Indoor environment (pediatrics)

The body fluids are the internal environment of the organism. In body fluids, the solvent is water and substances are dissolved in it in ionized or non-ionized form. The ionized form is represented by ``electrolytes*, i.e. substances that, when dissolved in water, form positively or negatively charged particles: cations and anions. All metabolic processes take place in body fluids. Maintaining the optimal amount and composition of body fluids is a necessary condition for the functioning of organs, for basic vital functions. We call the stability of the internal environment* ***homeostasis****.*

Total Body Water

While most vital processes take place in ICT, ECT primarily serves as a medium for the transport of substances necessary for these processes. During the development of an individual, not only the total volume of body fluids changes, but also individual compartments, while the concentration of solutes is relatively constant.

Distribution of total body water (CTV)

- intracellular fluid (ICT),
- extracellular fluid (ECT),
    - intravascular fluid (IVT = plasma): is bounded by endothelial cells and creates an environment for blood elements,
    - interstitial fluid (IST) and lymph: make up the largest part of ECT, it is inserted between ICT and other parts of ECT, exchange of water and solutes between ICT and ECT takes place in it,
    - transcellular fluid = GIT secretions, urine, CSF, intraocular fluid, sweat in sweat glands etc.,
    - the fluid of fibrous tissue, cartilage and bones: it is actually part of the interstitial fluid, but some solutes such as glucose or larger molecules do not pass freely into this space.

It is true that the younger the child, the greater the proportion of fluids in body weight, and the greater part of body fluids is extracellular, mainly as IST. The younger the child, the smaller the volume of muscles and organs (they contain more ICT) compared to an adult. ECT is also exchanged in an infant during 24 hours 4 times more intensively, with respect to a unit of body weight or body surface, than in an adult organism. Critical conditions in children are always complicated by significant lability of body fluids (rapid onset of dehydration) and relatively high physiological need.

Normal volume of blood in quantity per 1 kg of body weight

- newborn: 90 ml,
- 1 to 6 years: 80 ml,
- 6 to 8 years: 75 ml,
- adult: 60 to 70 ml.

Representation of major solutes

	ICT	**ECT'**
cations	▪ potassium ▪ magnesium	▪ sodium ▪ potassium
anions	▪ phosphates ▪ proteins	▪ chlorides ▪ bicarbonate

Osmolality

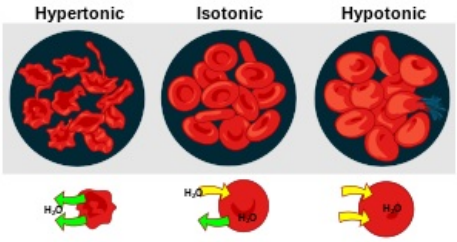
The *osmolality* of body fluids is determined by the amount of particles dissolved in them, which are able to act on the water around them or on the other side of the water-permeable membrane. Particle size does not matter. The amount of particles (solutes) in a unit of solvent mass, expressed per kg or per liter of water, is called "osmolality" and is given in units of mmol/kg, respectively. mOsm/kg. The difference in the amount of osmotically active (water-acting) particles on both sides of the water-permeable membranes is **osmotic pressure**, the osmotic concentration gradient. We are able to measure and therapeutically influence the osmolality of IVT. Since the main osmotically active component of ECT and blood plasma is sodium, significant deviations in water management are typically manifested in the form of hyponatremia (Na < 130 mmol/l), or hypernatremia (Na > 150 mmol/l). The organism must ensure not only iso-osmolality, but also isoion, not only in the ECT, but also in other compartments.

Effective osmolality (tonicity)

From a clinical point of view, the so-called *effective osmolality* (tonicity) is more important, which depends on the number of "non-penetrating" particles in ECT (mainly sodium and anions) and ICT (mainly potassium and phosphate with their anions). It is these solutes that form an osmotic concentration gradient, which develops

osmotic activity and thereby affects the distribution of water between ICT and ECT, i.e. it keeps water on its side of the cell membrane.

The values of tonicity and osmolality are mostly identical, but there may be cases when this is not the case: so-called "penetrating" solutes, e.g. temporarily) influence on the osmotic movement of water between individual body compartments. In other words, although azotemia increases total plasma osmolality, it does not affect plasma tonicity. Uncritically accepted values of total osmolality in these patients can therefore lead to an incorrect therapeutic conclusion. Some substances, on the other hand, increase the effective osmolality and are not included in the calculation according to the formula (see formula 2). It can be substances that we use therapeutically (e.g. mannitol) or substances that are found in intoxication (alcohol, methanol). If other exogenous osmotically active substances (e.g. mannitol) are not present in the plasma, osmolality or tonicity can be calculated according to simple formulas:



Effect of different osmotic pressure on erythrocytes

- *Formula 1:* **S-osmolality = 2x Na + glycemia + urea**
- *Formula 2:* **Effective osmolality, S-tonicity = 2x (Na + glycemia)**; 2x Na + 10

[1]

S-tonicity calculates only with "non-penetrating" solutes and represents, from a clinical point of view, the so-called effective osmolality. It only calculates with ions and glucose.

The organism maintains the osmolality of individual compartments within a narrow range, and values of 280 to 295 mmol/kg are considered to be the physiological range of S-osmolality.

Hypoosmolality of plasma S-osmo < 275 mmol/kg indicates a relative excess of body water in relation to body solutes. **Hyperosmolality of plasma** S-osmo > 295 mmol/kg indicates a relative deficit of body water in relation to body solutes.

🔎 *For more information see Serum Osmolality.*

Idiogenic osmoles

When the patient's ECT osmolality suddenly changes, a water shift occurs that immediately balances the differences in osmotic concentration on either side of the cell membrane. Although this rapid compensation reduces the magnitude of the osmotic load in ECT, it is only at the cost of simultaneous drainage and shriveling of the cells (at hyperosmolality of the plasma), or their swelling (with plasma hypoosmolality). The CNS cells also have another compensatory mechanism to prevent osmotic damage, but it is fully manifested only after 6 to 12 hours of plasma hyper/hypoosmolality. With a long-term increase in osmolality, osmotically active particles, so-called ``idiogenic osmoles*, are formed by the gradual degradation of cellular macromolecules. Their formation is accompanied by a subsequent rise in intracellular osmolality and an adjustment in the volume of CNS cells. Thanks to this compensation, patients with chronic hypernatremia or diabetic ketoacidosis can tolerate extremely high plasma osmolality values. On the contrary, with a prolonged decrease in osmolality, CNS cells can reduce the number of intracellular solutes and thereby regain their original volume despite the persistent hypoosmolality of the plasma. The existence of this secondary "delayed" compensation must be taken into account in the correction of long-lasting disorders of water homeostasis.*

Osmotic window

In some clinical situations, it is useful to determine the *osmolar/osmotic window* (osmolal/osmotic gap, OG), which expresses the difference between the osmolality directly measured by the osmometer and the osmolality calculated according to formula 1.

The physiological value of the osmotic gap is 4 – 12 mmol/kg.

OG is created by measuring solutes that are not included in the formula with an osmometer. If the plasma contains a significant amount of these unaccounted for osmotically active substances (e.g. methanol, ethanol, mannitol, idiogenic osmoles in diabetic ketoacidosis), there will be a large difference between the measured and calculated osmolality values. We will use OG especially in the diagnosis of poisoning. In case of an osmotic window value > 20 mOsm/l with simultaneous MAC of unclear etiology, intoxication with osmotically active substances such as ethanol, methanol, ethylene glycol must be ruled out.

Regulation of body fluid volume

The constancy of the volume of body fluids is monitored very carefully. Deviations in the range of plus or minus 1% from the steady state are already registered. Among the various compartments of body fluids, the plasma volume, which is monitored by special *volume receptors (voloreceptors)*, plays a key role in the regulation of CTV. They are on the one hand high pressure baroreceptors in the arterial bed (arcus aortae and sinus caroticus) and low

pressure volumoreceptors in the large veins, in the heart and chest. Signals from these receptors are transmitted to regulatory centers in the CNS via the glossopharyngeal nerve, n. vagus and sympathetic. Here in the medulla oblongata, pons Varoli and hypothalamus, stimuli are processed and effector mechanisms such as [[ADH] are activated according to the volume and osmolality of body fluids], systems renin-angiotensin-aldosterone, kallikrein-bradykinin, renal prostaglandins, natriuretic peptides, [[autonomic nervous system]] and more. All these mechanisms maintain the balance of body fluid volume (and osmolality) by changes in cardiac activity, vascular lumen, sodium and water excretion. Excretion occurs primarily through the kidneys, skin, exhaled gases and the digestive tract, and is affected by an increase or decrease in thirst and fluid intake.

The primary mechanism of volume regulation of ECT and ICT is renal sodium excretion and increased or decreased fluid intake by the thirst mechanism. Interestingly, volume changes in the body are detected independently of the sodium concentration: through volumoreceptors, but volume regulation is mainly mediated by the regulation of sodium excretion by the kidneys.

Regulation of osmolality of body fluids

Stable osmolality of body fluids is maintained by the ability of the kidney to change the osmolality of urine and by influencing water intake through the thirst mechanism. The kidneys are able to change the osmolality of urine in a wide range of 50 to 1400 mmol/kg and thus change the amount of excreted solutes and water as needed.

'*Changes in osmolality* are monitored by the **osmoreceptors** of the osmoregulation center in the hypothalamus, which already trigger regulatory mechanisms to adjust osmolality when the osmolality changes by 1%. An increase in serum osmolality is mainly due to an increase in water intake through the thirst mechanism and the secretion of ADH with the formation of concentrated urine. The opposite processes start when osmolality is reduced. The stimulus for ADH secretion is increasing serum osmolality as well as some non-osmolar factors such as hypovolemia, pain, hypoxia, RAAS. ADH secretion is inhibited by S-osmolality < 280 mmol/kg, hypervolemia, left atrial distension. The osmolality at which we feel thirsty (thirst mechanism) is 290 mmol/kg.

Electroneutrality of body fluids

Electroneutrality of body fluids together with osmolality are determining factors of body fluid composition. In body fluids, the so-called *Gibbson-Donnan equilibrium* applies. The electroneutrality of the extracellular fluid can be expressed by the equation (*Formula 3*):

$$Na + K + Ca + Mg + H = OH + Cl + HCO3 + CO2 + albumin + phosphates$$

But precisely to maintain electroneutrality, the concentration of ions in all ECT compartments is not the same. IST has more chlorides than plasma because of the high protein content. In the equation (*Formula 3*) this is expressed on the anion side by albumin. The negative charge of proteins also contributes to sodium retention in IVT and IST. **Starling's Law** states that intracapillary hydraulic pressure predominates on the arterial side of the capillary, while at the venous end plasma proteins play a major role in the return of fluid from the IST to the IVT with their [[oncotic pressure|oncotic pressure]]. Pathological influences, such as hypoalbuminemia or arterial hypertension, can affect water transport.

When it comes to maintaining the electroneutrality between ECT and ICT, active **enzymatic mechanisms**' such as *Na-K-ATPase* play a significant role. The electrical forces of non-filterable intracellular anions attract cations from the ECT, primarily sodium. It is actively transported back from the cell. To maintain electroneutrality and osmolality, it is exchanged for potassium that is actively transported intracellularly, where it is the main cation. The maintenance of Na and K concentration gradients is a very energy-demanding process, and factors affecting it can cause serious disturbances in the composition of ECT and ICT.

Too rapid adjustment of hyperosmolality can lead to edema in CNS cells => intracranial hypertension, rapid adjustment of hypoosmolality brings the risk of "shrinking" of CNS cells => pontine myelinolysis syndrome.

Electrolyte homeostasis in neonates

Water and electrolyte homeostasis of neonates born at term or preterm differs in many ways from other age categories of children. The water balance of newborns is characterized by very rapid changes in the distribution of water from ECT, but also from ICT, and this mainly happens through the kidneys. Water losses are accompanied by sodium losses, premature infants lose more sodium than term newborns. This can be well documented by examining the excretion fraction for sodium (FE Na), which is usually >5%. Its reduction usually occurs during the 1st month of life, in premature babies this interval is longer. It is a result of renal tubular immaturity. Newborns and premature babies are therefore in a negative sodium balance shortly after birth, which sometimes requires supplementation. Achieving a positive sodium balance is important for further proper growth and development. It is not uncommon for premature infants to manifest late hyponatremia by 4 to 6 weeks of age. This is not a consequence of excessive losses, but is the result of increased incorporation of sodium into tissues during growth acceleration.

The most common causes of hyponatremia in newborns/premature infants:

- excessive parenteral supply of glucose solutions,
- diarrhea,
- severe sepsis (sodium pump dysfunction),
- Heart Failure,
- pharmaceuticals (diuretics, indomethacin).

The most common causes of hypernatremia in newborns/premature infants:

- phototherapy
- congenital skin defects
- defects of the closure of the anterior abdominal wall (increased insensible losses)
- resuscitation with excessive supply of bicarbonateu

Recommendations on the issue of indoor environment

When monitoring changes in homeostasis and their possible correction, we have to keep in mind some general attitudes.

- The decisive factor is the patient's clinical condition. The goal is not "normal" serum osmolality but good patient status: proper gas exchange, adequate ECKO effectively circulating blood volume, good consciousness and diuresis, good peripheral circulation. If there is a discrepancy between the clinical findings and the results of laboratory examinations, then we repeat the examination and evaluate the results using the largest possible set of information. The mere fact that the concentration of potassium in the serum is 4.8 mmol/l does not mean anything. To interpret this result, we need at least to know the pH value, the Na and Cl concentration in the serum, the patient's hydration status, kidney, EKG waveform and muscle strength.
- **Individual parameter** has a very limited meaning. The trend of changes in homeostasis, monitoring the changes of many parameters over time is important. This is done by balances, waste monitoring of Na, K, Cl, ureas and water, etc. The stability of the internal environment is a dynamic event.
- Changes in homeostasis usually occur *slowly*, within 48 hours or longer. The organism registers changes, compensates and adapts to them. Trying to correct the deviation from the homeostasis reference range quickly, within minutes, is usually dangerous for the patient. We only correct changes in homeostasis that threaten the patient's vital functions.
- A **Quick** correction within seconds to minutes is required by:
    - hypoxia,
    - hypotension,
    - hypoglycemia,
    - convulsions.

All other changes in homeostasis give us the opportunity to comprehensively examine and monitor the patient clinically and with the help of laboratory tests. Judicious correction of possible homeostasis disturbances will be necessary for them so as not to disturb the adaptive and compensatory changes of the organism.

Links

Related Articles

- Serum osmolality
- Diabetic ketoacidosis

References

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