Body Water – Body Weight

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Introduction

This educational article discusses the concepts of body weight – body water. These two (2) concepts which should be –mentally– inseparable when planning the hemodialysis procedure. Body water is the most abundant single substance in the body in the normal, healthy adult. A basic, simple, and clear understanding of body weight – body water should be essential for all who care for End Stage Renal Disease (ESRD) patients.

Proper control of body weight – body water, like dialysis dose, is one of the important issues and risk factors that contribute to the morbidity and mortality of ESRD patients. Without knowledge of body weight – body water the health-care giver can not render adequate dialysis care. In a hemodialysis facility, the classic four vital signs of: temperature, pulse, respirations, and blood pressure should be supplemented with the patient's actual weight both pre and post dialysis.

Objectives

1   List the percentages of the total body water for the two (2) principal compartments.

2   Describe the two principal (2) body fluid compartments.

3   Explain transcellular water.

4   Describe the term "third space" fluid accumulation.

5   State what percentage of total body water accounts for total body weight in the following: lean adult male, obese woman, and infant.

6   Differentiate between hypotonic, hypertonic and isotonic solutions.

7   What does the serum sodium (Na^+) indicate regarding total body water?

8   Describe four (4) signs and/or symptoms of extracellular volume (ECV) excess.

9   Identify the major cause of hypertension in more than 90% of the ESRD patient population.

10   Identify the rationale for not allowing some patients to eat during their dialysis treatment.

11   Describe the relationship with the serum glucose and the serum sodium.

12   Identify the correction factor for the serum sodium (Na^+) when a patient is hyperglycemic.

Total Body Water (TBW)

Water is the single most abundant substance in the normal human body. Water can be said to be very stuff of life. Water is *almost* a universal solvent. A true universal solvent can not be kept in a container. A true universal solvent would dissolve its container, leak downward, pulled by the force of gravity, and fall to the center of the earth. There it would remain until the end of the earth's time. Water is not a universal solvent, if it were, we would not exist as water soluble, carbon based beings.

Total Body Water

Intracellular Water is 2/3 of TBW 28 Liters	Extracellular Water is 1/3 of TBW 14 Liters

Figure 1 - Total Body Water

TBW Compartments

Most body water[1] is contained inside of tissue and muscle cells. This is *intra-cellular* water. Fat cells, cells used to store almost water-free fat, contain much less water, on the order of ten percent (10%) of the water in muscle, skin or other cells. A BMI of thirty (30) or more, *see* Equation 7, is defined as morbid obesity. Morbid obesity causes a falsely high TBW. Body fat contains very little water.

Extra-cellular Water (ECV)

The water outside of cells is called *extra-cellular* water and is composed of water between cells (interstitial water) and plasma water.

Figure 1 is a drawing of the total body water (TBW) compartments of an idealized 70 kilogram (Kg) healthy, normal, adult male. In this example, we use a TBW of sixty percent (60%) of body weight rather than the more difficult to calculate and remember –though scientifically more precise– fifty-eight percent (58%). The TBW is composed of the intra-cellular water which is two-thirds (2/3) of the TBW or 28 liters; and the extra-cellular water which represents one-third (1/3) or 14 liters. The total TBW is forty-two (42) liters. The TBW is remarkably constant; though the range in a group of individuals of both sexes and all ages varies from forty to seven-five percent (40 - 75%) of body weight.

The TBW is closely related to muscle mass. An estimate of lean body mass can be easily obtained if the TBW is actually *measured.* Muscle and tissue cells –the major components of lean body mass– are about seventy-three percent (73%) water. If the individual's TBW is 42 liters then his/her lean body weight or mass of body muscle and non-fat cells is (42/73%) or 57.53 kilograms, see Equation 1.

$$\text{Lean Body Weight} = \frac{\text{TBW}}{.73}$$

Equation 1- Lean Body Weight

Trans-cellular Water

There is a small amount of water, one to three percent (1 - 3%) of TBW called *trans-cellular* water which exists in various body compartments:

- cerebrospinal
- intra-ocular
- pleural
- peritoneal
- gastro-intestinal (GI) tract.

Except for the GI tract fluid, these watery spaces are tiny, *virtual* quantities of fluid in the normal state. In the abnormal state, transcellular water can contain large volumes of fluid which are clinically given the term "third space" fluid accumulation. In non-dialysis normal medical parlance, "third spacing" of fluid is associated with pathology as minor as a traumatic knee effusion to as major as massive ascites due to fulminant pancreatitis. Transcellular water is different in composition from extracellular water because the transcellular spaces are separated from the blood plasma not only by a layer of capillary endothelium but also by another layer consisting of cells which modify the amount and composition of the transcellular fluid.

Third Space

Figure 2 is a drawing of the TBW compartments. It depicts how little transcellular water contributes to the total water volume as well as denoting that the transcellular compartment is the "third space." In Figure 1, the intra-cellular water (IC) can be referred to as the "first space." The extra-cellular water (EC) is called the "second space." The "third space" is an abnormal accumulation of water outside of these two spaces. Except for the GI tract during active digestion, the normal amount of water contained in the trans-cellular water compartments is very small.

Peritoneal Dialysis is "Third Spacing"

Expanding the peritoneal space by instilling one or more liters of high glucose containing fluid is the method used in peritoneal dialysis to remove excess ECV. Unlike hemodialysis, using ultrafiltration to remove ECV with peritoneal dialysis is impossible. The excess ECV is removed by introduction of a hypertonic glucose solution into the peritoneal space causes extra-cellular fluid to move from blood into the peritoneal space. This excess ECV is removed in the peritoneal dialysis outflow. Since the peritoneal space normally contains only a few milliliters of fluid, this technique induces a third space phenomenon or condition in the patient. Hemodialysis ultrafiltration may remove two to three (2 - 3) *liters* of ECV per hour and subject the patient to substantial hypotension or shock. In peritoneal dialysis, this ECV loss is more gradual and occurs over a twenty-four (24) hour period.
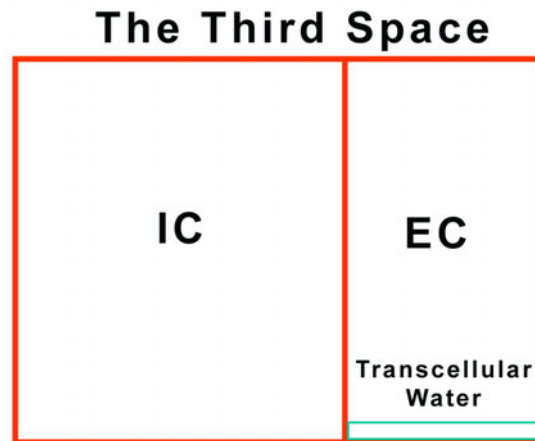
The Third Space

IC   EC

Transcellular
Water

Figure 2 - Transcellular Water

Whole Blood Is Both Extra-cellular & Intra-cellular

Plasma water is about one-third (1/3) to one-forth (1/4) of the ECV water. If one uses one-fourth of the fourteen (14) liters of ECV, then that plasma water volume is (14/4) or 3.5 liters. Since red blood cells make up the majority of the rest of whole blood, then the volume of whole blood can be calculated by knowing the patient's Hct:

$$\text{Blood Volume} = \frac{\text{Plasma Water}}{1 - \text{Hct}}$$

Equation 2 - Calculating Blood Volume

With a Hct of 35% and a plasma water of 3.5 liters, the blood volume is {3.5/(1-.35)} or 5.385 liters. Whole blood contain both intra-cellular and extra-cellular water.

Physiology Rules

The physiology and control of the TBW, like all of human physiology, dwarfs mankind's mechanical devices, computers, and skills. In a twenty-four (24) hour period, the TBW may fluctuate by one or more liters due to fluid ingestion, sweating, or elimination. The body exquisitely controls its internal fluid balance. The normal human kidney performs a major amount of this almost magical manipulations of fluid control. With hemodialysis, even with the best knowledge and equipment, we imperfectly and crudely control TBW.

TBW Varies By Age And Sex

Table 1 represents a generalized outline of some TBW values measured by age and sex. Men, generally have less body fat and more muscle than women and thus have somewhat increased TBW. With age, body fat increases and body muscle decreases. Note that infants have the highest amount of TBW.

Age in years	Male, %	Female, %
Newborn	80	75
1 - 5	65	65
10 - 16	60	60
17 - 39	60	50
40 - 59	55	47
60 +	50	45

Table 1 - TBW in Humans

TBW Is a Volume Measure

The TBW is measured in liters or kilograms and is a measurement of volume. A solution consists of a solvent and one more solutes. The water is the solvent. The substances that are dissolved in this water are the solutes. The solutes take many forms. We will discuss –briefly and imperfectly– some solutes such as the serum Na^+ and serum glucose.

Different major solutes comprise the intra-cellular and the extra-cellular compartments. Table 2 depicts some of these differences. Note that urea is the only common substance that is exactly the same in plasma and in the intra-cellular water; thus urea's contribution to serum tonicity, its osmolality, can be ignored when attempted to gauge: water excess or depletion. Also note that though glucose contributes a substantial amount of milliosmoles (mOsm/L) to the plasma tonicity, it is not measurable in the intra-cellular water.

Substance	Plasma, mOsm/L	Intracellular, mOsm/L
Na^+	138	12
K	4	140
Cl	100	10
Ca	4.4	0
Mg	1	20
HCO3	24	10
Glucose	5.6	
Urea	3	3
Other		85
Total	280	280

Table 2 - Some Solutes in Plasma & Intra-cellular Water

Tonicity, Osmolality & Other Difficult Terms

TBW describes a *volume* of water, the amount of water in the human body. Just as milk in a bottle is described in terms of liters or quarts, body water is described in liters or kilograms. The TBW is contained in many compartments, each separated by cells and membranes. Water passes freely through these membranes and cells, but not so the solutes; the dissolved particles such as Na^+. These solutes are either diffused from compartment to compartment dependent upon their molecular size, electrical charge, and shape or are actively moved by energy pumps.

Some solutes such as albumin and other proteins have high molecular weights and are not freely diffusible. Often these impermeable solutes are moved from compartment to compartment by energy pumps. In normal circumstances, all water and all solutes in the body –except for the kidney– are isotonic to each other. They all contain the same number of solute particles per volume. With dialysis, we impose, *hypertonic* and *hypotonic* transport across the artificial kidney membrane. Permeable solutes move in both directions attempting to equilibrate themselves. The arti-

ficial kidney also performs ultrafiltration. The ultrafiltrate may be hypotonic as to Na^+ and other solute concentrations.

Intra-cellular & Extra-cellular Tonicity Are the Same

Table 1 shows some, not all, of the solutes in the plasma, an extra-cellular space, and the intra-cellular space. The solutes are different, Na^+ is the principal cation of the extra-cellular space and potassium (K^+) is the principal cation of the intra-cellular space; the *total* tonicity, osmolality or osmolarity are identical. Thus, we can use the major extra-cellular cation, Na^+ as an osmostat for water balance disturbances.

Tonicity

The tonicity of that volume is the number of particles per liter or kilogram of that fluid. Tonicity can be expressed as:

1   osmolality, mOsm/Kg

2   osmolarity, mOsm/L

3   milliequivalents per liter, mEq/L

The above terms are used to describe solutes such as serum Na^+ which is expressed in mEq/L or serum glucose which is expressed in mg/dL. Both solutes can also described in the form of mOsm/Kg.

Tonicity can –more simply– be described as:

1   Isotonic: normal, serum Na^+ normal

2   Hypotonic: too much water, serum Na^+ low

3   Hypertonic: too much solute, serum Na^+ high

Serum Na^+ reflects TBW

The terms "sodium," or "salt water, " or saline" as taught by Doctor Scribner were used to refer to the volume of the ECV. These terms were <u>not</u> used to refer to the tonicity, the osmolality, of the solutes of the TBW. A *high* serum Na^+ means a *low* TBW and a *low* serum Na^+ means a relatively *high* TBW. The serum Na^+ does not mean nor reflect the quantity of the ECV.

Fifty years ago Doctor Scribner's fluid balance concepts were revolutionary; for some to many present day teaching programs these ideas remain revolutionary. There are USA textbooks of physiology published in the twenty-first century which state that the serum Na^+ has no relationship to tonicity. Since physicians are taught from these USA textbooks of physiology, the health-care student may receive heated and profound disagreement from such physicians.
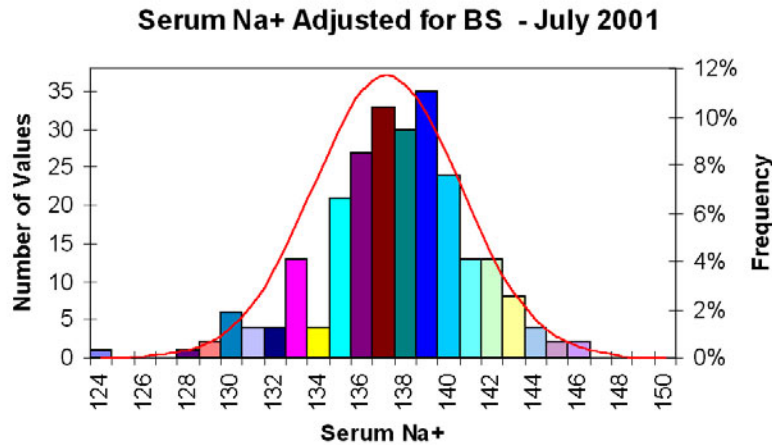
What is a normal serum Na$^+$ for an ESRD Patient?

Figure 3 - Serum Na$^+$ Values for 247 Patients

A common laboratory range for serum Na$^+$ in normal, healthy adults is: 136 to 145 mEq/L. USA laboratories report a range of two (2) standard deviations {ninety-five percent (95%)} of normal values. Thus the mean serum Na$^+$ is: {(136+145)/2} 140.5 mEq/L and the standard deviation is {(145-136)/4} 2.25.

In the beginning of chronic hemodialysis in Seattle, Washington, the dialysate Na$^+$, was set to be 132 mEq/L. This dialysate Na$^+$ closely matched the serum Na$^+$ of these early ESRD patients. These early dialysis patients had low serum Na$^+$ values probably due to sick cell syndrome. As nephrologists attempted to deal with shock and leg cramps, the dialysate Na$^+$ was increased. The increased dialysate Na$^+$ minimized the episodes of leg cramping but may have led to a worsening of hypertension in many ESRD patients. Matching the patient's serum Na$^+$ to the dialysate Na$^+$ may be a critical factor in controlling hypertension. Matching the patient's Na$^+$ to his/hers dialysate Na$^+$ should be part of the ESRD dialysate prescription.

Figure 3 displays a histogram of serum Na$^+$ values for 247 hemodialysis patients corrected for their blood glucose levels. The mean serum Na$^+$ is 137.2 and the median is 137.3. The shape of the histogram and the matching of the mean and median values, suggest that these serum Na$^+$ values are normally distributed. The idealized normal (Gaussian) curve is superimposed over the columns of different serum Na$^+$ values. The standard deviation is 3.4. This range of serum Na$^+$ values {plus and minus (±) two (2) standard deviations} is 130 to 144 mEq/L. This is a range close to that seen in normal adults.

Three Ways to Increase ECV

Figure 4 diagrams the three (3) methods of inducing an ECV gain in the ESRD patient. The most common one is an isotonic ECV gain due to salt water or saline gain as shown at the top of Figure 4. The last or third method of ECV gain is one that deserves a thorough explanation. Forty percent (40%) of ESRD patients have diabetes mellitus. These patients may present for

dialysis with an elevated serum glucose. If it is important to match the patient's pre-dialysis Na^+ to the dialysate Na^+ used for that patient, then the issue of an elevated pre-dialysis blood glucose which causes a <u>falsely</u> <u>low</u> <u>laboratory</u> <u>determination</u> <u>of</u> <u>the</u> <u>pre-dialysis</u> <u>dialysis</u> <u>serum</u> <u>Na^+</u> must be examined. The patient with a pre-dialysis blood sugar of four or five hundred (400 - 500) will have both:

1   an expanded ECV because of the elevated blood sugar

2   a lowered serum Na^+

The above condition is diagrammed in <u>Figure 4</u> as "Hypertonic ECV." Lest the student think that hyperglycemia is a trivial cause of hypertonic ECV expansion, be aware that unbridled hyper-glycemia in the patient with renal failure can cause acute pulmonary edema and heart failure.[2]
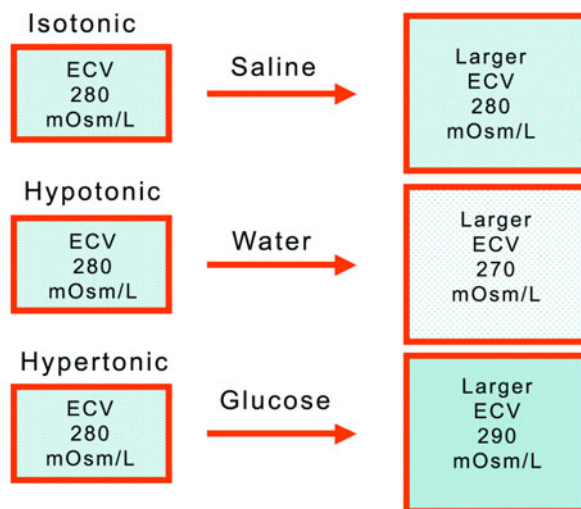

Figure 4 - ECV Increase Due to Volume

Hyponatremia Due to Hyperglycemia

Glucose, as a measurable solute, is confined to the extra-cellular space. Hyperglycemia, (defined for this discussion as a blood glucose above the normal level of 100 mg/dL) causes water to <u>move</u> <u>from</u> <u>the</u> <u>intra-cellular</u> <u>space</u> <u>into</u> <u>the</u> <u>plasma</u> <u>water</u>. The total Na^+ in the extra-cellular space is fixed. With hyperglycemia, the serum Na^+ is *lowered*, reflecting –falsely– a water ex-cess state. It is vital, when assessing TBW by use of the serum Na^+ that the blood glucose be ob-tained. Failure to correct for hyperglycemia will lead the student astray and cause the patient harm if the dialysate Na^+ is adjusted using this false serum Na^+ level.

Convert Serum Glucose to mOsm/Kg

In order to express solutes like serum glucose in their osmolar form, as mOsm/Kg, the concentra-tion of serum glucose must be converted from mg/dL to mOsm/Kg. The serum glucose is an un-

ionized particle, it can not be expressed in mEq/L. A normal serum glucose of 100 mg/dL is converted to mOsm/Kg by the formula:

$$\text{Blood Glucose in mOsm/Kg} = \frac{\text{Blood Glucose in mg/dL}}{18}$$

Equation 3 - Conversion of Glucose To mOsm/Kg

The molecular weight of glucose is 180. Eighteen (18) is used in Equation 3 because the serum glucose is expressed in mg/dL or per 100 ml; one-tenth (1/10) of a liter. A serum glucose of 100 mg/dL is (100/18) 5.6 mOsm/Kg. The European convention is to express serum glucose in mmol/L which, for non-ionized particles such as the serum glucose, is the same as mOsm/Kg. One mmol/L of serum glucose is 18 mg/dL, see Equation 4 below.

$$\text{mg/dL} = \frac{\text{mmol/L x atomic weight}}{10}$$

Equation 4 - Convert mmol/L to mg/dL

Americans will find the Equation 5, below more useful as it is the formula to convert substances reported in mg/dL to mmol/L:

$$\text{mmol/L} = \frac{\text{mg/dL x 10}}{\text{atomic weight}}$$

Equation 5 - Convert mg/dL to mmol/L

Correction Factor Of Serum Na$^+$ For Hyperglycemia

In mid twentieth century USA, the rule of thumb for correcting the serum Na$^+$ for hyperglycemia was to add 2.8 mEq/L[3] to the serum Na$^+$ for every 100 mg/dL increase in serum glucose above normal. This number was obtained by converting serum glucose in mg/dL to mOsm/Kg, see Equation 3. A serum glucose of 100 mg/dL is 5.6 mOsm/Kg. Since the serum Na$^+$ is part of a pair of ions in the extra-cellular water the effect on the serum Na$^+$ is one-half or (5.6/2) or 2.8 mEq/L. Under Doctor Scribner's tutelage, we were taught to use 2.5 mEq/L as a rule of thumb. For a serum glucose of 400 mg/dL, an upward correction of (2.5*3) or 7.5 mEq/L is added to the serum Na$^+$. Note that a serum glucose of 100 mg/dL is considered normal and this number is deducted from the total serum glucose before this calculation is made. The authors of the seminal study in 1949 on how to correct the serum Na$^+$ upwards for hyperglycemia, did not actually measure the serum Na$^+$ with changes in serum glucose. They based their conclusions on the mathematical assumptions noted above.

In 1973,[4] another author noted that since TBW and ECV were fixed in volume that addition of glucose to the extra-cellular space, to the ECV would cause a *hypertonic state*, and a smaller correction factor of 1.6 mEq/L was proposed. That correction factor has been used as the standard until this, the twenty-first century. Note that for fifty (50) years this important estimate of serum Na$^+$ correction was calculated, never actually measured.

Acute Hyperglycemia changes to Serum Na^{+}

In 1999,[5] Hillier and others studied six (6) healthy adults. The ability of these normal volunteers to release insulin was blocked. Their blood glucose elevated by infusing them with intra-venous (IV) glucose. If they calculated the correction factor up to a blood glucose of 400 mg/dL, it was 2.4 mEq/L. The correction factor was much higher, 4.0 mEq/L and higher for blood glucose levels above 400 mg/dL. Figure 5 is a graph redrawn from Hillier's data. The upper curve reflects these two correction factors. The lower, steeper and straight line curve is for <u>all</u> <u>data</u> and indicates an average serum Na^{+} decrease of 4.0 mEq/L per 100 mg/dL of serum glucose increase.
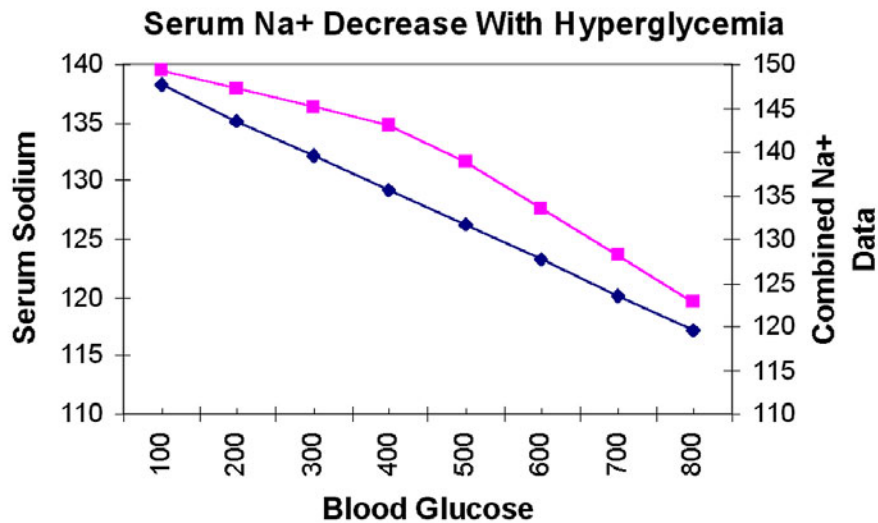

Figure 5 - Both Blood Glucose Curves

Chronic Hyperglycemia changes to Serum Na^{+}

One could argue that ESRD patients have gradual increases in their serum glucose over many hours and that the above acute experiments in normal volunteers have no real value in the ESRD setting. But medical studies of the effects of hyperglycemia, in particular, the studies of Doctor Tzamaloukas[6] in hemodialysis and peritoneal dialysis patients, substantiate Hillier's results. Doctor Tzamaloukas reported a mean serum Na^{+} decrease of 2.4 mEq/L per 100 mg/dL glucose increase (-0.43 mmol/L Na^{+} per mmol/L glucose). Some of his results *exceeded* the experimental results of Doctor Hillier. One should correct each individual's pre-dialysis serum Na^{+} for any hyperglycemia before estimating their pre-dialysis serum Na^{+}.

Formula to Correct Serum Na^{+} For Hyperglycemia

Again, the most common cause of a falsely low serum Na^{+} is an elevated serum glucose. Since about forty percent (40%) of dialysis patients have type II diabetes mellitus, the student needs to remember a simple formula, Equation 6:

$$\text{Corrected Serum Na}^+ = \frac{\text{(Blood Glucose - 100)}}{100} \times 2.5 + \text{Serum Na}^+$$

Equation 6 - Formula to Correct Serum Na$^+$

Other, rare, causes of depression of the serum Na$^+$ by other blood solutes are:

- mannitol

- globulins, several grams percent, due to a rare form of plasma cell tumor

- very high concentrations of lipids such as triglycerides that would render the plasma milky, and thus easily diagnosed if the spun plasma or serum was viewed

- IV bolus doses of 50% glucose.

Mannitol

IV mannitol is still used in some dialysis facilities to assuage muscle cramps. Mannitol's use depresses the serum Na$^+$. We discontinued the use of mannitol in the 1970's after finding that serum Na$^+$ levels were depressed due to its liberal use –which did not correlate well– with relief of muscle cramps. We believe that mannitol for this purpose should be abandoned.

Water & Salt Water Problems

There are four (4) simple conditions which cause pathology when the TBW is changed:

1 TBW Excess, water intoxication; the serum Na$^+$ is low and the body weight is high

2 TBW Depletion, dehydration; the serum Na$^+$ is high and the body weight is low

3 ECV Excess, saline excess; the serum Na$^+$ is not effected and the body weight is high

4 ECV Depletion, saline depletion, the serum Na$^+$ is not effected and the body weight is low.

In hemodialysis, the third condition, ECV Excess, is the most common and associated with:

1 Heart failure

2 edema

3 elevated neck vein pressure

4 Increased blood pressure

Seriously shortening of the patient's life span due to accelerated vascular disease and muscle hypertrophy of the heart.

Saying "Water" Is Not Enough

The use of the word "water" to describe a fluid balance problem or an abnormal fluid state in a ESRD patient is inaccurate. In Seattle, the term "water" was never used without qualifying terms to describe the ECV and TBW status. On medical rounds, if a student said, "The patient lacks water, her blood pressure is low," Doctor Scribner didn't need to speak. Most of the medical students and house staff would begin a lecture. They would want to know what fluid compartment was the student referring to, the intra-cellular or the extra-cellular compartment. They would want the physical findings and laboratory data for the TBW and ECV abnormalities.

ECV Changes Due to Volume Changes

It is unappreciated that an ESRD patient who –out of habit or perversity– who drinks large quantities of pure water can develop the clinical picture of heart failure. Profound water intoxication may induce: cerebral edema, seizures, and non-cardiogenic pulmonary edema. This condition of water intoxication has been documented in healthy Marathon runners[7] who ingest gallons of water with minimal or no solute.

The common clinical picture of ECV gain to leading to heart failure in ESRD patients is:

First: eating food high in salt {sodium chloride (NaCl)} content

Second: developing thirst

Third: drinking water to dilute the ingested salt

Fourth: a markedly increased ECV with edema and heart failure.

Figure 4 is a drawing of the three (3) conditions which can induce an ECV gain in the ESRD patient. The most common one is the first or an isotonic or salt water gain due to dietary ingestion of first salt then water. The tonicity of the ECV remains constant and there is evidence of excess ECV with:

1   edema: periorbital, sacral, pretibial, pedal

2   elevated neck veins indicating right heart overload

3   elevated blood pressure

4   shortness of breath

5   inter-dialytic weight gain of several kilograms.

The second condition depicted in Figure 4 is rare and occurs in the ESRD patient who is a compulsive water drinker, either by habit or by specific instruction by physicians who instructed this person to, "drink eight glasses of water of day to flush those kidneys!" The diagnosis of this pa-

tient is not more difficult, it just requires more circumspection and thought. This ESRD patient will evidence:

1   interdialytic weight gain of several kilograms

2   normal to elevated blood pressure

3   shortness of breath

4   a lower than normal serum Na^+.

Note that edema, the hallmark of an ECV excess of three (3) or more liters, may not be detectable, though it should be. This patient is usually misdiagnosed as having garden variety ECV excess due to dietary salt ingestion and all its sequelae.

Hypovolemia Due To Eating On Dialysis

During active digestion of a high carbohydrate meal, there may be enough water transfer into the GI tract to reduce the plasma water and raise a *normal* individual's hematocrit (Hct)[8]. In a large dialysis unit, there may be patients who should *not* eat during their dialysis treatment. These are the patients who:

1   gain the most amount of inter-dialytic weight

2   eat the most while on dialysis

3   routinely go into shock when ultrafiltration is applied to remove that inter-dialytic weight gain.

No diagnosis can be made without first suspecting it. Eating a large meal while on dialysis at the same time the health-care staff is attempting to remove several kilograms of excess ECV may trigger shock. The diagnosis is made by first determining a history of the above conditions and second noting that with the same or similar amount of weight gain with the same amount of ultrafiltration, and *no eating* on dialysis results in a satisfactory dialysis with removal of the excess ECV.

The diagnosis can *not* be done by tracking the intra-dialysis Hct changes. These Hct changes are due to both ultrafiltration and eating of a large meal on dialysis. The student is requested to survey their own hemodialysis population for this disorder. Hypotension due to eating on dialysis is an important issue to remember the next time the student cares for a hemodialysis patient who develops *hypotension* on dialysis while or after eating a large meal which results in inadequate ECV removal by ultrafiltration.

Sodium Modeling May Cause Sodium Overload

Newer dialysis machinery allow sodium and ultrafiltration computer modeling. Used correctly sodium modeling will prevent shock and muscle cramps on dialysis. Used incorrectly, sodium modeling may render the patient *hypertonic* post-dialysis. That patient will have an artificially expanded ECV and experience profound thirst in the immediate post-dialysis period. These people are easily identified by the simple method of weighing them pre-dialysis, post-dialysis and the morning following their sodium modeled dialysis. A simple diagnostic technique which is rarely performed.

Medical Opinion Versus Medical Science

When medical opinion fails to match human physiology, it should be discarded. Incorrect corrections for serum Na^+ correction for hyperglycemia have be taught for over a quarter of a century; based not on physiology, but on theory. For another example of medical theory without supporting medical fact, the student is directed to our first educational article, "Dialysis Dose."

Salt Water, Saline, Extra-cellular Volume (ECV)

One of the reasons that the first chronic hemodialysis system developed in Seattle, Washington was so successful may be Doctor Belding H Scribner's ingenious fluid balance teaching. All medical students and medical house staff were taught fluid balance. From the mid-fifties of the twentieth century, those medical doctors were conversant with water, salt, potassium, and acid-base problems.

When the first chronic hemodialysis patients appeared in the late 1950's, these physicians applied their expertise with aplomb. Patient care, though not simple, was possible. This was not necessarily true in other teaching hospitals in the USA.

Doctor Scribner used simple drawings and concepts to explain TBW, blood volume, and blood pressure control. His teaching and fluid balance manual[9] paved the way for his pioneering work in blood pressure control of the ESRD patient. There are many of us who were fortunate and learned these brilliant and simple concepts directly from Doctor Scribner.

Hypertension is Caused by Extra-cellular Volume Excess

Prior to each and every dialysis the health-care worker caring for the patient should make a clinical assessment of the patient's ideal, or "dry" body weight. This should be the standard of care for all dialysis patients. Fully ninety percent (90%) of ESRD patients have high blood pressure either partially or totally due to and expanded extra-cellular compartment, a fluid compartment that can be assessed by knowing the patient's body weight.

Blood Pressure Reflects ECV

The Scribnerian approach defined and measured ECV by determining how full the patient's blood stream was. Was the blood pressure high? Were the patient's neck veins full with the pa-

tient sitting upright? Did the patient have edema? The term "saline," or "salt water", or volume, or "ECV" was used to describe the states of ECV surfeit, lack, or just enough.

If the patient was edematous, short of breath because of congestive heart failure (CHF), and had elevation of his neck vein while sitting, he almost always has "saline excess."

If the patient has poor skin turgor, low blood pressure which became lower when he sat up, no edema, and flat neck veins; he almost always had, "saline depletion."

The use of the term "saline" was done with the full appreciation and understanding that intra-venous normal saline is not the same in composition as the fluid in the extra-cellular space. However, intra-venous normal saline is the common replacement fluid for a lower than normal ECV. Understanding how to diagnose "volume excess" or "saline excess" led students to examine hypertension, especially in the ESRD patient, as a "saline excess" state. In the ESRD patient, it almost always is just that.

Is Normal Saline Normal?

Probably the most common IV replacement fluid in the USA is normal saline or 0.9% sodium chloride in sterile water. One (1) liter of normal saline contains 154 mEq/L of Na^+ and 154 mEq/L of Cl^- for a total osmolality of 308 mOsm/L. This IV fluid is *hypertonic* to normal plasma which is about 280 mOsm/L. Why is a hypertonic solution used to replace ECV? We have found no references to explain this quandary. ESRD patients have their serum Na^+ set at an upper limit of about 137 mEq/L. Thus using two, three, or four liters of IV normal saline gives them a hyper-tonic sodium load. Post-dialysis, they will drink water to dilute out this excess sodium given intravenously.

Water Intoxication From Incorrect Dialysate Composition.

If the dialysate machinery manufactures a substantially hypotonic fluid[10], but at a concentration that does not cause hemolysis, the patient may rapidly develop water intoxication, cerebral edema, seizures, and non-cardiogenic pulmonary edema. Signs and symptoms that the dialysis staff will misinterpret as requiring more ultrafiltration and more dialysis!

But What Does This All Mean!?

"How does any of this stuff about TBW, ECV, and hyperglycemia help me to better manage my hemodialysis patients!?" That is the ringing cry from the RNs who deal with the reality of hemodialysis units. A reality that includes: patients that gain too much weight between dialysis, too short dialysis time, and too many patient medications that induce hypotension on dialysis. If health-care workers are taught just to, "Get them in, wring them out, and get them out the door…" this article should give them pause. The dialysis procedure should be tailored to the patient… and not the reverse.

What To Do

- Match the dialysate Na^+ to the patient's average serum Na^+

- Watch for those patients who eat large meals on dialysis who then go into shock

- Estimate a "dry" weight prior to each and every dialysis

- Verify that the patient has held all anti-hypertensive medications prior to dialysis

- Watch out for the rare patient with a low serum Na^+

- Correct the patient's serum Na^+ *upwards* for any hyperglycemia

- Discourage use of hypertonic: mannitol, saline, or glucose to control hypotension on dialysis

- Minimize use of IV saline to support the patient's blood pressure as you are replacing isotonic fluid with hypertonic normal saline

- Put yourself on a low-sodium diet for a month before you ask a dialysis patient to do so.

- An increasing pre-dialysis creatinine, such as 1 mg/dL in a month's time is either due to faulty dialysis or increasing muscle mass. The first condition requires longer or better dialysis, the second condition is associated with increasing true body weight (muscle weight).

Post Test

1. Total body water is distributed in what proportions?

    A. One half in the intracellular compartment and one half in the extracellular compartment

    B. Two thirds in the extracellular compartment and one third in the intracellular compartment

    C. One third in the extracellular compartment and two thirds in the intracellular compartment

    D. One third in the intravascular compartment, and two thirds in the intracellular compartment

    E. None of the above

2.   There is a small amount of water, one to three percent (1 - 3%) of TBW called *trans-cellular* water which exists in various body compartments. Which one of the following examples is NOT contained in *trans-cellular* water?

   A. Cerebrospinal

   B. Intra-ocular

   C. Plasma

   D. Peritoneal

   E. Gastro-intestinal (GI) tract

3.   An abnormal accumulation of water outside the intracellular and extracellular compartments is referred to as:

   A. Transcellular water

   B. Third spacing

   C. Hypervolemia

   D. Edema

   E. None of the above

4.   Total body water accounts for what percentage of total body weight in a lean adult man?

   A. Approximately 90%
   B. Approximately 60%
   C. Approximately 45%
   D. Approximately 75%
   E. Approximately 30%

5.   A solution that has a higher osmolality than body fluids.

   A. Hypotonic solution
   B. Hypertonic solution
   C. Hypervolemia
   D. Hypovolemia
   E. Isotonic solution

6.   Which of the following laboratory values indicate water excess?
   A. Serum sodium 180 mEq/L
   B. Serum sodium 142 mEq/L
   C. Hematocrit 40%
   D. Potassium 3.5 mEq/L
   E. Serum sodium 128 mEq/L

7.   Which of the following statements best describes the serum sodium?

A. It tells you how much salt the patient is eating.

B. It indicates how much salt water is in the plasma compartment

C. Is a measure of the concentration of sodium in the blood and reflects the amount of water in the body.

D. It reflects the amount of salt water in both the interstitial and intravascular compartments.

E. None of the above.

8.   Dialysis patients with saline excess or an increase in extracellular volume will typically show a number of signs and symptoms. Which one of the following signs and symptoms listed, is usually *NOT* observed?

A. Distended or elevated neck veins

B. Shortness of breath

C. Generalized edema including periorbital, sacral, pretibial and pedal

D. Decrease in blood pressure

E. Increase in total body weight

9.   With hyperglycemia, the serum Na^+ is *lowered*, reflecting –falsely– a water excess state. It is vital, when assessing TBW by use of the serum Na^+ that the blood glucose always be obtained. The serum sodium must be corrected upward for every 100 mg/dL the serum glucose is above normal. The correction factor for obtaining an accurate serum sodium is:

A. A correction factor of 1.0 mEq/L

B. A correction factor of 2.0 mEq/L

C. A correction factor of 2.5 mEq/L

D. A correction factor of 3.0 mEq/L

E. None of the above.

10.   The most common cause of hypertension in approximately ninety percent (90%) of the ESRD patient population is:

A. Extracellular volume excess

B. Intracellular water excess

C. Transcellular water excess

D. Third spacing

E. Interstitial volume excess

RETURN POST TEST FORM TO:

**Hemodialysis, Inc
1560 E Chevy Chase Drive, Suite 435
Glendale, CA 91206-4175
Voice: 818-956-5357**

Name (First and Last) _____

Street Address (Include Apt #) _____

City _____ State_____ Zip Code_____

Home Phone (Include Area Code) _____

RN ❑ LVN ❑ PCT ❑ MD ❑ PhD ❑, Other:_____

License or Certificate No. _____

State of Licensure _____ Date_____

Post Test Answers – Please circle ⭕ the correct response

1.	A B C D E
2.	A B C D E
3.	A B C D E
4.	A B C D E
5.	A B C D E
6.	A B C D E
7.	A B C D E
8.	A B C D E
9.	A B C D E
10.	A B C D E

September 2003

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This educational article is especially designed for two (2) contact hour (CH) credits for registered nurses (RNs), Patient Care Technicians (PCTs), and other direct care personnel who are

licensed or certified by the Board of Registered Nursing (BRN) of California. Most (not all) American states recognize and accept the California BRN certified CHs. Thus, most American health-care personnel can receive CHs which are applicable for re-certification or re-licensure. It is the reader's responsibility to contact their state BRN or its equivalent prior to submitting the post test for CH credits to their state agency.

Other Values of These CHs

Other nursing organizations also recognize California BRN CHs. Again, it is the reader's responsibility to contact these organizations to verify that they accept California BRN CHs. We make no claim or representation that the earned CHs are applicable outside of California. Since 1998, Hemodialysis, Inc (**Hi**) has published nursing literature containing CHs. These educational instruments have been purchased by dialysis and other nursing personnel in most if not all of the fifty (50) American states as well as overseas and Canada. Letters from purchasers whose state or country does not have a BRN nor requirement for CHs have indicated that employers use and value these CHs for evaluation of the employee for promotion and salary enhancement. Thus, these CHs have substantial value even if they can not be applied towards re-certification or re-licensure.

Hemodialysis, Inc (Hi), Provider of the Free CHs

The certifying agent for these CHs is **Hi**, a Southern California health-care corporation. **Hi** makes these CHs available as a free perquisite to the readers of this educational product. Arrangements are underway to have this educational product published by ESRD related magazines in order to make these CHs more widely available to the health-care community as a community service.

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Those health-care personnel who wish to receive a certificate for these two CHs are required to correctly answer and submit the ten (10) question post test by mail to **Hi.** Please do not fax the post test; it will not be processed.

Must Submit Post Test with Stamped Envelope

A first-class affixed stamp to a self-addressed business envelope (9 x 4 ¼") ***must*** be enclosed with the eleven (11) question post test in the mailing to **Hi**. No request for CHs will be processed without this requirement.

Educational Article Content

Excellent medicine and nursing care is a moving target. The content of this educational article, the questions, and the graphics, are current, topical, and have been generated specifically for this article. The authors have chosen to present fresh data, opinion, and information not widely disseminated in the ESRD community but vitally important to excellent medical and nursing care.

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Glossary

Caveat Lector

The following is a glossary of words and phrases used in this monograph. If there is a synonym for the word to be defined; that synonym may the only definition used…. Most definitions are brief. Sometimes, historical or other information is added to perk the long term memory of the reader. Longer definitions may be used for words that are of particular importance in ESRD.

These definitions are unlike those in Dorland's and Stedman's medical dictionaries. Those authorities may mystify students with their medical completeness and complexity. These brief definitions apply to ESRD patients. These definitions do not fully describe or define:

- normal physiology
- acute renal failure states
- other pathophysiologic state.

Word(s)	Definition
Anion	A negatively charged ion such as the chloride (Cl^-) ion, see cation.

BMI	Acronym for Body Mass Index. A formula to estimate nutritional status. The formula using the American units of pounds and inches is:

$$BMI \; = \; \frac{\text{Weight in Pounds times 703}}{\text{Height in Inches squared}}$$

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Equation 7 - BMI Formula for USA

</div>

Cation	A positively charged ion such as the sodium (Na^+) ion, see anion.
Decaliter (dkL)	The prefix, "deca" means ten (10). The prefix "deci" means one-tenth (1/10), see deciliter.
Deciliter (dL)	One-tenth of a liter or 100 mL.
Diffusion	Movement of a solute from an area of higher solute concentration to an area of lower solute concentration. Diffusion occurs between two (2) solutions across a semipermeable membrane and when one solution is pored into another.
Dry weight	Weight of a patient with normal total body water and no fluid excess in the interstitial and plasma compartment. A clinical guess of the patient's true and normal extracellular volume.
Electrolyte	Electrolytes are ions in solution. A substance able to conduct an electric current. Common electrolytes include: sodium (Na+), potassium (K+), calcium (Ca++), magnesium (Mg++), chloride (Cl-), bicarbonate (HCO3-), phosphate (HPO4-), and acetate (Ac-). The American unit of measure for electrolytes is milliequivalents per liter (mEq/L).
ESRD	End stage renal disease. The acronym "ESRD" implies chronic, progressive, permanent kidney damage.
Extracellular fluid	All fluid in the extracellular compartment. In common dialysis parlance, referred to as: "ECV," "salt water," "saline," and "volume."
Extracellular volume (ECV)	The fluids which exist outside the cells. One third (1/ 3) of the body fluid is outside the cells, two-thirds (2/3s) is intracellular. The extracellular compartment is divided into two (2) additional compartments, the intravascular and interstitial compartments.
Hemodialysis	"hemo" meaning blood and "dialysis" meaning loosening from something else. Hemodialysis is the process of diffusion of blood across a semipermeable membrane to remove toxins, restore acid base balance, and remove excess ECV by ultrafiltration.
Hypernatremia	A high serum sodium, the marker for a water depletion state. Seen in normals when deprived of water in a hot dry climate. Seen in the debilitated patient treated with hypertonic tube feeding who can't or is unable to state his/her state of thirst. Seen in dialysis patients who are dialyzed with a very high bath sodium.
Hypertonic solutions	Solution that has a higher osmolality than body fluids. Sodium chloride solutions of 3.0% and 23.4% NaCl are hypertonic solutions.

Hypervolemia	Increased volume of blood. Associated with edema and hypertension in the dialysis patient.
Hyponatremia	A low serum sodium, usually indicates a relative TBW excess.
Hypotonic solutions	Solution with a lower osmolality than normal blood. A sodium chloride solution of 0.45% NaCl is a hypotonic solution.
Hypovolemia	Decrease volume of blood, associated with poor skin turgor and low blood pressure in the dialysis patient.
Interstitial fluid	Fluid between the cells and outside the blood vessels.
Intracellular compartment	A virtual body compartment that consists of all the fluid inside cells. Two thirds (2/3) of the total body water (TBW) is in cells.
Intravascular compartment	The body compartment that contains the fluid inside the blood vessels. Intravascular fluid. A portion of this fluid is the plasma water.
Ionized particles	An ionized particle carries a positive (+) or negative (-) charge. When solid NaCl (table salt) dissolves in water, it separates into two ions, Na^+ and Cl^-. Ions that carry a positive charge are called cations. Static electricity with ionization can be produced by rubbing the fur of a tabby cat. Ionized tabby cats are not cations.
Isotonic solutions	A solution that has almost the same osmolality as body fluids. Normal saline (0.9% Na^+Cl^+) is considered an isotonic solution though normal saline contains 154 mEq/L of sodium and chloride for a total of 308 ionized particles. Normal plasma is somewhat less with an osmolality of 280 mOsm/Kg.
Lean body weight	The muscle and other non-fat cell weight of an adult; can be estimated from the TBW. Body cells contain about seventy-three (73) percent water. Lean body weight can be estimated by dividing the TBW by 73%. The "ideal" body weight is higher and is estimated from life insurance tables which use the patient's: weight, height, age, body habitus, and sex.
Milliequivalents per liter (mEq/L)	An equivalent is a unit of measure equal in grams to the molecular weight of an ion. A milliequivalent of an ion is 1/1000 of that amount. IV solutions of electrolytes are expressed in milliequivalents/Liter, mEq/L.
Milligrams per deciliter (mg/dL)	Weight of a solute in 100 milliliters of solvent or one- tenth of a liter. The expression milligrams per deciliter is abbreviated as mg/dL.
Milligrams percent (mg%)	Weight of a solute in 100 cubic centimeters (cc or mL) of solvent. This unit of measure is not as specific as milliosmoles per liter (mOsm/L) or milliequivalents per liter (mEq/L). Milligrams percent is abbreviated as mg%. Milligrams per deciliter is the same unit of measure and is abbreviated as mg/dL and is the more commonly taught measure. See "Milligrams per deciliter (mg/dL)."
Milliosmoles per Kg	Number of particles (ionized or unionized) in a known weight of water, a kilogram of water, mOsm/Kg. This measure is more precise than mOsm/L and is the unit of measure associated with the term "osmolality."

Milliosmoles per Liter	Number of particles (ionized or unionized) in a known volume, mOsm/L. This is the unit of measure associated with the term, "osmolarity."
Sick cell syndrome	A clinical phrase used to describe poorly understood disease states associated with: poor wound healing, failure to thrive, and a depressed serum Na^+.
Solute	Substance that dissolves in a solvent. Sugar is an example of a solute. Table salt (NaCl) dissolves in water to form two ionic solutes, Na^+ and Cl^-.
Solution	A solution consists of two components, a solute and a solvent. Combining the solute salt with the solvent water yields a solution of salt water.
Solvent	Substance that dissolves a solute. Water is the –almost– universal solvent
Virtual	Synonyms are: near, implicit, and essential. Words, which have the opposite meaning of a word are called antonyms. Antonyms for virtual are: actual or real. Virtual reality is non-real reality.

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