FLUIDS AND ELECTOLYTES

DR : Khalil Mazen Abu Nada

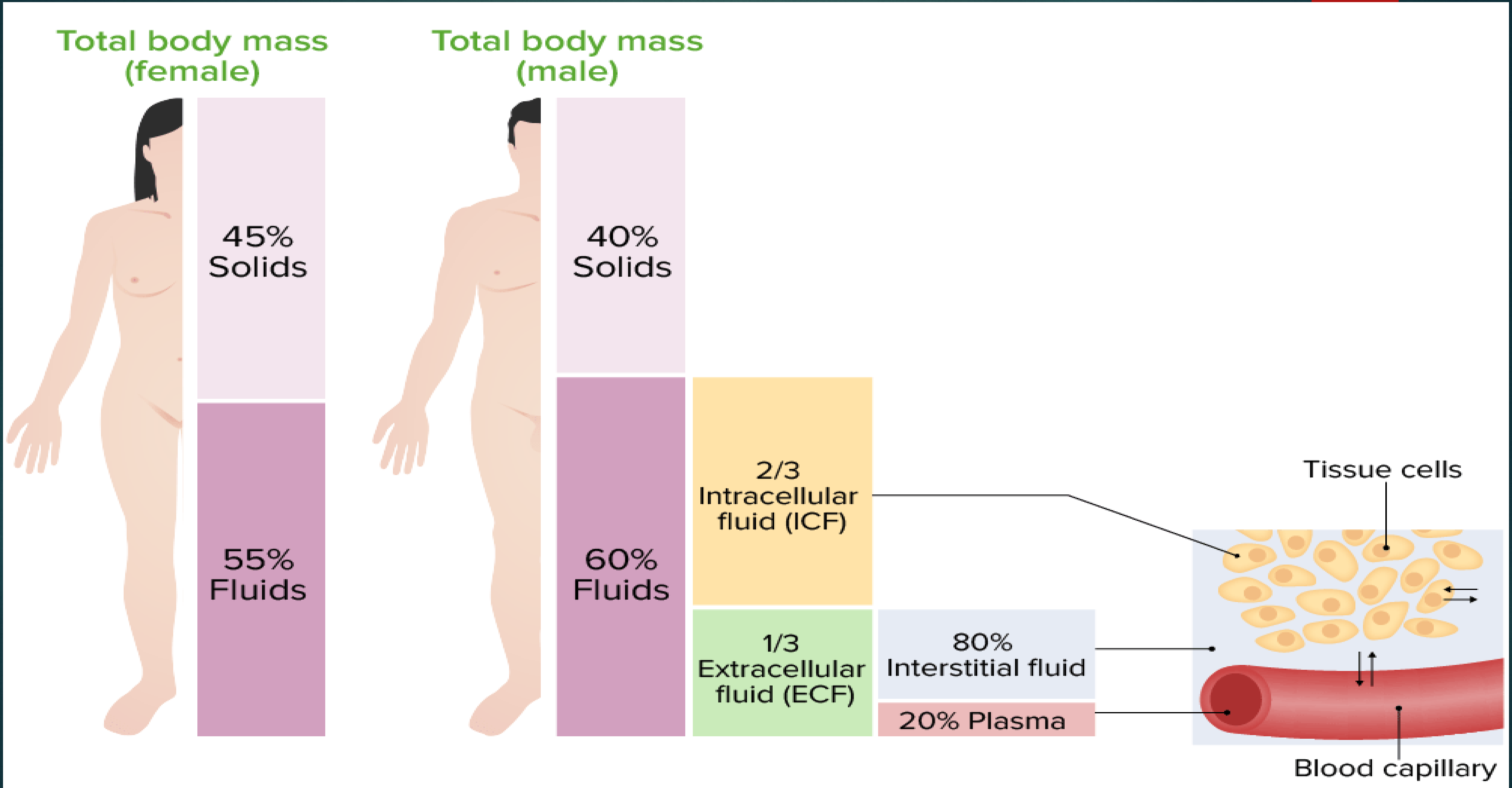
Overview

Water in the adult human body makes up approximately 60% of the total body weight. The fluid is distributed in various organs, organ systems, and tissues. The sum of the water in these tissues is known as total body water.

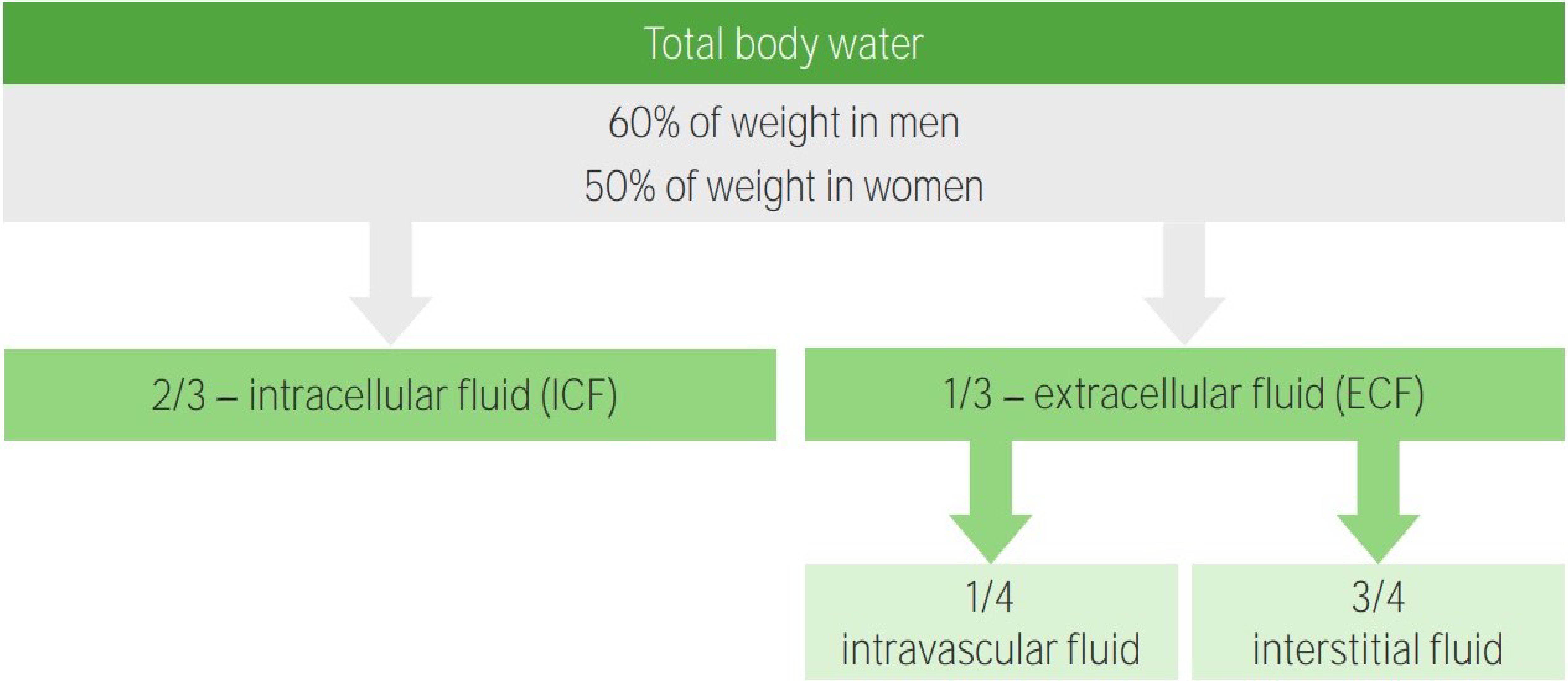
- Percentage of water in the body changes with the development of the body:
  - As high as 70% of the body mass in infants
  - 50%–60% in normal adults
  - As low as 45% in older adults
- Weight of total body water accounts for:
  - 60% of lean weight in men
  - 50% of lean weight in women

The total body water is distributed primarily between 2 compartments, namely, extracellular fluid (ECF) and intracellular fluid (ICF) compartments.

- ECF is present outside cells:
  - Makes up about ⅓ of total body water
  - ECF includes:
    - Intravascular fluid (¼ of ECF): primary component of plasma
    - Interstitial fluid (¾ of ECF): lies outside blood vessels
- ICF is present inside cells:
  - Makes up about ⅔ of total body water
  - Principal component of the cytoplasm of cells


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

Total body water = percentage of lean body weight



Movement of fluid between compartments

Fluid is separated into compartments by semipermeable membranes. The membranes are highly permeable to water but require energy to transport ions.

Distribution of fluid between intracellular and extracellular compartments is determined by the concentration of Na^+, chloride (Cl^-), and other electrolytes

Water moves between compartments following osmotic gradients.

A change in the relative concentration of solute or water will cause water to shift between compartments.

2 processes are responsible for the passive movement of fluid across membranes:

- Diffusion: A substance passes from an area of higher concentration to an area of lower concentration.
- Osmosis: Water is drawn across a membrane toward a region where there is a higher solute concentration.

Changes in the Fluid Compartment

Hypo-osmotic volume expansion

Results in an increase in total body water and reduction in osmolality
Can be seen in cases of:
- Excessive water intake
- SIADH

Changes in ECF constituents:
- Decrease in Na^+ level
- Decrease in total protein

Endocrine response:
- Decrease in aldosterone level (suppressed by hypervolemia)
- Decrease in antidiuretic hormone level (e.g., diabetes insipidus)

Hypo-osmotic volume contraction

Decrease in total body water along with a decrease in the total osmolality of solutes
Usually seen in the case of adrenal insufficiency
Changes in ECF result in:
- Reduction in blood pressure due to decrease in volume
- Decrease in Na^+ level
- Increase in total protein level

Endocrine response:
- Increase in aldosteron (stimulated by hypovolemia and hypokalemia)
- No change in antidiuretic hormone level

Iso-osmotic volume expansion

- Volume expansion where there is no change in osmolality
- Seen with IV solution volume expansion
- Changes in ECF result in:
  - Increase in blood pressure
  - No change in Na^+ level
  - Decrease in total protein level
- Endocrine response to iso-osmolar volume expansion:
  - Decrease in aldosterone (suppressed by volume expansion)
  - No change in antidiuretic hormone level

Iso-osmotic volume contraction

- Volume contraction occurring without any change in osmolality
- Seen in cases of iso-osmotic fluid loss (e.g., diarrhea and vomiting)
- Changes in ECF result in:
  - Decrease in blood pressure
  - No change in Na^+ level
  - Increase in total protein level
- Endocrine response:
  - Increase in aldosterone levels (stimulated by volume contraction)
  - No change in antidiuretic hormone level

Hyper-osmotic volume expansion

Increase in osmolality
alongside the increase in volume

Seen in cases of:

- Aldosterone hypersecretion
- Ingestion of salty foods
- Individuals with a tumor

Changes in ECF result in:

- Increase in blood pressure
- Increase in Na^+ level
- Reduction in total protein level

Endocrine response:

- Reduction in aldosterone level
- Increase in antidiuretic hormone level

Hyper-osmotic volume contraction

- Reduction of total body water but osmolality increases:
  - Seen in cases of dehydration
  - Sweat contains more water than solute; thus, excessive sweating results in hyperosmotic volume contraction.
- Changes in ECF result in:
  - Decrease in blood pressure
  - Increase in Na^+ level
  - Increase in total protein level
- Endocrine response:
  - Increase in aldosterone level
  - Increase in antidiuretic hormone level

Body Fluid Composition

Body fluid compartments contain water, ions and osmolar molecules at different concentrations.

Relative concentration of the components depends on the exchange between cells and tissues in the body which is determined by the activity of transporters on cell membranes.

Composition of each fluid compartment is rigorously maintained by the continuous movement of water and other substances between compartments.

Ion	Concentration/mol m^3	
	SBF	Human Blood Plasma
Na^+	142.0	142.0
K^+	5.0	5.0
Mg^{2+}	1.5	1.5
Ca^{2+}	2.5	2.5
Cl^-	147.8	103.0
HCO_3^-	4.2	27.0
HPO_4^{2-}	1.0	1.0
SO_4^{2-}	0.5	0.5

Electrolyte balance

The ICF and ECF compartments have different and unequal electrolyte distribution to maintain physiological function.

Intracellular fluid :

- K^+: main intracellular cation
- Mg^{2+}
- Phosphates ($HPO_4^{2-}/H_2PO_4^-$) electrically balance the intracellular cations along with the negatively charged proteins.

Extracellular fluid :

- Na^+:
  - Main extracellular cation
  - Important in determining serum osmolarity (solutes/L)
  - Controls ECF volume and water distribution in the body
- Calcium (Ca^{2+})
- Chloride and HCO_3^-:
  - Chloride is the most abundant anion in the ECF.
  - Anions balance the extracellular cations.

Sodium

Overview

- Normal range: 135–145 mEq/L
- 95% of the ingested Na^+ is absorbed by the gut.
- Excretion:
  - 90%–95% excreted by the kidneys
  - Remainder through feces and sweat
- Functions:
  - Establishes osmotic pressure
  - Na^+ transcellular gradient:
    - Regulated by ATP-dependent cell membrane channels : Na^+-K^+ ATPase
    - Essential in maintaining the resting membrane potential
  - Transient influx of Na^+ generates action potential that leads to:
    - Nerve conduction
    - Muscle contraction
    - Cardiac conduction
    - Activation of intracellular signaling pathways

Regulation

Na^+ homeostasis:

Regulated through the kidneys (majority in the proximal tubules)
Occurs by sensing changes in the effective circulating volume (ECV):

- ↑ Na^+ causes ↑ ECV
- ↓ Na^+ causes ↓ ECV

RAAS :

Juxtaglomerular apparatus and carotid sinus /aortic arch baroreceptors trigger renin release from kidneys when ECV ↓

If Na^+ is low: ↓ ECV → renin → angiotensin (causing vasoconstriction) → **aldosterone** is secreted:

- Na^+ reabsorption from the renal tubules
- Promotes K^+ secretion in urine

Natriuretic peptides :

Includes atrial natriuretic peptide and BNP

If Na^+ is high: ↑ ECV → cardiac baroreceptors sense an ↑ in ECV → **natriuretic peptide** is secreted

- Stimulates urinary Na^+ excretion (natriuresis)
- Also promotes excretion of water
- Inhibits angiotensin II production

Potassium

Overview

- Normal range: 3.5–5.2 mEq/L
- Excretion: 90% is excreted in the urine, 10% in feces
- Functions:
  - Resting cellular membrane potential and the propagation of action potentials
  - Hormone secretion and action
  - Vascular tone
  - Systemic BP control
  - GI motility
  - Glucose and insulin metabolism
  - Concentrating ability of kidneys and pH regulation

Regulation

Kidneys are responsible for 90%–95% of the overall K^+ regulation.

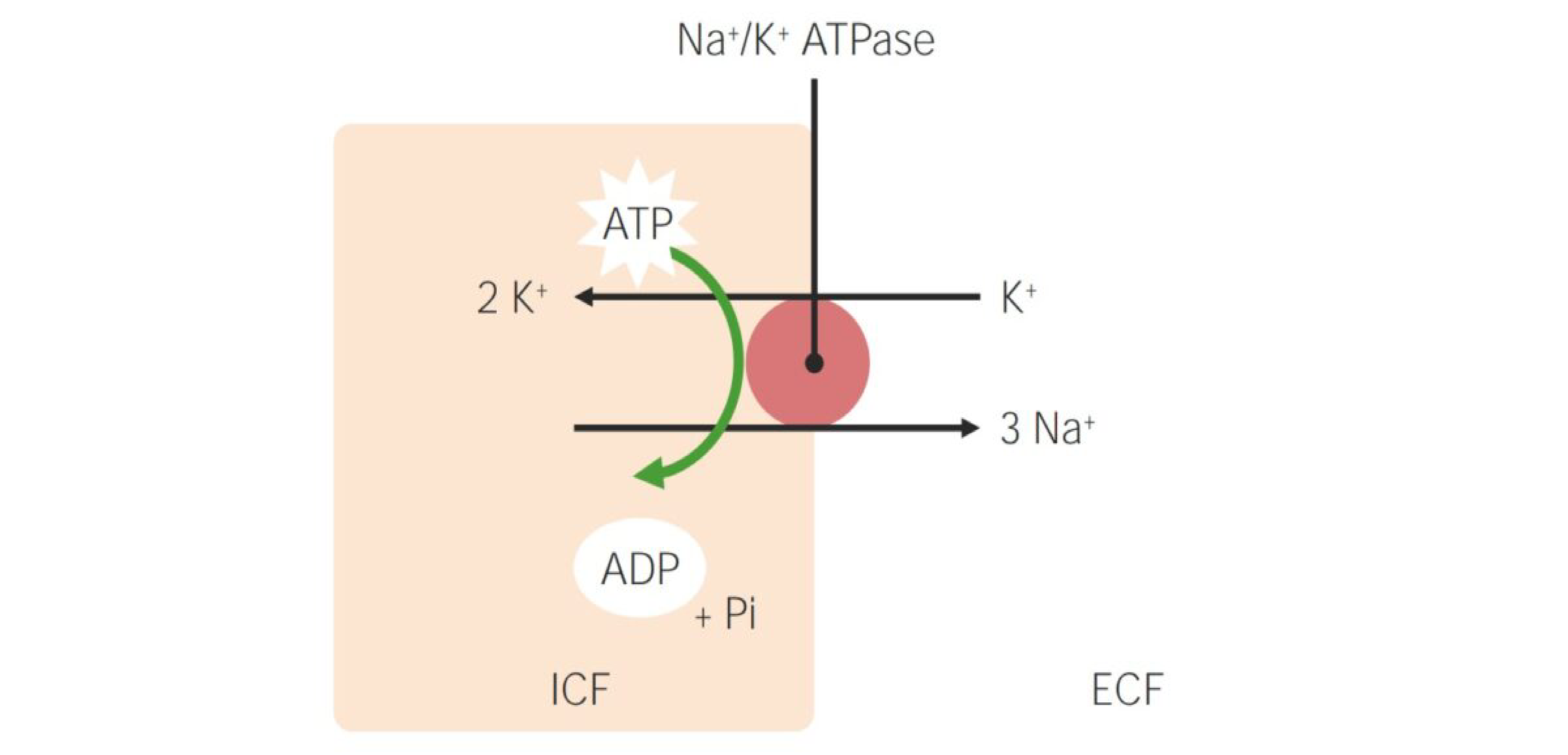
- ↑ ECF K^+ level triggers mechanisms for renal K+ excretion
- Aldosterone:
  - Stimulates Na+-K^+ ATPase
  - Increases K+ excretion into distal tubules and collecting ducts

Transcellular shifting (mediated by insulin and sympathetic nervous system) prevents the excessive increase in ECF K^+ levels.

- β2 receptor activation:
  - Stimulates K^+ uptake into cells (primarily into muscle and liver cells)
  - β2 antagonists block K^+ uptake and cause hyperkalemia.
  - α1 receptor activation causes a shift of K^+ out of the cells.
- **Insulin**:
  - Stimulates Na^+-K^+ ATPase
  - Increases K^+ uptake into cells
  - Responsible for dietary uptake of K^+ into cells after a meal

Other factors:

- Acid-base status:
  - Acidosis causes K^+ to move out of cells.
  - Alkalosis causes K^+ to move into cells.
- Exercise: moves K^+ out of muscle cells


Na+/K+ ATPase
ATP
2 K+
K+
3 Na+
ADP
+ Pi
ICF
ECF

Bicarbonate

Overview

Normal range: 22–28 mEq/L

Functions:

- Indirect indicator of total CO_2 level in serum
- Vital component of pH regulation
- HCO_3^- buffer system: the balance between carbonic acid (H_2CO_3), HCO_3^-, and CO_2, which maintains blood pH :

$$CO_2 + H_2O \quad H_2CO_3 \quad H^+ + HCO_3^-$$

Regulation

To maintain homeostasis, the following mechanisms are triggered to keep the pH in the physiological range (7.35–7.45):

Respiratory compensation :

Changes in ventilation compensate for changes in the blood HCO_3^- levels.

Lungs respond to metabolic **acidosis** by **↑ventilation**

Lungs respond to metabolic **alkalosis** by **↓ventilation**

Renal compensation :

Kidneys regulate the secretion of H^+ into the urine, and, at the same time, reabsorb HCO_3^- (normally 100% is absorbed).

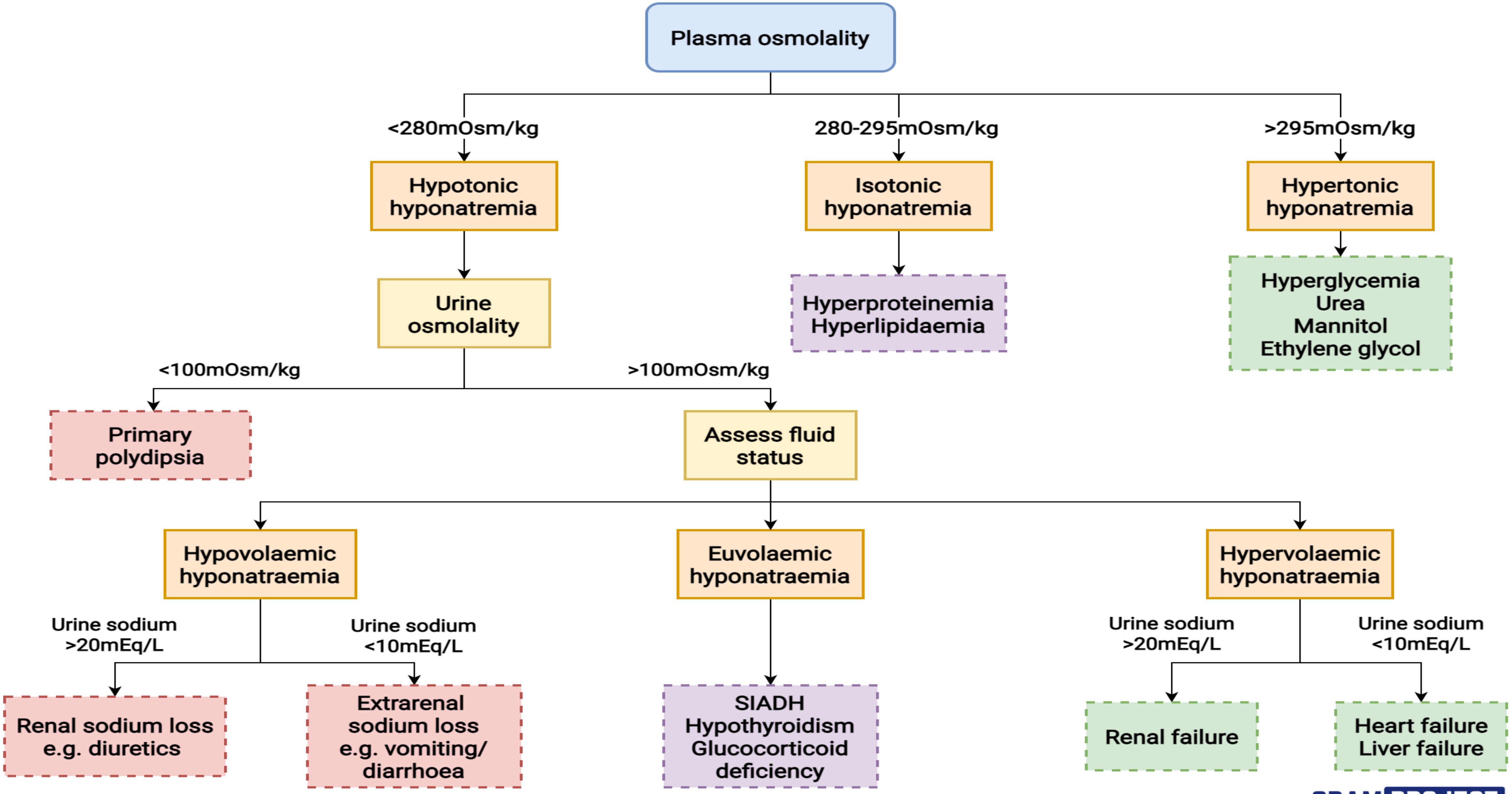
Kidneys respond to respiratory **acidosis** by **increasing serum HCO_3^-** levels through ↑ secretion of H^+

Kidneys respond to respiratory **alkalosis** by **decreasing serum HCO_3^-** through ↓ secretion of H^+ and urinary excretion of HCO_3^-

Related disorders

- Metabolic disorders: primarily caused by abnormal HCO_3^- levels
  - Metabolic acidosis
  - Metabolic alkalosis
- Respiratory disorders: primarily caused by abnormal CO_2 levels
  - Respiratory acidosis
  - Respiratory alkalosis

Hyponatremia



GRAM PROJECT

HYPERNATREMIA

"THE MODEL"

(Causes of ↑ serum sodium)

- **M** Medications, meals (too much sodium intake)
- **O** Osmotic diuretics
- **D** Diabetes insipidus
- **E** Excessive H_2O loss
- **L** Low H_2O intake

HYPOkalemia:

More at: RegisteredNurseRN.com

Normal Level: 3.5-5 mEq/L

Causes:

"Your body is trying to **DITCH** K+."

Drugs: loop diuretics "Furosemide", laxatives, glucocorticoids "Hydrocortisone"

Inadequate consumption of K+

Too much water intake

Cushing's Syndrome (causes kidneys to excrete K+)

Heavy fluid loss: (nasogastric tube suction, vomiting, diarrhea, wound drainage)

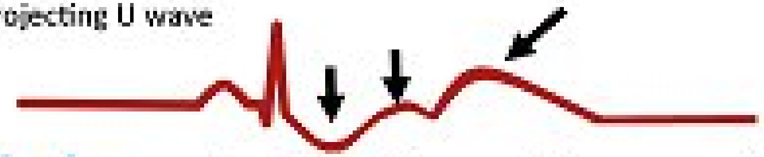
*S & S:

*Asymptomatic until moderately to severely LOW

"7 L's (low)"

1. **L**ethargic
2. **L**ow, shallow respirations...failure
3. **L**ethal cardiac dysrhythmias

*ST depression, shallow T wave, projecting U wave



4. **L**ots of urine (freq. & large volume)
5. **L**eg cramps
6. **L**imp muscles
7. **L**ow blood pressure (severe)

Image Credit (top left): Aleksandra Gigowska/Shutterstock.com

Image Credit (PQRST complex): Simple Deigns/Shutterstock.com...Additions by: RegisteredNurseRN

HYPERkalemia:

More at: RegisteredNurseRN.com

Normal Level: **3.5-5 mEq/L**

Causes:

"The body **CARED** too much about K+."

Cellular movement of K+ from intracellular to extracellular (burns, tissue damage, etc.)

Adrenal Insufficiency w/ Addison's Disease

Renal Failure

Excessive K+ intake

Drugs (potassium-sparing drugs: spironolactone, ACE inhibitors, NSAIDS)

S & S:

"Murder"

Muscle weakness

Urine output little or none (renal failure)

Respiratory failure (due to muscle weakness)

Decreased cardiac contractility (weak pulse/low HR)

Early: muscle twitches/cramps

Rhythm changes: Tall peaked T waves, prolonged PR interval