Physiology Lecture 7

Plasma osmolarity and its determinants

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Lecture Objectives:

- Understand how to calculate the osmolarity of solution.
- Compare the concentration of osmotically active substances in ECF and ICF
- Know the relative osmolarity of various body fluids compartments and the primary determinants of osmolarity in plasma under normal conditions.
- Calculate the plasma osmolarity based on the osmolar concentration of Na ions, glucose, and urea.
- Understand how to calculate osmolar gap
- Compare and contrast plasma osmolarity and tonicity.
- Describe changes in cell volume when exposed to osmotic stress.

Osmotic equilibrium between ICF and ECF

- The osmotic pressure of a solution is calculated by the **van’t Hoff law**:

$$\boldsymbol{Osmotic\ pr.(\pi) = Osmolarity}\ (mOsm/L) \times \mathbf{19.3}\,\frac{mmHg}{mOsm}/L$$

- From the law, one milliosmole increase in the concentration gradient generates an increase of 19.3 mmHg of osmotic pressure across the cell membrane.
- Therefore, a relatively small changes in the concentration of *impermeant solutes* in the extracellular fluid can cause large changes in cell volume.

Tonicity

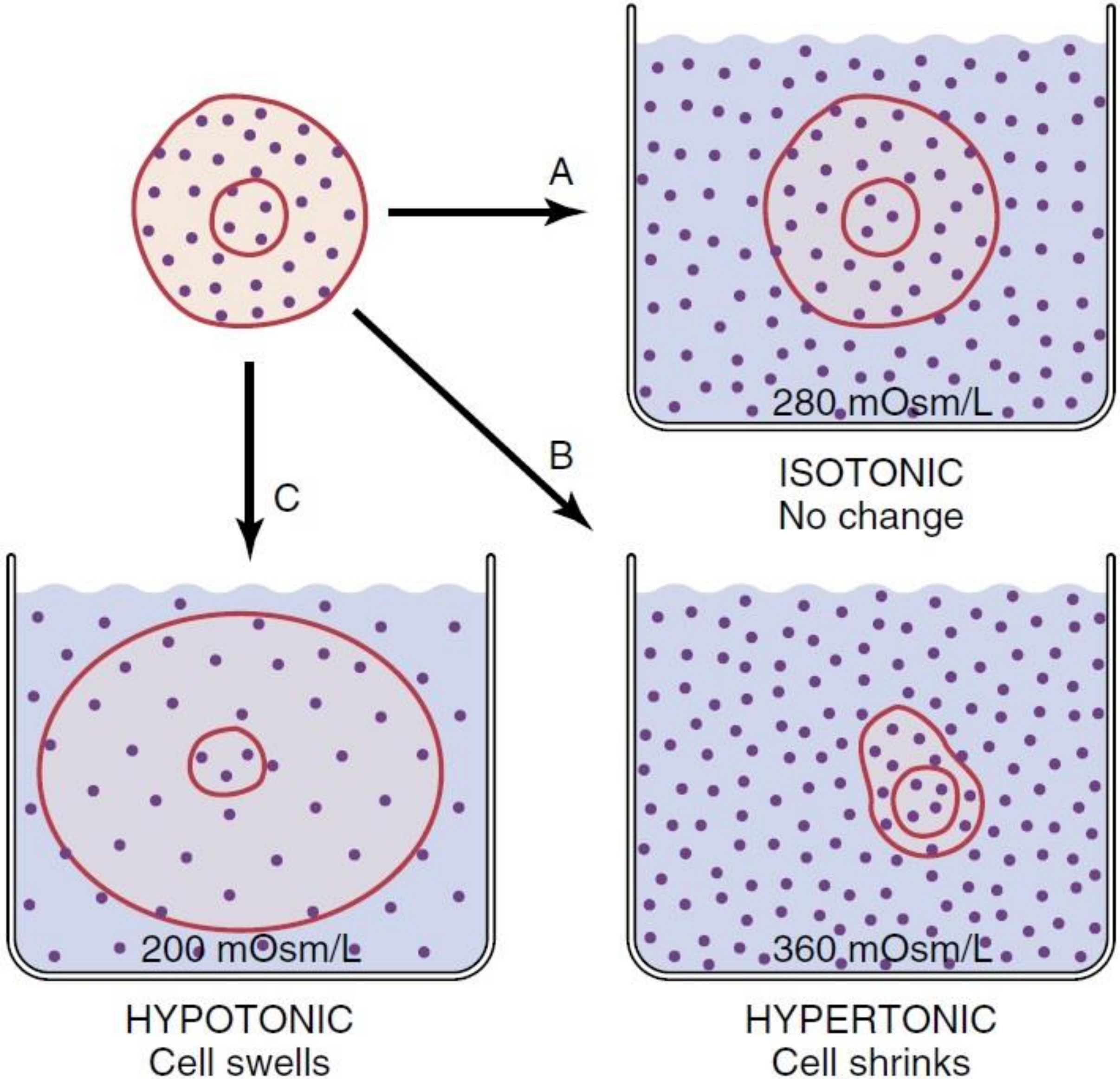
- Def. – The tonicity of a solution is the ***effect of the solution on cell volume***.
- The tonicity is of a solution is determined by its osmolality of the non-penetrating solutes.
- Each non-penetrating particle, large or small, is equally effective in its ability to pull water through a semipermeable membrane. Thus, it is the number, rather than the size, of the non-penetrating particles that determines the osmotic activity of a solution.
- Solutes that can penetrate the plasma membrane quickly become equally distributed between the ECF and ICF, so they <u>do not contribute to osmotic differences</u>.

Osmotic equilibrium between ICF and ECF

- Isotonic solution – a solution having an osmolarity equal to that of the plasma (i.e. 282 mOsm/L). Cells neither shrink nor swell if placed in such a solution. The solute should be unable to permeate the cell membrane. Examples 0.9% NaCl solution.

Note: It is important to keep the ECF isotonic because cells, especially brain cells, do not function properly if they are swollen or shrunken.

- Hypotonic solution – a solution that has an osmolarity lower to that of the plasma. Water will diffuse into the intracellular compartment if cells are placed in such a solution (cell swell).
- Hypertonic solution – a solution that has an osmolarity higher to that of the plasma. Cells will shrink if they are placed in such a solution, as water will flow out of the cell.



Effects of isotonic (A), hypertonic (B), and hypotonic (C) solutions on cell volume.

Measurement of plasma osmolarity

- Accurate plasma osmolality can be measured by freezing-point depression. The freezing point of normal human plasma averages -0.54°C, which corresponds to an osmolal concentration in plasma of 290 mOsm/l.
- Compared with pure water, which freezes at 0°C, a solution with an osmolality of 1 Osm/kg H_2O will freeze at -1.86°C.
- The calculated osmolality for the sum of all the cation and anion in plasma is over 300 mOsm/L. The actual osmolality is not this high because plasma is not an ideal solution and ionic interactions reduce the number of particles free to exert an osmotic effect.
- The predominant osmotically active particles in the ECF are Na^+ and its attendant anions (Cl^- and HCO_3^-), which together account for 90% to 95% of the osmotic pressure.
- Blood urea nitrogen and glucose, which also are osmotically active, account for less than 5% of the total osmotic pressure in the extracellular compartment.

Measurement of plasma osmolarity (cont.)

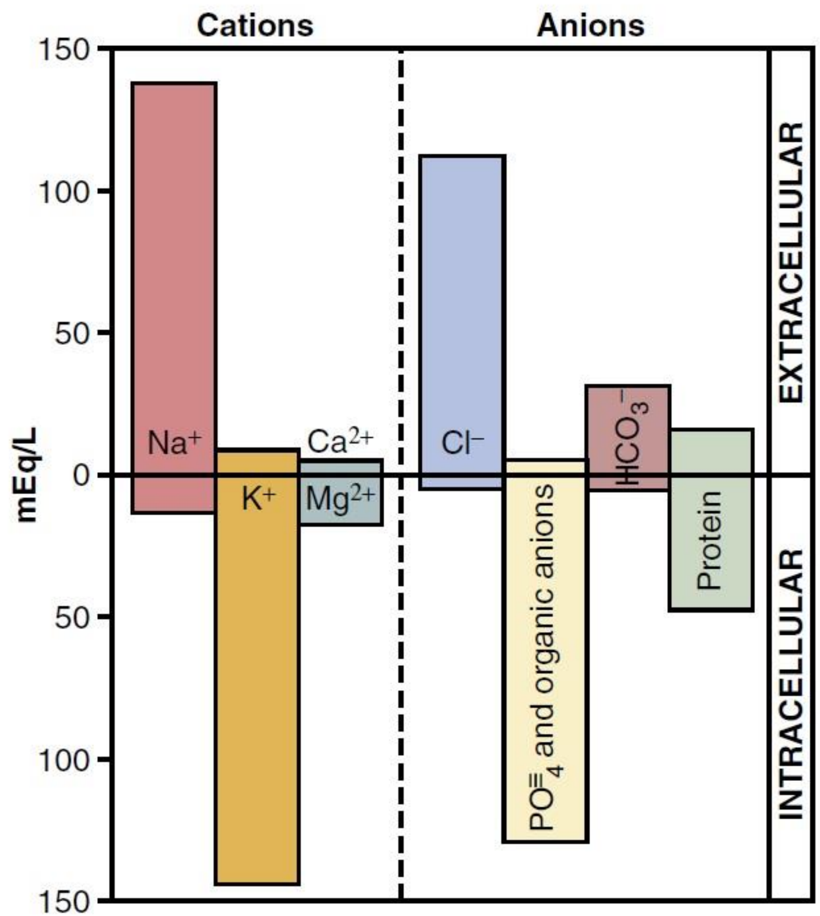
- Serum osmolality can be estimated using the following equation:

$$Serum\ osmlarity = 2[Na^{+}] + \frac{[glucose]}{18} + \frac{[urea]}{2.8}$$

  - The glucose and urea concentrations are expressed in units of milligrams per deciliter (mg/dl).
  - The Na ion concentration is expressed in units of milliequivalent per liter (mEq/L).
- The difference between the estimated and measured osmolality is called the **osmolar gap**.
- An osmolar gap larger than 10 mOsm suggests the presence of an unmeasured, osmotically active substance such as alcohol, acetone, or mannitol (sometimes injected to shrink swollen cells osmotically).

Osmolar Substances in Extracellular and Intracellular Fluids

Substance	Plasma (mOsm/L H_2O)	Interstitial (mOsm/L H_2O)	Intracellular (mOsm/L H_2O)
Na^+	142	139	14
K^+	4.2	4.0	140
Ca^{2+}	1.3	1.2	0
Mg^{2+}	0.8	0.7	20
Cl^-	106	108	4
HCO_3^-	24	28.3	10
HPO_4^-, $H_2PO_4^-$	2	2	11
SO_4^-	0.5	0.5	1
Phosphocreatine			45
Carnosine			14
Amino acids	2	2	8
Creatine	0.2	0.2	9
Lactate	1.2	1.2	1.5
Adenosine triphosphate			5
Hexose monophosphate			3.7
Glucose	5.6	5.6	
Protein	1.2	0.2	4
Urea	4	4	4
Others	4.8	3.9	10
Total mOsm/L	299.8	300.8	301.2
Corrected osmolar activity (mOsm/L)	282.0	281.0	281.0
Total osmotic pressure at 37°C (98.6°F) (mm Hg)	5441	5423	5423



Major cations and anions of the intracellular and extracellular fluids. The concentrations of Ca^{2+} and Mg^{2+} represent the sum of these two ions. The concentrations shown represent the total of free ions and complexed ions.

Osmotic equilibrium between ICF and ECF (cont.)

Note:

- If the solute can permeate the cell membrane (such as urea) the solutions will be termed isosmotic, hypo-osmotic, and hyperosmotic respectively. Such solutions have transient effect on intracellular and extracellular fluids.
- If a difference in osmolarity occurs between intracellular and extracellular fluids, osmotic equilibrium is achieved within seconds or, at the most, minutes. This is because of the rapid movement of water across the cell membrane. However, 30 minutes are needed to achieve osmotic equilibrium everywhere in the body after drinking water.

Test Question:

Q. The osmolality of:

A. Sodium provides about half of osmotically active particles in extracellular fluid.
B. Intracellular fluid is about twice that of extracellular fluid.
C. Plasma proteins mainly responsible for enhancing the leak of fluid out of capillaries.
D. 5 per cent dextrose solution is about five times that of 0.9 per cent saline.
E. Plasma is due more to its protein than to its electrolyte content.