General Physiology-2024
Lecture 10

كلية الطب البشري
Faculty of Medicine

Changes In Body Fluid Compartment Volume And Osmolarity In Different Abnormal States
Problem Set Discussion

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Objectives

1.Interpret a volume-osmolality diagram, representing alterations in the body fluid status of a patient.

2.Evaluate the impact of different clinical scenarios on the steady-state plasma volume and osmolality variables in a patient.

3. Apply the knowledge of body fluid concepts to new cscenarios on summative assessments.

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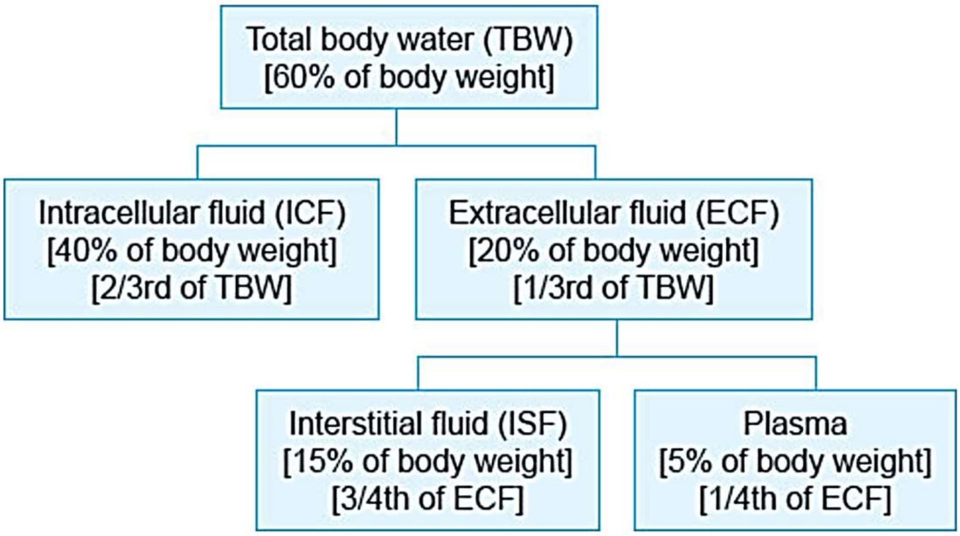
Body Water as % Body Weight



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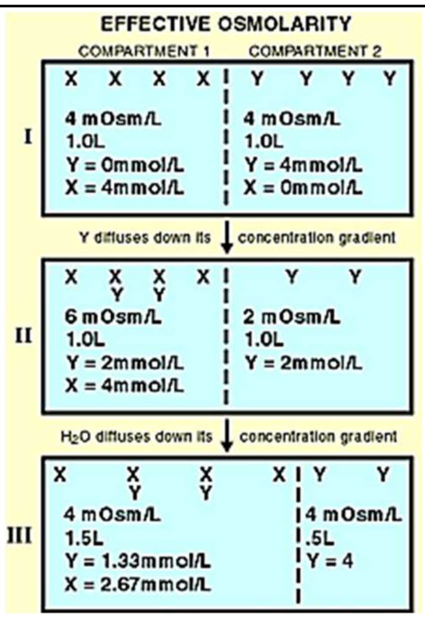

Consider two compartments separated by a membrane which is freely permeable to water. Compartment 1 contains the non-electrolyte molecule X to which the membrane is impermeable at a concentration of 4 mmol/L which equals 4 mOsm/L. Compartment 2 contains the non-electrolyte molecule Y to which the membrane is permeable, also at a concentration of 4 mOsm/L.

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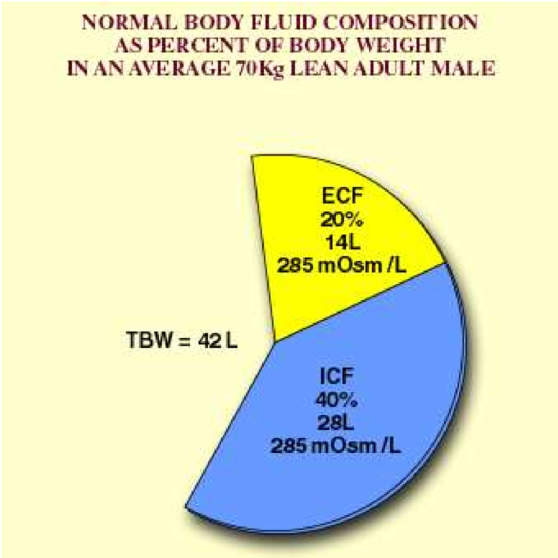

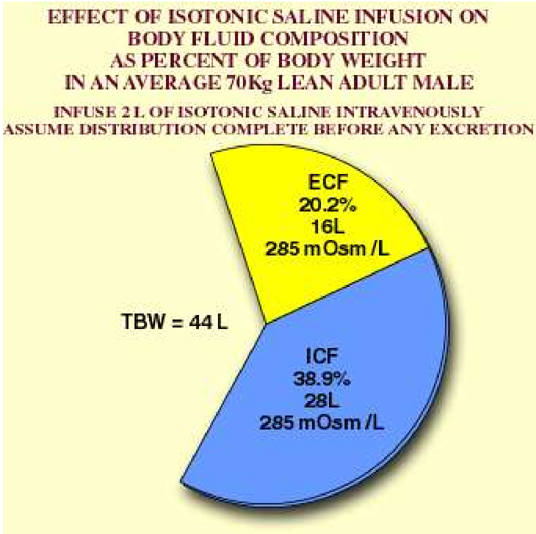

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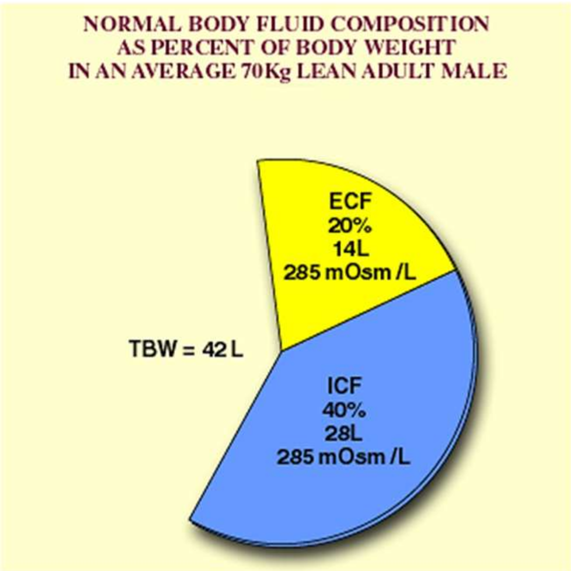

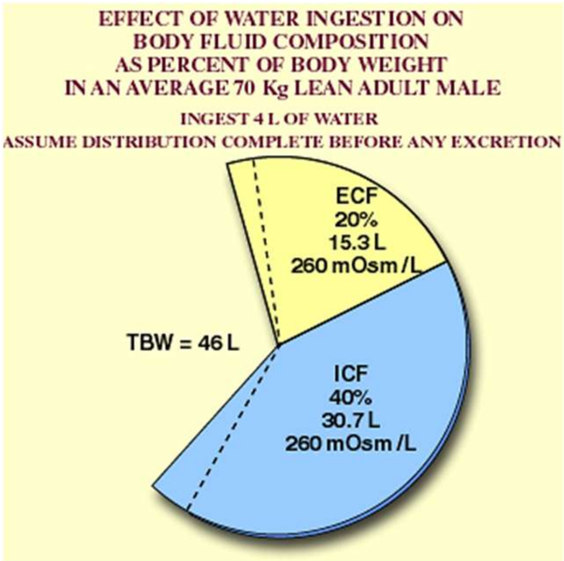

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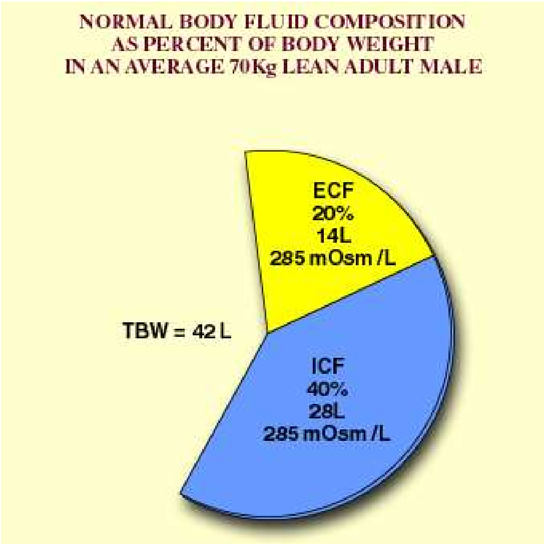

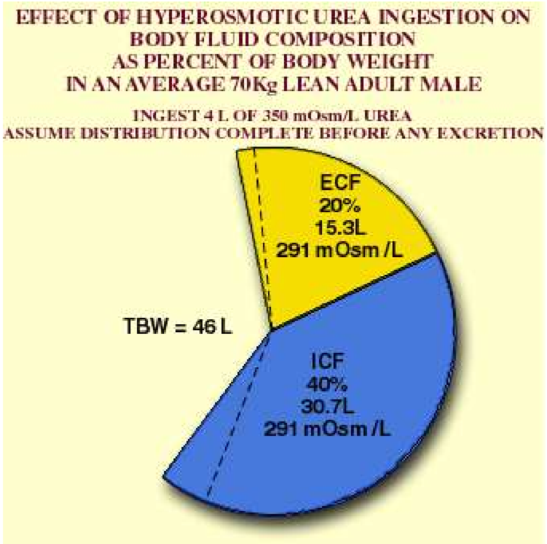

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Moles

A mole is the molecular weight of the substance in grams. Each mole (mol) consists of 6 × 10^{23} molecules. The millimole (mmol) is 1/1000 of a mole, and the micromole (μmol) is 1/1,000,000 of a mole.

Example: 1 mol of NaCl = 23 g + 35.5 g = 58.5 g, and 1 mmol = 58.5 mg. (Atomic weight of Na = 23 and Cl = 35.5)

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OSMOLE

It expresses concentration of osmotically active particles.
1 Osmole = Mol/Number of freely moving particular each molecule liberates in solution

Examples:

- 1 mol of NaCl = 2 osmoles because each NaCl molecule given one Na^+ and one Cl^- particle is solution.
- 1 mol of Na_2SO_4 = 3 osmoles because each Na_2SO_4 molecule gives 2 Na^+ and 1 SO_4 in solution.
- 1 mol of, $CaCl_2$ = 3 osmoles, because each molecule of $CaCl_2$ give 3 particles (1 calcium and 2 Cl^-) in solution.

TONICITY

Definition: This is the osmolality of a solution with respect to plasma osmolality.

Example: 0.9% NaCl is isotonic; 5% glucose is isotonic initially; later has become hypotonic.

Normal saline

- **Q1. What is the molarity and osmolality of normal saline (0.9 % NaCl solution)**

Normal saline

Solution

1. Find how many grams of NaCl in 0.9 % solution

0.9% means that there 0.9 gm NaCl in 100 ml of water

Therefore. Weight of NaCl in in one liter = 0.9*10 = 9 gm/L

***The molecular weight of sodium chloride is 58.5 g/mol**

2. Convert gms to moles by dividing the weight in gm to the molar mass ie Moles = gms/molar mass

Number of moles = 9/58.5 = 0.1538 M

3, Convert the number of moles to mM

mM = M*1000 = 0.1538 *1000= 153.8

Normal saline

A.Molarity = Number of mM/one liter

= 153.8 mM/L

- **How do you calculate osmolarity?**

Osmolarity can be calculated by multiplying the molar concentration of a solute by the number of particles that it dissociates into. This can be represented by the formula: Osmolarity = (molarity of solute) x (number of particles in solution).

$$\text{Osmolarity} = g\,C$$

where

Osmolarity = Concentration of particles (mOsm/L)

g = Number of particles per mole in solution (Osm/mol)

C = Concentration (mmol/L)

Normal saline

B. Osmolarity:

The osmolarity is 2 x 0.154 = 0.308 osm/L = 308 mOsm/L

308 mOsm/L x 0.93 (osmotic coefficient) = 286 mOsm/L is the actual osmolarity of 0.9 % NaCl

Calculate The Osmolaity Of 5 % Glucose Solution .

1. Mass of glucose in solution:

D5W = 5 g/dL = 50g/L 50 g/L

2. Moles of glucose:

mass of glucose / molecular weight of glucose

50 g / 180 g/mol = 0.278 mol

3. Conversion to mOsmol/kg (or mOsmol/L in this case)

(0.278 mol)(1000 mmol / mol)(n)

Since n = 1 for glucose, we have

(0.278)(1000 mmol / mol)(1) = 278 mOsmol/kg = 278 mOsmol/L

- The following Darrow–Yannet Diagram shows a graphic representation of body fluid compartments and osmolality at equilibrium following the administration of normal isotonic saline, hypotonic and hypertonic NaCl solutions.

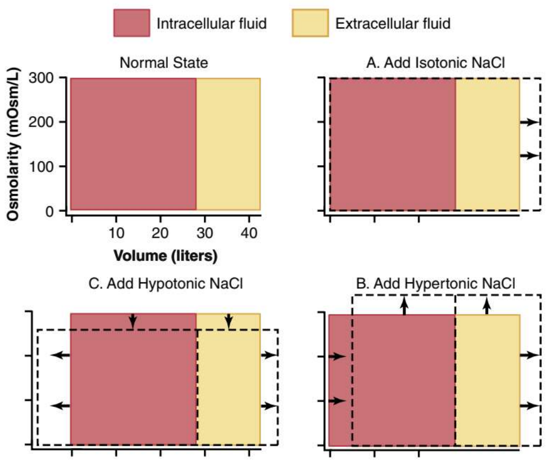


Figure 25-6. Effect of adding isotonic (A), hypertonic (B), and hypotonic solutions (A) to the extracellular fluid after osmotic equilibrium. The normal state is indicated by the *solid lines*, and the shifts from normal are shown by the *shaded areas*. The volumes of intracellular and extracellular fluid compartments are shown in the abscissa of each diagram, and the osmolarities of these compartments are shown on the ordinates.

Using the above diagrams, show changes in body fluid compartments volume and osmolarity in the following conditions:

I. **Dehydration** in a person caused by fluid restriction for 24 hours

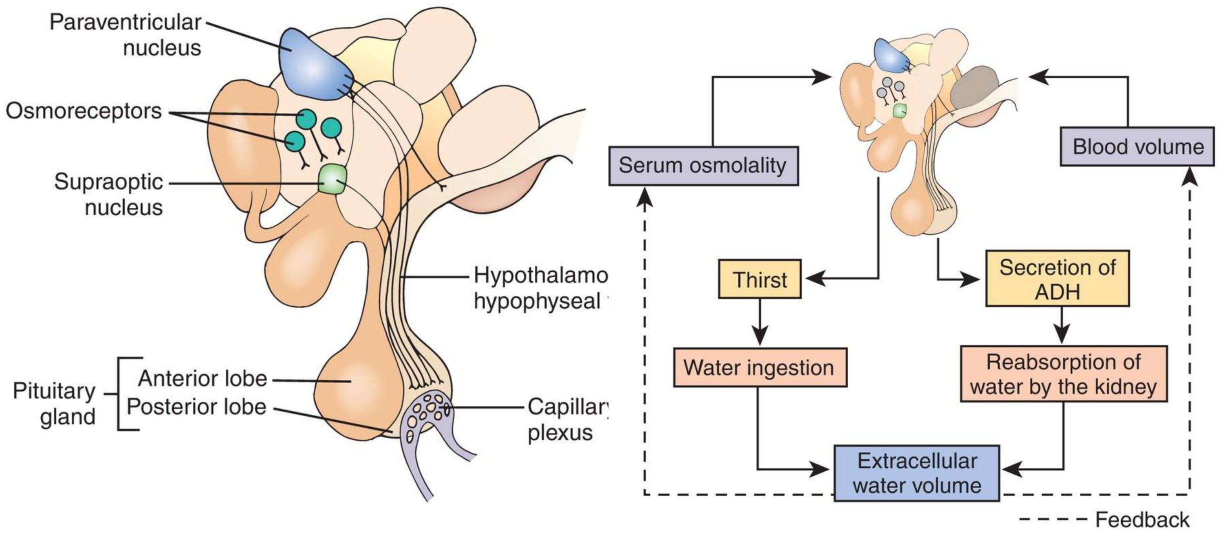
II. **Over-hydration** due to excessive release of ADH in a patient diagnosed with lung cancer associated with the syndrome of inappropriate secretion of antidiuretic hormone (SIADH) .

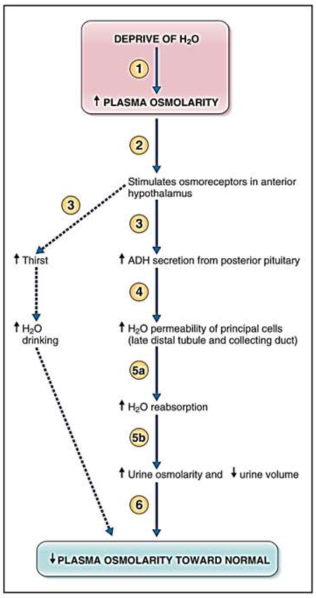
III. **Hyponatremic dehydration** in a patient diagnosed with adrenal insufficiency which is associated with aldosterone secretion

IV. **Isosomotic dehydration** caused by sever loss of blood.

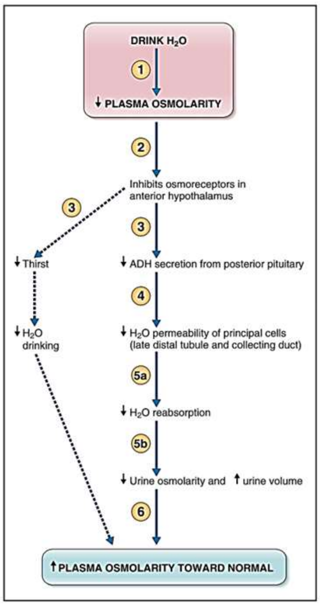
Dehydration versus over-hydration

- **Dehydration** is a clinical condition with an abnormal reduction of one or more of the major fluid compartments (ie, total body water with shrinkage of blood volume or ISF).
- **Overhydration** refers to a clinical condition with an abnormal increase in total body water resulting in an increased ECV.

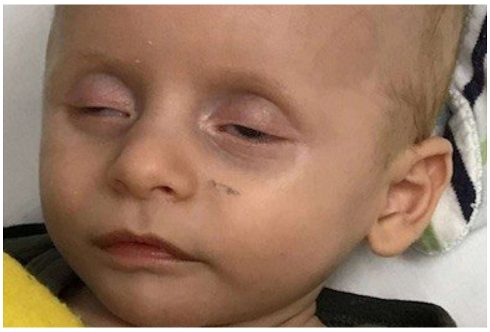




Response to hyperosmolarity and hypo-osmolality



Dehydration



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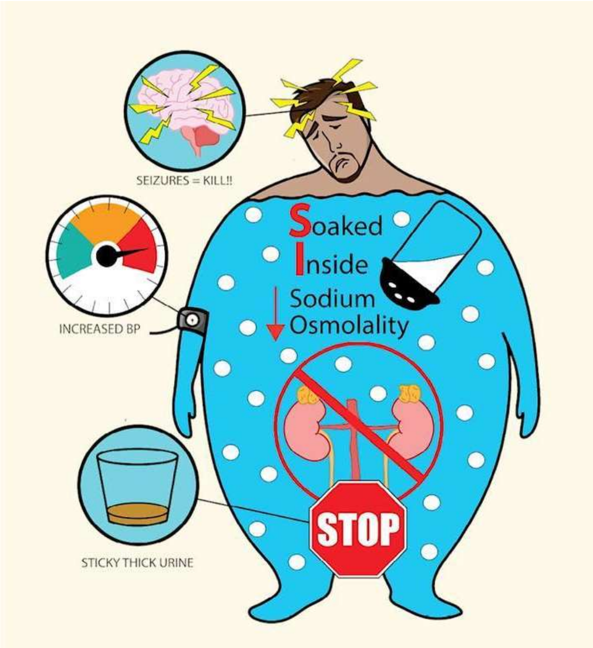

Syndrome of Inappropriate Antidiuretic Hormone Secretion (SIADH)

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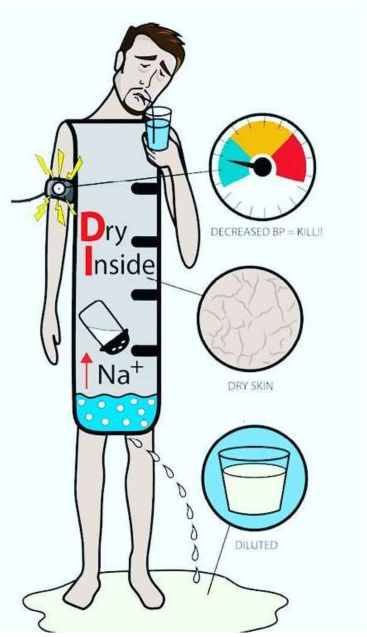
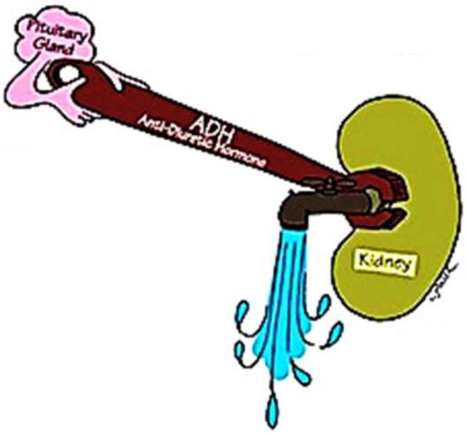
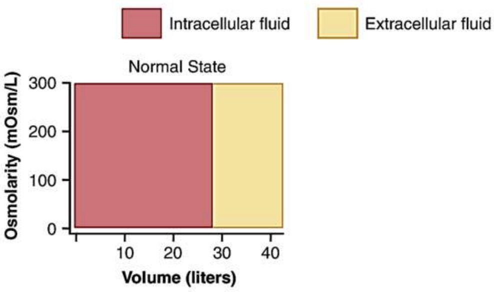
Diabetes Insipidus





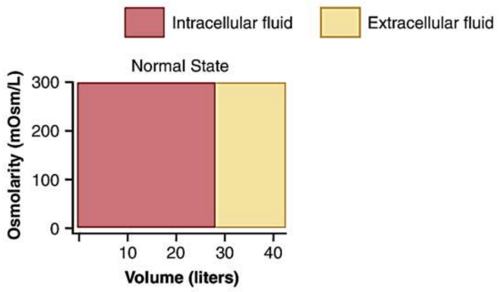
Remember:

- Water moves rapidly across cell membranes; therefore, the osmolarities of ICF and ECF remain almost exactly equal to eachother except for a few minutes after a change in one of the compartments.



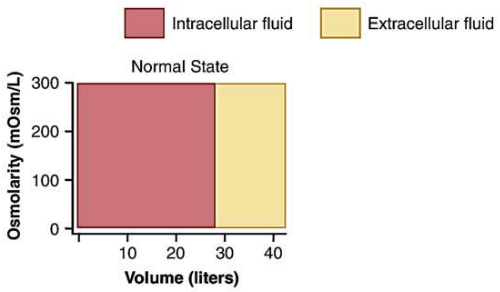
Remember:

- Cell membranes are almost completely impermeable to many solutes; therefore, the number of osmoles in the ECF or ICF generally remains constant unless solutes are added to or lost from the ECF compartment.



Remember:

- Y-axis: Solute concentration or, osmolality
- X-axis: Volume of ICF (2/3) and ECF (1/3)



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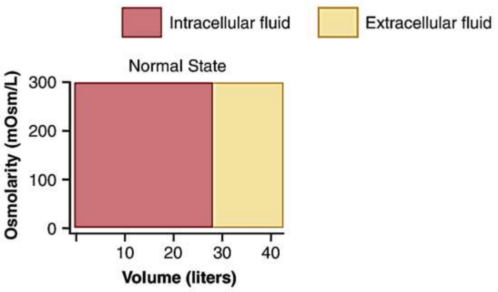
Remember:

- In normal control state, osmolality of ICF and ECF is equal.
- Whenever any solution is added or, lost from body, its changes the ECF volume or, osmolality or, both according to the type of solution (isotonic, hypotonic or, hypertonic).
- ICF volume varies with ECF osmolality and ICF osmolality changes inversely to volume change.



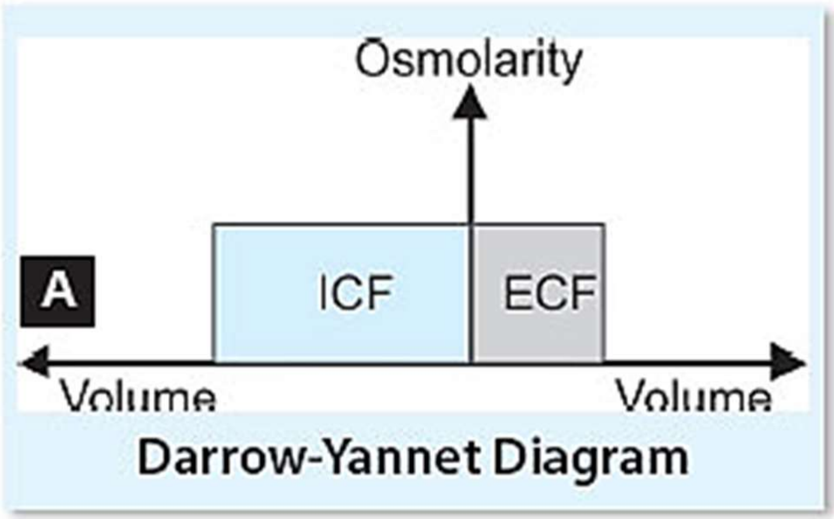
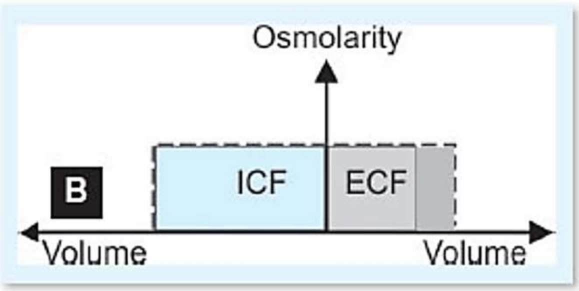


Table 1.4: Changes in volume and osmolarity of body fluids.

Type (diagram no)	*Example*	*ECF volume*	*ICF volume*	*ECF osmolarity*
Gain of isotonic fluid (B)	Isotonic NaCl infusion	Increased	No change	No change
Loss of isotonic fluid (C)	Hemorrhage Diarrhea Vomiting	Decreased	No change	No change
Gain of hypotonic fluid (D)	SIADH Drinking of tap water	Increased	Increased	Decreased
Loss of hypotonic fluid (E)	Sweating, Diabetes insipidus	Decreased	Decreased	Increased
Gain of hypertonic fluid (F)	Excessive NaCl intake, mannitol	Increased	Decreased	Increased
Loss of hypertonic fluid (G)	Adrenocortical insufficiency	Decreased	Increased	Decreased

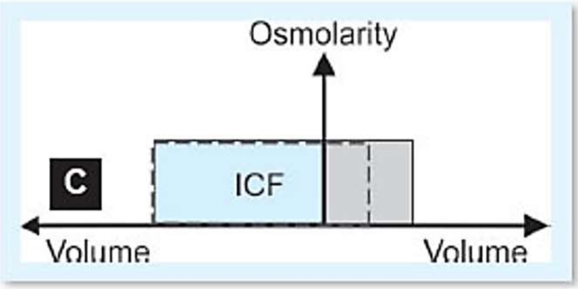
Gain of Isotonic Fluid (B)

Infusion of isotonic solution will lead to increase ECF volume but no change in osmolality. Because there is no change in osmolality, ICF volume remains same.



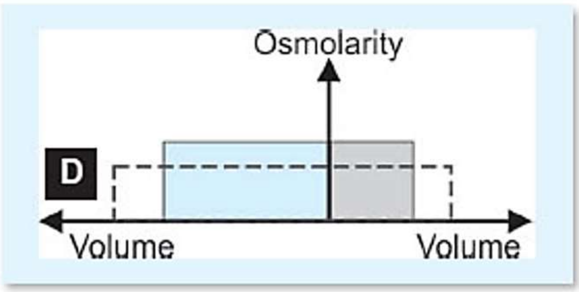
Loss of Isotonic Fluid (C)

Will only decrease the ECF volume.



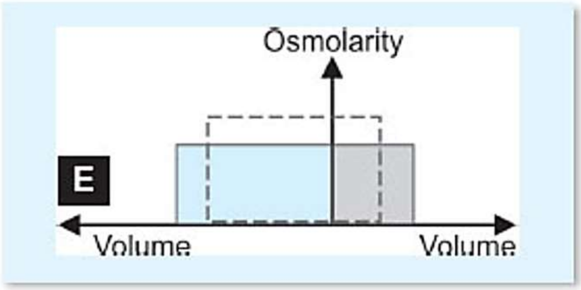
Gain of Hypotonic Fluid (D)

It increases the ECF volume, but because of its hypotonicity, the final osmolality of ECF decreases. Water shifts from ECF to ICF (osmosis), which leads to increase ICF volume. Because its only shift of water from ECF to ICF, osmolality of ICF reduces until new equilibrium reached.



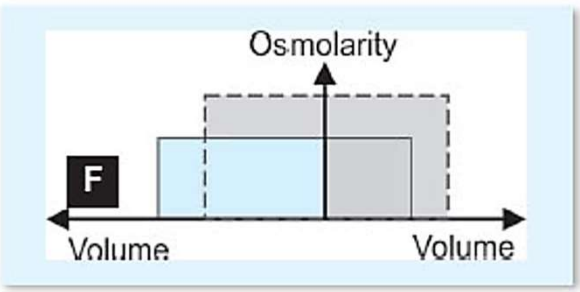
Loss of Hypotonic Fluid (E)

Hypotonic loss leads to decrease volume but increase osmolality of ECF. Water shifts from ICF to ECF (osmosis), which decrease ICF volume.



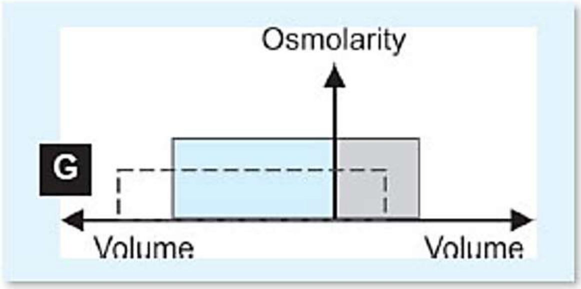
Gain of Hypertonic Fluid (F)

Increase in effective volume and osmolality of ECF. Water shifts from ICF to ECF, which leads to decrease ICF volume and increase osmolality until new equilibrium reached.



Loss of Hypertonic Fluid (G)

Decrease ECF volume and tonicity because of hypertonic fluid loss. Decrease tonicity of ECF, shifts the fluid from ECF to ICF (osmosis). So, ICF volume increases and tonicity decreases.



Calculation of Fluid Shifts and Osmolarities, after Infusion of different solutions

Calculation of fluid shifts

If 2 liters of a hypertonic 3.0% sodium chloride solution were infused into the extracellular fluid compartment of a 70-kg patient whose initial plasma osmolarity is 280 mOsm/L.

What would be the intracellular and extracellular fluid volumes and osmolarities after osmotic equilibrium?

Calculation of fluid shifts

Step 1. Initial Conditions

	Volume (liters)	Concentration (mOsm/L)	Total (mOsm)
Extracellular fluid	14	280	3920
Intracellular fluid	28	280	7840
Total body fluid	42	280	11,760

The total milliosmoles added to the extracellular fluid in 2 liters of 3.0% sodium chloride:

- A 3.0% solution = 3.0 g/100 ml=30 grams of sodium chloride per liter.
- The molecular weight of sodium chloride is about 58.5 g/mol= 0.5128 mole of sodium chloride per liter of solution= 1.0256 mole of sodium chloride for 2 liters of solution.
- Because 1 mole of sodium chloride is equal to approximately 2 osmoles (sodium chloride has two osmotically active particles per mole), the net effect of adding 2 liters of this solution is to add **2051** milliosmoles of sodium chloride to the ECF.

Calculation of fluid shifts

Step 2. Instantaneous Effect of Adding 2 Liters of 3.0% Sodium Chloride

	Volume (liters)	Concentration (mOsm/L)	Total (mOsm)
Extracellular fluid	16	373	5971
Intracellular fluid	28	280	7840
Total body fluid	44	No equilibrium	13,811

Calculation of fluid shifts

Step 3. Effect of Adding 2 Liters of 3.0% Sodium Chloride After Osmotic Equilibrium

	Volume (liters)	Concentration (mOsm/L)	Total (mOsm)
Extracellular fluid	19.02	313.9	5971
Intracellular fluid	24.98	313.9	7840
Total body fluid	44.0	313.9	13,811

These calculations assume that the sodium chloride added to the extracellular fluid remains there and does not move into the cells.

- Assume the standard 70 kg male, in whom the original osmolality of the ECF is 290 mOsm/kg water. Assume that 2 liters of glucose 5% solution where added to the ECF by intravenous route. Calculate the effect of this addition on the volumes and osmolality of the ECF and ICF at equilibrium. Assume that all of glucose is metabolized and there is no change in the number of mOsm added to the body fluid compartments , the infusion of glucose solution will be similar to the ingestion of 2 liters of water . Table 1 shows the initial volume of body fluid compartments and their osmoarity and table 2 shows , changes that occur after the infusion of 2 liters of glucose solution at equilibrium.

Initial conditions:

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

Final conditions:

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

It will be apparent that one might get these results in other ways (for example, note that the added two liters distributes between the two compartments in proportion to their original size (2/3 to ICF, 1/3 to ECF). However, the systematic approach has advantages because it can predict the correct result even when the body fluid changes include alterations to both water and solutes simultaneously.

- **What is your conclusion?**
- **Using a similar approach calculate the initial volumes of body fluid compartments and osmolarity in the first table and the calculated volume of body fluids compartments and their osmolarities after the infusion of 1 liters of normal saline after equilibrium.**

- **A 70 kg male has a body fluid osmolality of 290 mOsm/kg water. Assume 1 liters of isotonic saline (0.9 % NaCl) are infused intravenously and were added to the ECF. Calculate the final osmolality of the body fluids and the final ECF, ICF volumes. Assume that NaCl does not cross the cell membrane and 60 % of body weight is water.**

-What is the approximate osmolality of 0.9 % saline?
-How many mosm are added to the ECF when 2 liters of saline are added?
-How many litters were added to the ECF

-What is the approximate osmolality of 0.9 % saline?

Answer:

A.Molarity = Number of mM/one liter

= 153.8 mM/L

B. The osmolarity is 2 x 0.154 = 0.308 osm/L = 308 mOsm/L

308 mOsm/L x 0.93 (osmotic coefficient) = 286 mOsm/L is the actual osmolarity of 0.9 % NaCl

-How many mosm are added to the ECF when 2 liters of saline are added ?

Number of mosm/L Multiplied by 2

= 286 *2 = 572

-How many liters were added to the ECF

2L

- In the following table, please calculate the variables listed in left column in the initial conditions before saline infusion.

Initial volume of TWB	
Initial volume of ICF	
Initial ECF volume	
Initial number of solutes in body water	
Initial member of mOsm in ICF	
Initial number of mOsm in ECF	

- In the following table, please calculate the variables listed in left column in the initial conditions before saline infusion.

Initial volume of TWB	Body W Kg (*) 60%
Initial volume of ICF	40/100 (*) Body weight Kg
Initial ECF volume	20/100 * body weight
Initial number of solutes in body water	Plasma osmolality * TBW
Initial member of mOsm in ICF	Plasma osmolality * ICF volume
Initial number of mOsm in ECF	Plasma osmolality * ECF volume