WATER AND ELECTROLYTE BALANCE

The water and electrolyte balance plays a central role in infusion therapy. First the most important areas of the organism where water is located are explained followed by the most important salts in the body. Furthermore, an explanation about the basic regulation mechanisms is given. These mechanisms help to maintain the water and electrolyte balance. The chapter closes with explanations about the water balance in human beings including the process of fluid intake and loss.

4.1 Water (H₂O)

Water makes up approx. 60% of the total weight of an adult human body. The cellular and tissue structure divides the organism into various segments containing water or aqueous solutions. We distinguish between intracellular and extracellular areas. Here again the extracellular area is divided into interstitial and intravascular parts. Table 1 gives the percentage share of body fluids in the different areas.
Intracellular Space (ICS)

All metabolic processes in the somatic cells occur within an aqueous milieu.

Extracellular space (ECS)

Outside the cells, water serves as a means of transport to and from the cells and as a solvent for the somatic colloids. The extracellular space is further divided into the:

- **Interstitial part**
  
  All cells are separated by fine spaces. These extracellular spaces are called interstitial. They warrant that all body cells are rinsed by the same fluid, which contains the necessary salts and nutrients for the supply of the cells.

- **Intravascular part**
  
  The intravascular part is the plasma water.

Table 1: Distribution of body fluid and fluid percentage of body weight for men, women, and children

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
<th>Children</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total body fluid</td>
<td>60 %</td>
<td>50 %</td>
<td>75 %</td>
</tr>
<tr>
<td>Intracellular space (ICS)</td>
<td>40 %</td>
<td>30 %</td>
<td>48 %</td>
</tr>
<tr>
<td>Extracellular space (ECS)</td>
<td>20 %</td>
<td>20 %</td>
<td>27 %</td>
</tr>
<tr>
<td>Interstitial part</td>
<td>15 %</td>
<td>16 %</td>
<td>22 %</td>
</tr>
<tr>
<td>Intravascular part</td>
<td>5 %</td>
<td>4 %</td>
<td>5 %</td>
</tr>
</tbody>
</table>

**Important**

The fluid spaces are separated from one another both functionally and anatomically.
4.2 Salts

Human body fluids contain various salts, which dissociate in the aqueous solution into charged particles (ions). The dominant salt contained in the extracellular fluid is dissolved sodium chloride. (approx. 9 gr. per litre). We distinguish between positively charged ions (cations) and negatively charged ions (anions), which are listed in table 2. Besides these, there are other dissolved substances such as glucose, urea, creatinine.

Table 2: Cations and Anions

<table>
<thead>
<tr>
<th>Positively charged ions</th>
<th>Negatively charged ions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium, Na⁺</td>
<td>Bicarbonate, HCO₃⁻</td>
</tr>
<tr>
<td>Potassium, K⁺</td>
<td>Chloride, Cl⁻</td>
</tr>
<tr>
<td>Calcium, Ca²⁺</td>
<td>Phosphate, HPO₄⁻</td>
</tr>
<tr>
<td>Magnesium, Mg²⁺</td>
<td>Proteins</td>
</tr>
<tr>
<td>Hydrogen, H⁺</td>
<td>Organic acids</td>
</tr>
</tbody>
</table>

The electrolytic mixture and concentration differs among the fluid spaces. The organism is always working to maintain constant levels of water and electrolyte distribution. Various mechanisms for the operation to maintain this homeostasis (balance) are described in the following.

4.3 Osmosis

Osmosis is the passage of a component in one phase through a membrane into another phase. Semipermeable membranes are only passable for certain components, while other components cannot pass.

The cell walls are semipermeable membranes, i.e. structures that allow water molecules to pass through, but not dissolved particles. When, for instance, the extracellular electrolyte concentration rises, water diffuses out of the cell, raising the intracellular concentration level and diluting the extracellular fluid.
In fig. 4 the process of osmosis is explained: Water diffuses freely through the semipermeable membrane (M), while the main direction of flow is from the less dense (less concentrated) solution (B) into the denser (more concentrated) solution (A) - see arrow.

![Diagram of osmosis](image)

Figure 4: Diagramme of osmosis. The concentration of the solute in the fluid is shown by the black dots, which indicate the dissolved particles.

### 4.3.1 OSMOTIC PRESSURE

This pressure is determined by the total number of ions and molecular components contained in a solution. It is measured in milliosmoles (mOsm). The total osmotic concentration of the plasma (fluid part of blood) is approx. 280 mOsm/l.

Solutions which have the same osmolarity as plasma are called isoosmotic; Solutions with a higher osmolarity are hyperosmotic and those with lower osmolarity are called hypoosmotic.

Table 3: Osmotic pressure in plasma:

<table>
<thead>
<tr>
<th>Osmotic pressure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isoosmotic</td>
<td>300 mOsm/l</td>
</tr>
<tr>
<td>Hyperosmotic</td>
<td>More than 300 mOsm/l</td>
</tr>
<tr>
<td>Hypoosmotic</td>
<td>Less than 300 mOsm/l</td>
</tr>
</tbody>
</table>
4.3.2 COLLOID-OSMOTIC OR ONCOTIC PRESSURE

A further mechanism for the distribution of fluids in areas, is the colloid-osmotic (or oncotic) pressure. This means the ability of dissolved protein particles to bind water. The intravascular space is particularly rich in proteins due to the blood plasma content, so that water is maintained. About 90% water lost into the interstitial space at the arterial end of the capillaries is taken back at the venous end due to this effect (the other 10% flow through the lymphatic system back into the vena cava). If the blood plasma protein level drops too low an accumulation of fluid inside the interstitial space (oedema) will be the consequence.

4.4 pH-Regulation

(Regulation of the acid-base balance)

Definition: pH = unit of measure for the concentration of hydrogen ions in aqueous solutions; these ions determine the acid/base content of the solution.

- Acidic solutions have a pH below 7.0 (and down to not more than 0) and have an excess of hydrogen ions.
- Basic solutions have a pH above 7.0 (to a maximum of 14). These solutions are capable of absorbing hydrogen ions.

The pH of blood corresponds to the hydrogen concentration (H⁺ - ion concentration) in the plasma and indicates the acid-base content. As given in fig. 6, the normal pH in the human arterial blood is 7.40. Also shown is the normal physiological range (7.35 – 7.45) as well as the values for acidosis and alkalosis (see glossary).
Figure 6: Acid-Base Balance

Normally, the kidney and lungs are responsible for excreting an excess of acid and basic substances. In case one or both of these two organs fail or if the organism suffers from an excess of acid or base or loses large amounts of either, a deviation from the normal value occurs, i.e. a pH shift. The balanced state must be reinstated as soon as possible: **The body activates its buffer systems.**

These systems are capable of giving off or binding \( H^+ \) ions as required. This buffer capacity is, however, exhausted after a certain period of time. **Buffer substances** are proteins, bicarbonate, phosphate, and haemoglobin. The most important **buffer substance** is the bicarbonate \( HCO_3^- \), which is released during breathing.

Normally both mechanisms, buffering and excretion of \( H^+ \) ions, lead to a constant pH. If they are no longer capable of doing so, the acid-base balance is disturbed and a pH-shift occurs. If this is due to a pulmonary failure (related to the breathing apparatus), we speak of a respiratory acidosis or alkalosis; otherwise these are described as metabolic conditions.
4.5 Hormonal Regulation

The interaction of various hormones enables the body to maintain a constant balance of water and electrolytes as long as losses are replaced. If the capacity of the body’s regulatory mechanisms is strained, the fluid and electrolyte balance is disturbed.

4.6 The Water Balance in a Healthy Person

As already said, water makes up approx. 60% of the total weight of an adult human. This water content is kept constant in an extremely exact manner. Water intake and output are possible in different ways. Fig. 7 gives a survey of the average water intake and output of an adult.

<table>
<thead>
<tr>
<th>Intake</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>700 ml</td>
</tr>
<tr>
<td>Drinks</td>
<td>1000 bis 1500 ml</td>
</tr>
<tr>
<td>Oxydation water (resulting from oxidation of calorific substrates)</td>
<td>300 ml</td>
</tr>
<tr>
<td>Total</td>
<td>2000 - 2500 ml</td>
</tr>
</tbody>
</table>

| stool | 100 ml |
| urine | 1000 bis 1500 ml |
| Unnoticed output (perspiratio insensibilis) | 500 ml |
| Total | 2000 - 2500 ml |

Figure 7: The average adult water intake and output.

4.6.1 INTAKE OF FLUID

Normally, the fluid cycle in a healthy adult involves 2-3 l per day. Intake does not only include drinks, but also water in solid food (pre-formed water) as well as water resulting from oxidation (oxidation water). Most of the intake, however, is accounted
for by the daily amount drunk - approx. 1 1/2 l. Intake is the sum of the following three volumes (see table 4). The water contained in solid food has considerable influence on the body’s drinking requirements.

Table 4: Drinking water, pre-formed water, oxidation water in comparison

<table>
<thead>
<tr>
<th>Drinking water</th>
<th>Pre-formed water</th>
<th>Oxidation water</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Drinking water is quickly absorbed into the plasma compartment. If no solid food intake takes place, this process requires less than 1 hour. A direct consequence is an increase in blood volume and blood pressure, leading to the opening of inactivated capillary segments and venous vessels in the liver and spleen. Following this, water enters the interstitial space and finally, since the increased interstitial water volume lowers the osmotic pressure in this space, it enters the cells.

The behaviour of the kidneys during this adaptation period depends on the fluid status prior to fluid intake. Given a prior haemoconcentration (thick blood) situation due to lack of fluids, the kidneys do not begin to excrete until all three compartments (plasma, cells, interstitial space) have reached their normal volume levels. Excessive fluid intake is of course excreted immediately by the kidneys.

4.6.2 REMOVAL OF FLUID

Fluid excretion is regulated mainly by the kidneys. The other excretion pathways are not as much in evidence, but are nonetheless of vital importance. Whereas water is excreted in liquid form together with stool and urine, water vapour is removed from the body through the lungs. Water is also given off through the skin, usually in the form of vapour. Water loss through the skin can also take the visible form of perspiration when the body overheats. "Perspiratio insensibils" is the term used for the unnoticed loss of fluid via skin and lungs. It amounts to approx. 1 l per day.

This level is raised by a further 500 ml per degree of fever.
4.6.3 SHIFTS IN GASTROINTESTINAL FLUID BALANCE

A special fluid balance exists between the blood plasma and the digestive tract secretions, which are formed of plasma as well. The total amount of fluids separated out in the intestinal tract may reach 8,200 ml in 24 hours. Fig. 8 explains the loss of fluid types and their constituent amount.

This large amount of fluid is reabsorbed through the mucosa of the large and small intestines into the bloodstream. This explains the fact that prolonged periods of vomiting or diarrhoea can lead to death within hours unless the lost fluid is replaced. This can be avoided by a massive infusion intake.

Figure 8: Fluid types (with constituent amount) that are lost because of vomiting and diarrhoea.
4.7 Summary

The human water and electrolyte balance plays a central role in infusion therapy. The cellular and tissue structures divide the organism into various segments containing water or aqueous solutions. We distinguish between intracellular and extracellular areas. Here again the extracellular area is divided into interstitial and intravascular parts.

The fluid parts are functionally and anatomically separated. The electrolytic mixture and concentration differ among the fluid spaces. The organism is always working to maintain constant levels of water and electrolyte distribution. Various mechanisms operate to maintain this homeostasis (balance): The osmosis (passing of water through water permeable membranes that won’t let dissolved substances pass), mechanisms of the pH-regulation (excretion and activation of the buffer systems) and hormonal regulation.

The share of water in the human weight is very high (approx. 60%). The water intake is based on the intake of drinking water, pre-formed water and oxidation water. The fluid output takes place through urine, stool and unnoticed water output through the lungs and skin (“perspiratio insensibilis”). The water balance is kept constant in an extremely exact manner. A special situation of fluid constancy exists between the blood plasma and the secretions of the alimentary tract. Diarrhoea and prolonged periods of vomiting can lead to death within hours unless the lost fluid is replaced by infusion therapy.
4.8 Comprehension Questions

- Name the different areas in the body in which water or aqueous solutions are present.
- What are the percentage amounts of body fluids in the different areas?
- Name the most important cations and anions in the human body fluids.
- Shortly explain the most important mechanisms which can be used for the maintenance of homeostasis.
- How high is the osmotic pressure of the blood plasma? How do you call the pressure increase or decrease?
- What is the normal pH-value in a human artery? What is an acidosis or an alkalosis?
- What happens with the buffer systems during a pH-shift?
- Name the most important buffer substances in case of a pH-shift.
- Explain the average water intake and output of an adult!
- What is the ratio between drinking water, pre-formed water and oxidation water?
- Describe the possible consequences of fluid constancy between blood plasma and the secretions of the alimentary tract.