WATER AND MINERALS
• Stability of internal environment of the organism
• Regulation of basic parameters
  - temperature
  - pH
  - volume of body fluids
  - osmotic pressure
  - blood pressure
• aim: to minimalize influence of the changes of external environment on the life of the organism
Water - functions

• basis of life
• polar solvent
• membranes creation
• environment for chemical reactions in the organism
• transport of (dissolved in water) compounds
• thermoregulation
• component of all body fluids
Water – distribution

• TBW – total body water (60% of body weight)
  - 40% intracellular fluid (ICF)
  - 20% extracellular fluid (ECF)
  - 15% interstitial fluid (ISF) + lymph
    • 4% intravasal fluid (IVT) - blood plasma
    • 1% transcellular fluid (TCT) - body cavities (CSF, intraocular, pleural, peritoneal, synovial, digestive secretions)
Balance of water

• Intake
  - GIT (2 - 2,5 l/day) - liquids + food
  - Metabolic water (0,25 - 0,5 l/day)

• Losses:
  - urine (1,5 - 2,0 l/day)
  - faeces (cca. 0,1 l/day)
  - skin + respiration (cca. 0,7 l/day) (perspiratio insensibilis)
  - perspiratio sensibilis - sweating
    • depends on body temperature
Extracellular fluid

- Represents around 1/3 of TBW
  - in 80 kg adult around 16 kg (litres) of water
- Mainly blood plasma and interstitial fluid separated by capillary membrane
  - highly permeable for all compounds except of proteins
    (interstitial fluid- similar to blood plasma just less proteins)
- main cation - sodium
- main anions - chlorides and bicarbonates
Intracellular fluid

- around 2/3 of TBW
  - in 80 kg adult around 32 kg (liters) of water
- Separated from ECF by plasma membrane
  - is semipermeable, contains various transportes and channels
    - is 50-100x more permeable for K⁺ than for Na⁺
- main cations - potassium, magnesium
- main anions - phosphates, sulphates, organic anions
Distribution of cations and anions in ECF and ICF
Osmolarity of ECF

- Sum of concentration of all osmotically active particles in the solution (in the compartment)
- Reference value: 290 ± 5-10 mosmol/l
  - 96% ions (75% Na⁺, 21% other ions)
  - 3% glucose and urea
  - 1% aminoacids and proteins
- Hypoosmolarity of ECF (compared to ICF)
  - movement of water from ECF into ICF (edema of the cells)
  - Hyperosmolarity of ECF (compared to ICF)
  - movement of water from ICF into ECF (dehydration of the cells)
Osmolarity of serum - calculation

• $S\text{-osm} = 2 \times S\text{-Na}^+ + S\text{-Glc} + S\text{-Urea}$
  • $2 \times 140 + 4,5 + 7,5 = 292$ mosmol/l

• $S\text{-osm} = 2 \times (S\text{-Na}^+ + S\text{-K}^+) + 5$
  • $2 \times (140 + 5) + 5 = 295$ mosmol/l
At venous end of the capillary around 80% of filtered fluid returns back and 20% is drained by lymphatic system (including proteins from ICF).
EDEMA

1. Decreased osmotic (oncotic) pressure
   (decreases return of the water from interstitium into blood)
   - hypoproteinemia
     - kidney diseases
     - liver diseases
     - protein malnutrition (severe starvation)

2. Increased hydrostatic pressure (blood pressure)
   (increases filtration of fluid from blood stream into interstitium)
   - decreased outflow of venous blood \[\rightarrow\] increased venous blood pressure
     (e.g. portal hypertension)
     cirrhosis
- heart decompensation (failure)

Increased venous blood pressure
- pulmonary edema
- peripheral edema
- ascites
- increased capillary permeability
- liver damage (decrease of plasma proteins)

3. Increased oncotic pressure of ISF
   (decreased outflow of lymph)

4. Increased capillary permeability
   (inflammation processes)
**WATER**

<table>
<thead>
<tr>
<th>Adult</th>
<th>Content of water in body</th>
<th>Intake in 24 hours</th>
<th>Losses in 24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fetus: 76-94%</td>
<td>1-1,5 l - liquids</td>
<td>1-2 l - urine</td>
<td></td>
</tr>
<tr>
<td>Newborn: 77%</td>
<td>0,5-1 l - food</td>
<td>0,6-0,8 l - perspiration</td>
<td></td>
</tr>
<tr>
<td>Adult: 55-60%</td>
<td>0,3-0,5 l - metabolic water</td>
<td>0,4-0,5 l - respiration</td>
<td>0,1 l - faeces</td>
</tr>
</tbody>
</table>

**Defects:**

**HYPERHYDRATION** → **outflow of H\(_2\)O into ISF– EDEMA**
- Primary defect of the kidneys
- Increased activity of ADH
  - hypersecretion primary - injury of CNS
  - ectopic production of ADH - e.g. tumour cells (lungs carcinoma)

**DEHYDRATION**
- decreased intake
- increased losses
  - DM, Diabetes Insipidus (\(\downarrow\)ADH)
  - together with losses of Na\(^+\), Cl\(^-\) - kidneys
  - sweating
  - vomiting, diarrhea (mainly children!)

**CHILDREN:**
\[
\text{stores in ECF} \frac{1.4}{0.7} = 2
\]

**ADULTS:**
\[
\text{stores in ECF} \frac{16}{2} = 8
\]
**SODIUM**

<table>
<thead>
<tr>
<th>Physiological levels</th>
<th>Intake (mmol/24 hod)</th>
<th>Losses (mmol/24hod)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECT: 135-145</td>
<td>140-260</td>
<td>Urine: 120-140</td>
</tr>
<tr>
<td>ICT: 5-35</td>
<td></td>
<td>Faeces: 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sweat: 10</td>
</tr>
</tbody>
</table>

**Roles:**
1. Maintenance of osmotic pressure (together with anions 90% of total osmotic pressure)
2. together with Na\(^+\), Cl\(^-\) a K\(^+\) - membrane potentials
3. activator of enzymes

**Regulation:**
Na\(^+\) together with Cl\(^-\) and H\(_2\)O
Stimuli for secretion of aldosterone
- decrease of BP
- decrease of BP in vas afferens
- decrease of [Na\(^+\)] in serum
- decrease of [Na\(^+\)] in distal tubule

by means of:
- a) juxtaglomerular apparatus - renin - angiotensin - aldosterone
- b) directly by decrease of Na\(^+\) and increase of K\(^+\) in serum
- c) ACTH (mainly in stress)
REGULATION OF VOLUME OF WATER AND MINERALS IN THE ORGANISM

ADRENAL CORTEX

ANGIOTENSIN II

\( \text{ACE} \)

Angiotensin I

\( \text{renin} \)

ANGIOTENSINOGEN

ALDOSTERONE

\[ \text{Na}^+ \text{ in urine} \]

VOLUME ECT

\[ \text{Na}^+ \]

\[ \text{Blood pressure} \]

\[ \text{K}^+ \]

KIDNEY

HYPOTHALAMUS

HYPOPHYSIS

THIRST

\[ \text{H}_2\text{O INTAKE} \]

\[ \text{VOLUME OF ECF} \]

\[ \text{Na}^+ \text{ reabsorption} \]

\[ \text{H}_2\text{O reabsorption} \]
ADH
(antidiuretic hormone / vasopresine)

- Two names, two effects
- $V_1$ receptor - peripheral vessels - $G_p$ protein
- $V_2$ receptor - kidneys - $G_s$ protein
  - transfer of aquaporines into membrane
  - increased permeability for water (and urea)
    - water moves into hyperosmolar renal medulla
  - decrease of effective osmolarity by retention of water
  - Produnio of lower volume of hypersmolar urine
    - (higher density, higher concentration of compounds, darker color)
Renin-angiotensin + aldosterone

• **Angiotensin II**
  - peptide - formed from angiotensinogen in blood
  - general vasoconstriction
  - stimulates synthesis of aldosterone
  - stimulates thirst and secretion of ADH
  - Stimulates activity of sympathetic NS

• **Aldosterone**
  - steroid hormone, effects delayed
  - increases capacity of Na⁺-K⁺-ATPases in tubules
  - increases reabsorption of Na⁺ and excretion of K⁺
RENIN (protease) → ANGIOTENSINOGEN (α2 globulin) → residue α2 globulin

ANGIOTENSIN I (10 AA) → ACE (convertase) → ANGIOTENSIN II (8 AA) → His-Lys

\( \text{Ca}^{2+} \) → PLC → DAG → PKC → Ca\(^{2+} \)

VESICLE → Ca\(^{2+} \) → IP\(_3 \) → DAG → PLC

ALDOSTERONE → Na\(^+ \) \(, \) H\(_2\)O \(, \) Cl\(^- \)

JGA → Na\(^+ \) \(, \) H\(_2\)O \(, \) Cl\(^- \)

EXCRETION OF K\(^+ \) BY URINE

V, BP, Na\(^+ \) (S), Na\(^+ \) (URINE)

Atrial natriuretic peptide

Stress

ACTH

BP

ANF

Alcohol
WATER INTAKE

Dehydration

Hyperosmolar

Izoosmolar

Hyposmolar

LOSS
**POTASSIUM**

**Functions:**
- Inside the cell – activator of enzymes
- membrane potentials, transmission of nerve impulse

**Defects:**

**HYPERKALEMIA**
- destruction of the cells
- decreased production of aldosterone
- acute and chronic failure of kidneys
- acidosis
- increased intake of KCl (medicaments)
- transfusion
- K⁺ saving diuretics

**HYPOKALEMIA**
- losses of potassium by GIT (diarrhea)
- hyperaldosteronism
- alkalosis

**Excitability**
\[
\frac{[\text{Na}^+][\text{K}^+][\text{OH}^-]}{[\text{Ca}^{2+}][\text{Mg}^{2+}][\text{H}^+]}\]

**Table:**

<table>
<thead>
<tr>
<th>pH</th>
<th>7</th>
<th>7,2</th>
<th>7,4</th>
<th>7,6</th>
</tr>
</thead>
<tbody>
<tr>
<td>potassium [mmol/l]</td>
<td>4,7</td>
<td>3,7</td>
<td>3,0</td>
<td>2,3</td>
</tr>
<tr>
<td>6,2</td>
<td>4,9</td>
<td>4,0</td>
<td>3,2</td>
<td></td>
</tr>
<tr>
<td>8,0</td>
<td>6,2</td>
<td>5,0</td>
<td>3,8</td>
<td></td>
</tr>
<tr>
<td>10,0</td>
<td>7,3</td>
<td>6,0</td>
<td>4,5</td>
<td></td>
</tr>
</tbody>
</table>

**NORM** – 3,8–5,3 mmol/l
CHLORIDES

<table>
<thead>
<tr>
<th>Physiological levels</th>
<th>Intake in 24 hrs.</th>
<th>Losses in 24 hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>100±5 mmol/l in ECF</td>
<td>170-260 mmol</td>
<td>170-250 mmol</td>
</tr>
</tbody>
</table>

Regulation:
- together with NaCl
- Active transport in loop of Henle

Functions:
- maintenance of osmolarity and volume of ECF
- HCl in gastric juice
- membrane potentials, transmission of nerve impulse

Defects:
**HYPERCHLOREMIA**
- kidney diseases - decreased excretion
- metabolic acidosis - chronic renal failure
  (as the result of tubular acidosis)
- alkalosis - administration of NaCl in infusion - acidification factor

**HYPOCHLOREMIA**
- loss of stomach content - vomiting
- Bartter’s syndroma - selective defect of Cl absorption in loop of Henle