Isosmotic is not always isotonic: the five-minute version

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What is the difference between osmolarity and tonicity? Recently, I was tasked with explaining this in 5 min at the 2016 annual meeting of the Human Anatomy and Physiology Society (HAPS). The HAPS conference now highlights a new presentation session called Synapse, which is run PechaKucha-style (4) with automatically advancing slides. The theme this year was “You thought you knew X, but really . . . .”. As I worked on my talk, I realized that we often try to teach this complicated subject without putting it into a memorable context. So here is the 5-min version explaining why isosmotic is not always isotonic. The PowerPoint slides are available as Supplemental Material on the *Advances in Physiology Education* web site and appended to this Illuminations article.

Slide 1. Osmolarity is not the same as tonicity. Both terms describe solutions, but the similarity ends there. Osmolarity is concentration expressed in units of solute/liter. It can be measured on a machine called an osmometer, and it has units, usually osmoles or milliosmoles per liter (osmolality is expressed using kilograms of water instead of liters).

Slide 2. Tonicity is a behavioral term. It describes what a solution would do to a cell’s volume at equilibrium if the cell were placed in the solution. A cell placed in a hypotonic solution will gain volume and swell. A cell placed in a hypertonic solution will lose volume and shrink. Tonicity cannot be measured on an osmometer, and it has no units. It tells what effect a solution has on a cell, and it depends both on the osmolarity of the solution and on whether or not solutes in the solution can enter the cell (i.e., are they penetrating?).

Slide 3. Why do we care about the difference between osmolarity and tonicity? We care because understanding tonicity is the basis for intravenous (iv) fluid therapy, and administering the wrong iv solution to patients can harm or even kill them. Unfortunately, many easily accessed resources attempting to explain osmolality and tonicity are either wrong or so vague that they create misunderstanding. Let’s look at some examples.

Slide 4. Here are just a few recent examples of the misinformation found on the Web:

- “Tonicity is the relative concentration of solutions that determine the direction and extent of diffusion” (5).
- “Tonicity: . . . is related to the number of particles found in solution. Osmolarity is most often used when referring to blood, and tonicity is most often used when referring to iv fluid, but the terms may be used interchangeably” (1).
- “Isotonic solution: a solution that has the same salt concentration as cells and blood” (2).
- “When two environments are isotonic, the total molar concentration of dissolved solutes is the same in both of them” (3).

Slide 5. Let’s look at the osmolarity and tonicity of two of the most commonly used iv solutions: normal saline (or 0.9% NaCl) and D-5-W (or 5% dextrose (glucose)) in water. If we measure their concentrations on an osmometer, we find that they are both 278 mOsmol/l, so they are isosmotic.

But if we administer them to a person by an iv infusion, we find that normal saline is isotonic because NaCl does not enter cells, whereas D-5-W is hypertonic because glucose goes into cells. Here is an important example of when isosmotic is not isotonic.

Slide 6. How can you explain this difference in tonicity to students? One way is to have them remember blood glucose homeostasis. If you give someone an iv of glucose solution, such as D-5-W, over time all of the glucose you gave them will go into cells. As glucose enters cells, the movement of solute from the extracellular fluid into the cells causes water to follow by osmosis. The cell gains volume, so the solution is hypotonic.

But the story doesn’t stop there. Glucose inside the cell is metabolized by aerobic respiration with the end products of CO₂ and water. So the end result of giving a D-5-W solution is the same as if you gave the person pure water.

Slide 7. The bottom line: isosmotic solutions are not always isotonic. Hyperosmotic solutions are not always hypertonic. But hypotonic solutions are always hypotonic.

The response to this rapid fire presentation of osmolality and tonicity was overwhelmingly positive. It also brought a few questions that require additional explanation.

Is the tonicity of a solution always the same? No, it depends what cell you are comparing with the solution. An isosmotic solution of sucrose will be isotonic to a mammalian cell because mammals do not have transporters for sucrose, and sucrose cannot enter the cell. On the other hand, plant cells do have sucrose transporters, so an isosmotic sucrose solution will be hypotonic to the plant cell.

What determines the tonicity of a solution? The tonicity is determined by comparing the concentration of nonpenetrating solutes, those that cannot enter the cell, in the solution to the concentration of the cell. If the solution has a lower concentration of nonpenetrating solutes than the cell does, then there will be no net movement of water into the cell at equilibrium and the solution is hypotonic. A solution of 5% dextrose has zero nonpenetrating solutes, and therefore, it is hypotonic.

How can a hyperosmotic solution be hypotonic? Tonicity depends only on the concentration of nonpenetrating solutes, so any solution of pure glucose will be hypotonic, no matter what its osmolality, and tonicity describes only the change in cell volume at equilibrium. Water crosses cell membranes faster than solutes do, so a cell placed in a hyperosmotic but
hypotonic solution of 10% dextrose will initially lose volume as water leaves and then start regaining volume as glucose is transported into the cell and water follows by osmosis. Using the rule of nonpenetrating solutes, at equilibrium the cell will have gained volume, and the 10% dextrose solution is hypotonic.

Using the presentation. I have not yet tried this PechaKucha style of presentation in my teaching, although I have used many of the slides from the presentation with my classes. The novelty in this approach is tying together the concepts of hypotonic glucose solutions, blood glucose homeostasis, and glucose metabolism. Students do not usually have trouble with the latter two concepts, so it is my hope that by linking them with iv fluids, it will help students expand their understanding of osmolarity and tonicity beyond red blood cells shrinking and swelling.

This fall, I plan to add the presentation to my classroom teaching. I expect my students to read and take a preclass reading quiz prior to coming to class, so it will be easy to check their comprehension using a classroom response system. I am hopeful that their responses will be similar to that of an undergraduate nursing student at the HAPS meeting who told me, “That made it so clear! I never really understood tonicity before.”

DISCLOSURES
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D.U.S. conception and design of research; D.U.S. drafted manuscript; D.U.S. edited and revised manuscript; D.U.S. approved final version of manuscript.

REFERENCES