2.4: Colloid Osmotic Pressure

2.4.1: Colloids

Definitions

Colloids is a term used to collectively refer to the large molecular weight (nominally MW > 30,000) particles present in a solution. In normal plasma, the plasma proteins are the major colloids present.

As the colloids are solutes they contribute to the total osmotic pressure of the solution. This component due to the colloids is typically quite a small percent of the total osmotic pressure. It is referred to as colloid osmotic pressure (or sometimes as the oncotic pressure).

In plasma, the oncotic pressure is only about 0.5% of the total osmotic pressure. This may be a small percent but because colloids cannot cross the capillary membrane easily, oncotic pressure is extremely important in transcapillary fluid dynamics.

Measurement

Oncotic pressure can be easily measured in the laboratory with instruments called oncometers.

The principle is to have 2 chambers which are enclosed and separated from each other by a semi-permeable membrane which is:

- permeable to water and small MW substances, but
- not permeable to molecules with a MW greater then 30,000 (ie colloids)
Relative to this membrane, the colloids are the only effective solutes present. The reference chamber contains isotonic saline and the test solution is added to the sample chamber. If the test solution contains colloids, water moves from the reference chamber to the sample chamber. The decrease in pressure in the test chamber is detected by a pressure transducer (strain gauge) mounted between the two chambers. Modern oncometers can provide accurate results with samples as small as 50 microlitres in a couple of minutes.

2.4.2: van't Hoff Equation

Osmotic pressure and oncotic pressure can be measured by suitable instruments. They can also be determined for a solution by appropriate substitutions in the van't Hoff equation. This equation expresses the relationship between solute concentration and osmotic pressure for ideal solutions. (An ideal solution is a solution with thermodynamic properties analogous to those of a mixture of ideal gases - see a chemistry text for more details.)

The van't Hoff Equation

\[
\text{Osmotic pressure} = n \times \frac{c}{M} \times RT
\]

where:

- \( n \) is the number of particles into which the substance dissociates ( \( n = 1 \) for plasma proteins)
- \( c \) is the concentration in G/l
- \( M \) is the MW of the molecules
- \( c/M \) is thus the molar concentration of the substance (mol/l)
- \( R \) is the universal gas constant
- \( T \) is the absolute temperature (K)

As an example, if values are substituted in this equation for a typical plasma sample:

- \( T = 310K \) (i.e. temp of 37°C)
- \( R = 0.082 \frac{\text{litre \cdot atm}}{K \cdot \text{mol}} \)
- \( n = 1 \) (for plasma proteins as they do not dissociate)

and:

- Multiplying by 0.001 to convert from Osmoles to mOsmoles
- Multiplying by 760 to convert the result from atmospheres to mmHg
- Multiplying by 280 to convert the osmotic pressure per mOsm/kg to a value for plasma with an osmolality of 280 mOsm/kg

then:

\[
\text{Total plasma osmotic pressure} = 1 \times 0.082 \times 310 \times 0.001 \times 760 \times 280 = 5409 \text{ mmHg}
\]

For a plasma osmolality of 280 mOsm/kg at 37°C, total osmotic pressure is about 5409 mmHg (ie about 7.1 atmospheres!)
Each mOsm/kg of solute contributes about 19.32mmHg to the osmotic pressure

Now consider the case of plasma proteins alone and calculate the colloid osmotic (oncotic) pressure.

Using typical values for concentration & MW of the plasma proteins, the protein concentration is about 0.9 mOsmol/kg which predicts an onotic pressure of 17.3 mmHg (ie 19.32 x 0.9). Measurement in an oncometer shows the actual plasma oncotic pressure is about 25 mmHg which is equivalent to a plasma protein concentration of 1.3 mmol/kg.

2.4.3: Measured versus predicted values

Why is there a difference between the actual measured value and the value calculated using the van't Hoff equation?

The two reasons are:

- The proteins are charged & non-permeant => Gibbs-Donnan effect
- The proteins are large => Excluded Volume effect

As protein is both charged and non-permeant across the capillary membrane, it sets up a Gibbs-Donnan equilibrium which affects the concentration of the diffusible ions on both sides of the membrane. The net result in this case is an increase in the number of particles per unit volume on the intravascular side of the membrane. The protein concentration appears to be larger than it is because of these extra particles and the effective oncotic pressure is therefore increased.

Additionally as protein molecules are large the volume they occupy in the solution is significant and this is another reason for the discrepancy from the van't Hoff equation which is derived for infinitely dilute (ie ideal) solutions. This second effect is known as the excluded volume effect.

What is the nature of these extra particles which are contributing an extra 7 to 8 mmHg (equivalent to about 0.4 mOsm/kg) to the measured oncotic pressure? They are mostly Na\(^+\) ions as these are the cations present in by far the highest concentration. The [Na\(^+\)] in plasma is increased by about 6 to 7 mmol/l because of the Gibbs-Donnan effect.

This increase of 6 to 7 mmol/l is much more than the 0.4 mOsm/l required to account for the increase in oncotic pressure. What is the explanation for this apparent discrepancy? The answer is that there is also a decrease in anion concentration which counteracts much of the increase in cation (ie Na\(^+\)) concentration so the net change in concentration is an increase of 0.4 mOsmoles/l.

Final note: Additional complicating factors not discussed here are that the net charge on the proteins is affected by:

- temperature
- pH
- types of protein present (eg albumin versus globulins)