Water-electrolyte balance

Kiril Terziski, MD, PhD
Pathophysiology Dept.
Medical University of Plovdiv
Crawling out of ... water

Evolution
Belief is optional. Participation is not!
Water is life

Medium for metabolism
Solvent for secretions
Absorption
Transport
Thermoregulation

...
Getting solid with age
Water distribution

- Total body water:
  - Intracellular (66%)
  - Extracellular (33%)
- Extracellular fluid:
  - Interstitial (25%)
  - Plasma (8%)
- Intracellular fluid compartments include:
  - Cellular compartment
  - Extracellular fluid compartment (cerebrospinal, synovial, serous fluids, etc.)
Water flows

Osmotic pressure
Oncotic pressure

Donnan’s Law

...the behavior of charged particles near a semi-permeable membrane that sometimes fail to distribute evenly across the two sides of the membrane
**Ion drive**

- Na$^+$ - 135-145 mmol.L$^{-1}$
- K$^+$ - 3.5-5.5 mmol.L$^{-1}$
- Cl$^-$ - 95-105 mmol.L$^{-1}$
- Ca$^{2+}$ - 2.12-2.62 mmol.L$^{-1}$
Give what you get

WATER BALANCE
A. WATER GAIN = WATER LOSS

- METABOLIC
  - FOOD: 800 ml
  - LIQUID: 1500 ml
- TRANSPIRATION: 250 ml
- FECES: 100 ml
- URINE: 1500 ml

Thirst (water intake)

Urine production (water loss)

Nuclei of the Hypothalamus
- Paraventricular nucleus (Water Balance / Thirst)
- Lateral hypothalamic area
- Dorsomedial hypothalamic area
- Anterior hypothalamic area
- Median preoptic area
- Posterior hypothalamic area

Other areas:
- Frontal cortex
- Sphenoid sinus
- Optic chiasm
- Anterior pituitary
- Posterior pituitary
- Glomerulus
- Proximal convoluted tubule
- Distal convoluted tubule
- Nephron
The role of the kidneys

Filtration

Countercurrent multiplier

ADH action site

Juxtamedullary and cortical nephrones

unregulated water reabsorption
water is reabsorbed with solutes

regulated water reabsorption

loop of Henle:
- descending limb
  - permeable to water
- ascending limb
  - impermeable to water
RAAS, ADH and thirst

- Atrial Natriuretic Peptide
- Brain Natriuretic Peptide
- Prostaglandines (renal)
The regulation in action
Disturbances in water-electrolyte balance - classification

• Dehydration
  – Isotonic (Isoosmolal)
  – Hypotonic (Hypoosmolal)
  – Hypertonic (Hyperosmolal)

• Hyperhydration
  – Isotonic (Isoosmolal)
  – Hypotonic (Hypoosmolal)
  – Hypertonic (Hyperosmolal)
Dehydration

Dehydration:

More than 5% reduction of total water, ECV in particular.

Hyperosmolar
- Triggers increased ADH secretion with antidiuresis
- Primarily, water is dragged out of ICV
- Intracellular dehydration

Hyposmolar
- Loss of salt in excess of high water loss or when drinking too little water.

Isosmolar
- No driving force for a shift ICV
- No water shift ECV

Water loss, or water deprivation stimulates osmosis and thirst.

Hyperosmolarity liberates ADH to restrict water loss.

Oliguria.

Proportional loss of salt and water from ECV due to chronic vomiting, diarrhoea or burns.

Diabetes insipidus
Diabetes mellitus
Extreme sweating

Addison’s disease
Brain tumors

No thirst!
Hyperhydration

Overhydration: Abnormal increase in total water, ECV in particular.

- Hyperosmolar
  - Salt-drags water out of the cells
  - Intracellular dehydration with hallucinations, coma and respiratory arrest
  - Na^+ accumulation

- Isosmolar
  - No driving force for a shift
  - ICV
  - ECV

- Hyposmolar
  - Intracellular overhydration with headache, disorientation, coma
  - Water accumulation (water intoxication) combined with renal failure or ADH - excess

Water intoxication

Salt-water drinking

Extreme thirst!

Fluid compartments and the osmotic factors governing the distribution of body water:

- H_2O ↔ H_2O ↔ H_2O
- K^+ ↔ Na^+
- Na^+ ↔ K^+
- Intracellular fluid ↔ Interstitial fluid ↔ Plasma
- ATPase, adenosine triphosphatase.
Signs of dehydration

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Sign Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>Thirst</td>
</tr>
<tr>
<td>1%</td>
<td>Stronger thirst, vague discomfort</td>
</tr>
<tr>
<td>2%</td>
<td>Decreased blood volume, impaired physical activity</td>
</tr>
<tr>
<td>3%</td>
<td>Increased effort for physical work, nausea</td>
</tr>
<tr>
<td>4%</td>
<td>Difficulty concentrating</td>
</tr>
<tr>
<td>5%</td>
<td>Failure to regulate excess temperature</td>
</tr>
<tr>
<td>6%</td>
<td>Dizziness, labored breathing with exercise, increased weakness</td>
</tr>
<tr>
<td>7%</td>
<td>Muscle spasms, delirium, wakefulness</td>
</tr>
<tr>
<td>8%</td>
<td>Inability of decreased blood volume to circulate normally, failure in renal function</td>
</tr>
</tbody>
</table>

Tachycardia
Arterial hypotension
No micturition
Hypovolemic shock
Vulnerable populations

Body surface area/ Body mass
Net ammount of water
(Im)maturity of homeostasis
Concentration ability of kidneys
Dependence on caregivers
Inability to speak
Frequent pathology

Net ammount of water
Imperfect homeostasis
Concentration ability of kidneys
Dependence on caregivers
Dementia
Frequent pathology
Vulnerable populations

### Signs of dehydration

<table>
<thead>
<tr>
<th>STATUS</th>
<th>No Dehydration</th>
<th>Some Dehydration</th>
<th>Severe Dehydration</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONDITION</td>
<td>Well, alert</td>
<td>Restless, Irritable*</td>
<td>Lethargic or unconscious; Reppy*</td>
</tr>
<tr>
<td>EYES (Tears)</td>
<td>Normal (present)</td>
<td>Sunken (not present)</td>
<td>Very sunken and dry (not present)</td>
</tr>
<tr>
<td>MOUTH &amp; TONGUE</td>
<td>Moist</td>
<td>Dry</td>
<td>Very dry</td>
</tr>
<tr>
<td>THIRST</td>
<td>Drinks normally, not thirsty</td>
<td>Thirsty, drinks eagerly*</td>
<td>Drinks poorly or not able to drink*</td>
</tr>
<tr>
<td>SKIN PINCH</td>
<td>Goes back quickly</td>
<td>Goes back slowly*</td>
<td>Goes back very slowly*</td>
</tr>
<tr>
<td>DECIDE</td>
<td>The child has no signs of dehydration</td>
<td>If the child has 2 or more signs, including at least 1 major sign, there is some dehydration</td>
<td>If the child has 2 or more signs, including at least 1 major sign, there is severe dehydration</td>
</tr>
</tbody>
</table>

* = A major sign

Information provided by the Centers for Disease Control and Prevention (CDC), located in Atlanta, Georgia, USA. CDC is an agency of the United States Department of Health and Human Services.

* "Turning again towards childish treble, pipes And whistles in his sound. Last scene of all, That ends this strange eventful history, Is second childishness and mere oblivion, Sans teeth, sans eyes, sans taste, sans everything. " The Seven Ages of Man" by W. Shakespeare*
Oedemas
Common mechanisms

Factors, influencing water exchange in the tissues:

- Hydrodynamic pressure (HP)
- Oncotic pressure (OP)
- Capillary permeability
- Lymph drainage

- HP-OP=Filtration pressure (force)
- OP-HP=Absorption (force)
Filtration pressure alongside the capillary

AUC2 < AUC1

Positive water balance in the interstitium

Lymph drainage
Simplified example

Filtration pressure alongside the capillary

\[ +10 \]

\[ \text{AUC1} \]

\[ \text{AUC2} \]

\[ -8 \]

\[ \text{AUC2} < \text{AUC1} \]

Positive water balance in the interstitium

Lymph drainage
Simplified example

Filtration pressure alongside the capillary

\[ AUC_1 > AUC_2 \]

Positive water balance in the interstitium

Lymph drainage
Filtration pressure alongside the capillary

\[ +10 \quad \text{AUC}_1 \]

\[ -8 \quad \text{AUC}_2 \]

\[ \text{AUC}_2 < \text{AUC}_1 \]

Positive water balance in the interstitium

\[ \ddot{y} \quad \text{Lymph drainage} \]
Different diseases, different mechanisms

- **#IP**
  - Chronic heart failure
  - Varices
  - Inflammation*

- **$OP**
  - Nephrotic syndrome
  - Hypoproteinemia
  - Inflammation*

- ó **#Permeability**
  - ó Allergy
  - ó Inflammation*

- ó **$Lymph drainage**
  - ó Parasites
  - ó Surgery
A little bit of Greek

- Anasarca - extreme generalized oedema
- Ascites - accumulation of fluid in the peritoneal cavity
- Hydrothorax - effusion in the pleural cavity
- Hydropericardium - effusion in the pericardial cavity
- Hydrocephalus - abnormal accumulation of fluid in the cerebral ventricles
- Hydrocele - effusion in the scrotal pouch
- Synovial hydrops - abnormal accumulation of fluid in the joints
Pulmonary oedema

- Exogenous (toxins, hyperoxia)
- Endogenous
  - Cardiogenic (LV-CHF)
  - Non-cardiogenic (Shock)
Pulmonary oedema

- **Alveoli**
  - Wash-out of surfactant
  - #Retraction force
  - #H2O suction

- **Interstitial space**
  - Capillary membrane

- **Capillaries**
  - Prooedematous factors (#HP)

### Types of Oedema

- **Alveolar oedema**
- **Interstitial oedema**
- **Pulmonary congestion**

### Pleural Space
- Negative P
- μ-comunications
Pulmonary oedema – from Pathophysiology to symptoms

1. Pulmonary congestion
   - Moderate dyspnea
   - Dyspnea
   - Dry sonoric ronhi
   - Wheezing
   - J-reflex
   - Tachypnea
   - Hyperventilation
   - Arteriolospasm
   - μ-communications
   - Hypocapnia
   - Low pressure system
   - CO2 washout

2. Interstitial oedema
   - Mild dyspnea
   - Dry sonoric ronhi
   - Wheezing
   - J-reflex
   - Tachypnea
   - Hyperventilation

3. Alveolar oedema
   - Severe dyspnea
   - “Boiling pot”
   - Frothy sputum
   - Emergency condition
Brain oedema

• Etiology
  – Head trauma
  – Hyponatremia
  – High altitude
  – Brain tumors
  – Hydrocephalus

• Symptoms
  – Headaches
  – Confusion
  – Unconsciousness/Coma

• Peculiarities
  – Intracellular oedema
  – Confined in the skull
Size does matter!

Brain herniation in foramen magnum causes compression of the vital centers in the forelying brainstem.
KEEP CALM AND DRINK WATER