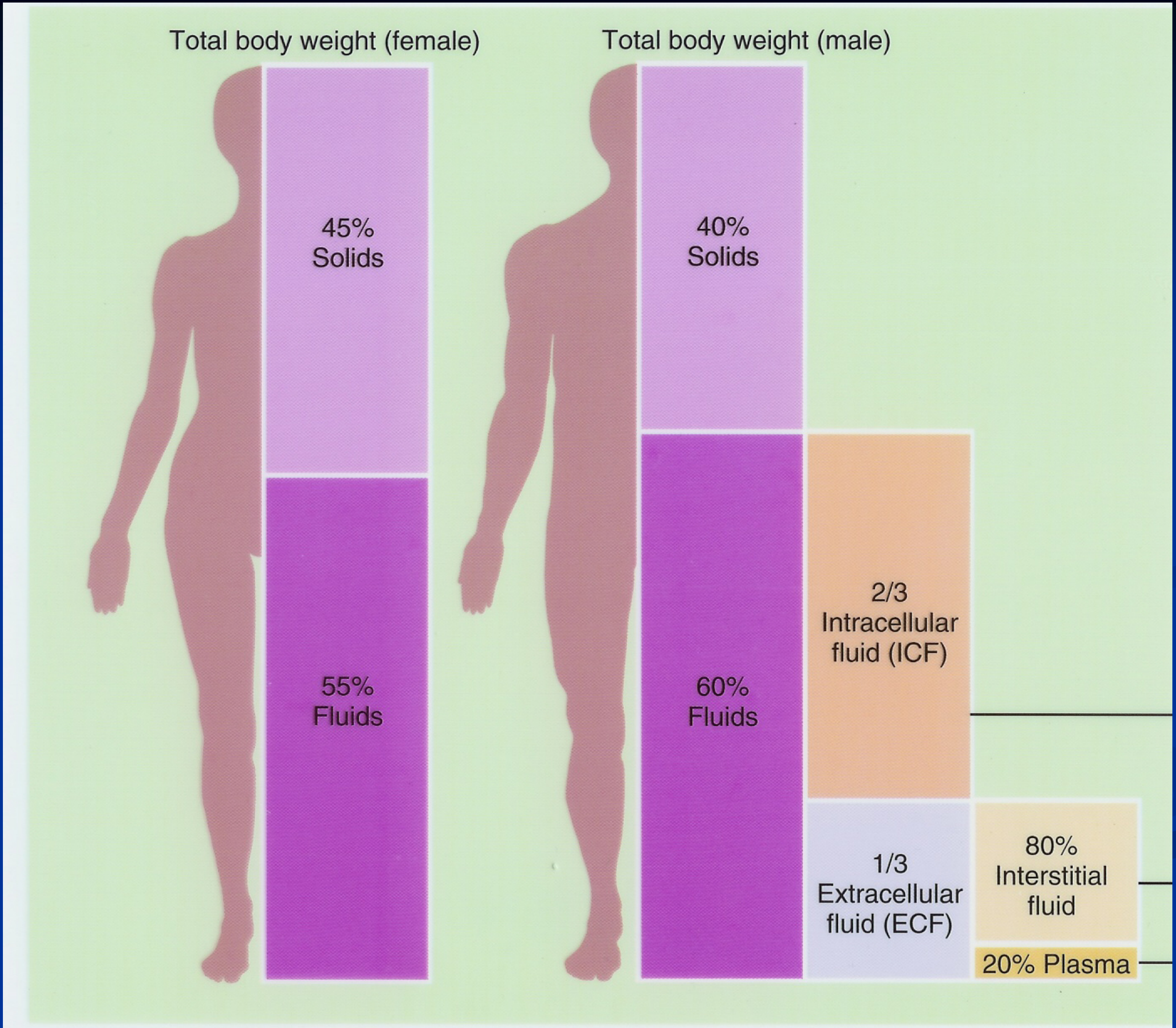
- Calculation of Osmolarity
  - Osm = 2 x [Na_s] + [glu / 18] + [BUN / 2.8]
  - Normal osmolarity is 280-300 mOsm/L
- Na^+ resorption and excretion are the driving forces for osmolarity
  - Calculating TBW deficit
    - TBWD males = [(140 – SNa^+) x 0.6 x IBW (kg)]/ 140
    - TBWD females = [(140 – SNa^+) x 0.5 x IBW (kg)]/ 140

Fluid Balance

- Here's a trick
  - For every 3.5 mEq the Na^+ is over 140, there is an estimated free water deficit of 1 L.

Normal Physiology

- Total body water
  - 60% IBW of males
  - 50-55% IBW of females
    - directly related to muscle mass (70% water)
    - inversely related to fat content (10% water)
    - This is why witches float
- Compartments
  - Intracellular
  - Extracellular
  - Interstitial

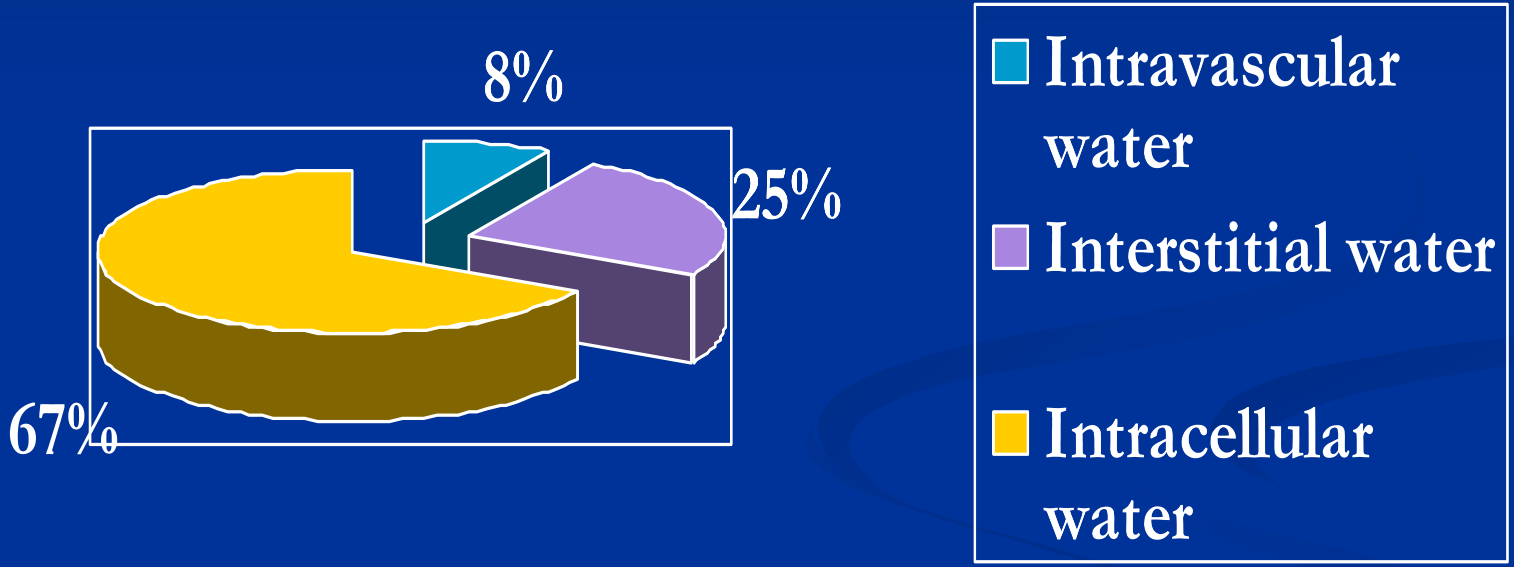


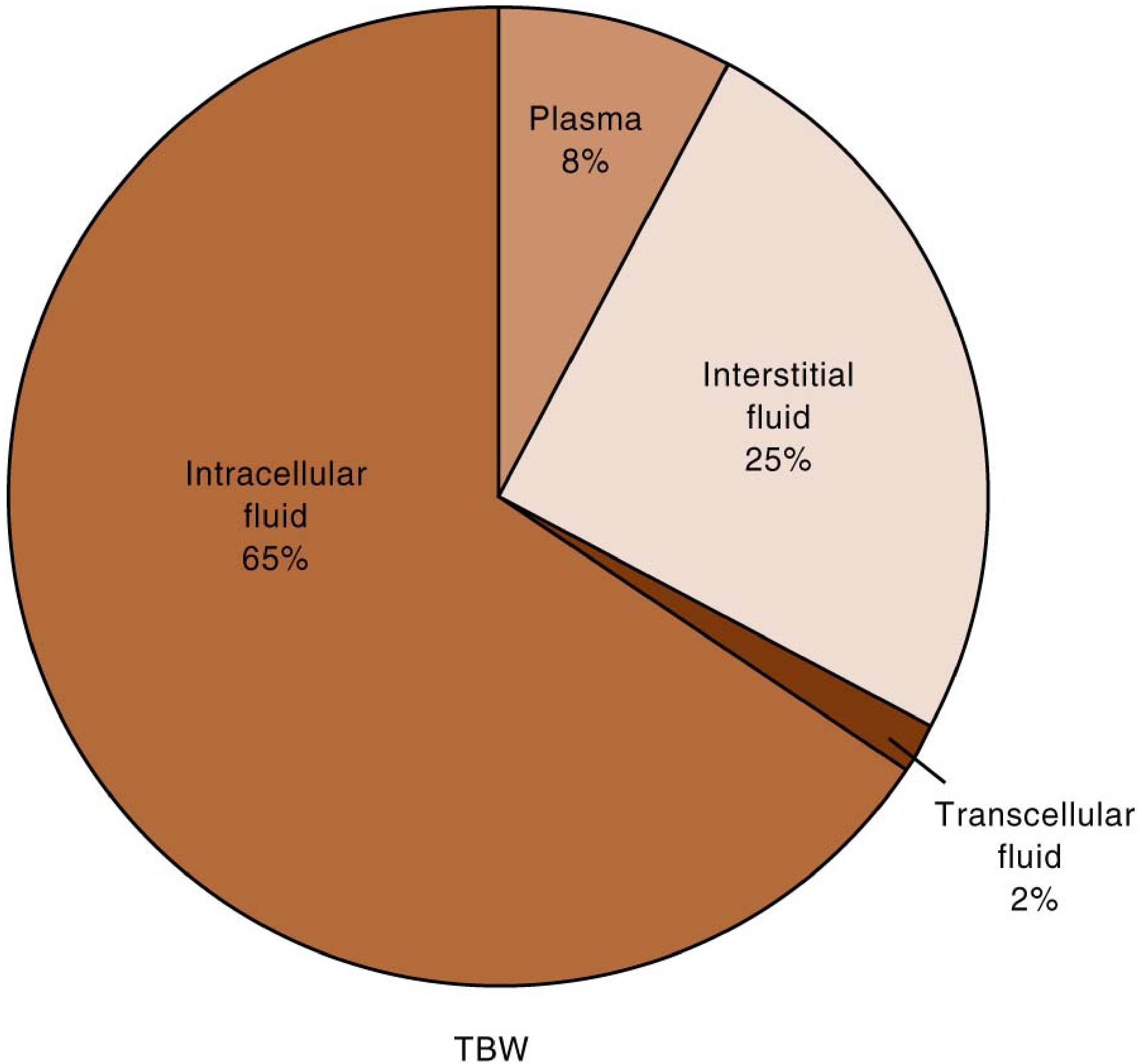
Total body weight (female)
Total body weight (male)
45% Solids
55% Fluids
40% Solids
60% Fluids
2/3 Intracellular fluid (ICF)
1/3 Extracellular fluid (ECF)
80% Interstitial fluid
20% Plasma

Body Fluid Compartments

- 2/3 (65%) of TBW is intracellular (ICF)
- 1/3 extracellular water
  - 25 % interstitial fluid (ISF)
  - 5- 8 % in plasma (IVF intravascular fluid)
  - 1- 2 % in transcellular fluids – CSF, intraocular fluids, serous membranes, and in GI, respiratory and urinary tracts (third space)

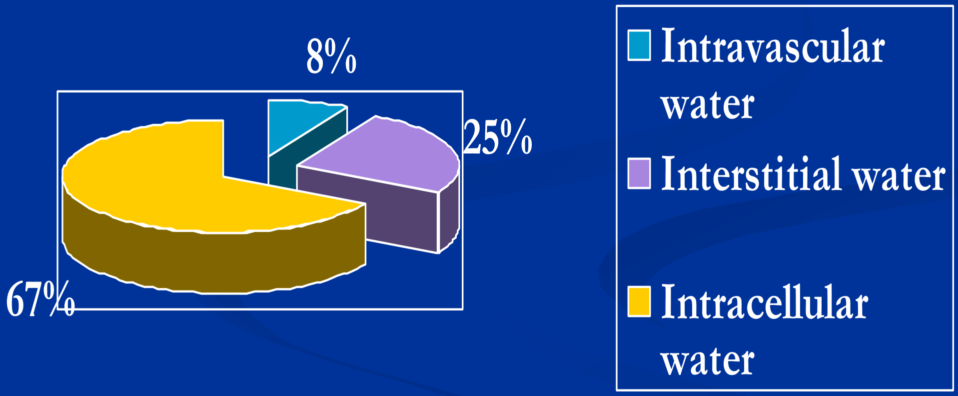
Normal Physiology

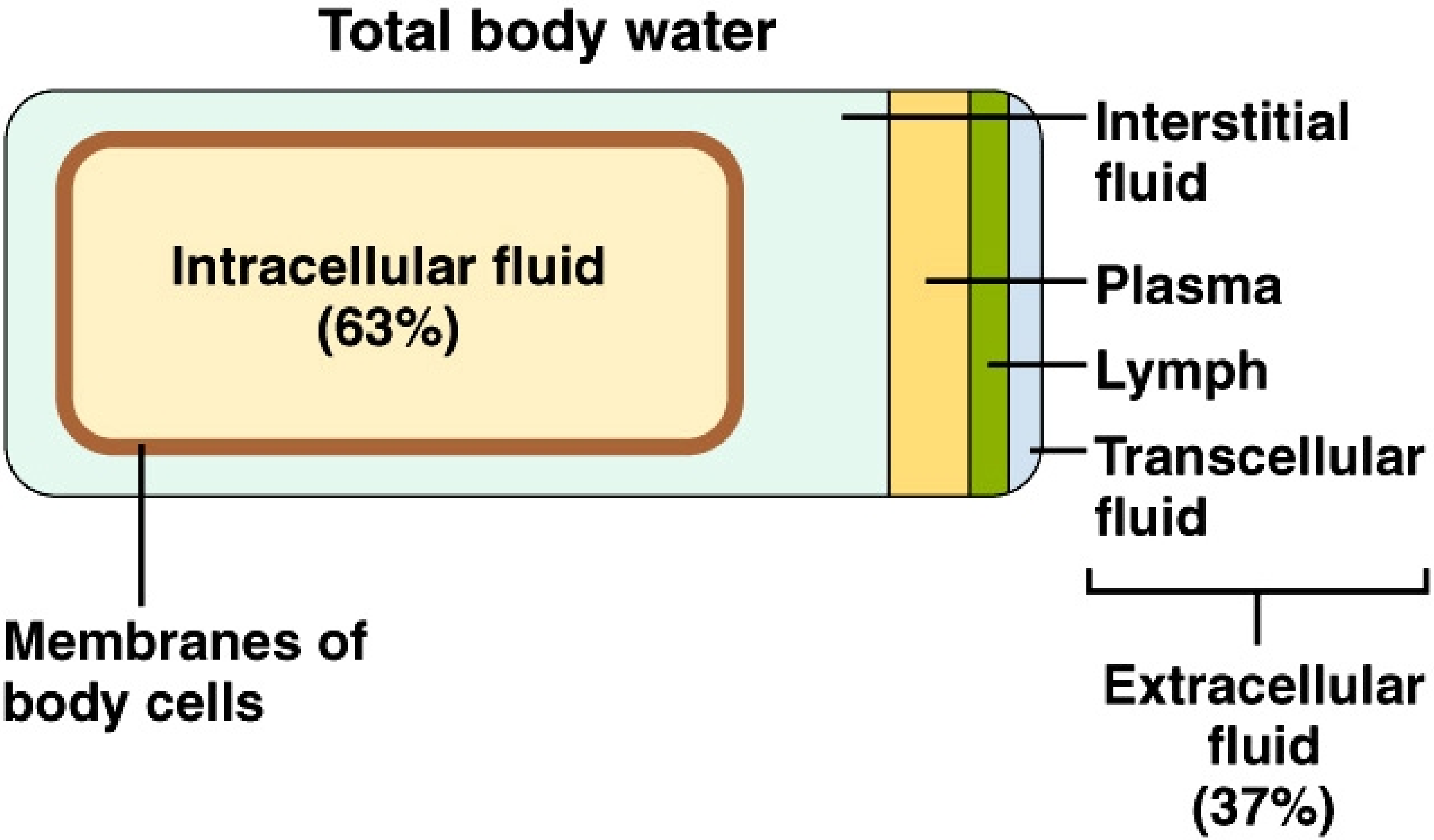



Plasma
8%
Interstitial
fluid
25%
Intracellular
fluid
65%
Transcellular
fluid
2%
TBW

Normal Physiology

- Two main compartments
  - Intracellular
    - 2/3 of TBW
    - 40% body weight
  - Extracellular
    - Intravascular and Interstitial compartments
    - 1/3 of TBW
    - 20% body weight

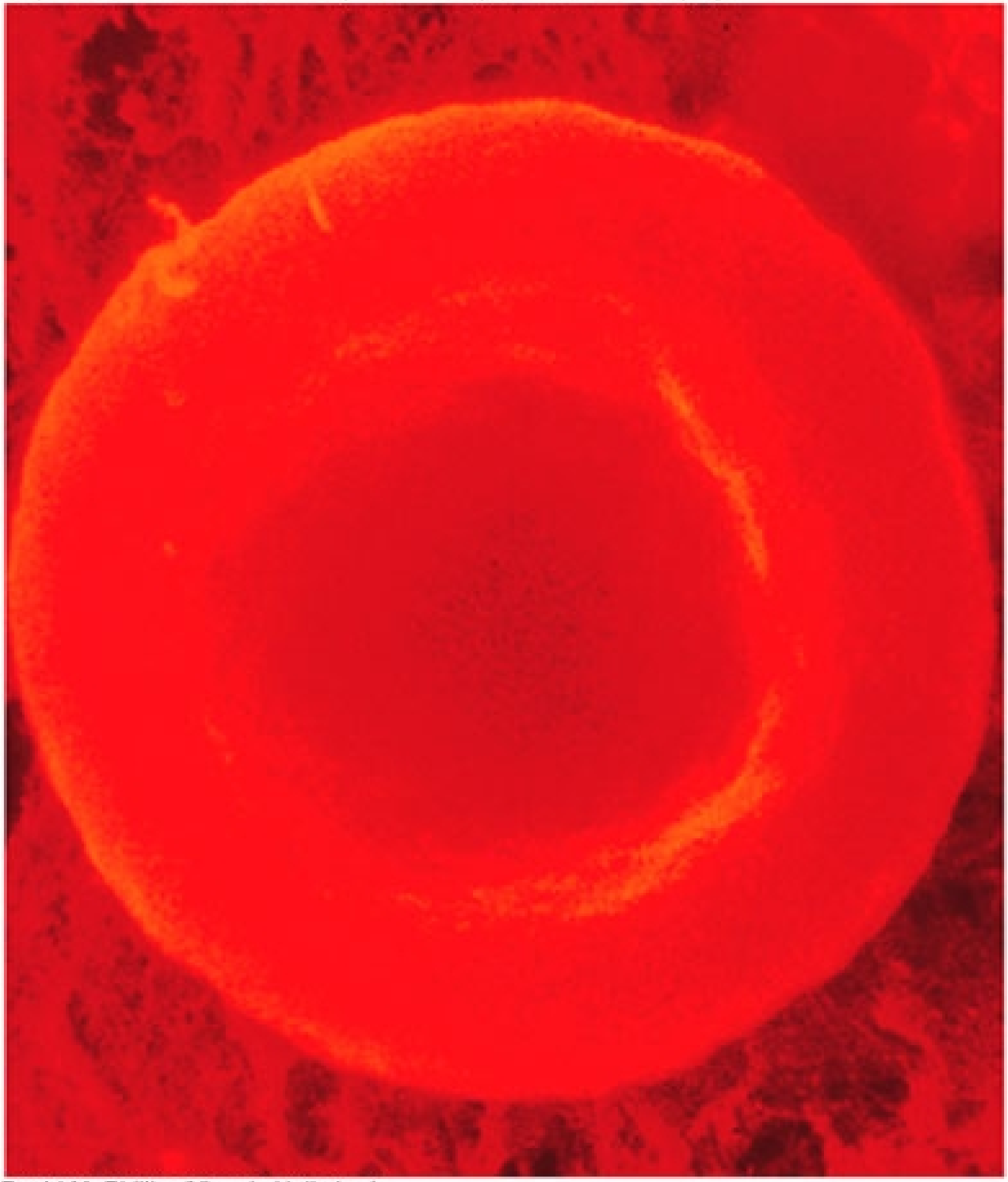




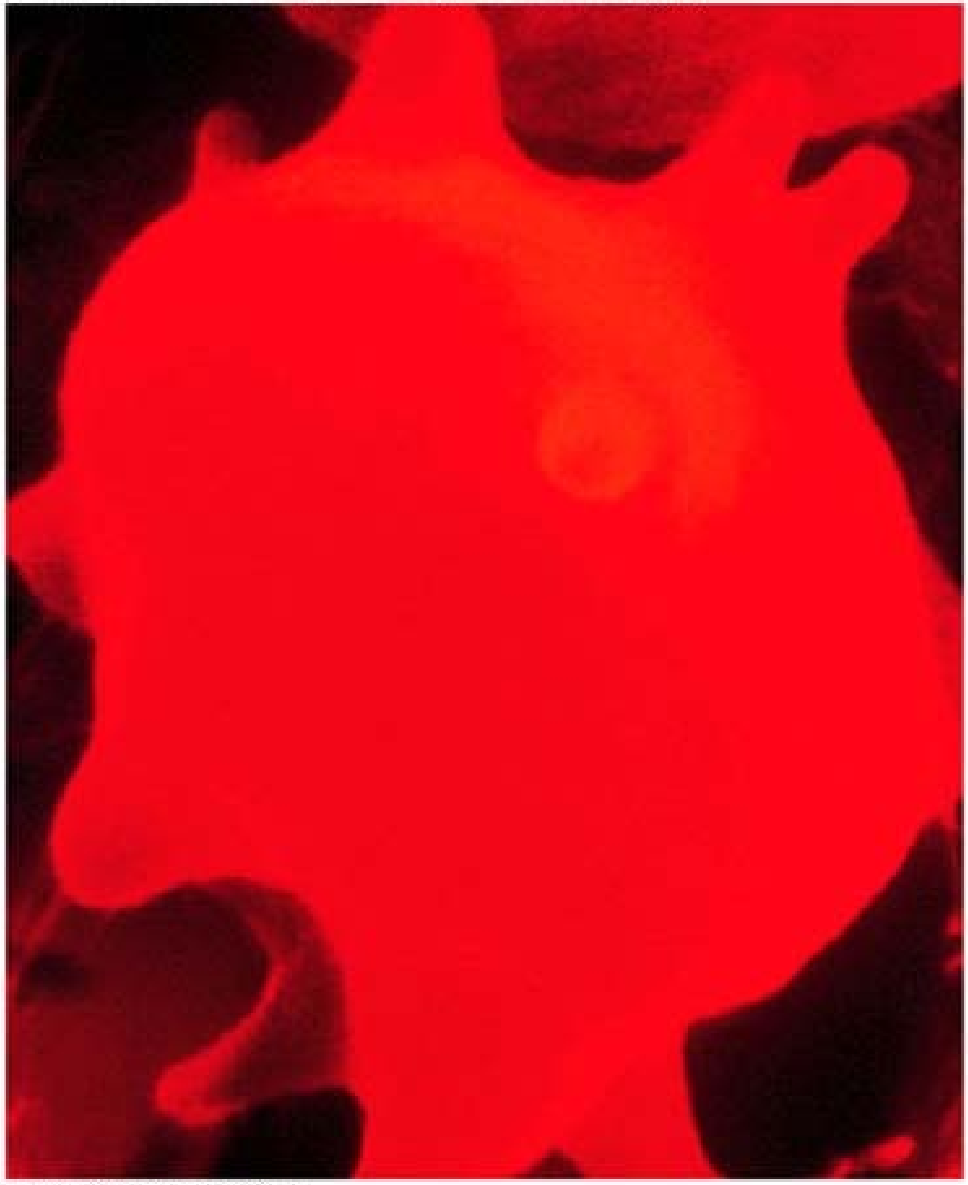
Total body water
Intracellular fluid
(63%)
Interstitial
fluid
Plasma
Lymph
Transcellular
fluid
Membranes of
body cells
Extracellular
fluid
(37%)

- Fluid compartments are separated by membranes that are freely permeable to water.
- Movement of fluids due to:
  - **hydrostatic pressure**
  - **osmotic pressure**
- Capillary filtration (hydrostatic) pressure
- Capillary colloid osmotic pressure
- Interstitial hydrostatic pressure
- Tissue colloid osmotic pressure

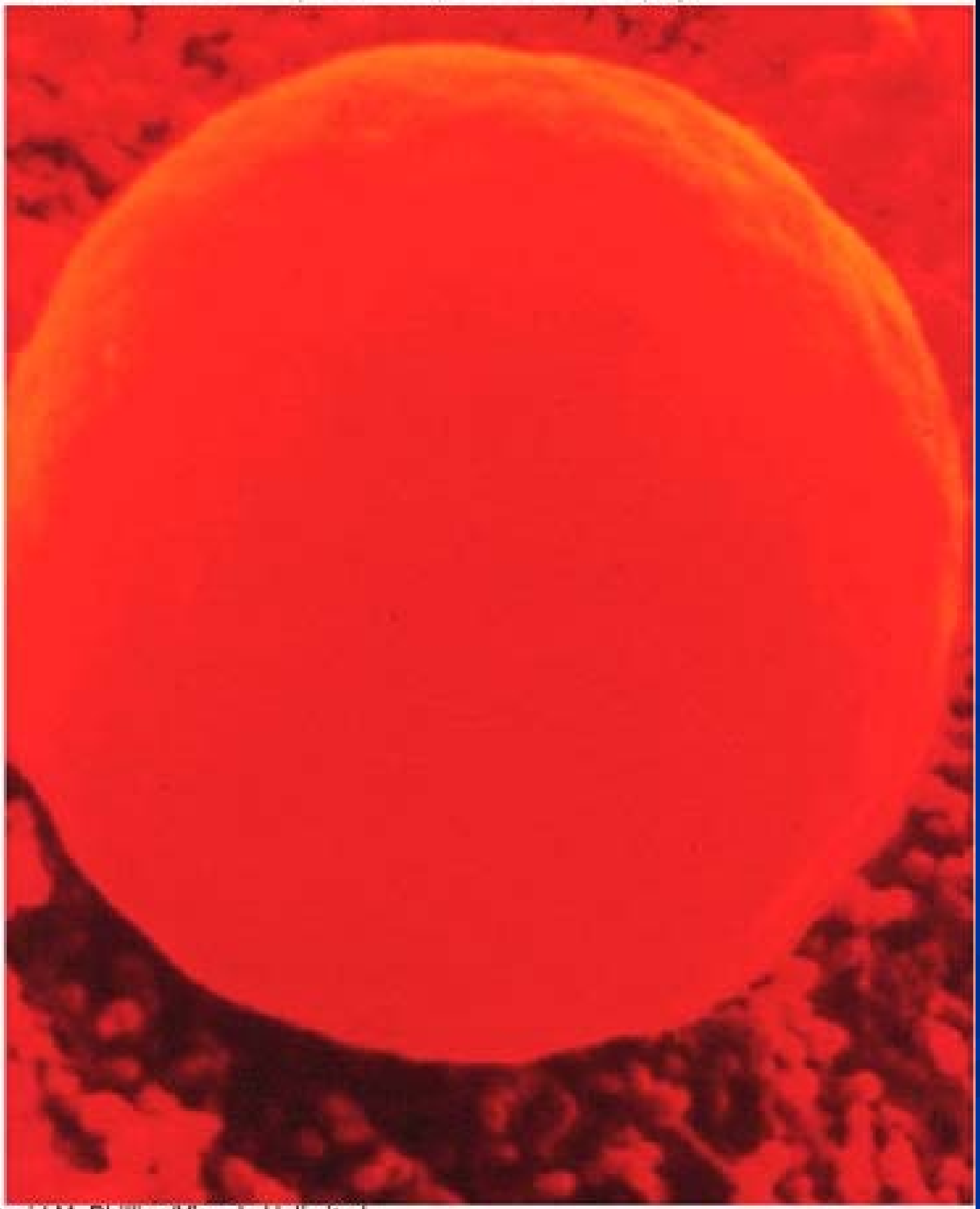
Cell in Isotonic Solution

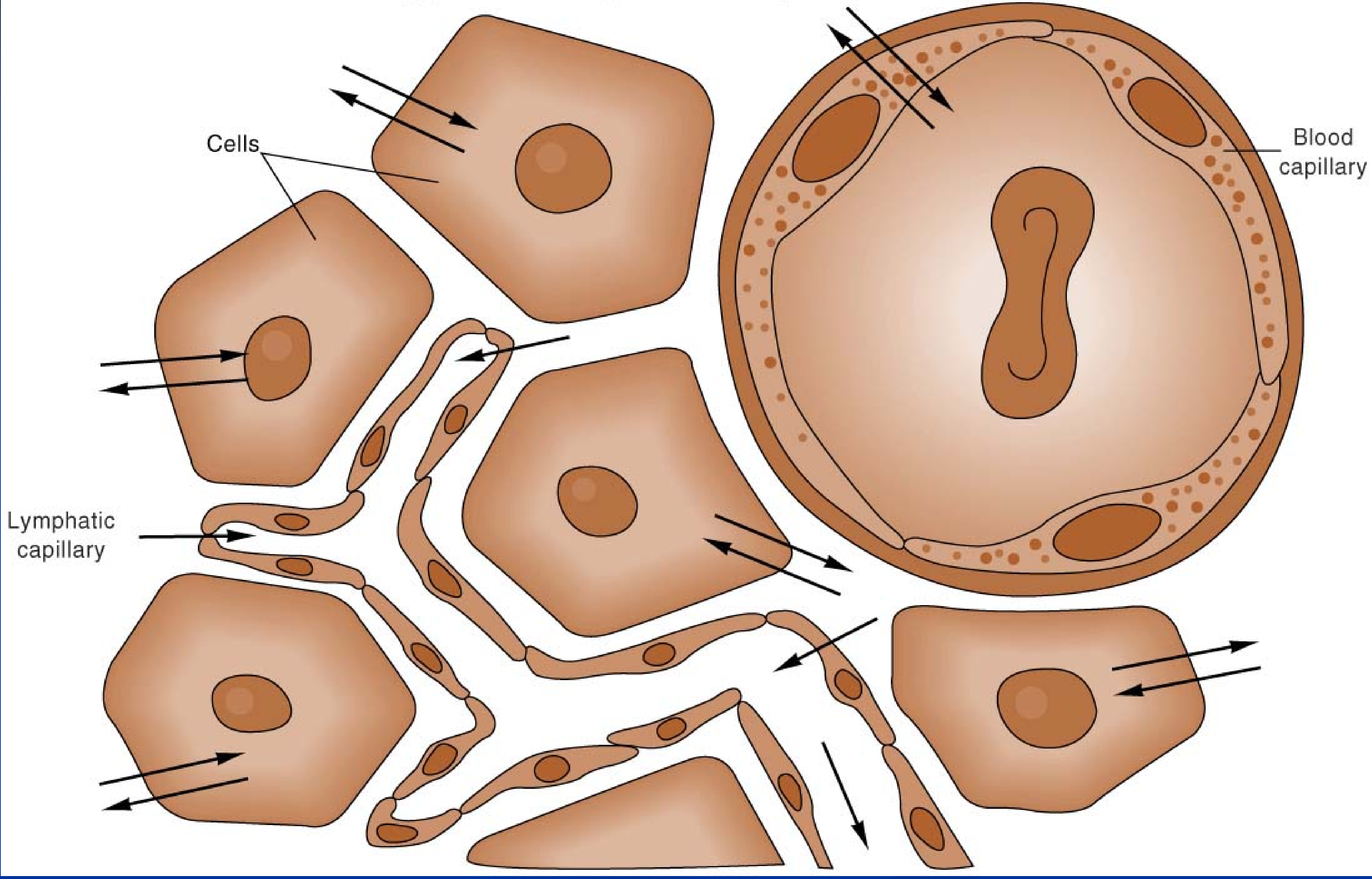


Cell in a hypertonic solution



Cell in a hypotonic solution




Cells
Blood capillary
Lymphatic capillary

Balance

- Fluid and electrolyte homeostasis is maintained in the body
  - Neutral balance: input = output
  - Positive balance: input > output
  - Negative balance: input < output

Solutes – dissolved particles

- Electrolytes – charged particles
  - Cations – positively charged ions
    - Na^+, K^+ , Ca^{++}, H^+
  - Anions – negatively charged ions
    - Cl^-, HCO_3^- , PO_4^{3-}
- Non-electrolytes - Uncharged
    - Proteins, urea, glucose, O_2, CO_2

- Body fluids are:
  - Electrically neutral
  - Osmotically maintained
    - Specific number of particles per volume of fluid

Homeostasis maintained by:

- Ion transport
- Water movement
- Kidney function

Basic Definitions

MW (Molecular Weight) = sum of the weights of atoms in a molecule

mEq (milliequivalents) = MW (in mg)/ valence

mOsm (milliosmoles) = number of particles in a solution

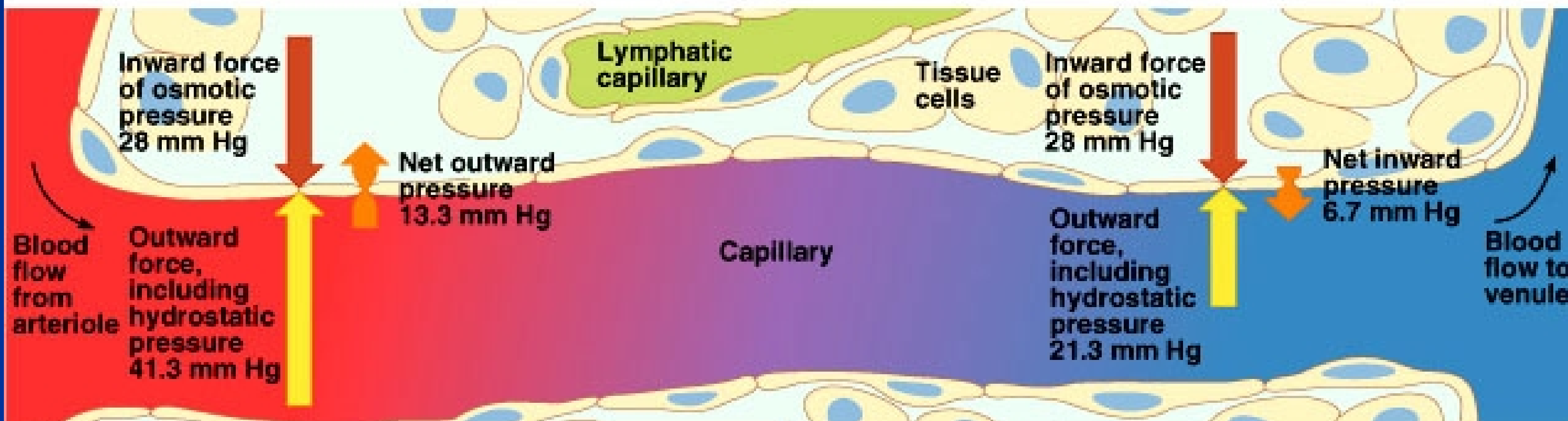
Movement of body fluids

“ Where sodium goes, water follows.”

Diffusion – movement of particles down a concentration gradient.

Osmosis – diffusion of water across a selectively permeable membrane

Active transport – movement of particles up a concentration gradient ; requires energy



Net force at arteriolar end	
Outward force, including hydrostatic pressure	= 41.3 mm Hg
Inward force of osmotic pressure	= 28 mm Hg
Net outward pressure	= 13.3 mm Hg

Net force at venular end	
Outward force, including hydrostatic pressure	= 21.3 mm Hg
Inward force of osmotic pressure	= 28 mm Hg
Net inward pressure	= 6.7 mm Hg

Normal Physiology

- Na^+ resorption secondary to aldosterone
  - Occurs in distal convoluted tubules
  - Active exchange for K^+ and H^+ ions
  - Maintains extracellular volume and osmolarity
- Water resorption secondary to antidiuretic hormone
  - Occurs in collecting ducts
  - Modulated by intracranial osmoreceptors and atrial stretch receptors

Normal Physiology
Na^+ modulation

Renal perfusion decreases

JG apparatus secretes renin

Renin cleaves angiotensinogen to angiotensin I

Angiotensin I converted to II by ACE

Angiotensin II stimulates aldosterone secretion from adrenal cortex

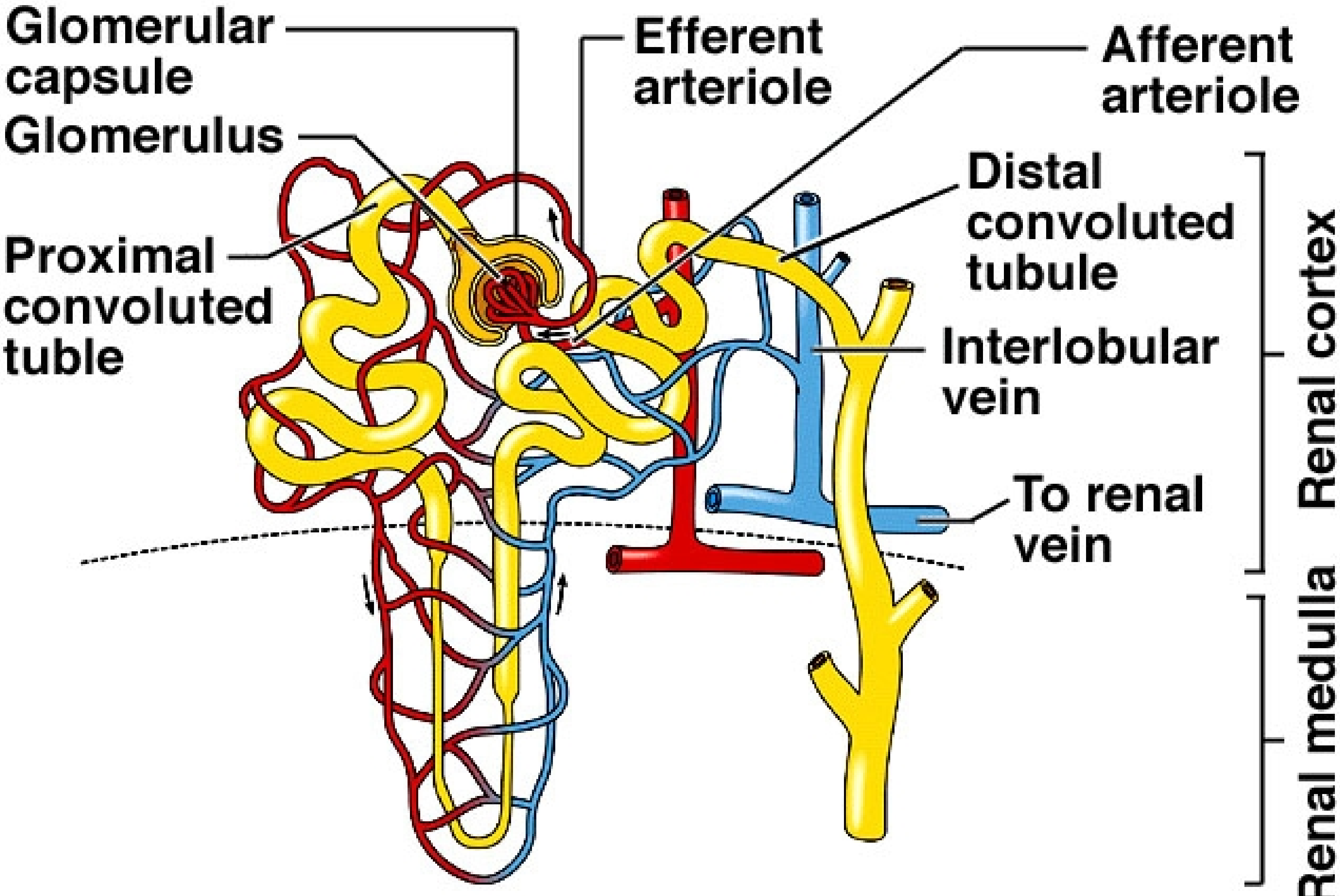
Aldosterone increases Na^+ resorption in exchange for K^+ in DCT

Extracellular volume expansion as water follows Na^+

Renal perfusion increases

Renin secretion ceases

Nephron Structure (1)



Normal Physiology
Na+ modulation

Result:

increased water consumption

increased water conservation

Increased water in body

increased volume and

decreased Na+ concentration

Dysfunction and/or Trauma

Leads to:

Decreased amount of water in body
Increased amount of Na^+ in the body
Increased blood osmolality
Decreased circulating blood volume

Regulation of body water

- ADH – antidiuretic hormone + thirst
  - Decreased amount of water in body
  - Increased amount of Na+ in the body
  - Increased blood osmolality
  - Decreased circulating blood volume
- Stimulate osmoreceptors in hypothalamus
  ADH released from posterior pituitary
  Increased thirst

Normal Physiology
Free H_2O modulation

Intracranial osmoreceptors detect increased plasma osmolarity

Adenohypophysis (posterior pituitary) secretes ADH

Renal collecting ducts become more permeable to water

Plasma osmolarity decreases

Intracranial osmoreceptors detect decreased osmolarity

Adenohypophysis ceases ADH secretion

Renal collecting ducts become less permeable to water

Plasma osmolarity increases

Acid/Base Balance

- The management of Hydrogen ions
  - measured as pH
  - maintained at 7.4 +/- 0.05
- Three mechanisms (differing effective intervals)
  - buffering systems in plasma
  - ventilatory changes for CO_2 excretion
  - Renal tubular excretion of Hydrogen ions

Acid/Base Balance

- Henderson-Hasselbalch
- Remember
  - $H_2O + CO_2 = H_2CO_3 = HCO_3^- + H^+$

$$pH = 6.1 + \log[HCO_3^-]/0.03 \times PaCO_2$$

or

$$[H^+] = 24 \times PaCO_2 / [HCO_3^-]$$

Acid/Base Balance
Extracellular Regulation

Pulmonary regulation of $PaCO_2$ and renal tubular regulation of HCO_3^- are important determinants of extracellular pH.

Basically, the pH is determined by the ratio of

$[HCO_3^- / H_2CO_3]$

- Normally 20:1 (7.40)
- As one increases, the other increases to re-establish the 20:1 ratio

Acid/Base Balance
Intracellular Regulation

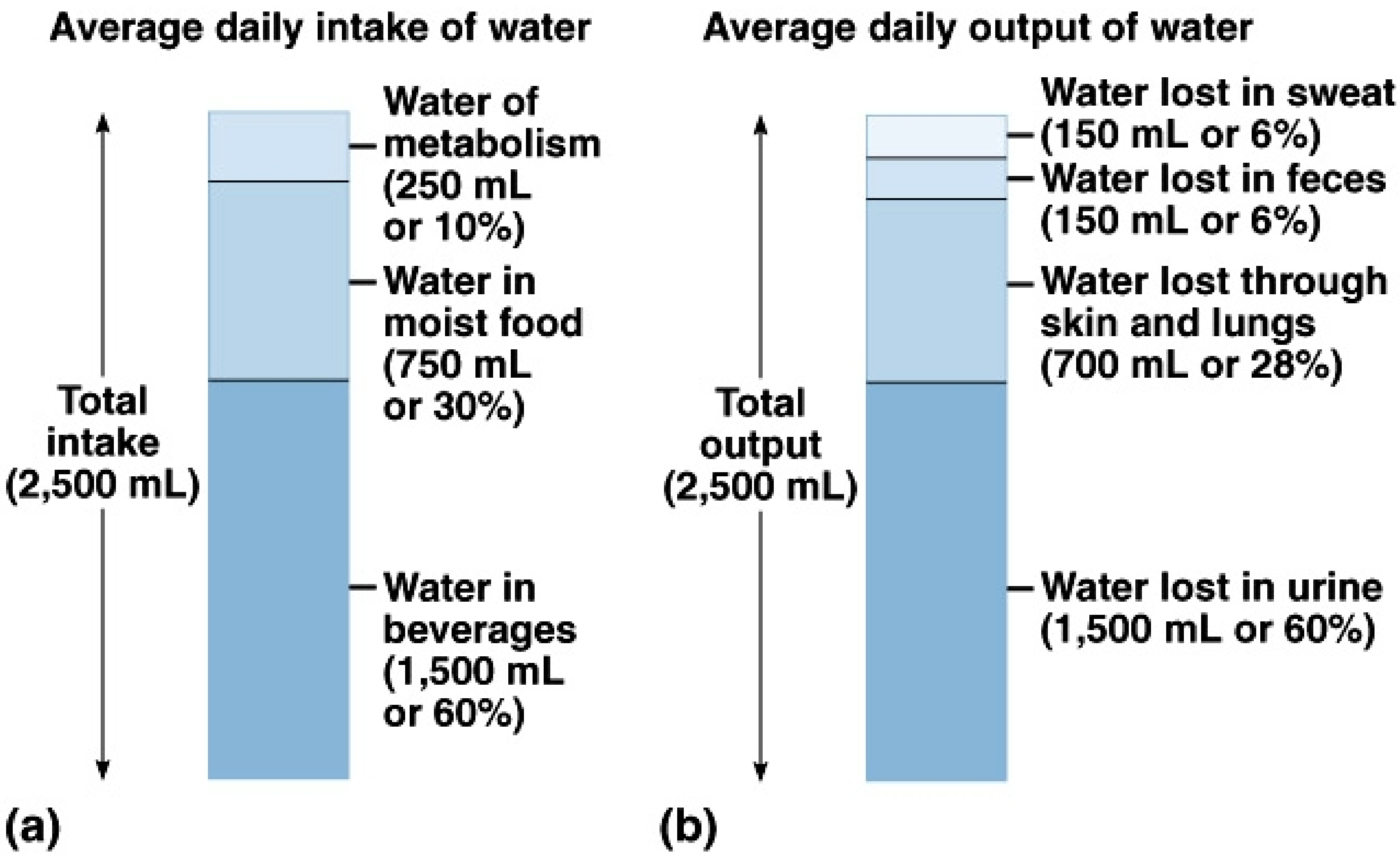
- Intracellular buffering
  - Excessive CO_2 retention or excretion
    - 50% of fixed acid loads (lactate)
    - 95% of hydrogen ion changes
  - Reciprocal K^+ ion exchange
    - Alkalosis
      - H^+ moves extracellularly
      - K^+ moves intracellularly
    - Acidosis
      - H^+ moves intracellularly
      - K^+ moves extracellularly
  - This can have significant clinical effect, especially regarding myocardial function

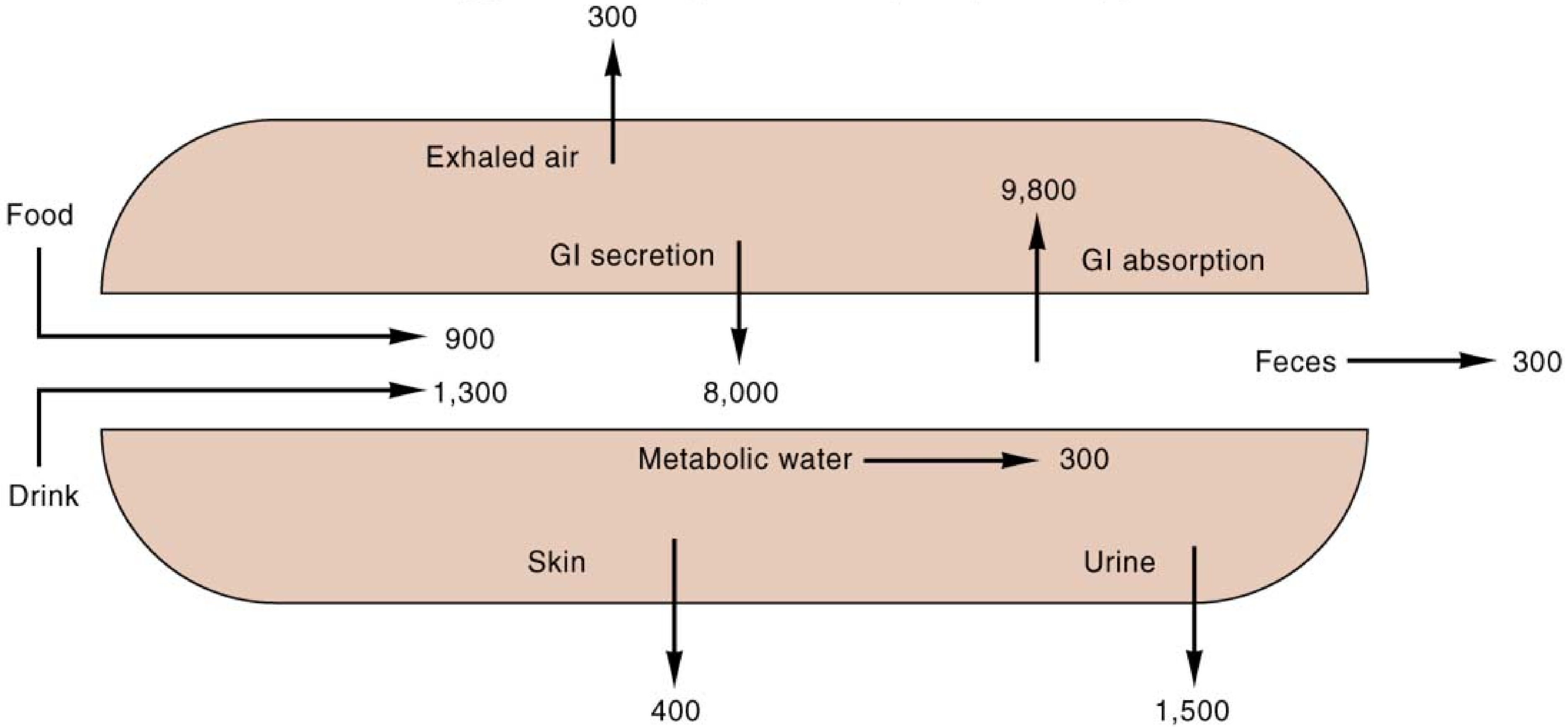
Fluids and Electolytes in the Postoperative Period

- Maintenance
- Resuscitation
- Replacement of Losses

Fluids and Electrolytes in the Postoperative Period

- Maintenance
  - Normal daily outputs
    - Urine = 12-15 cc/kg
    - Stool = 3 cc/kg
    - Sweat = 1.5 cc/kg
    - Respiratory and Skin insensible losses = 10 cc/kg
      - Increased by 8%/degree F for fever
  - Normal daily endogenous input
    - Oxidation of carbohydrates and fat = 3 cc/kg
  - Standard nomograms estimate daily requirements


Average daily intake of water
Water of metabolism (250 mL or 10%)
Water in moist food (750 mL or 30%)
Water in beverages (1,500 mL or 60%)
Total intake (2,500 mL)
(a)
Average daily output of water
Water lost in sweat (150 mL or 6%)
Water lost in feces (150 mL or 6%)
Water lost through skin and lungs (700 mL or 28%)
Water lost in urine (1,500 mL or 60%)
Total output (2,500 mL)
(b)


300
Exhaled air
Food
9,800
GI secretion
GI absorption
900
Feces
300
1,300
8,000
Metabolic water
300
Drink
Skin
Urine
400
1,500

Fluids and Electrolytes in the Postoperative Period

- Third Space Fluid Losses
  - Fluids sequestered into extracellular and intersitial spaces
    - Peritonitis
    - Intestinal obstruction
    - Soft tissue inflammation/edema
    - Traumatic losses
  - Evidence of diminished volume
    - Hemodynamic changes
      - Tachycardia
      - Narrowed pulse pressures
      - Hypotension

Edema

The accumulation of fluid within the interstitial spaces.

Leads to:

- increased hydrostatic pressure
- lowered plasma osmotic pressure
- increased capillary membrane permeability
- lymphatic channel obstruction

Hydrostatic pressure increases

Venous obstruction:

thrombophlebitis (inflammation of veins)

hepatic obstruction

tight clothing on extremities

prolonged standing

Salt or water retention

congestive heart failure

renal failure

Decreased plasma osmotic pressure

↓ plasma albumin (liver disease or protein malnutrition)

plasma proteins lost in :

glomerular diseases of kidney

hemorrhage, burns, open wounds and cirrhosis of liver

Increased capillary permeability:

Inflammation

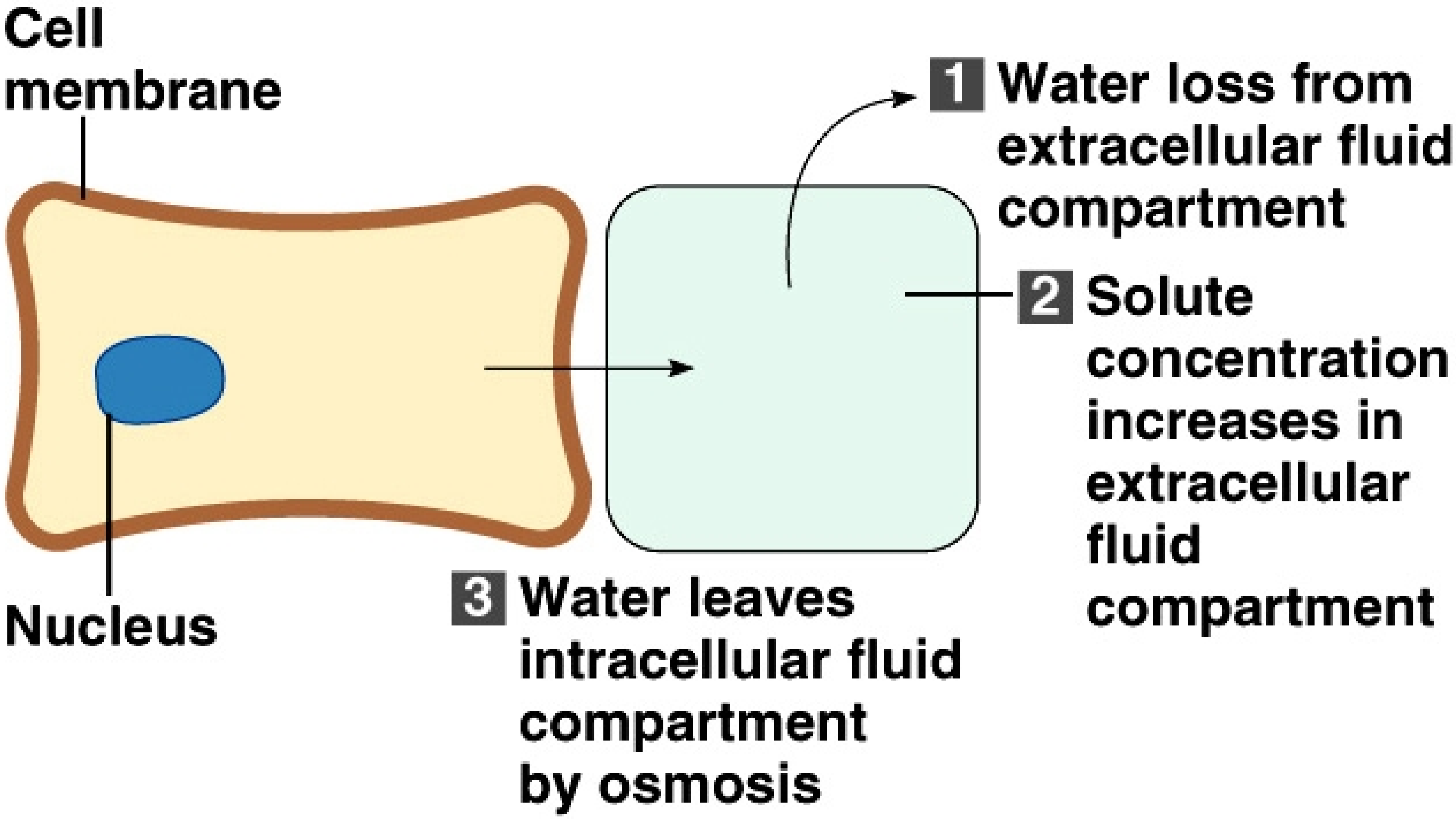
immune responses

Lymphatic channels blocked:

surgical removal
infection involving lymphatics
lymphedema

Electrolyte imbalances: Sodium

- Hypernatremia (high levels of sodium)
  - Plasma $Na^+ > 145$ mEq / L
  - Due to ↑ Na^+ or ↓ water
  - Water moves from ICF → ECF
  - Cells dehydrate


Cell membrane
1 Water loss from extracellular fluid compartment
2 Solute concentration increases in extracellular fluid compartment
Nucleus
3 Water leaves intracellular fluid compartment by osmosis

Hypernatremia

- Causes
  - Hypertonic IV soln.
  - Oversecretion of aldosterone
  - Loss of pure water
    - Long term sweating with chronic fever
    - Respiratory infection → water vapor loss
    - Diabetes – polyuria
  - Insufficient intake of water (hypodipsia)

Clinical manifestations of Hypernatremia

- Thirst
- Lethargy
- Neurological dysfunction due to dehydration of brain cells
- Decreased vascular volume

Treatment of Hypernatremia

- Lower serum Na+
  - Isotonic salt-free IV fluid
  - Oral solutions preferable

Hyponatremia

- Overall decrease in Na+ in ECF
- Two types: depletional and dilutional
- Depletional Hyponatremia

  Na+ loss:

  - diuretics, chronic vomiting
  - Chronic diarrhea
  - Decreased aldosterone
  - Decreased Na+ intake

- Dilutional Hyponatremia:
  - Renal dysfunction with ↑ intake of hypotonic fluids
  - Excessive sweating→ increased thirst → intake of excessive amounts of pure water
  - Syndrome of Inappropriate ADH (SIADH) or oliguric renal failure, severe congestive heart failure, cirrhosis all lead to:
    - Impaired renal excretion of water
  - Hyperglycemia – attracts water

Clinical manifestations of Hyponatremia

- Neurological symptoms
  - Lethargy, headache, confusion, apprehension, depressed reflexes, seizures and coma
- Muscle symptoms
  - Cramps, weakness, fatigue
- Gastrointestinal symptoms
  - Nausea, vomiting, abdominal cramps, and diarrhea
- Tx – limit water intake or discontinue meds

Hypokalemia

- Serum $K^+ < 3.5$ mEq /L
- Beware if diabetic
  - Insulin gets K^+ into cell
  - Ketoacidosis – H^+ replaces K^+, which is lost in urine
- β – adrenergic drugs or epinephrine

Causes of Hypokalemia

- Decreased intake of K^+
- Increased K^+ loss
  - Chronic diuretics
  - Acid/base imbalance
  - Trauma and stress
  - Increased aldosterone
  - Redistribution between ICF and ECF

Clinical manifestations of Hypokalemia

- Neuromuscular disorders
  - Weakness, flaccid paralysis, respiratory arrest, constipation
- Dysrhythmias, appearance of U wave
- Postural hypotension
- Cardiac arrest
- Others – table 6-5
- Treatment-
  - Increase K^+ intake, but slowly, preferably by foods

Hyperkalemia

- Serum K+ > 5.5 mEq / L
- Check for renal disease
- Massive cellular trauma
- Insulin deficiency
- Addison's disease
- Potassium sparing diuretics
- Decreased blood pH
- Exercise causes K+ to move out of cells

Clinical manifestations of Hyperkalemia

- Early – hyperactive muscles , paresthesia
- Late - Muscle weakness, flaccid paralysis
- Change in ECG pattern
- Dysrhythmias
- Bradycardia , heart block, cardiac arrest

Treatment of Hyperkalemia

- If time, decrease intake and increase renal excretion
- Insulin + glucose
- Bicarbonate
- Ca^{++} counters effect on heart

Calcium Imbalances

- Most in ECF
- Regulated by:
  - Parathyroid hormone
    - ↑Blood Ca^{++} by stimulating osteoclasts
    - ↑GI absorption and renal retention
  - Calcitonin from the thyroid gland
    - Promotes bone formation
    - ↑ renal excretion

Hypercalcemia

- Results from:
  - Hyperparathyroidism
  - Hypothyroid states
  - Renal disease
  - Excessive intake of vitamin D
  - Milk-alkali syndrome
  - Certain drugs
  - Malignant tumors – hypercalcemia of malignancy
    - Tumor products promote bone breakdown
    - Tumor growth in bone causing Ca^{++} release

Hypercalcemia

- Usually also see hypophosphatemia
- Effects:
  - Many nonspecific – fatigue, weakness, lethargy
  - Increases formation of kidney stones and pancreatic stones
  - Muscle cramps
  - Bradycardia, cardiac arrest
  - Pain
  - GI activity also common
    - Nausea, abdominal cramps
    - Diarrhea / constipation
  - Metastatic calcification

Hypocalcemia

- Hyperactive neuromuscular reflexes and tetany differentiate it from hypercalcemia
- Convulsions in severe cases
- Caused by:
  - Renal failure
  - Lack of vitamin D
  - Suppression of parathyroid function
  - Hypersecretion of calcitonin
  - Malabsorption states
  - Abnormal intestinal acidity and acid/ base bal.
  - Widespread infection or peritoneal inflammation

Hypocalcemia

- Diagnosis:
  - Chvostek's sign
  - Trousseau's sign
- Treatment
  - IV calcium for acute
  - Oral calcium and vitamin D for chronic

?