

Topics in Hemodialysis: *Milliequivalents, Conductivity and Osmolality*

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INTRODUCTION

Standards of competence for dialysis personnel are being developed to define the level of knowledge and ability required for practice in the clinical dialysis area. Such definition is itself a difficult task since one must know some chemistry, mathematics and medicine as well as some sociology and psychology.

In this presentation we shall attempt to discuss three topics that are encountered daily and to provide an intensive introduction to these subjects. It is assumed that the reader has had some basic chemistry and is familiar with the language used. As a general chemistry reference, we recommend White, Erickson and Stevens.¹

MILLIEQUIVALENTS

The milliequivalent is an alien term. It appears in medical usage simply because it is a better way to count ions. Concentration of solutions can be measured several ways. One is to use weight per volume, as grams (g) or milligrams (mg), per 100 milliliters (ml) of solution. This is commonly used to quantitate non-ionized substances such as blood glucose. It does not allow one to conveniently compare related ionized substances such as sodium (Na) and potassium (K). Sodium is a small particle with a molecular weight (MW) of 23. Potassium is somewhat larger with a MW of 39.1. A solution having 100 mg per 100 ml (mg%) of sodium has more particles than a similar solution of potassium. (See Table 1.)

TABLE 1
CHEMICAL CONSTANTS FOR SOME DIALYSATE SOLUTES

Ion	Symbol	Molecular Weight	Ionic Charge
Sodium	Na	23.0	+1
Potassium	K	39.1	+1
Calcium	Ca	40.1	+2
Magnesium	Mg	24.3	+2
Chloride	Cl	35.5	-1

The mole (M) notation defines solutions in terms of the number of particles present in solution. The number of moles can be determined by dividing the weight of the substance by its molecular weight. A solution containing 2.3 g/L of sodium ion is 1/10 molar as also is a solution containing 3.91 g/L of potassium ion. Few biological solutions are as strong as 1M; therefore the usual unit in biology or physiological chemistry is the millimole (mM), which is 1/1000 M.

An additional problem is presented when one tries to compare singly charged ions with double charged ions. (Table 1.) A solution containing 100 mM/L of calcium ions has twice the positive charge of a similar solution of sodium. The use of equivalents and milliequivalents resolve this problem by measuring the combining power of the ion. An equivalent (Eq) is defined as one mole divided by the charge. Thus a 0.1 M/L calcium solution is 0.2 Eq/L. Milliequivalents (mEq) are the common units measured in biological solutions. As an example, Renalyte 85

dialysate⁽²⁾ contains 0.22 g/L of calcium chloride ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$). This represents 0.0599 g/L of Ca^{++} , 0.1063 g/L of Cl^- , and 0.0539 g/L of water. By determining the number of moles and the number of equivalents, one finds that this fluid has 3.0 mEq/L of Ca^{++} . Table 2 provides a convenient chart to convert concentrations from one set of units to another.

TABLE 2
CONVERSION TABLE FOR CONCENTRATION UNITS

To Convert From These Units	mg/100ml	To These Units, Multiply by	g/L	mM/L	mEq/L
mg/100ml	—	$\frac{1}{100}$	$\frac{10}{\text{M.W.}^*}$	$\frac{(10) (\text{Charge})}{\text{M.W.}}$	
g/L	100	—	$\frac{1000}{\text{M.W.}}$	$\frac{1000 (\text{Charge})}{\text{M.W.}}$	
mM/L	$\frac{\text{M.W.}}{10}$	$\frac{\text{M.W.}}{1000}$	—	Charge	
mEq/L	$\frac{\text{M.W.}}{(10) (\text{Charge})}$	$\frac{\text{M.W.}}{(1000) (\text{Charge})}$	$\frac{1}{\text{Charge}}$	—	

*M.W. = Molecular Weight

CONDUCTIVITY

Passage of electrical current through aqueous solutions takes place with an interaction of electrolytes in the solution. An electrolyte is a *solute* that has a large effect on the conductivity of its solution, although all ions effect conductivity to some degree.

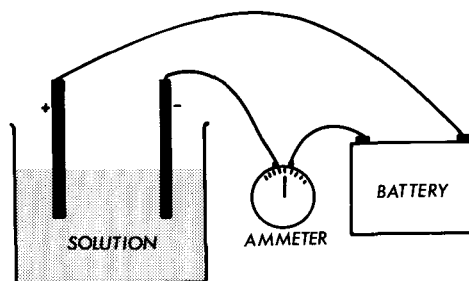


FIGURE 1. An electrolytic cell.

Figure 1 shows a cell composed of two electrodes immersed in a fluid. The electrodes are connected by wires through a battery and an ammeter; the ammeter measures the flow of current through the circuit. If the cell is shorted out by connecting the electrodes with a wire, current flows. If the only path between the electrodes is *pure* water, no current flows; there is nothing in solution to carry the current from one electrode to the other.

If we now add an electrolyte, such as sodium chloride, to the solution, current will flow. Sodium ions are attracted to the negative electrode where the Na^+ ion accepts an electron (e^-). At the same time, a chloride ion (Cl^-) reacts at the positive electrode where it gives up an electron. In effect, an electron has “flowed” from one electrode to the other.

The amount of current that can flow depends upon the: 1) number and 2) type of ions present. Large ions, such as lactate, move slowly through solutions and are poor electrolytes. Small ions move rapidly throughout solutions and are much better electrolytes. In dialysate, such ions are sodium, potassium and chloride.

Ionized particles in solution tend to attract a shell of water molecules around them. These molecules increase the average size of the ion, and affect the rate that

such ions move in solution. The potassium ion has a smaller hydrated size than does sodium; this accounts for much of the physiological power of potassium. The chloride ion in solution is smaller than sodium or potassium. Chloride is, accordingly, more mobile in solution, and therefore a better electrolyte, and more rapidly affects the electrical conductivity of a solution.

The total number of ions present also affects the conductivity of a solution. The more ions present, the easier it is for current to be carried across the solution. This property allows us to estimate the concentration of dialysis fluid by measuring its electrical conductivity.

Sodium chloride is the most important electrical solute in the dialysate, since it is the major source of chloride ions. Because chloride is such a potent ion, conductivity meters for dialysis are commonly calibrated in terms of the chloride concentration. By testing a sample with a standardized meter, we can quickly tell if the conductivity is within normal limits. It should be emphasized that dialysate meters must be calibrated to the particular dialysate being used, since the overall effect of all of the ions present are totaled. Two dialysates, each with 102 mEq/L of Cl^- , will have different conductivities if other components are present in different amounts.

Conductivity is a useful index of the dilution of dialysate. Electrical measurement is also assessed by regarding the solution as a *resistor*. That is, pure water is a high resistor, while an electrolytic solution is a poor one. Some dialysate meters have a knob which is turned until the light goes out. Such a meter measures the *resistance* of the fluid; a quite satisfactory instrument. Other meters, however, are calibrated in units of *chloride concentration*, which is satisfactory but may give erroneous information if it is used on different types of dialysate without appropriate calibration for total content.

Some meters read directly in Mhos or in millimhos, the units of *conductance*. This is probably preferable, since each user has to calibrate the meter to his fluids to determine what millimho values are within his normal limits.

OSMOLALITY

Osmosis is the movement of water from a weak solution to a strong solution through a semi-permeable membrane. Osmolality is the measurement of this property. Figure 2 shows an apparatus that can ideally quantitate osmotic pressure. Solution A is more concentrated than Solution B. The membrane is freely permeable to water, but impermeable to solute. Normally water would move from B to A. The amount of force needed on the piston to stop the flow is a measure of the osmotic pressure.

A more practical method of measurement depends on the colligative properties of solutions. These properties, such as the boiling point and the freezing point, relate to the number of solute particles present. Laboratory osmometers precisely measure the freezing point of a test solution to determine its osmolality. A disadvantage in the clinical situation is the cost of several thousand dollars for the osmometer.

The unit of osmotic pressure is the Osmole (Osm), and biologically speaking, the milliosmole (mOsm). A solution containing 1 mole of non-ionized solute (as sucrose) per 1000 ml of water has an osmolality of 1.0 Osm/L. A solution of 1

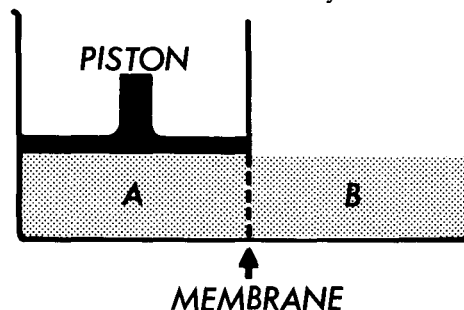


FIGURE 2. An ideal osmometer.

mole of sodium chloride would have a theoretical osmolality of 2.0 Osm/L since each NaCl particle dissociates into two ions (Na^+ and Cl^-) in solution; actual osmolality is slightly less since the ionic dissociation of NaCl is not quite complete.

Normal blood plasma measures about 290 mOsm/L.¹ This value represents the contributions of electrolytes, nitrogenous wastes, glucose and proteins that are dissolved in the plasma. Normal dialysis fluid usually has a slightly lowered osmolality, because it contains only the electrolytes, and perhaps glucose, present in normal plasma. In the treatment of chronic dialysis patients, this is of little clinical significance. The slight tendency of the blood to attract water can be overcome by increased drip chamber positive pressure, or increased negative pressure on the dialysate side.

In treating severely uremic patients with very high blood urea and creatinine levels, however, this osmotic differential can be very important. A high solute load in the plasma increases the osmolality of the blood. Since all water in the body is in osmotic equilibrium with blood, the water *inside* the cells also has a high osmolality. If such a patient is dialyzed aggressively and his blood osmolality is reduced rapidly by removing the nitrogenous wastes, an osmotic gradient will be formed between the water in the trapped cell and the interstitial fluid outside the cell. Such an osmotic gradient brings water into the cells and causes them to swell. Brain cells cannot expand, and the resulting increased intracranial pressure is thought by many to be the cause of the disequilibrium syndrome.

Symptoms of this syndrome are nausea, vomiting, headaches, disorientation, and seizures. Some workers have tried to prevent the symptoms by avoiding the osmotic gradient. Glucose has been added to the dialysis fluid so that as urea dialyzes out, an osmotically equal amount of glucose diffuses into the blood. This has not been very successful, in part at least, because an amount of glucose adequate to prevent the syndrome may violently upset the patient's glucose-insulin balance. Other solutes have been used—urea, mannitol, and sorbitol. None of these are reliable, and we have not used them for several years. A gentle introduction to hemodialysis is the better way; treating the dialysis equilibrium by prophylaxis.

We have found daily dialysis for at least three days on a 3-4-5 hour plan, possibly at a reduced blood flow, adequately removes the overload of solutes without bringing on the symptoms of disequilibrium. On the fifth day the patient can usually be started on a routine 6 hour dialysis. Occasionally, the plan must be extended so that even the fifth or sixth dialysis is one of reduced blood flow or time, but the critical factor is the prevention of rapid change in plasma osmolality. The slow reduction in accumulated wastes prevents the osmotic gradient from forming in the brain, and the serious complications—such as seizures—can be prevented. A recent paper by Port, Johnson and Klass³ discusses the prevention of dialysis disequilibrium by the use of high sodium dialysis fluid.

SUMMARY

An introduction to three topics in hemodialysis that are encountered every day has been presented. Many readers may wish more detail—for them the literature citations which follow may serve as a source of more information.

REFERENCES

1. White, Wilma L., Erickson, Marilyn M. and Stevens, Sue C. (1970). *Chemistry for Medical Technologists*, 3rd ed. Mosby.
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3. Port, Fredrich K., Johnson, William J. and Klass, Donald W. (1973). Prevention of dialysis disequilibrium syndrome by use of high sodium concentration in the dialysate. *Kidney International* 3:327-333.