Physiology of the body fluids, Homeostasis

The Body as an open system

1. Open system: The body exchanges material and energy with its environment
2. Homeostasis: The process through which bodily equilibrium (internal milieu) is maintained.
   1. Fluid composition
   2. Temperature
   3. Ph
   4. .....
Daily intake and output of water  
(water steady state)

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluids Ingested</td>
<td>2100 ml</td>
</tr>
<tr>
<td>From metabolism</td>
<td>200 ml</td>
</tr>
<tr>
<td>Insensible, Skin</td>
<td>350 ml</td>
</tr>
<tr>
<td>Insensible, Lungs</td>
<td>350 ml</td>
</tr>
<tr>
<td>Sweat</td>
<td>100 ml</td>
</tr>
<tr>
<td>Feces</td>
<td>100 ml</td>
</tr>
<tr>
<td>Urine</td>
<td>1400 ml</td>
</tr>
<tr>
<td>Total output</td>
<td>2300 ml</td>
</tr>
</tbody>
</table>

Pathologic losses:
- bleeding
- vomiting
- diarrhea...

Constituents of body fluids

1. Electrolytes: Like water, we must consume and eliminate equal quantities of electrolytes
   - Sources:
     - Physiological conditions: food
     - Clinical situation: parenteral administration
   - Losses
     - Physiological conditions: renal excretion, stool, sweating
     - Clinical situation: vomit, diarrhea
2. Metabolized substances: chemically altered therefore balance sheets for this type of substance must kept in terms of chemical conservation between substrates and end products. Sources: like electrolytes
Expressing fluid composition

1. Molality: Moles solute per kg of solvent  
3. Electrochemical Equivalence (Eq): Salts such as NaCl and CaCl₂ dissociate into positive ions (cations) and negative ions (anions). An “equivalent” is the weight in grams of an ionic substance that replaces or combines with one gram (mole) of monovalent H⁺ ions.  
   - For monovalent ions one equivalent is equal to one molar (GMW)  
   - For divalent ions one equivalent is equal to one-half of a molar (GMW)  
   - ……..

Complications in determining plasma concentrations:
- Not all substances in plasma are freely dissociated, many of them binds to proteins or other substances (Ca²⁺, bilirubin…etc)  
- Plasma volume is only 93% water, the other 7% is protein and lipid. Thus, ionic concentrations in plasma water are somewhat underestimated when expressed in terms of whole plasma volume.

The indicator dilution principle

\[
\text{Volume A} = \frac{(\text{Volume B} \times \text{Concentration B})}{\text{Concentration A}}
\]

If Volume A >> Volume B
Indicator dilution method with one compartment

Indicator dilution method with two compartments
Semipermeable membrane

Compartment 1

Compartment 2

Compartment 3

Indicator dilution method with three compartments

Indicator concentration (Arbitrary unit)

Time

Distribution of water in body fluid compartments

- Cell water: 25 L
- Interstitial fluid: 8 L
- Dense connective: 3 L
- Plasma: 3 L
- Bone: 2 L
- Transcellular: 1 L

60%
19%
7%
7%
7%
5%
2%
### Measurement of Body Fluid Volumes

<table>
<thead>
<tr>
<th>Volume</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Body Water</td>
<td>$^3$H$_2$O, $^3$H$_2$O, antipyrine</td>
</tr>
<tr>
<td>Extracellular Fluid</td>
<td>$^{22}$Na, $^{125}$I-iothalamat, thiosulphate, inulin</td>
</tr>
<tr>
<td>Intracellular Fluid</td>
<td>Calculated: TBW – ECF</td>
</tr>
<tr>
<td>Plasma Volume</td>
<td>$^{125}$I-albumin, Evans blue</td>
</tr>
<tr>
<td>Blood Volume</td>
<td>$^{51}$Cr-labeled red blood cells</td>
</tr>
<tr>
<td>Interstitial Fluid</td>
<td>Calculated: ECF - PV</td>
</tr>
</tbody>
</table>

### Compartments of body fluid

1. Intracellular fluid (cell water): Approximately 36% of body weight
2. Extracellular fluid: Approximately 24% of body weight with many subcompartments
   - Plasma: 3 L ~ 4.5% of body weight. This is the primary accessible compartment.
   - Interstitial space: 8 L ~ 11.5% of body weight. This is the environment of cells.
   - The remaining 6 L of extracellular fluid is distributed in minor compartments like bone, dense connective, transcellular….etc.
3. Pathologic fluid compartments (fluid production)
   - Transsudatum: increased local blood pressure
     - Clean (water-like) fluid
     - No protein (Negative Rivalta test)
     - Low density
   - Exsudatum: increased permeability of barriers
     - Turbid
     - Protein (Positive Rivalta test)
     - High density
1. Osmotic forces: When two compartments with different concentration of a solute are separated by a semipermeable membrane which obstructs the movement of solute particles but not water, water will cross the membrane until the solute concentration on both sides of the membrane is equal.
2. Osmosis: Movement of water caused by concentration difference.
3. Osmotic concentration
   - osmolarity: concentration of a solution in term of numbers of particles per liter of solution (Osmol/l)
   - Osmolality: concentration of a solution in term of numbers of particles per liter of solution
4. Osmotic pressure: The precise amount of pressure required to prevent the osmosis.
   - van’t Hoff’s law: \( \pi = CRT \)

**Osmolarity of fluids relative to plasma osmolarity**

1. Physiologic value of plasma osmolarity: 286 mOsmol/L (280-290)
   - Isotonic (isosmotic) fluid: osmotic concentration is within physiologic range
2. Non physiologic osmolarity
   - Hypotonic (hyposmotic): \( \pi < 280 \)
   - Hypertonic (hyperosmotic): \( \pi > 280 \)
3. Different body fluid compartments have slightly different osmolarity.
   - Plasma osmolarity is higher than osmolarity in interstitial space (Starling forces)
   - Negative force underneath the skin causes absorption of the fluid. Less than 1 mm Hg positive pressure is required to inject big volumes of fluid into loose subcutaneous tissue.
   - In most natural cavities of the body where there is a free equilibrium with the surrounding interstitial tissues, the hydrostatic pressure is negative (Epidural: -4 to -6, Joints: -4 to -6, Intrapleural: -8 mm Hg)

s.c., i.m. (but not i.v.) injection of non isotonic solution is painful
Effect of common clinical conditions on body water and electrolytes

1.: Body fluid volume

1. Hypervolemia: circulating blood volume is increased
2. Hypovolemia: circulating blood volume is decreased
3. Increased ECF volume: Water or fluid intoxication as a consequence of excess water uptake. Plasma osmolarity can be high, low or normal depending the nature of fluid taken up. As long as ECF is isosmotic cell intracellular volume is probably normal
4. Decreased ECF volume: Stimulates thirst and ADH secretion, clinically manifested as Dehydration. Caused by vomiting, diarrhea, burns.
5. Dehydration (exiccosis): Decreased ECF volume due to excess water loss. Plasma osmolarity is increased. The main danger is hypovolemia.

2.: Electrolytes

1. Hypernatremia: generally indicative of decreased intracellular fluid volume (cell shrinkage with brain cells being of particular significance)
2. Hyponatremia: generally indicative of increased intracellular fluid volume (cell swelling)
3. Hyperglycemia: glucose induces osmosis leading to hyponatremia
4. Changes in K, Ca^{2+} and Mg^{2+} concentration does not affect body fluid volume (other dangers are sever!!!).
Effect of common clinical conditions on body water and electrolytes.

3.: Osmolarity

1. Increased extracellular osmolarity:
   1. Increased water loss (insensible!!)
   2. Excessive Sweat Loss. Normally, sweat is mainly water with only a little sodium.
   3. Diabetes insipidus (central or nephrogen).
2. Decreased extracellular osmolarity:
   1. Large water ingestion
   2. Syndrome of Inappropriate ADH Secretion (SIADH). Too much ADH leads to water retention, hyponatremia and excretion of concentrated urine.

Effect of common clinical conditions on body water and electrolytes.

4.: Therapy

1. The osmotic concentration of solutions administered clinically is generally compared to the osmotic concentration of plasma
   1. Isotonic solution: cell volume is not altered.
2. Most frequently used I.V. solutions
   1. Dextrose solution: rapidly metabolized thus increased ECF and reduces osmolarity
   2. Saline solutions: Come in variety of concentrations (0.2%, 0.9% and 5%)
   3. Dextrose saline: Come in variety of concentrations, used for volume replacement and caloric supplement.
4. Plasma expanders: Hypertonic solution of non capillary permeable substances with large molecular weight (Dextran, mannitol, inulin). These solutions are confined to the vascular compartment, induce osmosis from perivasal space thus expand plasma volume.