Fluid–Electrolyte Balance

- Water makes up 55 - 75% of the total body weight.
- Electrolytes are the ions found in body fluids; most are minerals.

Water Compartments

- Intracellular fluid (ICF): water within cells; about two-thirds of total body water.
- Extracellular fluid (ECF): water outside cells; includes plasma, lymph, tissue fluid, & specialized fluids (cerebrospinal fluid, synovial fluid, aqueous humor, & serous fluid).
- Water constantly moves from one compartment to another.

Water compartments.

<table>
<thead>
<tr>
<th></th>
<th>Intake</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquids</td>
<td>1600</td>
<td>Urine 1500</td>
</tr>
<tr>
<td>Food</td>
<td>700</td>
<td>Sweat (and insensible water loss) 500</td>
</tr>
<tr>
<td>Metabolic water</td>
<td>200</td>
<td>Exhaled air (water vapor) 300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feces 200</td>
</tr>
</tbody>
</table>

REGULATION OF WATER INTAKE & OUTPUT

- Hypothalamus
  - It contains osmoreceptors that detect changes in osmolarity of body fluids. Dehydration raises osmolarity of blood, & we feel thirst.
  - It stimulates release of ADH from posterior pituitary in dehydration. ADH ↑ reabsorption of water by kidney tubules.
- Aldosterone ↑ reabsorption of Na ions & water by kidney back to blood.
- Atrial natriuretic peptide (ANP), secreted by atria
  - when ↑ blood volume or blood pressure → secretion of ANP → ↓ reabsorption of Na ions by kidneys, → ↑ urinary output of Na & H2O.
ELECTROLYTES
- They are chemicals that dissolve in water & dissociate into ions; most are inorganic.
- Cations are positive ions such as Na⁺ & K⁺.
- Anions are negative ions such as Cl⁻ & HCO₃⁻.
- By creating osmotic pressure, electrolytes regulate osmosis of water between compartments.
- Tissue fluid—same as plasma (principal cation is Na⁺; principal anion is Cl⁻) except that in tissue fluid; protein anions are insignificant.

INTAKE, OUTPUT, AND REGULATION
- Intake—electrolytes are part of food & beverages.
- Output—urine, sweat, feces.
- Regulation; through;
  - aldosterone—Na⁺ & K⁺;
  - ANP—Na⁺;
  - PTH & calcitonin—Ca²⁺ & HPO₄²⁻.

ACID–BASE BALANCE
- Normal pH Ranges;
  - blood: 7.35 - 7.45; tissue fluid: similar to blood.
  - ICF: 6.8 - 7.0;
- Normal pH of body fluids is maintained by;
  - Buffer systems (Bicarbonate, phosphate, & protein) respond within fraction of second.
  - Respiration. Respond within 1-3 min.
  - Kidneys. Respond within several hours – days.

BUFFER SYSTEMS
- Each consists of a weak acid & a weak base; react with strong acids or bases to change them to substances that do not greatly affect pH.
- React within a fraction of a second, but have the least capacity to prevent pH changes, because a limited number of molecules of these buffers are present in body fluids.

Bicarbonate Buffer System
- Important in both blood & tissue fluid; base to acid ratio is 20 to 1.
- The two components of this buffer system are
  i. Carbonic acid (H₂CO₃), a weak acid.
  ii. Sodium bicarbonate (NaHCO₃), a weak base.
- If a potential pH change is created by a strong acid, the following reaction takes place:
  \[ \text{HCl} + \text{NaHCO₃} \rightarrow \text{NaCl} + \text{H₂CO₃} \]
  (strong acid) (weak acid)
- If a potential pH change is created by a strong base, the following reaction takes place:
  \[ \text{NaOH} + \text{H₂CO₃} \rightarrow \text{H₂O} + \text{NaHCO₃} \]
  (strong base) (weak base)

Phosphate Buffer System
- Important in regulation of pH in ICF & in kidneys.
- The two components of this buffer system are;
i. Sodium dihydrogen phosphate (NaH2PO4), a weak acid,
ii. Sodium monohydrogen phosphate (Na2HPO4), a weak base.

If a potential pH change is created by a strong acid, the following reaction takes place:

\[
\text{HCl} + \text{Na}_2\text{HPO}_4 \rightarrow \text{NaCl} + \text{NaH}_2\text{PO}_4
\]

If a potential pH change is created by a strong base, the following reaction takes place:

\[
\text{NaOH} + \text{NaH}_2\text{PO}_4 \rightarrow \text{H}_2\text{O} + \text{Na}_2\text{HPO}_4
\]

**Protein Buffer System**

- The most important buffer system in ICF.
- Hb buffers H+ ions formed during CO2 transport.
- a.a that make up proteins each have a **carboxyl group** (COOH) & an **amine group** (NH2).
  - Carboxyl group act as an acid because it can donate H+ ion to fluid to counteract ↑ing alkalinity:
  - Amine group act as a base because it can pick up an excess H+ ion from fluid to counteract ↑ing acidity.

**RESPIRATORY MECHANISMS**

- It affects pH because it regulates amount of CO2 present in body fluids.
- Resp. system may be the cause or may correct pH imbalance (from other causes).

**Respiratory acidosis**

*Causes:* ↓ rate or efficiency of respiration (eg asthma, & pneumonia) → excess CO2 → excess H+ ions formation → lower pH of body fluids:

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \rightarrow \text{H}^+ + \text{HCO}_3^-
\]

*Compensation:* Kidneys excrete H+ ions & reabsorb Na+ ions & HCO3- ions.

**Respiratory alkalosis** (less common)

*Causes* ↑ rate of respiration (eg; anxiety, high altitude) → ↑ amount of CO2 exhaled. Because there are fewer CO2 molecules in body fluids → fewer H+ ions are formed, & pH tends to rise.

*Compensation:* Kidneys retain H+ ions & excrete Na+ ions & HCO3- ions

**Respiratory Compensation for Metabolic pH Changes**

Metabolic acidosis or alkalosis are changes in pH caused by other than a respiratory disorders. Respiratory mechanism does not have the capacity to fully compensate an ongoing metabolic pH imbalance (In such cases, respiratory compensation is 50 - 75% effective).

**Metabolic acidosis**

*Causes:* e.g kidney disease, uncontrolled diabetes mellitus, excessive diarrhea or vomiting.

*Compensation:* excess H+ ions in body fluids → stimulates respiratory centers in medulla → ↑ rate of respiration to exhale more CO2 → ↓ H+ ion formation.

**Metabolic alkalosis** is not common,

*Causes:* eg overuse of antacid medications or vomiting of stomach contents only.

*Compensation:* As pH begins to rise → breathing slows & ↓ amount of CO2 exhaled (CO2 retained within body) → ↑ H+ ions formation.

**RENAI MECHANISMS**

- Kidneys regulate pH of ECF by excreting or conserving H+ ions & by reabsorbing (or not) Na+ ions & HCO3- ions.
- Although renal mechanisms have the greatest capacity to buffer
• E.g ketoacidosis in untreated diabetes mellitus (metabolic acidosis).
  ☐ As ketones (acid) accumulate in blood,
  ☐ capacity of ECF buffer systems is quickly exhausted.
  ☐ Breathing rate then ↑, & more CO2 is exhaled to ↓ H+ ion formation. There is a limit
to how much respiratory rate can ↑,
  ☐ Renal buffering mechanisms will then become effective.

**EFFECTS OF pH CHANGES**

**Acidosis** is most detrimental to CNS, causing ↓ impulse transmission at synapses. A person in
acidosis becomes confused & disoriented, then lapses into a coma.

**Alkalosis** affects both CNS & PNS.↑ synaptic transmission, even without stimuli. It is first
indicated by irritability & muscle twitches & Progress to muscle spasms & convulsions.

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