Water and mineral balance and its disorders

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Dehydration

- Dehydration means our body does not have as much water and fluids as it should. ***Dehydration can be caused by losing too much fluid, not drinking enough water or fluids, or both***. Vomiting and diarrhea are common causes.
- ***Infants, children*** are more susceptible to dehydration than adults because of their smaller body weights and higher turnover of water and electrolytes.
- ***The elderly*** and those with illnesses are also at higher risk.
- Severe dehydration is a ***life-threatening emergency***

Causes, incidence, and risk factors

- ***Our body may lose too much fluids from***:
- Vomiting or diarrhea
- Excessive urine output, such as with uncontrolled diabetes or diuretic use
- Excessive sweating (for example, from exercise)
- Fever

- ***We might not drink enough fluids because of*****:**
- Nausea
- Loss of appetite due to illness
- Sore throat or mouth sores

Symptoms

- Dry or sticky mouth
- Low or no urine output; concentrated urine appears dark yellow
- Not producing tears
- Sunken eyes
- Markedly sunken fontanelles in an infant
- Lethargic or comatose (with severe dehydration)

Signs and tests

- Low blood pressure
- Blood pressure that drops when you go from lying down to standing
- Rapid heart rate
- Poor skin turgor -- the skin may lack its normal elasticity and sag back into position slowly when pinched up into a fold; normally, skin springs right back into position
- Delayed capillary refill
- Shock

Skin turgor


Skin with decreased turgor remains elevated after being pulled up and released

Glasgow Coma Scale

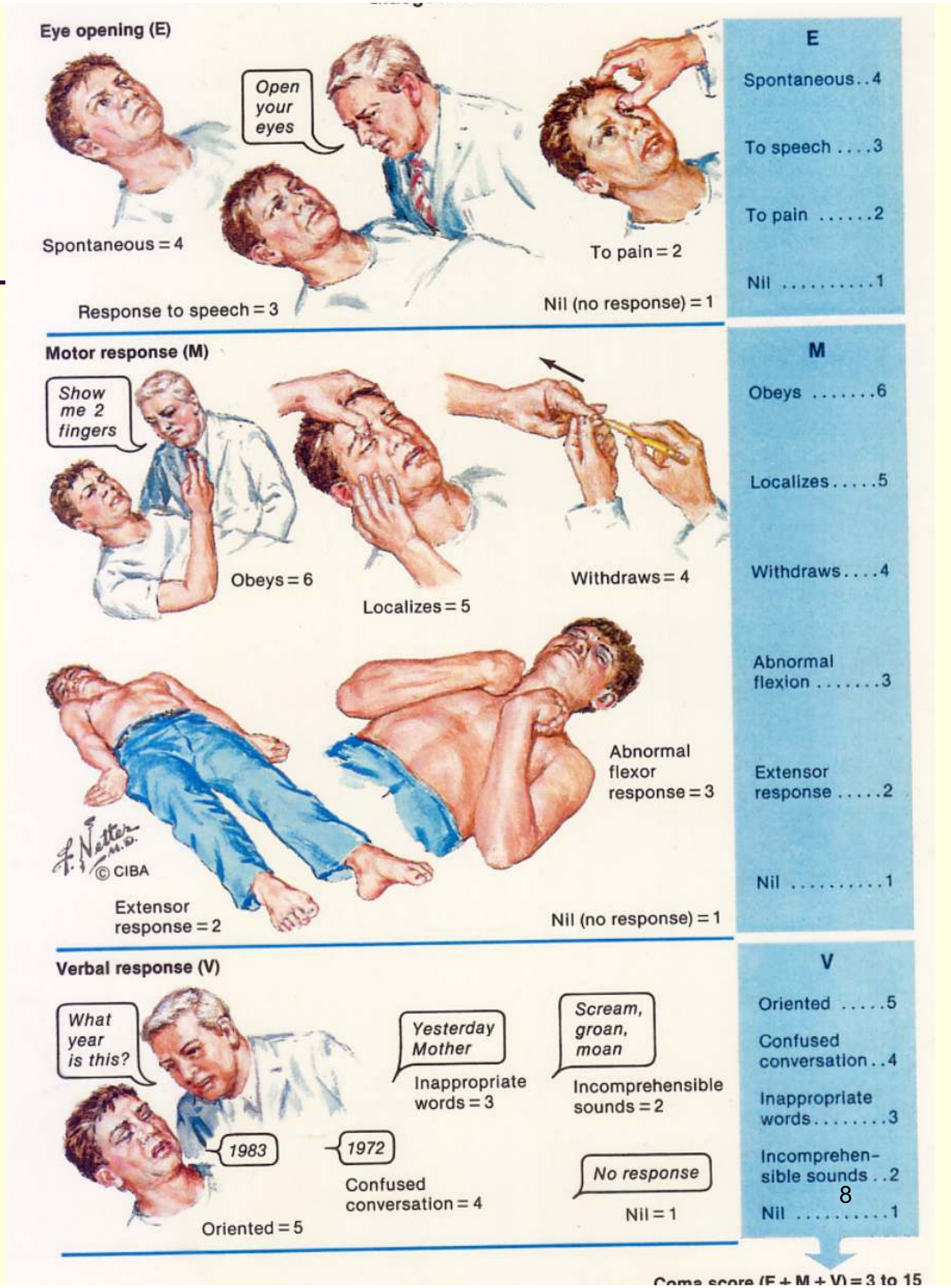
Coma/ Unconsciousness (GCS: 3), Norm/ Consciousness (GCS: 15)

Glasgow Coma Scale

	1	2	3	4	5	6
Eyes	Does not open eyes	Opens eyes in response to painful stimuli	Opens eyes in response to voice	Opens eyes spontaneously	N/A	N/A
Verbal	Makes no sounds	Incomprehensible sounds	Utters inappropriate words	Confused, disoriented	Oriented, converses normally	N/A
Motor	Makes no movements	Extension to painful stimuli (decerebrate response)	Abnormal flexion to painful stimuli (decorticate response)	Flexion / Withdrawal to painful stimuli	Localizes painful stimuli	Obeys commands

The scale comprises three tests: eye, verbal and motor responses. The three values separately as well as their sum are considered. The lowest possible GCS (the sum) is 3 (deep coma or death), while the highest is 15 (fully awake person).

Glasgow coma scale/ un-consciousness



Coma (GCS: 3),
norm/ consciousness (GCS: 15)

Tests Include

- Blood chemistry (to check electrolytes, especially sodium, potassium, and bicarbonate levels)
- Urine specific gravity (a high specific gravity indicates significant dehydration)
- BUN (blood urea nitrogen - may be elevated with dehydration)
- Creatinine (may be elevated with dehydration)
- Complete Blood Count (CBC) to look for signs of concentrated blood

Treatment

- ***Drinking fluids is usually sufficient for mild dehydration***. It is better to have frequent, small amounts of fluid (using a teaspoon or syringe for an infant or child) rather than trying to force large amounts of fluid at one time. Drinking too much fluid at once can bring on more vomiting.

- ***Electrolyte solutions*** or freezer pops are especially effective. These are available at pharmacies. Sport drinks contain a lot of sugar and can cause or worsen diarrhea. In infants and children, avoid using water as the primary replacement fluid.

- ***Intravenous fluids and hospitalization may be necessary for moderate to severe dehydration***. The doctor will try to identify and then treat the cause of the dehydration.

Hyperhydration …

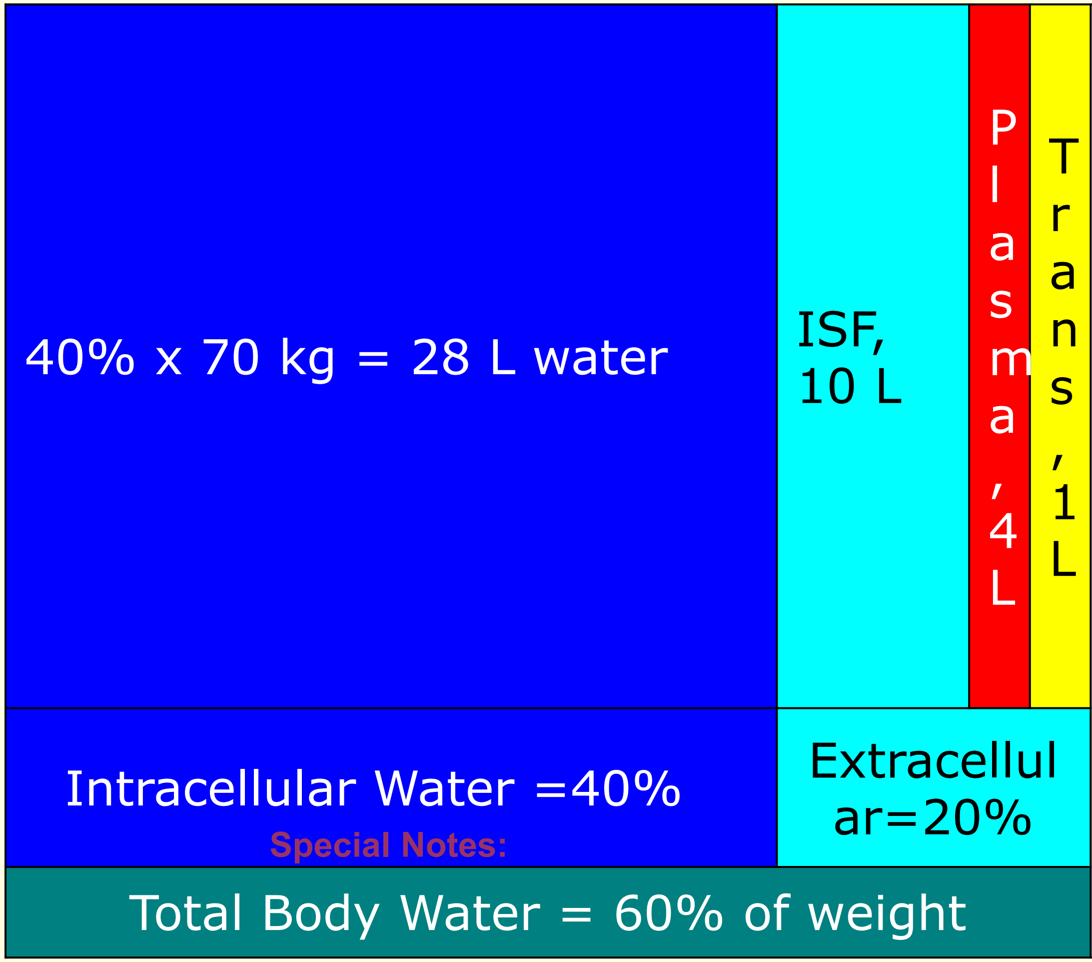
- Hyperhydration may be caused by kidney failure
- Or by improperly administered infusion therapy
- Hyperhydration can be manifested by cardiac problems, heart overload, heart failure

Fluid Compartments in the Body

- **Intracellular Fluid (ICF)** comprises 2/3 of the body's water. If your body has 60% water, ICF is about 40% of your weight. The ICF is primarily a solution of potassium and organic anions, proteins etc. (Cellular Soup!). The cell membranes and cellular metabolism control the constituents of this ICF. ICF is not homogeneous in your body. It represents a conglomeration of fluids from all the different cells.

- **Extracellular Fluid (ECF)** is the remaining 1/3 of your body's water. ECF is about 20% of your weight. The ECF is primarily a NaCl and $NaHCO_3$ solution. The ECF is further subdivided into three subcompartments:
  - **Interstitial Fluid (ISF)** surrounds the cells, but does not circulate. It comprises about 3/4 of the ECF.
  - **Plasma** circulates as the extracellular component of blood. It makes up about 1/4 of the ECF.
  - **Transcellular fluid** is a set of fluids that are outside of the normal compartments. These 1-2 liters of fluid make up the CSF, Digestive Juices, Mucus, etc.

Fluid Compartments in the Body



The 60-40-20 Rule:
60 % of body weight is water
40% of body weight is intracellular fluids
20% of body weight is extracellular fluid

Measuring the Volumes of the Fluid Compartments

- The volumes of some of the compartments can be measured by the dilution method.
- One adds an extrinsic, measurable, compound that distributes fully within the compartment of interest.
- This method relies on the formula:

  Volume = Amount Added-Amount Lost / Measured Concentration

Measuring the Volumes of the Compartments

- **Directly Measurable volumes:**

  Total Body Water: Use D2O or T2O, radioactive water (tritiated)/ etanol C2H5OH. Distributes throughout all aqueous solutions.

  ECF Volume: Use Inulin (a starch) or Sucrose. These distribute throughout body, but are excluded from cells.

  Plasma Volume: Use radioactive albumin or dye (Evans Blue) that stay in plasma only.

- **Indirectly Measurable Volumes:**

  There is no practical way to measure only the intracellular or the interstitial volumes. Rather, these are calculated by combining the measured volumes given above.

  Interstitial Volume: Equal to the Extracellular volume minus the plasma volume.

  Intracellular Volume: Equal to the Total Water minus the Extracellular Volume.

Calculating Osmolarity in Solutions

- **Osmolarity of a simple solution is equal to the molarity times the number of particles per molecule. (Glucose has 1 particle, NaCl has two, MgCl2 has three...)**

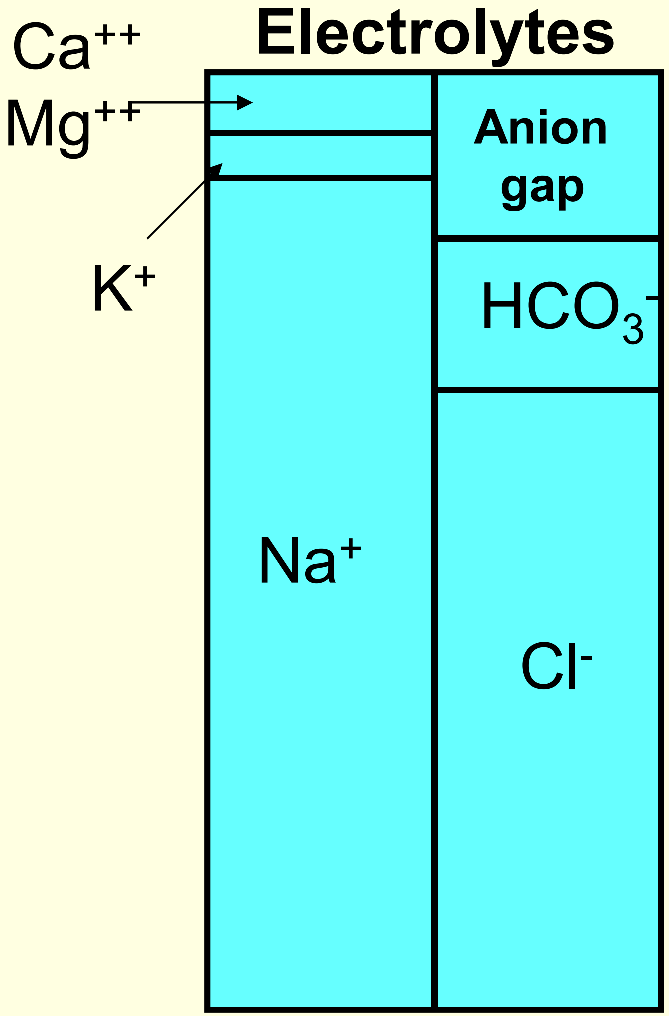
- **Take the reported Na concentration**

(mEq/ Liter Plasma) and double it.

Osmolarity in Solutions

- Two solutions are **isosmotic** when they have the same number of dissolved particles, regardless of how much water would flow across a given membrane barrier. In contrast, two solutions are **isotonic** when they would cause no water movement across a membrane barrier, regardless of how many particles are dissolved.
- A 150 mM NaCl solution would be isosmotic to the inside of a cell, **and it would also be isotonic**--the cell would not swell or shrink when placed in this solution. On the other hand, a 300 mM urea solution, while still isosmotic would cause the cell to swell and burst (due to its permeability). This isosmotic ureas solution is **not isotonic**. Instead it has a lower tonicity (called hypotonic).

Osmolarity of the Body Fluids



$$\text{Osm} = 2\,(Na^{+} + K^{+}) + \text{Glc} + \text{Urea}$$

{Glc [mmol/l]} ={Glc [mg/dL] } /18

{Urea[mmol/l} ={Urea[mg/dL]} / 6

$\{\text{Osm}\}_{norm}$ = 280 – 296 mmol/l

Electro-chemical (Nernst) membrane potential

iont	*ECF [mmol/l]*	*ICF [mmol/l]*	E_x *[mV]*
K^+	4,5	160	–95
H^+	4×10^{-5} (pH 7,4)	1×10^{-4} (pH 7,0)	–24
Na^+	144	7	+80
Ca^{2+}	2,5	3×10^{-4}	+120

iont	*ECF [mmol/l]*	*ICF [mmol/l]*	E_x *[mV]*
Cl^-	114	7	–75
HCO_3^-	28	10	–27
$H_2PO_4^-$	2	100	+100
HSO_4^-	1	20	+80

Electro-chemical (Nernst) membrane potential

Related to nutritional state (!):

Anabolic state = glucose influx

= K^+ enters cells

Catabolic state = glucose deficit

= K^+ leaves cells

Margin added (2/3) Na^+ / K^+ -ATPase (pump)

Controlled by insulin

(both K^+ and Na^+ by aldosterone and other hormones)

Extra-cell. and intra-cell. concentration and pool (hotovost)

...moles/ Osmoles/ pressure ...

... pool = storage…

Extra-cellular and Intra-cellular Concentration and Pool (hotovost)

(1) EC a IC koncentrace a hotovost					
Látka	*jednotky*	*EC konc.*	*IC konc.*	*EC hotovost*	*IC hotovost*
Na^+	mmol/l	128–141	3–30	2000 mmol	1600 mmol
K^+	mmol/l	3,8–5,4	120–160	**60 mmol**	3200 mmol
Ca^{++}	mmol/l	2,25–2,75	$<10^{-3}$	**25 mmol**	kost 30 mol
Cl^-	mmol/l	96–113	30	1400 mmol	800–1000 mmol
$H_2PO_4^-$	mmol/l	0,6–1,2	100	5–7 mmol	(k)
(o)	mOsmol	280–300	–	19–22	–
H_2O	TBF, (t), 60 % = 20 % + 35 % + 5 %			5–101	20–301
energie	MJ/kg	–	10 MJ/kg	–	700 MJ

(Normal) 24 hours Turnover

(2) Obrat za 24 hodin, v mmol				
Látka	*příjem*	*výdej močí*	*stolicí*	*potem*
Na^+	100–260	100–260	10	40–50, i více
K^+	30–100	30–90	5–10	–
Ca^{++}	20–40	2,5–7,5	30–35	0–5<, i více
Cl^-	100–260	100–260	10	10–50<, i více
H_2PO_4	20–50	18–40	10	–
(o)	(q)	900–1200	10–50	50–400
H_2O	1,5–2,5 l + (m)	1,5–2,5 l	100–200 ml	300–800, (p)
(e) energie	příjem	rovný	výdeji	za 7–14 dnů

Water Turnover = Balance

Pøehled bilance vody (vše v ml za den):

PØÍJEM:	
pití	1000-1500 (i více)
v potravì	1000
oxidací	500
celkem	2500-3000

VÝDEJ:	
moèí	1000-1500
perspirací	550-800
dechem	400
stolicí	100
potem	0-2000

Oxidací se uvolní:

z 1 g bílkovin	0,4 ml	vody
z 1 g glycidù	0,6 ml	vody
z 1 g tukù	1,07 ml	vody

Ztráty perspirací závisejí na tìlesné teplotì (ml/d):

pøi norm. teplotì	550
pøi 37.2°C	600
pøi 37.8 °C	700
pøi 38.3 °C	800
pøi 38.9 °C	900
pøi 39.4 °C	1000

Daily_produced_metabolic_water =aka perspiratio_insensibilis
This is not obvious, this enables water balance monitoring

Ionic Composition of Body Fluids

Electrolyte	Plasma, (mEq/L) [molarity]	Plasma Water (mEq/L) [molality]	Interstitial Fluid (mEq/L)	Intracellular Fluid (mEq/L)
Cations:				
Sodium	142	153	145	10
Potassium	4	4.3	4	160
Calcium	5	5.4	5	2
Magnesium	2	2.2	2	26
Total ***Cations***	153	165	156	198

Ionic Composition of Body Fluids

Electrolyte	Plasma, (mEq/L) [molarity]	Plasma Water (mEq/L) [molality]	Interstitial Fluid (mEq/L)	Intracellular Fluid (mEq/L)
Chloride	101	108.5	114	3
Bicarbonate	27	29	31	10
Phosphate	2	2.2	2	100
Sulphate	1	1	1	20
Organic Acid	6	6.5	7	
Protein	16	17	1	65
Total Anions	153	165	156	198

The Anion Gap (In Acid-Base Balance)

The equivalents of cations in a solution **always balances** the equivalents of anions (= electroneutrality).

The simplest reports may only give the [Na+], [Cl-], and the [HCO3-].

The "real" balance is given by the equation:

[Na] + [other cations] = [Cl] + [HCO3] + [other anions]

Rearranging:

[Na] - ([Cl] + [HCO3]) = **[other anions] - [other cations]**

= **"Anion Gap„**

Normal values for the Anion Gap are 8-16 mEq/L plasma

The Anion Gap is a useful shorthand measure, particularly in the differential diagnosis of acid/base disorders.

Values of Anion Gap in Metabolic Acidosis

- Normal Anion Gap (16 mEq/L)
  - Ztráty bikarbonátu
    - **GIT (průjem)**
    - Ledviny – RTA (renal tubular acidosis)
  - Ztráta schopnosti regenerovat bikarbonát
    - **Deficit aldosteronu**
    - Insensitivita k aldosteronu
    - **Renální tubulární acidózy**
  - Podání okyselujících chloridových solí
    - Např. Chlorid amonný

- Higher Anion Gap (> 18 mEq/L)
- zvýšená metabolická produkce kyselin
  - **Ketoacidóza**
    - Diabetická
    - Alkoholová
    - Hladovění
  - **Laktátová acidóza**
- Zvýšený příjem kyselin
  - **Toxické látky**
    - Salicyláty
    - Etylen glycol
    - methanol
- Snížené vylučování kyselin
    - **Renální selhání**

Fluid movement

- Diffusion

  Diffusion of water down its concentration gradient is called **osmosis.**

- Facilitated Diffusion

  Proteins act as carriers or pores permit flux of substances that cannot diffuse directly through the membrane.

- Primary Active Transport

  Proteins in the membrane can also act as pumps. Example: Na-K ATPase

- Secondary Active Transport

  Cotransport moves 2 or more molecules in the same direction across the membrane. Example: Na-Glucose cotransport.

Exchange between Intracellular and Extracellular Compartments

- The ICF and the ECF are separated by the membranes of the body's cells.

- **In the body, these two compartments are always in osmotic equilibrium**, even though the composition of the fluids in them is very different.

- The addition or subtraction of water or solutes from one or more of the body's fluid compartments will result in water **exchange between the ICF and the ECF if there is an alteration in the resulting osmolarity**.

Thought Experiment:
70 kg male, ECF osmolality 290 mOsm/ kg water.

Addition of 2 liters of distilled water to the ECF.

Initial total body water	0.6 x 70 kg = 42 liters
Initial ICF volume	0.4 x 70 kg = 28 liters
Initial ECF volume	0.2 x 70 kg = 14 liters
Initial total body osmoles	TBW volume x osmolality 42 liters x 290 mOsm/liter **12180** mOsm
Initial ICF osmoles	ICF volume x osmolality 28 liters x 290 mOsm/liter **8120** mOsm
Initial ECF osmoles	ECF volume x osmolality 14 liters x 290 mOsm/liter **4060** mOsm

Thought Experiment:
70 kg male, ECF osmolality 290 mOsm/ kg water.

Addition of 2 liters of distilled water to the ECF.

Final osmolality	(Total body osmoles)/(new TBW) 12180 mOsm/(42+2) kg water **277** mOsm/kg water
Final ICF volume	(ICF osmoles)/(new osmolality) 8120 mOsm/(277 mOsm/kg water) 29.3 kg water = **29.3** liters
Final ECF volume	(ECF osmoles)/(new osmolality) 4060 mOsm/(277 mOsm/kg water) 14.65 kg water = **14.65** liters

Plasma-Interstitial Fluid Exchange

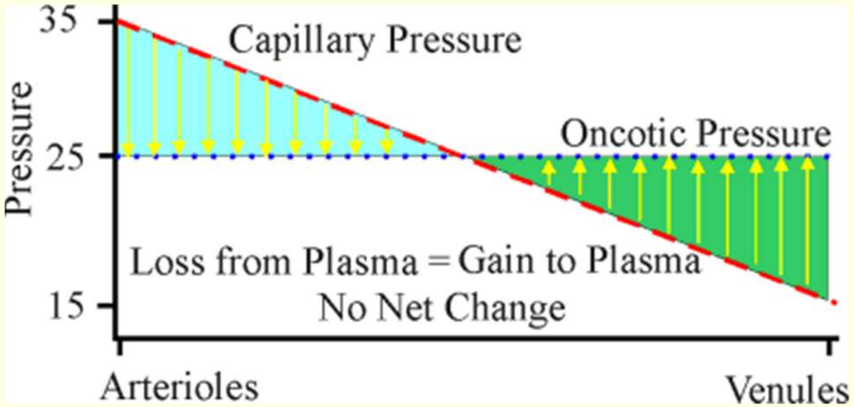
- Hydrostatic Pressure at the Capillary

  At the arteriolar end of the capillary, the pressure is usually about **35 mm Hg** (due to the pressure drop caused by the resistance arterioles).

  On the venule end of the capillary, the pressure is in the range of **15 mm Hg**.

- Osmotic forces in the capillaries

  Because the capillary wall is permeable to water, but essentially impermeant to the plasma proteins, these molecules generate an osmotic pressure - known as the **Colloid Oncotic Pressure**. The net Oncotic Pressure is thus about **25 mm Hg**. This value remains roughly constant over the length of most capillary beds.



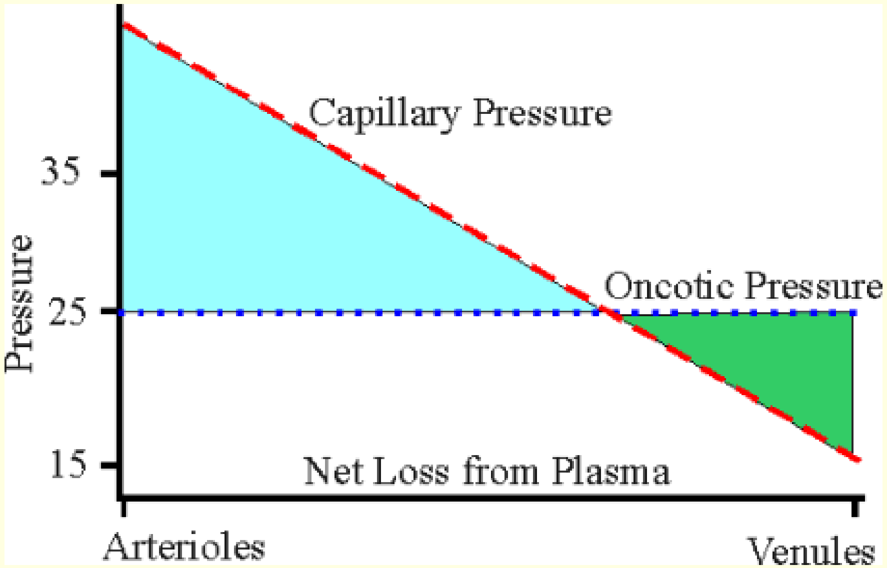
Starling's Relationship

Hydrostatic pressure tends to cause fluid to leave the plasma, and oncotic pressure pulls it back. These two forces tend to balance each other.

Starling forces in disease - Vasodilation

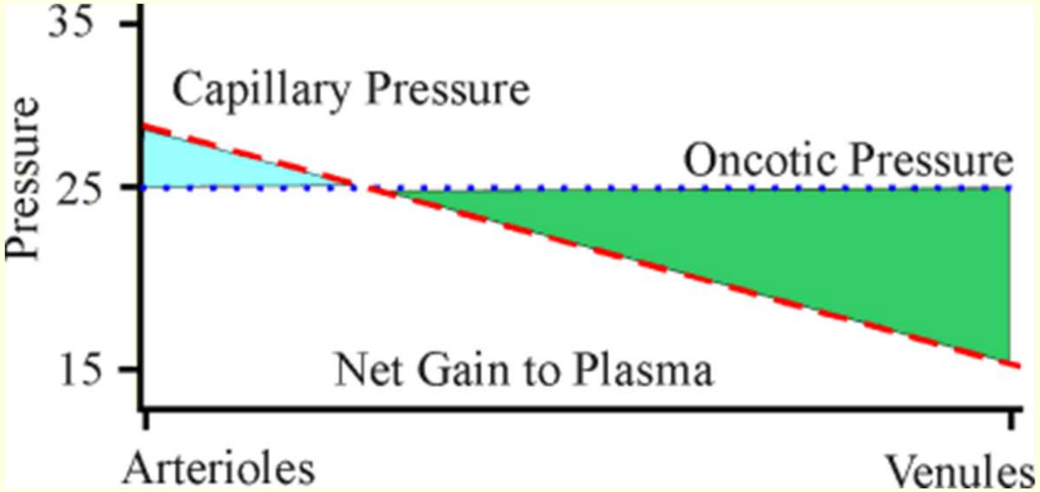
- ***Vasodilation reduces the pressure drop*** across the arterioles, bringing the capillaries closer to the arterial pressure. The venous pressure may not be altered. In this case, there is a greater region where fluid leaves the plasma, and a reduced regions where it returns.

- This imbalance results in a ***net loss of fluid from the plasma***. The result is an expansion of the interstitial fluid in this tissue. If this expansion continued, it would result in the clinical symptom known as ***edema***.



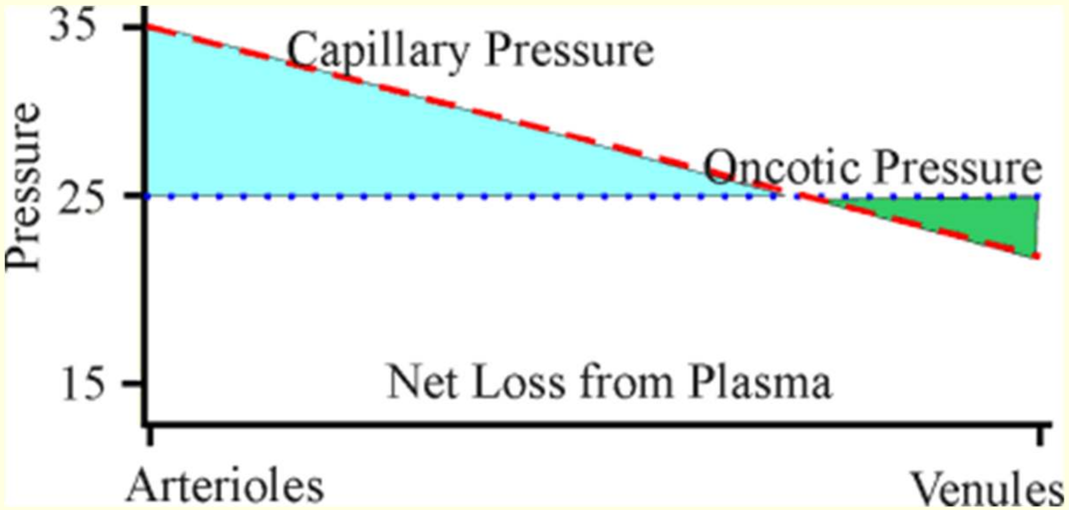
Starling forces in disease - Shock

- When the central blood pressure declines, the ***pressure at the capillaries usually also decreases***. In addition, most vascular beds will participate in reflex attempts to maintain the central blood pressure via <u>arteriolar vasoconstriction. This further reduces the pressure at the start of the capillary.</u>
- The decrease in hydrostatic pressure results in a diminution in the region where fluid is lost from the plasma, and an expansion in the region where fluid returns back to the plasma. There is a **net gain of fluid to the plasma**.



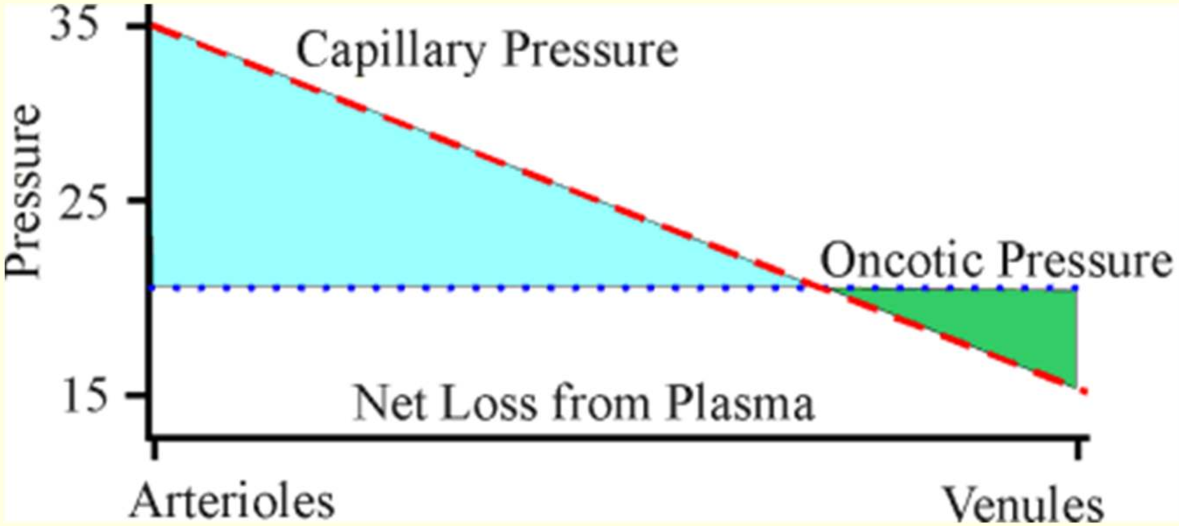
Starling forces in disease - Congestive Heart Failure

- When the heart's function is compromised, it cannot pump blood as effectively, so ***venous pressure rises***. This rise in venous pressure <u>diminishes the region where fluid is reabsorbed</u> into the plasma.
- As with the case (above) of vasodilation, this condition results in a net loss of fluid from plasma to ISF. The resulting ***edema can be seen in the swollen ankles (and other tissues) that are symptomatic of congestive heart failure***.



Starling forces in disease – Protein deficiency and tissue damage

- When the plasma does not contain sufficient protein - this results in a net increase in the region where hydrostatic pressure exceeds oncotic. **Edema** results.



Common body fluid disturbances

Condition	Example	EC Fluid		IC Fluid	
		Osmolality	Volume	Osmolality	Volume
Hyposmotic expansion	excessive water intake	↓		↓	
Hyposmotic contraction	salt wasting (Loss by kidneys)	↓	↓	↓	
Isosmotic expansion	IV infusion, edema	↔		↔	↔
Isosmotic contraction	hemorrhage, burns	↔	↓	↔	↔
Hyperosmotic expansion	Drinking of concentrated saline				↓
Hyperosmotic contraction	severe sweating		↓		↓

Summary of common body fluid distrubances

- **It is based on the condition of the ECF following the alteration.** For example, hypo-osmotic expansion means the osmolality is reduced and the ECF volume has increased. Therefore you can immediately predict the changes in the EC fluid based on the words used to describe the clinical condition.

- ***Also note that shifts in osmolarity are always in the same direction.*** This is because the EC and IC compartments are always in osmotic equilibrium. Focusing on the name of the disturbance thus gives you three of the four changes listed in the table.

- The number of disolved particles in the intracellular compartment is fixed (they don't cross the cell membrane), the only way for IC osmolarity to change transiently is by the addition or subtraction of water. ***If the osmolarity decreases, then the volume must go up.*** Note that in the chart below, the IC volume arrows are always opposite those for the IC osmolarity.

Thanks for your attention…