WATER AND SALT METABOLISM

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Water and electrolytes

Water

Water is a major constituent of all body fluids and the most abundant component of the human body, approximately 60% of the body weight (BW). Body water is divided into two main compartments – intracellular and extracellular spaces:

- TBW – total body water – 60% of body weight ~ 40–45 l
- ECW – extracellular water – 20% of body weight ~ 14–18 l
- ICW – intracellular water – 40% of body weight ~ 20–25 l

ECW is distributed into plasma ~ 3 l, interstitial fluid ~ 9 l, water in connective tissue and cartilage ~ 3 l, water in bones ~ 3 l and transcellular water ~ 1l (fluid in GIT, urogenital system etc.).

Only one third of total body water (~ 14 l) is quickly and freely exchangeable (plasma, interstitial fluid and part of connective tissue water). Therefore, strong control of water balance (particularly in kidney and intestine) is necessary. If daily loss of water to GI tract reach 7–10 l, patient can loose nearly all extracellular water within two days.

Adult patient needs 35–50 ml/kg/day (2.3–3.0 l per day) of water in EN or TPN. However, water requirement can be higher or lower depending on certain clinical situations.

Water balance in healthy adult subject

intake		output	
fluid ingested	2100 ml	insensible – skin	350 ml
metabolic water	200 ml	insensible – lungs	350 ml
		sweat	100 ml
		feces	100 ml
		urine	1400 ml
total	2300 ml	total	2300 ml

L. Sobotka, S.P. Allison, Z. Stanga: Water and Electrolytes.
In: Basic in Clinical Nutrition (edit L. Sobotka), Galén, Praha, 2004

Osmolality values mmol/kg H_2O

biological fluid	physiologic values	extreme values
serum	275-295	200-500
urine	400-1000	50-1400

Loss of osmoticaly active substances by urine:	
physiologically 600-1200 mmol/24 h	catabolic states 2000-3000 mmol/24 h

Calculation of osmolality (plasma, serum):

osmolality mmol/kg H_2O =

= 2 [Na^+] mmol/l + [urea] mmol/l + [glucose] mmol/l

Concentration of ions in body fluids

Ions	plasma mmol/l	Interstitial fluid mmol/l	Intracellular fluid mmol/l
Na^+	141	143	10
K^+	4	4	155
Ca	2,5	1,3	<0,001
Mg	1	0,7	15
Cl^-	103	115	8
HCO_3^-	25	28	10
H_2PO_4	1	1	65
SO_4^{2-}	0,5	0,5	10
org. acids	4	5	2
proteinates	17	1	47
pH	7,4	7,4	7,4

Concentration of ions and volumes of body secrets

Material	Na^+ mmol/l	K^+ mmol/l	Cl^- mmol/l	HCO_3^- mmol/l	volume ml/d
gastric juice strongly acid	20 (10-30)	10 (5-40)	120 (80-150)	0	1000-9000
gastric juice moderate acid	80 (70-140)	15 (5-40)	90 (40-120)	5-25	1000-2500
pancreatic juice	140 (115-180)	5 (3-8)	75 (55-95)	80 (60-110)	500-1000
bile	148 (130-160)	5 (3-12)	100 (90-120)	35 (30-40)	300-1000
small intestine	110 (80-150)	5 (2-8)	105 (60-125)	30 (20-40)	1000-3000
intestine, distal (caecum)	80 (40-135)	8 (5-30)	45 (20-90)	30 (20-40)	1000-3000
diarrhoea	120 (20-160)	25 (10-40)	90 (340-120)	45 (30-50)	500-17000
perspiration	50	7	40	?	300-2000
transsudation	140	5	115	?	various

saliva: Na^+ 44 mmol/l K^+ 20 mmol/l

REGULATION OF WATER AND SODIUM BALANCE

1. **ADH**

   change of osmolality – hypothalamic osmoreceptor – change of ADH secretion. Other stimuli: increased in hypovolemia, hypotension, hypokalemia. Decreased in pregnancy, hyperglycemia.

   Antagonism of prostaglandins in kidney.

2. **Renin – angiotensin – aldosteron** system: activation by decreased effective i.v. volume. Retention of water and Na in distal convoluted tubule. Antagonism of prostaglandins in kidney.

3. **Renal failure**

   a) with decreased glomerular filtration: elimination of free water limited, risk hyponatremia,

   b) in tubulointerstitial nefritis: mixed and water diuresis, risk of hypernatremia.

4. **Diuretics**

   a) loop diuretics: loss of water excceds loss of Na – hypernatremia,

   b) thiazides: loss of Na exceeds loss of water – hyponatremia.

5. **Natriuretic peptides (NP)**

   secretion stimulated by intrathoracal volumoreceptors.

   BNP: isolated from hypothalamus and heart ventricles.

   ANP: isolated from heart atria.

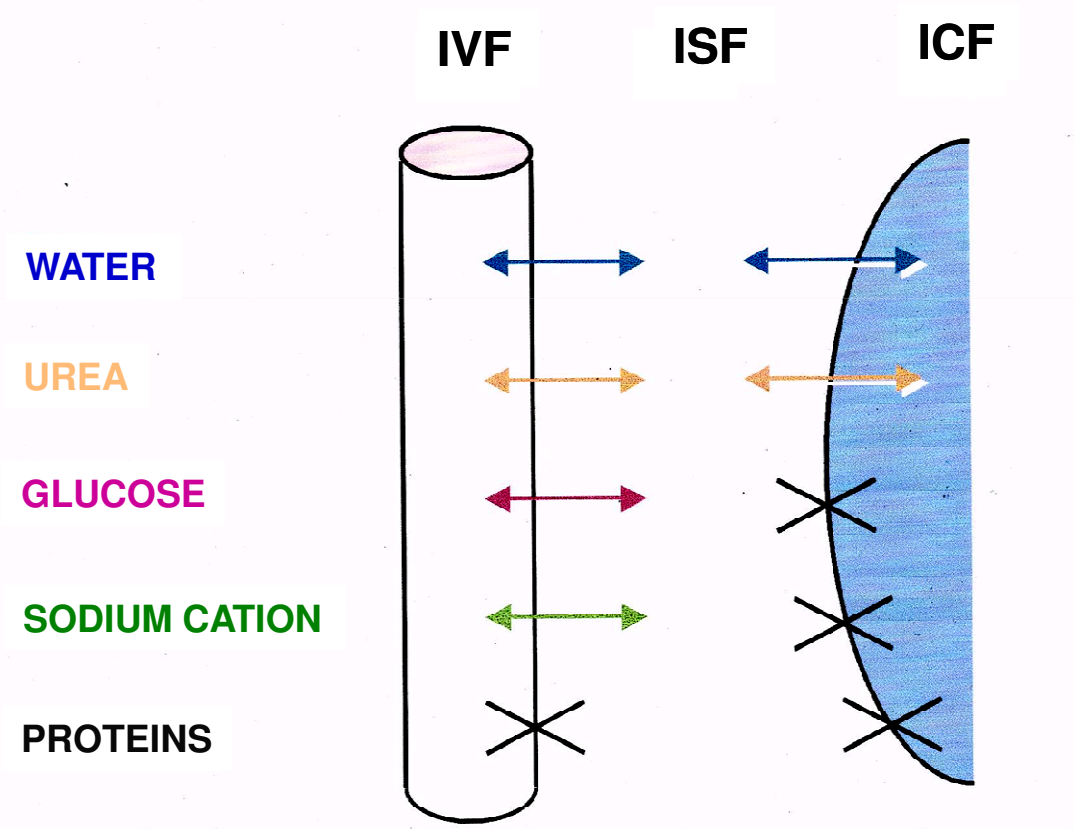
6. **„Digoxin like hormone“**

   origin in adrenal cortex, effect: natriuresis.

7. **Urodilatin**

   origin in distal tubulus, effect: natriuresis.

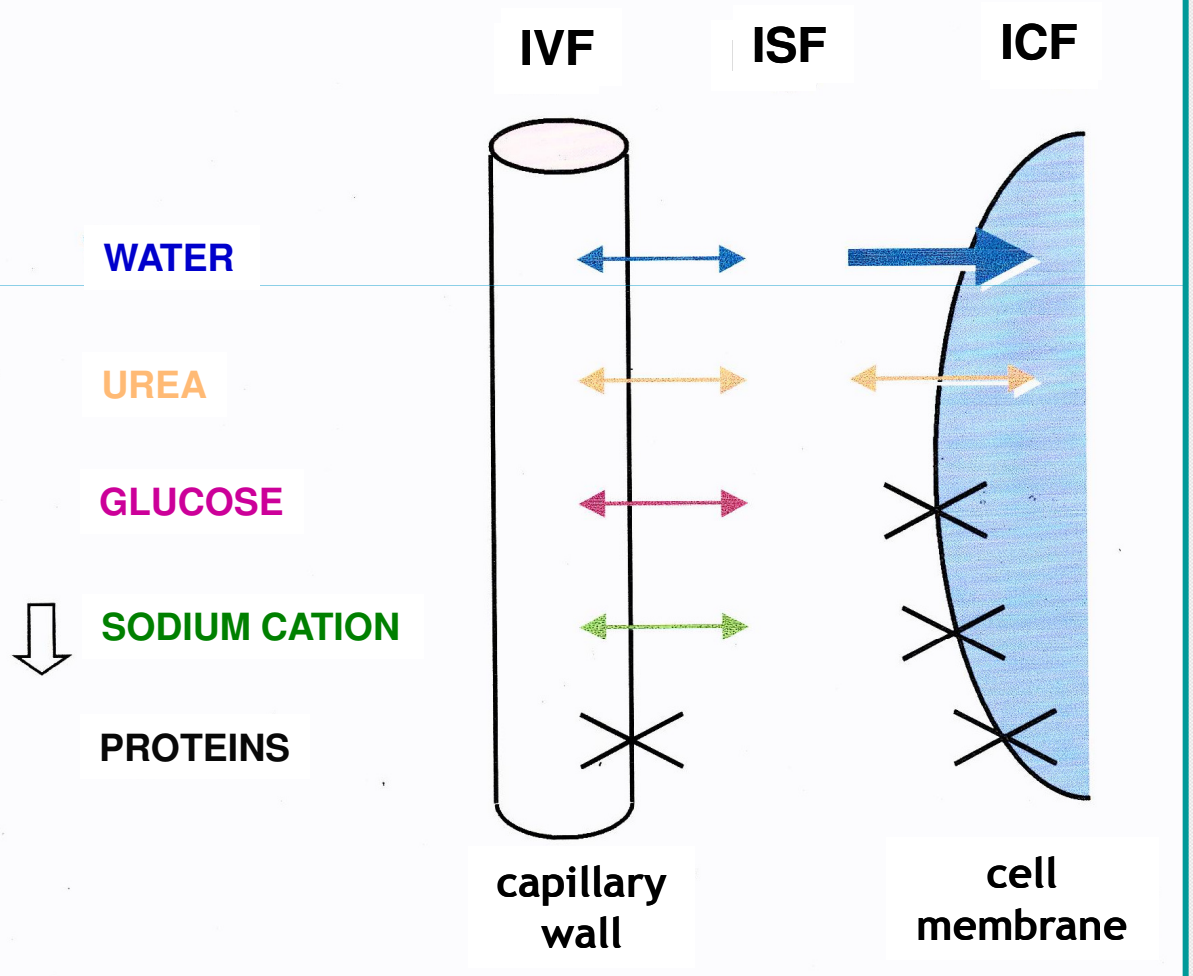
Three compartments of body fluids



The causes of hyponatremia

- Metabolic response to trauma
- surplus of water in organism
- isotonic fluid loss covered by water
- chronic catabolic states
- inappropriate secretion of ADH (SIADH)
- cerebral salt wasting syndrome (CSWS)
- sinking in fresh water

Three compartments of body fluids



Symptoms of decreased effective osmolality

Subjective symptoms: disorientation, lethargy, apathy (sometimes on the contrary excitement), headache, dislike for meals or vomiting.

Objective symptoms: sensory disturbances, decreased reflexes, pseudobulbar paresis, disturbances of conscience, in extreme situations unconsciousness.
Cheyne_Stokes type of breathing may be present as well as hypothermia.

Decreased effective osmolality manifests at following values:

in acute states:	S_Na <130 mmol/l S_osm <271 mmol/kg
during more days lasting development:	S_Na <120 mmol/l S_osm <250 mmol/kg

CEREBRAL CHANGES AFTER DECREASE OF EFFECTIVE OSMOLALITY IN EXTRACELLULAR FLUID

Mechanism of compensation

1. **Leakage of K (and Na)** from cells accompanied by shift of water from cells (maximum reached at about 24 hours).

2. **Decreasing content of cerebral organic osmotic components** accompained by shift of water from cells (maximum reached at about 48 hours).

   Following substances are involved:

   - polyols (myoinositol),
   - neutral aminoacids, amines and their derivates (Glu, Asp, N-acetyl asparagic acid, Gln, Tau),
   - choline compounds (glycerol phosphocholine),
   - phosphocreatinine.

Therapy of hyponatremia

- In case of acute disturbance lasting only 1 – 2 days, to elevate S_Na^+ maximally about 1-2 mmol/l/h
- By longer lastings states to increase S_Na^+ only about 0,5 mmol/l/h
- Limits of correction S_Na^+ mmol/time:
  a) 6 – 8 mmol/24 h (NON 10 and more)
  b) 12 – 14 mmol/48 h (NON 18 and more)
  c) 14 – 16 mmol/72 h (NON 20 and more)

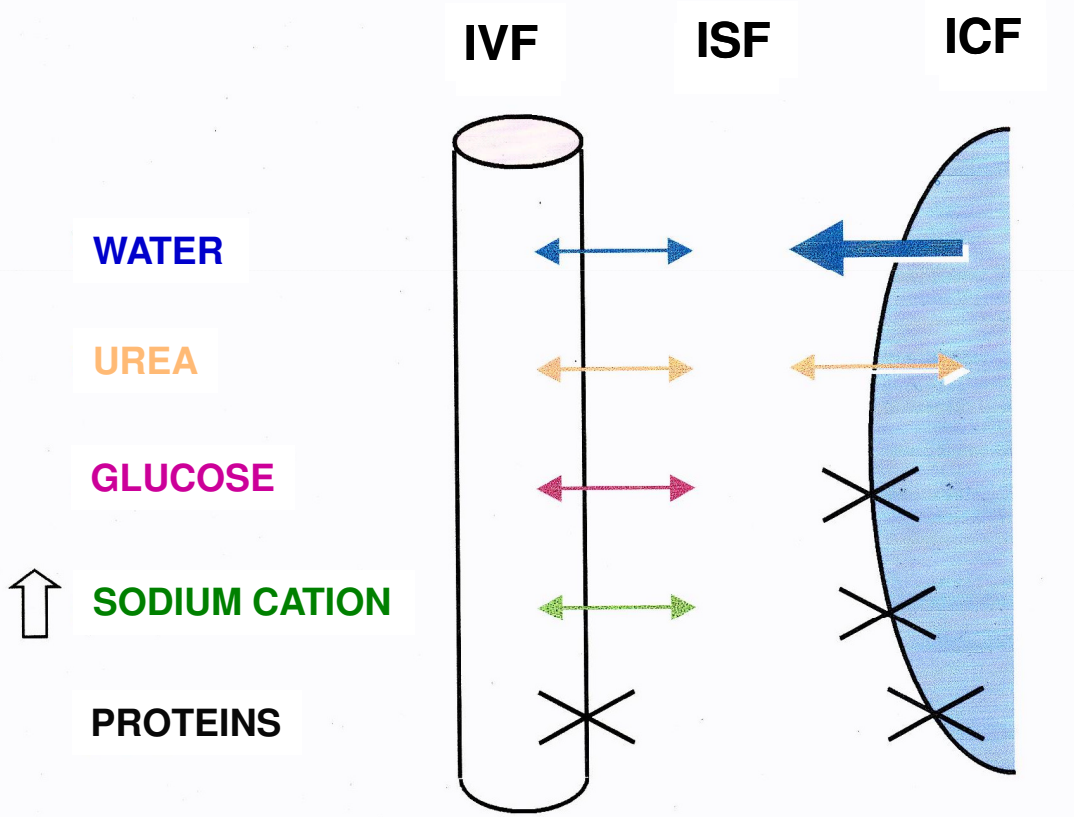
Sterns 2009

The need of Na must be covered by correction dose plus by substitution dose.

The causes of hyperosmolality

- loss of water
- burns
- incorrect parenteral and enteral nutrition
- cardiac resuscitation with bicarbonate
- sinking in seawater
- diabetes insipidus
- nephrogenic diabetes insipidus
- sepsis
- some patients with nephropathy
- acute catabolic states
- diabetic coma
- sinking in seawater

Three compartments of body fluids



Symptoms of increased effective osmolality

Subjective symptoms: irritability, restlessness, confuseness (sometimes on the contrary lethargy).

Objective symptoms: muscular spasms and increased reflexes. Serum osmolality above 350 mmol/kg may lead to unconsciousness.

Increased effective osmolality manifests at following values:

in acute states:	S_Na >150 mmol/l S_osm >310mmol/kg
during more days lasting development:	S_Na >160 mmol/l S_osm >330 mmol/kg

Therapy of hypernatremia

It is necessary to diagnose if hypernatremia is accompanied by hypo- normo- or hyper-volemia, how long does it last and to judge the clinical signs.

1. In presence of hypovolemia or hypotension suplementation of IVF by isotonic solutions (0,9% NaCl, Ringer-lactate) or by moderately hypotonic solutions (0,225% nebo 0,45% NaCl).
2. In presence of normovolemia or hypervolemia: thiazide diuretics and 5% glucose to keep the volume of circulating fluids.
3. The acute development is treated more intensively. There is not yet developed the compensation of the brain in contrast to longer lasting hypernatremia. The decrease of S_Na+ in acute states 1-2 mmol/l/h, and in longer lasting states 0,5 mmol/l/h is recommended.
4. Monitoring of S_Na^+ in symptomatic states every 2-4 h, later till to normalization every 4-8 h.
5. The daily decrease of S_Na+ not more as 8 (max 10) mmol/l/d. *Jabor 2008*
   Another authors accept maximally 10-12 mmol/d. *Bagshaw 2009*

Kraft 2005

Extent and frequency of the clinical-biochemical investigation in intensive care patients

parameter	frequency
serum (plasma)	
glucose	daily, or more frequently
urea	daily
creatinine	daily
Na^+, K^+, Cl^-	daily, K^+ may be more frequently
Ca^+, Mg^{2+}, P	2-3 times a week
osmolality	daily
albumin	daily
total protein	daily
acid-base balance	daily, may be more frequently
oxygen parameters	daily, 30 minutes after the change of ventilatory support
lactate	depending on clinical state
reactants of acute phase	daily
negative reactants of acute phase	2-3 times a week
liver function test	2-3 times a week
urine	
urea	daily
creatinine	daily
Na^+, K^+, Cl^-	daily
osmolality	daily
drainage, gastric juice	
Na^+, K^+, Cl^-	depending on loss

parameter	SIADH	CSWS	cDI
S_Na^+	< 135 mmol/l	< 135 mmol/l	> 145 mmol/l
S_osmolality	< 280 mosm/kg	< 280 mosm/kg	> 295 mosm/kg
U_Na^+	> 25 mmol/l	> 25 mmol/l	< 25 mmol/l
U_osm/S_osm	> 1	> 1	< 1
C_creatinine	increased	norm.	norm.
FE_H_2O	norm., decreased	increased	incrreased
FE_Na^+	norm., decreased	increased	norm., decreased
Diuresis	norm., decreased	norm., increased	increased
C_El	norm.	increased	norm.
EWC	decreased	norm.	increased
dU_Na^+	< 100–150 mmol/l	> 150 mmol	≤ income Na^+
Renin, aldosterone	norm.	norm., increased	norm., increased
ADH	norm., increased (in 10–15 % non-detectable)	increased	decreased
ANP	norm., increased	increased	norm., decreased
uric acid	decreased	norm.	

For the diagnosis of SIADH the following must be excluded: hypovolaemia, hypotension, oedemas (heart failure, cirrhosis), renal insufficiency, hypothyroidism, hypocorticalism.

Table 2. *Differential diagnosis of CSWS versus SIADH – clinical signs and selected laboratory parameters (9, 10)*

	CSWS	**SIADH**
Signs of dehydration on physical examination	variably present	absent
Central venous pressure	decreased	increased or normal
Plasma volume	decreased	increased or normal
Sodium balance	negative	variable
Hematocrit	increased	unchanged
Plasma urea/creatinine ratio	increased	normal
Plasma potassium concentration	increased	decreased or normal

Thank you

for your attention