Water And Electrolytes Balance and Imbalance

Water is an essential body constituent, and homeostatic processes are important to ensure that the total water balance is maintained within narrow limits, and the distribution of water among the vascular, interstitial and intracellular compartments is maintained.

The body maintains a balance of water intake and output by a series of negative feedback loops involving the endocrine system and autonomic nervous system.

Distribution of Water:

In a 70-kg man, the Total Body Water (TBW) is about 42 L and contributes about 60 per cent of the total body weight.

Two thirds of the water are in the Intra Cellular Fluid (ICF), and one third is in the Extra Cellular Fluid (ECF). Because the plasma membrane of most cells is highly permeable to water, ICF and ECF are in osmotic equilibrium.

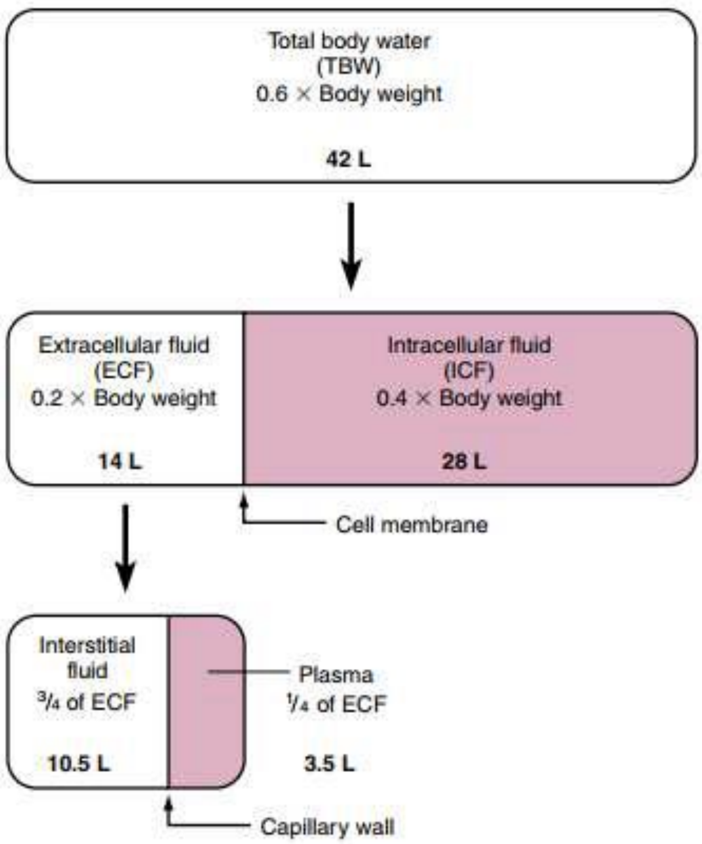
The ECF is divided into a vascular compartment (plasma) and an interstitial fluid compartment.

Expressed as percentages of body weight, the volumes of total body water, ICF, and ECF are:

Total body water = 0.6 × (body weight)

ICF = 0.4 × (body weight)

ECF = 0.2 × (body weight)



Water Intake—Water is supplied to the body by the following processes:

a. Dietary liquids

b. Solid foods

c. Oxidation of foodstuffs: It is obtained from the combustion of fats, proteins and carbohydrates. The oxidation of

fats yields 107 ml/100 gm, proteins 41 ml/100 gm and carbohydrates 56 ml/100 gm.

Water output: Water is lost from the body by the following routs:

a. Urine

b. Respiration

c. Lactation

d. Faeces

e. Evaporation from skin and lungs

f. Eyes (tears)

The balance sheet of water intake and loss is given as:

Water intake			*Water loss*		
Drinks	48 %	1350 ml	Lungs	12%	500 ml
Solid	40 %	900 ml	Skin	24%	700 ml
Oxidation of food	12%	450 ml	Urine	56%	1400 ml
			Faeces	08%	100 ml
	100%	2700 ml		100%	2700 ml

Disturbances of Water Homeostasis

- Gain or loss of extracellular fluid volume.
- Gain or loss of solute.

In many instances disturbances of water homeostasis involve imbalances of both volume and solutes.

Four specific examples of water homeostasis:

- Hypervolemia
- Overhydration
- Hypovolemia
- Dehydration

Hypervolemia:

Water and solute (increase)

ECF (increase)

Plasma osmolarity may remain normal.

Overhydration:

Too much water is taken by drinking

volume increases

Solute is not present

plasma osmolarity decreases.

Hypovolemia:

Occurs when water and solutes are lost at the same time.

Loss of plasma volume.

Plasma osmolarity usually remains normal

Volume is low.

Too much IV fluids can increase plasma volume dramatically, but with an isotonic solution the plasma osmolarity would remain normal and result in hypervolemia.

Dehydration:

Water lost

Solute remain

Loss of volume

Plasma osmolarity increases.

```
+----------------+        +----------------+
|  Hypervolemia  |        |  Overhydration |
+----------------+        +----------------+
| Water ↑        |        | Water ↑        |
| Solutes ↑      |        | Solutes →      |
| ECF ↑          |        | ECF ↑          |
| Plasma         |        | Plasma         |
| Osmolarity →   |        | Osmolarity ↓   |
+----------------+        +----------------+

+----------------+        +----------------+
|  Hypovolemia   |        |  Dehydration   |
+----------------+        +----------------+
| Water ↓        |        | Water ↓        |
| Solutes ↓      |        | Solutes →      |
| ECF ↓          |        | ECF ↓          |
| Plasma         |        | Plasma         |
| Osmolarity →   |        | Osmolarity ↑   |
+----------------+        +----------------+
```

Mechanisms of Fluid Balance

- The body have mechanisms that regulate fluid levels within a narrow range, the body fluids remain within certain physiological limits, an important aspect of homeostasis, four primary mechanisms regulate fluid homeostasis :

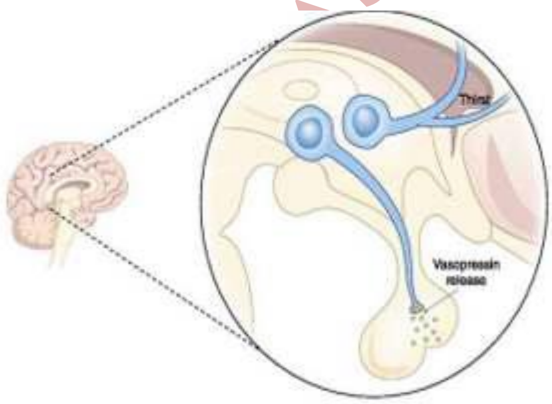
-Antidiuretic hormone or ADH

-Thirst mechanism

-Aldosterone

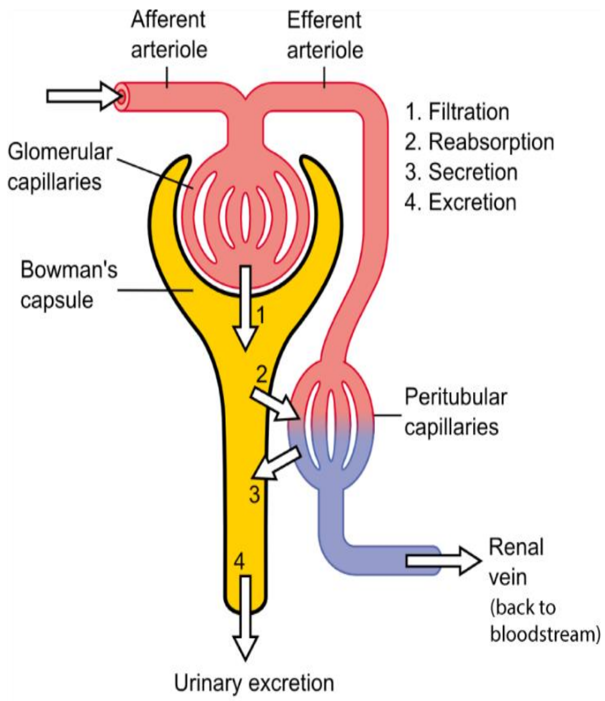
-Sympathetic nervous system

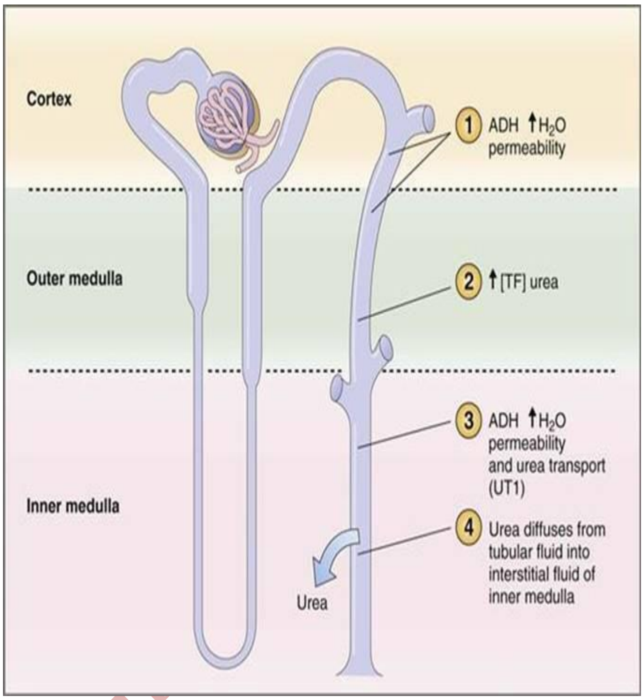
- **Kidney**   * **Nervous system**
- **Effect of ADH**
- When loses water by sweating, plasma becomes more concentrated in solutes.
- Osmoreceptors in the hypothalamus detect the increased osmolarity or concentration of solutes in the plasma.
- In response to this increased concentration, antidiuretic hormone is released into the blood at the posterior pituitary.
- The target tissue for ADH is the late distal convoluted tubule and collecting duct cells in the kidney.



ADH in the Nephron

- These cells become permeable to water only in the presence of ADH.
- ADH promotes the addition of water channels into the cells of the late distal convoluted tubule and collecting duct, allowing water to move from the filtrate to the plasma by way of osmosis.
- ADH therefore increases the reabsorption of water.





Thirst Mechanism

• The thirst mechanism is the primary regulator of water intake and involves hormonal and neural input as well as voluntary behaviors.

• There are three major reasons why dehydration leads to thirst:

1. When saliva production decreases, the mouth and throat become dry. Impulses go from the dry mouth and throat to the thirst center in the hypothalamus, stimulating that area.
2. When you are dehydrated, blood osmotic pressure increases, stimulating osmoreceptors in the hypothalamus and the thirst center in the hypothalamus is now further activated.
3. Decreased blood volume causes a decrease in blood pressure that stimulates the release of renin from the kidney.

This causes the production of angiotensin II which stimulates the thirst center in the hypothalamus.

• Stimulation of the thirst center in the hypothalamus gives you the desire to drink.

Results of Fluid Ingestion

• This fluid ingestion:

1. Relieves the dryness in the mouth and throat.
2. Fluid ingestion also stimulates stretch receptors in the stomach and intestine to send inhibitory signals to the thirst center.
3. When normal fluid volume is restored, dehydration is relieved. Renin secretion from the kidney and angiotensin II now decreases to baseline levels.

Effect of Aldosterone

•When a person donates large amounts of blood, they lose salts as well as water. When electrolytes and water are lost at the same time, blood volume decreases, threatening hypovolemia.

•When a person experiences blood loss, blood pressure decreases.

•Because a hypovolemic person experiences a decrease in blood pressure, juxtaglomerular cells in the arterioles of the kidney release renin.

Renin to Aldosterone

• As renin travels through the bloodstream, it binds to an inactive plasma protein, angiotensinogen, activating it into angiotensin I.

• As angiotensin I passes through the lung and other capillaries, an enzyme called Angiotensin Converting Enzyme, or ACE, converts angiotensin I to angiotensin II.

• Angiotensin II continues through the blood stream until it reaches the adrenal gland. Here it stimulates the cells of the adrenal cortex to release the hormone aldosterone.

• Angiotensin II also has a vasoconstriction effect that helps to increase the blood pressure.

• Aldosterone can also be released when potassium concentrations in the blood are high.

Aldosterone in the Nephron

• In the absence of aldosterone, the cells in the late distal convoluted tubule and collecting ducts allow little sodium and potassium ions to pass because there are few sodium and potassium channels in the cell membrane facing the kidney tubule. There are also few sodium/potassium ATPase pumps on the basal side of these cells.

• Aldosterone exerts its effect by inserting additional channels in the late distal convoluted tubule and collecting duct of the kidney. This allows more sodium to move from the filtrate into the blood and potassium to move from the blood into the filtrate.

Sympathetic Stimulation

• A decrease in blood volume and therefore blood pressure will further stimulate the sympathetic nervous system.

• When blood pressure is low, baroreceptors in the heart, aortic arch, and carotid arteries send sensory information to the medulla.

• The information sent from the baroreceptors to the medulla will cause an increase in the sympathetic impulses to the kidney.

Sympathetic Stimulation in the Nephron

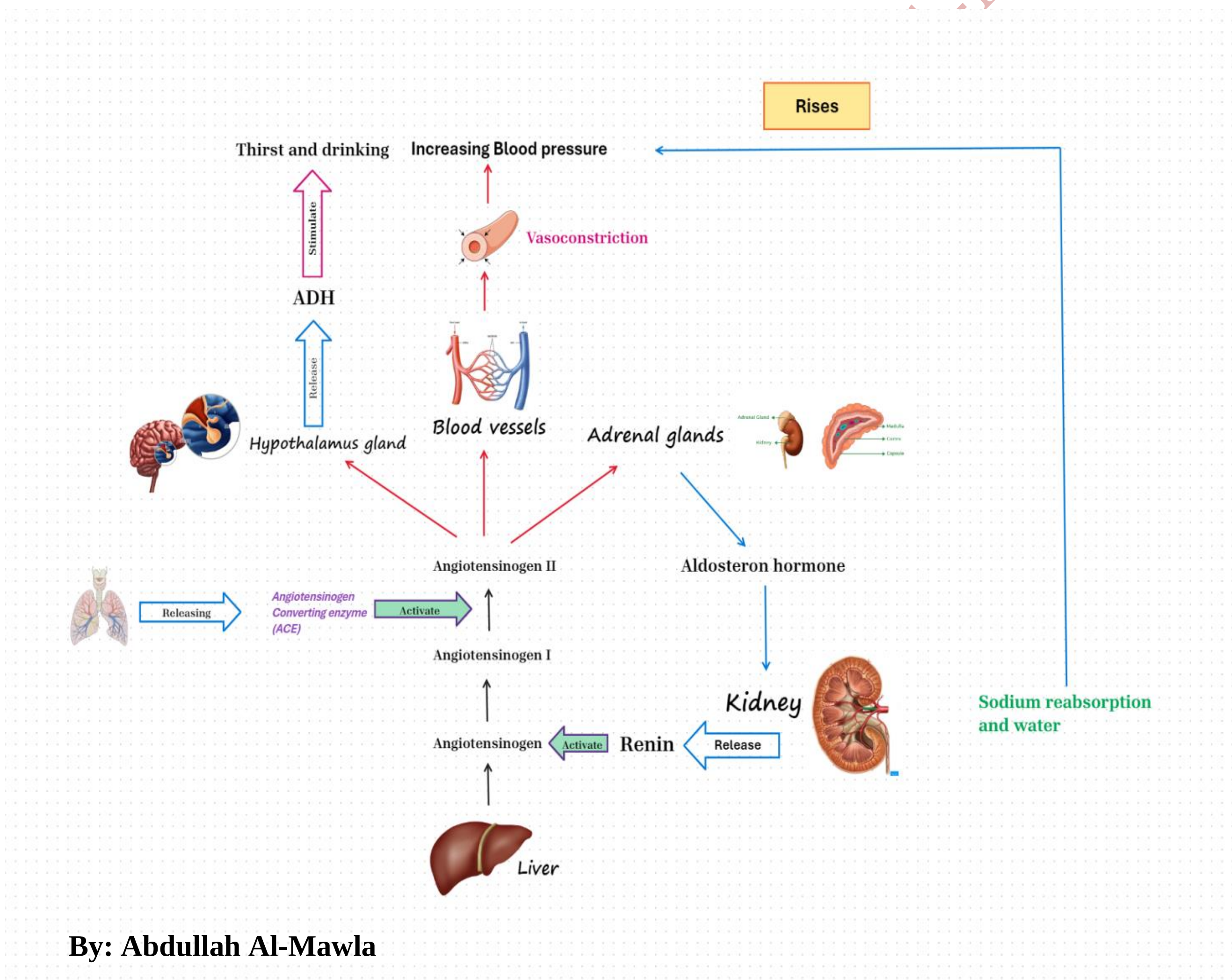
• Release of neurotransmitters from the sympathetic nerves in the kidney stimulates smooth muscle cells in the afferent arteriole to constrict.

• This process causes a decrease in blood flow into the glomerulus and a drop in glomerular filtration rate and results in less urine formation. Less water leaves the body.

• Sympathetic stimulation also causes the release of renin which, by stimulating aldosterone secretion, will increase the reabsorption of sodium.

• As a result, blood volume will stop decreasing and blood pressure may stabilize. However, because the blood pressure and blood volume have not yet returned to normal, the baroreceptors will continue to be stimulated to prevent further loss of blood volume.

• In order to bring this person back into to homeostasis, we need to increase the blood volume by drinking fluids. In fact, after an individual has given blood, they are encouraged to drink juice to increase their plasma level.



Minerals and trace elements metabolism

Minerals are inorganic substances mined from the earth. They are not of plant or animal origin. They exist naturally on and in the earth and many are critical parts of human tissue and are termed “essential” nutrients. Of the 92 naturally occurring elements, the 14 minerals that have been shown by research to be essential to human health are:

calcium, chromium, copper, fluorine, iodine, iron, magnesium, manganese, molybdenum, phosphorus, potassium, selenium, sodium and zinc.

Essential macro minerals are those needed in significant quantities (such as **calcium**) – usually measured in **milligrams**, and essential trace minerals are those needed in minute quantities (such as **selenium**) – usually measured in **micrograms** (one microgram [µcg] equals 1/1,000th of a milligram [mg]).

Minerals are required for a variety of physiological functions, their functions are:

1. Maintenance of osmotic pressure of cell
2. Transport of oxygen
3. Growth and maintenance of tissues and bones
4. Working of nervous system
5. Muscle contraction
6. Maintenance of electrolytic balance
7. Acid-base balance

Key Electrolytes and Their Distribution

Sodium (Na^{++}) :

Absorption and availability of sodium

- Intestinal sodium absorption is very efficient in both the small intestine and colon.
- Sodium is absorbed by a variety of processes. In the proximal intestine sodium is absorbed, in part by a solute dependent co-transport system, and is involved in nutrient absorption.
- In the more distal intestine and colon, sodium absorption is by a sodium/hydrogen interchange; in the colon this process is coupled to chloride/bicarbonate exchange.
- In the distal intestine and colon, the process is electro neutral and involves protein carriers.
- In the distal colon active sodium transport occurs against an electrochemical gradient.
    - **Main location**: Extracellular fluid.

- **Function**: Sodium is the major cation in the ECF and plays a key role in
  - Maintaining fluid balance
  - nerve impulse transmission
  - muscle contraction.
  - giving osmolarity and charge moves from the extracellular fluid into cells there is a change in charge and concentration
- **Concentration**:
  - **Plasma/ECF**: 135-145 mmol/L.
  - **ICF**: ~10 mmol/L.

Sodium depletion

- Sodium is lost largely via the urine, with only minimal loss occurring via the faeces or skin, unless there are abnormal situations such as diarrhea or excessive sweating. A reduced body sodium pool results in reduced extracellular fluid volume. Increased sodium loss in urine can occur in diseases, e.g., **diabetes mellitus** and **Addison's disease** (adrenal cortical insufficiency), following excessive doses of **diuretic drugs**, and in cases of **renal tubular damage**, as in **chronic renal failure**.
- -- Healthy kidneys maintain a consistent level of sodium in the body by adjusting the amount excreted in the urine. When sodium consumption and loss are not in balance, the total amount of sodium in the body is affected. The concentration of sodium in the blood may be
- **Too high (Hypernatremia)**

1. Water Loss without Sodium Loss

Dehydration: Lack of adequate water intake or excessive water loss (e.g., due to heat, diarrhea, or vomiting).

Diabetes Insipidus: This condition causes excessive urination due to a lack of antidiuretic hormone (ADH) or the kidneys' failure to respond to ADH.

Excessive Sweating: Significant water loss without adequate replacement can lead to hypernatremia.

2. Excessive Sodium Intake

Hypertonic IV Solutions: Administration of hypertonic saline (e.g., 3% saline) or sodium bicarbonate.

3. Renal Causes: In cases of renal diseases, the kidneys may lose the ability to concentrate urine properly, leading to excessive water loss.

4. Gastrointestinal Losses

Diarrhea: Especially when it is watery, leads to significant water loss without proportionate sodium loss.

Vomiting: Can also contribute to water loss, though sodium loss often accompanies it.

- ## Too low (Hyponatremia)

1. Excessive Water Intake (Water Intoxication) : Drinking large amounts of water can dilute sodium levels in the blood, leading to hyponatremia.

2. Syndrome of Inappropriate Antidiuretic Hormone Secretion (SIADH)

* SIADH: during the postoperative period ADH levels are often high, producing an increase in water reabsorption by the kidney. The hyponatremia becomes exaggerated when electrolyte-free fluids (e.g., 5% glucose in water) are used for intravenous fluid replacement.

3. Kidney Problems

4. Heart Failure: Congestive heart failure can lead to fluid retention, diluting sodium levels.

5. Liver Disease (Cirrhosis): Liver disease can cause fluid buildup in the body, contributing to low sodium levels.

6. Diuretic Use

7. Adrenal Insufficiency (Addison's Disease): The adrenal glands produce hormones that help regulate sodium levels. Insufficient production of these hormones can lead to sodium loss and hyponatremia.

8. Severe Vomiting or Diarrhea

9. Hypothyroidism: An underactive thyroid can interfere with water and sodium balance, causing hyponatremia.

10. Medications: Drugs such as certain antidepressants, antiepileptics, and pain medications can interfere with water and sodium balance.

Potassium (K^+)

- **Main location**: Intracellular fluid.
- **Function**: Potassium is the major intracellular cation and is essential for normal cell function, maintaining resting membrane potential, and regulating heart and muscle function.
- **Concentration**:
  - **ICF**: ~140 mmol/L.
  - **ECF/Plasma**: 3.5-5.0 mmol/L.

Transport and absorption of potassium:

- The transport of potassium into cells is under the control of the Na/KATPase enzyme, and allows transport of potassium against a concentration gradient.
- Over 90% of dietary potassium is absorbed in the proximal small intestine. In the small intestine potassium absorption is passive, but in the colon, it is an active process.
- In the sigmoid colon absorption is mediated by a K+/H+ mechanism. Body stores of potassium most of the potassium is intracellular, i.e., in the cell fluid compartment.

Hyperkalemia

The level of potassium in blood is too high. A high potassium level has many causes, including kidney disorders, drugs that affect kidney function, and consumption of too much supplemental potassium.

Causes:

1-**Kidney disorders** that prevent the kidneys from excreting enough potassium

2-**Drugs** that prevent the kidneys from excreting normal amounts of potassium (a common cause of mild hyperkalemia)

3-**A diet high in potassium**

4-**Treatments that contain potassium**

5-**Addison disease** can also cause hyperkalemia.

Hypokalemia

The level of potassium in blood is too low. A low potassium level can make muscles feel weak, cramp, twitch, or even become paralyzed, and abnormal heart rhythms may develop.

Causes :

Typically, the potassium level becomes low because too much is lost from the **digestive tract** due to **vomiting, diarrhea, or excessive laxative use**. Sometimes too much potassium is **excreted in urine**, usually because of **drugs** that cause the kidneys to **excrete excess sodium, water, and potassium (diuretics).** In many **adrenal disorders**, such as **Cushing syndrome,** the adrenal glands produce too much aldosterone, a hormone that causes the kidneys to excrete large amounts of potassium.

Chloride (Cl^-)

- **Main location**: Extracellular fluid.
- **Function**: Chloride is the primary anion in the ECF and works with sodium to maintain osmotic balance, fluid balance, and acid-base balance.
- **Concentration**:

- **ECF**: 95-105 mmol/L.
- **ICF**: ~5 mmol/L.

Hyperchloremia

is seen in:

1. Dehydration
2. Cushing's syndrome. Mineralocorticoids cause increased reabsorption from kidney tubules.
3. Severe diarrhea leads to loss of bicarbonate and compensatory retention of chloride.
4. Renal tubular acidosis.

Hypochloremia:

Causes

1. Excessive vomiting. HCl is lost, so plasma Cl– is lowered. There will be compensatory increase in plasma bicarbonate. This is called hypochloremia alkalosis.
2. Excessive sweating.
3. In Addison's disease, aldosterone is diminished, renal tubular reabsorption of Cl– is decreased, and more Cl– is excreted.

Magnesium (Mg^{2+})

- **Main location**: Intracellular fluid.
- **Function**: Magnesium plays a key role in enzyme activity, DNA and protein synthesis, and maintaining normal nerve and muscle function.
- **Concentration**:
    - **ICF**: ~20-30 mmol/L.
    - **ECF**: 0.7-1.0 mmol/L.

Hypermagnesaemia:

The level of magnesium in blood is too high. Hypermagnesemia is uncommon. It usually develops only when people with kidney failure are given magnesium salts or take drugs that contain magnesium (such as some antiacids or laxatives).

Hypomagnesemia:

The level of magnesium in blood is too low.

Causes

- Usually, the magnesium level becomes low because **people consume less** (most often, because of starvation) or **because the intestine cannot absorb nutrients normally** (called malabsorption). But sometimes **hypomagnesemia** develops **because the kidneys or**

intestine excrete too much magnesium. Hypomagnesemia may also result from the following:

- **Consuming large amounts of alcohol (common),** which reduces consumption of food (and thus magnesium) and increases excretion of magnesium
- **High levels of aldosterone, vasopressin (antidiuretic hormone), or thyroid hormones**, which increase magnesium excretion
- **Drugs** that increase magnesium excretion, including diuretics, the antifungal drug amphotericin B, and the chemotherapy drug cisplatin
- **Breastfeeding**, which increases requirements for magnesium.

Bicarbonate (HCO_3^-)

- **Main location**: Extracellular fluid.
- **Function**: Bicarbonate is crucial for maintaining the body's pH balance by acting as a buffer.
- **Concentration**:
  - **ECF (Plasma)**: 22-28 mmol/L.
  - **ICF**: Low concentration.

Phosphate (PO_4^{3-})

- **Main location**: Intracellular fluid.
- **Function**: Phosphate is essential for energy production (as part of ATP), bone health, and cellular signaling.
- **Concentration**:
  - **ICF**: 75 mmol/L.
  - **ECF**: 0.8-1.5 mmol/L.

Calcium (Ca^{++})

is one of the body's electrolytes, which are minerals that carry an electric charge when dissolved in body fluids such as blood (but most of the body's calcium is uncharged). About 99% of the body's calcium is stored in the bones, but cells (particularly muscle cells) and blood also contain calcium. About 40% of the calcium in blood is attached (bound) to proteins in blood, mainly albumin. Protein-bound calcium acts as a reserve source of calcium for the cells but has no active function in the body. Only unbound calcium affects the body's functions.

Calcium is essential for the following:

- Formation of bone and teeth
- Muscle contraction
- Normal functioning of many enzymes
- Blood clotting
- Normal heart rhythm

Calcium absorption and balance

- ☒ Calcium absorption is largely from the jejunum, but may also occur in the ileum and colon.
- ☒ Approximately 60% of the total plasma calcium is filtered in the kidney glomeruli, and in health 97% of this calcium is reabsorbed.
- ☒ Several hormones are involved, including PTH, with increased absorption of calcium and decreased tubular absorption of phosphate.
- **The level of calcium in blood is regulated primarily by two hormones:**
- -Parathyroid hormone
- -Calcitonin

Hypercalcemia:

- At first, people have digestive problems, feel thirsty, and may urinate a lot, but if severe, hypercalcemia leads to confusion and eventually coma. If not recognized and treated, the disorder can be life threatening.

Causes: Causes of hypercalcemia include the following:

- **Hyperparathyroidism:** One or more of the four parathyroid glands secrete too much parathyroid hormone, which helps control the amount of calcium in blood.
- **Too much calcium intake:** Occasionally, hypercalcemia develops in people with peptic ulcers if they drink a lot of milk and take calcium-containing antacids for relief. The resulting disorder is called the milk-alkali syndrome.
- **Too much vitamin D intake:** If people take very high daily doses of vitamin D over several months, the amount of calcium absorbed from the digestive tract increases substantially.
- **Cancer:** cells in kidney, lung, and ovary cancers may secrete large amounts of a protein that, like parathyroid hormone, increases the calcium level in blood. Calcium released into the blood when cancer spreads (metastasizes) to bone and destroys bone cells. Such bone destruction occurs most commonly with prostate, breast, and lung cancers. Multiple myeloma (a cancer involving bone marrow) can also lead to the destruction of bone and

result in hypercalcemia. Other cancers can increase the calcium level in blood by means not yet fully understood.

- **Bone disorders:** If bone is broken down (resorbed) or destroyed, calcium is released into the blood, sometimes causing hypercalcemia. In Paget disease, bone is broken down, but the calcium level in blood is usually normal. Severe hyperthyroidism can also cause hypercalcemia by increasing resorption of bone tissue.

Hypocalcaemia:

- The calcium level in blood is too low.
- A low calcium level may result from a problem with the **parathyroid glands**, as well as **from diet**, **kidney disorders**, or **certain drugs**. As hypocalcemia progresses, muscle cramps are common, and people may become confused, depressed, and forgetful and have tingling in their lips, fingers, and feet as well as stiff, achy muscles.
- Usually, the disorder is detected by routine blood tests. Calcium and vitamin D supplements may be used to treat hypocalcaemia. Thus, hypocalcaemia causes problems only when the level of unbound calcium is low. Unbound calcium has an electrical (ionic) charge, so it is also called ionized calcium.

Mechanisms Maintaining Electrolyte Distribution

The body employs several mechanisms to regulate the distribution of electrolytes between compartments and maintain balance:

- **Sodium-Potassium Pump (Na^+/K^+ ATPase)**: This pump moves sodium out of the cell and potassium into the cell, using ATP. It helps maintain the high concentration of sodium outside the cell and potassium inside the cell.
- **Kidney Function**: The kidneys filter blood and regulate electrolyte levels by adjusting the amount of electrolytes excreted in urine. Hormones like aldosterone and antidiuretic hormone (ADH) play critical roles in this process.
- **Osmosis and Diffusion**: Electrolytes move across cell membranes by diffusion and osmosis to maintain osmotic equilibrium.
- **Hormonal Control**:
    - **Aldosterone**: Increases sodium reabsorption and potassium excretion by the kidneys.
    - **Parathyroid Hormone (PTH)**: Regulates calcium and phosphate balance.
    - **ADH**: Regulates water retention, affecting the concentration of electrolytes like sodium.