Understanding Solutions in Nursing

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This case study will connect the concepts of concentration and molarity from general chemistry to the terminology used in a typical healthcare setting. Often the units used to measure concentration in these two settings are presented in a confusing and contradictory manner when, in fact, they are the same units. This case study will also explain the origins of some common healthcare terms used in modern practice.

It is the week of spring break. Katie, a first-year nursing student in a two-year RN program, is working on fulfilling her clinical requirements at a community hospital. Katie has volunteered to work with Donna, an experienced nursing professional, on an overnight shift. It is a quiet night. There are few patients on the regular medical-surgical floor.

Katie: Donna, can I ask you a question about some of the material in my nursing textbook?

Donna: Sure. What's the problem?

Katie: I am confused about the difference between the concentration units that I learned in my general chemistry course and the terms they use in my book.

Donna: Oh yes! I recall that there is a difference in terms. A lot of my friends had trouble making that connection! What do you want to know?

Katie: In gen chem, when we talked about concentration, we talked about molarity. Moles of solute per liter of solution. In my nursing text they are talking about normal solutions and equivalents. I don't understand how those terms are connected? For example, this chart in my book is talking about ion concentration in blood and the units are milli-equivalents per liter? I don't get it. What is an equivalent?

Ion	Normal Concentration Range ($\frac{mEq}{L}$)
Sodium	135–145
Potassium	3.6–5.1
Chloride	95–105
Calcium	≈2.0

Donna: The short answer is that an "equivalent" and "normality" is the same unit as molarity.

Katie: What? I don't understand? How can they be the same?

Donna: Well, you know that molarity is moles of solute per liters of solution. So if you have, say, one liter of 1.0 M NaCl solution, how many moles of NaCl do you have?

Katie: One mole of sodium chloride! Of course!

Donna: How about if you have two liters?

Katie: Two moles of sodium chloride!

Donna: Okay. You've got it. Now, what you must understand is that when a a solution is referred to in terms of "equivalents" or "normality" we are talking about the actual concentration of a specific ion in solution. So for NaCl, a 1.0 M solution is 1 Normal for the sodium ion, Na^+. Follow me?

Katie: I think so.

Donna: Now think of a solution of, say sodium phosphate, Na_3PO_4. If a solution is 1.0 M Na_3PO_4, then how many sodium ions are in solution?

Katie: Well, if the sodium phosphate has the chemical formula then there are 3 sodium ions for every one molecule of Na_3PO_4. So the concentration of Na^+ would be 3.0 M.

Donna: That's right! So we would say that the solution was 3 Normal Na^+. Get it? Your chemistry book probably used the phrase "mole equivalents" when it defined Normality.

Katie: Yes! It's so simple! So if we were talking about a 1.0 M solution of sodium sulfate, Na_2SO_4, then the solution would be 2.0 Normal Na^+, and 1.0 Normal SO_4^{-2}!

Donna: Yep! You've got it!

Katie: What about "equivalent" units?

Donna: An equivalent is the same thing as normality and molarity. For example, do you see the chart of "Common Crystalloid Solutions" in your book? It says that a 0.9% NaCl solution is 154 mEq/L Na^+. So if we assume that a liter of the solution weighs about 1000 g, then 0.9% NaCl would be about 9 grams. Sodium chloride is about 58 grams per mole, so 9 grams is about 0.154 moles, or 154 mmoles. So this solution is 0.154 M, or 154 mM Na^+, or 154 $\frac{mEq}{L}$ Na^+. The book lists the chloride concentration as 154 $\frac{mEq}{L}$ too. That makes sense because for every Na^+ ion, you would also have a Cl^- ion. Get it?

Common Crystalloid Solutions			
Solution	**Tonicity**	$\frac{mOsm}{kg}$	**Contents**
Dextrose[1] in Water			
5%	Isotonic[2]	278	50 g/L dextrose
10%	Hypertonic	556	100 g/L dextrose
Saline Solutions			
0.45%	Hypotonic	154	77 mEq/L Na^+ 77 mEq/L Cl^-
0.9%	Isotonic	308	154 mEq/L Na^+ 154 mEq/L Cl^-
3.0%	Hypertonic	1026	513 mEq/L Na^+ 513 mEq/L Cl^-
Dextrose in Saline			
5% in 0.25%	Isotonic	355	50 g/L dextrose 34 mEq/L Na^+ 34 mEq/L Cl^-
5% in 0.45%	Hypertonic	432	50 g/L dextrose 77 mEq/L Na^+ 77 mEq/L Cl^-
5% in 0.9%	Hypertonic	586	50 g/L dextrose 154 mEq/L Na^+ 154 mEq/L Cl^-
Multiple Electrolyte Solutions			
Ringer's Solution	Isotonic	309	147 mEq/L Na^+ 156 mEq/L Cl^- 4 mEq/L K^+ 4 mEq/L Ca^{+2}
Lactated Ringer's Solution	Isotonic	273	147 mEq/L Na^+ 156 mEq/L Cl^- 4 mEq/L K^+ 4 mEq/L Ca^{+2} 28 mM lactate

[1] Glucose
[2] Physiologically hypotonic.

Katie: OH! So they really are the same thing! I get it! But why do they call that solution isotonic? What does that mean?

Donna: Well, first let me explain osmolality. Osmolality is the amount of dissolved substances in solution. Usually you see units of osmolality per kg, $\frac{Osm}{kg}$, or milli-osmolality per kg, $\frac{mOsm}{kg}$. These are the same as molality, i.e. moles of solute per kilogram of solution.

Katie: Okay, the same way molarity is the same as equivalents and normality?

Donna: Right. So the typical cell has an osmolality of about 300 $\frac{mOsm}{kg}$. Solutions with the same concentration of dissolved solids are called isotonic. The prefix "iso" means equal.

Katie: I don't understand something. My chart of crystalloid solutions lists 0.9% saline as isotonic, but the concentration of NaCl is only 0.154 $\frac{mEq}{L}$.

Donna: For osmolality it's the total concentration of particles in solution that matters. Each ion is a particle. For this 154 $\frac{mOsm}{kg}$ NaCl solution there are 154 $\frac{mOsm}{kg}$ Na^+ and 154 $\frac{mOsm}{kg}$ Cl^-. This means that the solution has a total concentration of dissolved particles of 308 $\frac{mOsm}{kg}$. So this solution is isotonic. The same number of dissolved particles as a typical cell.

Katie: What about hypotonic and hypertonic?

Donna: The prefix "hypo" means "below". So a hypotonic solution has a lower osmolality than a typical cell. Less than 300 $\frac{mOsm}{kg}$. The prefix "hyper" means "over" or "excess". So a solution that is hypertonic has more dissolved solids than a typical cell. Greater than 300 $\frac{mOsm}{kg}$. I remember which is which by thinking of my kids. When they are hyperactive, they are excessively busy.

Katie: That makes sense. Why would a solution that has too much or too little dissolved solute be useful? Wouldn't you always want to give someone fluids with the same osmolality as a normal cell?

Donna: Sometimes you do. For example, when a patient is dehydrated then you want to give them an isotonic solution to re-hydrate them. The other solutions are useful too. For example, if you have a patient who has too much sodium chloride in their system, a condition called hypernatremia, you might treat the condition with a 0.45% NaCl solution. This solution is only 154 $\frac{mOsm}{kg}$ so it is called a hypotonic solution.

Katie: So you treat a condition like hypernatremia with a hypotonic solution?

Donna: Yes. The opposite is true too. You might treat hyponatremia with a hypertonic solution. If a patient has, say, too little sodium chloride in their system, a condition called hyponatremia, then you might give the patient a hypertonic solution. Like 3.0% NaCl. A 3.0% NaCl solution is $1026\,\frac{mOsm}{kg}$.

Katie: Why are solutions like this called "crystalloid"? What does that mean?

Donna: They are called crystalloid because they contain only soluble mineral salts. Like sodium chloride, phosphate, or bicarbonate. Sometimes a crystalloid solution will have simple sugars like dextrose or other things like lactate. Colloid solutions will contain proteins or sometimes polysaccharides. The most common colloid solutions are fresh frozen plasma or albumin solution.

Katie: when would you use the different types of solutions?

Donna: A crystalloid solution is typically used as a "volume expander" to increase the volume of fluid in the circulatory system. So back to our example of a dehydrated patient. You might give the patient a crystalloid solution, 0.9% NaCl, to help rehydrate. A colloid solution is typically used to draw fluids out of cells. This increases the volume of fluid in the circulatory system. You may have heard the term "oncotic pressure"? This means that the colloid solution makes the relative amount of water outside the cell greater than inside the cell. So water inside the cell diffuses to the exterior. Crystalloid solutions are cheaper to make than colloid solutions because they are mostly salt and water.

Katie: One more thing. What the heck is a "ringer"? What kind of chemical is that?

Donna: <Laughs> Ringer's. Capital "R" and possessive. It's not a chemical. It's a type of solution is named after Sydney Ringer. Hence "Ringer's solution". Ringer's solution is a solution of several salts dissolved in water. It's typically an isotonic solution. Basic Ringer's solution usually contains sodium chloride, potassium chloride, calcium chloride and sodium bicarbonate. The bicarbonate is used to balance the pH, just like in human blood and plasma. Sometimes other clinically useful solutes are added. Stuff like ATP, dextrose, as well as antibiotics and antifungals.

Post-Case Questions:

1. Define an isotonic solution, a hypotonic solution, and a hypertonic solution.

2. Define a crystalloid solution. What is a crystalloid solution used for?

3. Define a colloid solution. How does a colloid solution increase blood volume?

4. What is the osmolality of a typical cell?

5. Define Molarity. If a 1 1.0 liter solution is made with 9 grams of NaCl (58.443 g/mole), what is the molarity?

6. Define Normality in terms of molarity.

7. Define "equivalent units" in terms of molarity.

8. A solution contains 3.0% NaCl. Is this solution isotonic, hypotonic, or hypertonic? Why?

9. Define osmolality and $\frac{mOsm}{kg}$.

10. What is a "Ringer's solution"?