Part 1: Fluid Dynamics and Physiology

Water Basics: As the body is composed of almost 60 percent water, total body water (TBW) is divided into intracellular and extracellular fluid. Intracellular fluid (ICF), contained within all cells in the body, makes up approximately two-thirds of the TBW. Extracellular fluid (ECF), fluid surrounding cells and in tissues, comprises one-third of the TBW. The extracellular fluid is further broken down into intravascular fluid, making up our plasma, and interstitial fluid, which is stored in tissues. The majority of extracellular fluid is interstitial in nature, and the remaining portion is intravascular. One might think of interstitial fluid like a sponge soaked with water. You do not necessarily see all the water contained within, but it is heavy and releases more water when squeezed. When you picture this system, remember that fluids and solutes are not stagnant, they are constantly flowing and exchanging across cell membranes or capillary endothelium to maintain homeostasis.

Water Balance: Electrolyte Concentrations: Water is freely permeable across cell membranes and capillary endothelium. Thus, it travels between the cell and the outside extracellular spaces constantly, to maintain equilibrium. Solutes, however, are not always freely transferrable. Solutes include small particles, such as electrolytes, and larger sugars, such as glucose. Electrolytes are distributed either intracellularly or extracellularly.

Water Movement: Fluid Compartments:
- Osmotic pressure changes: changes of water across a membrane when an impermeable solute is present
- Hydrostatic changes: changes of water across a membrane when a permeable solute is present
- Water can move between the interstitial (tissue), intravascular (vessel) and intracellular compartments freely.
- Small solutes can move across the intracellular and intravascular compartments easily.
- Larger molecules, such as albumin, cannot readily move from the intravascular space to the intracellular or interstitial spaces.

Water Intake/Excretion: Gains and Losses: Water gains are simple to identify: animals eat and drink and maintain their fluid balance. However, fluid losses are not always that easy to identify, or quantify, for that matter. There are several categories of fluid losses. Sensible losses are those losses which can typically be quantified. Examples include urine, feces (diarrhea), and vomitus. Insensible losses are those which typically contribute to fluid imbalance but cannot be measured. Panting and sweating are typical examples. These losses may be ongoing, such as diarrhea, and may need to continually be replaced. In addition, animals require a daily maintenance water requirement, which must be added to these losses.
- Losses in the interstitial compartment result in dehydration of tissues
- Losses in the intravascular compartment result in hypoperfusion to organs

SO:
- Patients with interstitial losses show the following clinical signs:
  - Tacky MMs
  - Prolonged CRT
  - Prolonged skin tent
  - Elevated PCV and TS
  - Sunken eyes
- Patients with intravascular losses will show the following clinical signs:
  - Hypotension
  - Tachycardia
  - Obtundation
  - Hypothermia
  - Cool extremities
  - Prolonged CRT
  - Bounding/thread pulses
**Part 2: Crystalloids: The Backbone of Fluid Therapy**

Now that we know some about how fluids are distributed throughout the body, we must discuss the actual natural and synthetic products utilized in fluid therapy. There are two general categories of fluids we administer to our small animal patients: crystalloid and colloid solutions. Crystalloids are water solutions with small electrolytes added to either replace lost ones, or to balance pH and osmolality of the fluid being infused. Since they are water-based, they will provide aid by augmenting hydrostatic forces. Thus, they will increase blood pressure through increased hydrostatic pressure, and will eventually leak from the intravascular space into the interstitial space through capillary fenestrations. In addition, they will equilibrate across the intracellular and intravascular space, as cells are freely permeable to water.

**Solution Characteristics: Isotonic, Hypertonic, Hypotonic**

Crystalloids fall under three categories: hypertonic, isotonic, and hypotonic. Recall that tonicity refers, in part, to effective osmolality. It essentially refers to the ability of a solution to move water across a membrane. In picturing tonicity, you must visualize a cell within a blood vessel. Initially, everything is in equilibrium. All fluids are balanced. If we introduce a hypertonic solution (one with a solute concentration greater than that of bodily fluids), water will want to travel into the compartment with more solute to balance out the concentrations. Thus, if a hypertonic solution is injected into a vein, water from the interstitial and intracellular compartments will travel out, to dilute the hyper-concentrated solution in the intravascular compartment. The reverse is true if we use a hypotonic solution. Now the solution has a solute concentration less than that of bodily fluids. Since there is more water and less solute in a hypotonic solution, water will travel out of the intravascular compartment and into the interstitial and intracellular ones. Think of a sponge. Initially it is dried out, and when you put it in water it expands greatly. That mimics the action of cells in a hypotonic solution. Now if you take the sponge and wring it out, you shrink it, mimicking the action of a hypertonic solution.

A further classification of crystalloid solutions is whether they function to replace or maintain fluid composition within the body. The replacement solutions typically contain electrolytes that resemble the extracellular fluid compartment. This means they will have high concentrations of sodium, low concentrations of potassium, and a plethora of other electrolytes ensuring they equilibrate with the ECF. Maintenance solutions have less sodium and more potassium than replacement solutions. These solutions are not typically used as often as the replacement solutions, but are created to be used when a patient is fully hydrated.

**Replacement Fluids**

Replacement fluids include: Lactated Ringer’s® (Abbott), Normosol-R® (Hospira), Plasmalyte-148® (Abbott), and 0.9 percent sodium chloride. The electrolyte concentrations, osmolality, and pH of each solution are expressed in the chart below. 0.9 percent sodium chloride contains a higher sodium and chloride concentration than that of peripheral blood. It is also somewhat acidic. It also does not contain any other electrolytes but Na⁺ and Cl⁻. It is important to notice that 0.9 percent sodium chloride is iso-osmolar, illustrating it will cause little fluid shifts across membranes, but will cause increases in the sodium and chloride levels in the body. The differences between Lactated Ringer’s®, Normosol-R®, and Plasmalyte-148® lie in the composition of the electrolytes they contain. Lactated Ringer’s® contains slightly less sodium than the others. Plasmalyte-148® contains more potassium than the others. Lactated Ringer’s® and Plasmalyte-148® contain calcium, and Normosol-R® and Plasmalyte-148® contain magnesium. The buffer in Lactated Ringer’s® is lactate, while the buffers in Normosol-R® and Plasmalyte-148® are acetate and gluconate, and acetate and lactate, respectively. While each fluid may seem to be quite similar and interchangeable there are some recommendations for the use of each. Patients in diabetic ketoacidotic crisis, or occult liver disease should not receive Lactated Ringer’s®.¹ Lactate, being the buffer, is exclusively metabolized in the liver. Lactate, by itself, is not effective in treating acidosis, but must be metabolized into bicarbonate. This may not be possible in patients with liver dysfunction. Fluids with acetate and gluconate as buffers are superior as metabolism can take place in extra-hepatic sites.¹

**Maintenance Fluids**

Maintenance fluids are comprised of a lower sodium and higher potassium concentration in contrast to replacement fluids. This is due, in part, to the fact that normal daily fluid loss typically contains more potassium than the ECF. Lost fluids are also typically low in sodium, and hypotonic, meaning more free water is lost. The ideal maintenance fluid, therefore, contains more potassium, for replacement, and low sodium and more free water concentrations. A typical solution of this nature is hypotonic, meaning fluid will shift into the intracellular space, so 5 percent dextrose
is often added to balance the osmolality with that of plasma. However, this small amount of dextrose is quickly metabolized in the blood to carbon dioxide and water, and thus offers no true caloric value. Examples of maintenance fluids include: Normosol-M®, and Plasmalyte-56®, 0.45 percent sodium chloride, and 0.45 percent sodium chloride and 2.5 percent dextrose.

**Free-Water Solutions**
Free-water solutions are those that contain mainly sterile water, or precursors that will be metabolized into water. The most commonly used solution for free-water administration is 5 percent dextrose in water. Sterile water, by itself, is hypo-osmolar and contraindicated, but the addition of 5 percent dextrose makes it iso-osmolar. As the dextrose is rapidly metabolized, the solution entering the vein is pure water. This is an entirely hypotonic solution, but functions to correct hyperosmolar (hypernatremic) states. As these patients have a much higher solute (salt) concentrations in their ECF, water will flow out of the ICF to compensate. Thus, the addition of solute poor solutions (free water) into the ECF, will move fluid back into the ICF and restore equilibrium.

**Part 3: Colloids: Life-Saving Large Molecules**
Understanding colloids and their role in fluid therapy often evades technicians, and their differences from crystalloids appear subtle in nature. While they don’t rehydrate, their role in shock is essentially the same as a crystalloid fluid; to buffer up the vasculature, thereby enhancing perfusion to vital organs. However, the structure of a colloid and its interaction with the body is vastly different than a crystalloid. This article will explore the structure, function, and uses for colloidal support in the small animal patient.

**Capillary Anatomy**
Capillaries are comprised of an endothelial cell and basement membrane. The majority of capillaries are continuous, implying that they have no noticeable gaps between cells. Other types of capillaries include: fenestrated or discontinuous. Most capillaries are freely permeable to water and electrolytes like sodium (Na+) yet are impermeable to larger molecules such as proteins like albumin and immunoglobulins.

**Starling’s Forces, Reviewed**
In referring to earlier articles, the idea that fluid moves freely across the intravascular and interstitial spaces is limited by the various forces charged with maintaining the shape and form of the vascular and tissue compartments. To summarize the force interactions, as described in DiBartola’s Fluid Electrolyte and Acid-Base disorders in small Animal practice, the hydrostatic forces of the capillary and interstitium are equal to the osmotic pressure forces between the same two compartments (di bartola). This means that the water pressure (hydrostatic) forces pushing water out of the various compartments is counteracted by the plasma protein pressure (osmotic), acting to retain water within the intravascular or interstitial compartments.

**Colloid Structure and Osmotic, Oncotic Pressure!**
Colloids are sugars and other large molecular-weight that do not cross the endothelial membrane of blood vessels. Unlike crystalloids, colloids do not traverse from the intravascular space into the interstitial space, if the vascular endothelium is intact. In the event of a leak in the capillary membrane, colloidal molecules can spill into the interstitium. Various examples of colloid solutions include dextrans, hydroxyethyl starch (Hetastarch®), hemoglobin-based oxygen carrying fluids like Oxyglobin®, and plasma products for transfusion. As Oxyglobin® is not readily accessible and other literature about it exists, it will not be included in this article. Since these molecules are many magnitudes larger than water and electrolytes, they exert a pressure in solution. If added to a solution of water, they will displace water molecules (observed by a glass of water overflowing), or if added to a sealed container, will increase the pressure within the container. There are 4 main forces worth discussing here: intravascular oncotic pressure, interstitial oncotic pressure, intravascular hydrostatic pressure, interstitial hydrostatic pressure. As discussed above, the intravascular oncotic pressure is made up of the addition of large molecular-weight substances to the fluid of the capillary. Protein exists in the interstitial space, in addition to the intravascular space. There is a larger amount of albumin present in the extravascular space than the interstitial space (di bartola, Rothschild, extravascular albumin). The oncotic pressure in the interstitial space will act to retain water through the Gibbs-Donnan effect (reference), which illuminates how negatively charged particles, like albumin, will attract cations, like Na+, and thus affect an increased osmotic pressure than would normally be calculated if factoring in albumin alone. This effect demonstrates how water begins to be amongst a tug-of-war with the intravascular colloid pressure attracting it to stay within the capillary, and the concurrent force in the interstitium acting to keep fluid within tissues. These forces maintain the shape and form of the body. Intravascular hydrostatic pressure is
maintained by several factors including the systemic vascular resistance. Increased pressures cause water to disperse out of the capillary. Finally, interstitial hydrostatic forces are present to offset influx of water from the capillary into the interstitium.

**Structure and Function of Artificial Colloid Solutions**

Use of artificial colloids, in veterinary medicine, function to expand the intravascular compartment and augment COP in hypooncotic states. Evidence shows that smaller volumes of a colloid solution will affect an increased intravascular pressure than crystalloids (di bartola, shoemaker am journal surgery). As large molecules are not freely permeable and cannot readily diffuse into the interstitial space, the expansion effect persists longer with a colloidal infusion as opposed to a crystalloid one (shoemaker).

There are several categories of artificial colloid solutions; the used with the most frequency in the U.S. are the dextrans and the hydroxyethyl starch compounds. Dextran compounds are formed when sucrose is fermented in the presence of bacteria, yielding a polysaccharide molecule. Hydroxyethyl starch products are created with amylopectin (plant starch) is partially hydrolyzed. While there is typically only one product containing dextran commonly used in the U.S. (dextran 70) there are multiple hydroxyethyl starch (HES) products available. Before we discuss the various differences in HES products some nomenclatures needs explanation. There are various ways to describe HES products by concentration, average molecular weight, and molar substitution ratio. In a colloid solution, the number of molecules, not necessarily the size, is the determining factor in the effective increase in COP the solution can create. Although a solution with a plethora of molecules will cause a substantial increase in COP, the smaller molecules are filtered by the glomerulus and/or metabolized by circulating amylase. To offset degradation of the amylopectin molecules in a hetastarch solution, the compound is hydroxyethylated at specific carbon points (carbons 2, 3, 6) and a ratio of glucose units:hydroxyethyl groups is generated (substitution ratio) (di Bartola, Treib studies (142–145).

**Physiology of Edema**

Edema is an important physiologic phenomenon that is linked to hydrostatic and oncotic pressures. There are three major types of edema:

- **High pressure edema:** This typically occurs with cardiac dysfunction. Forward or backward flow states create an increase in hydrostatic pressure within the vasculature. This leads to water leakage from the intravascular space into the interstitial space.
- **Hypo-oncotic edema:** This typically results from low levels of plasma proteins within the vasculature. Because the vasculature no longer has proteins to hold water within, water leaks into the interstitium.
- **Vasculitis:** This results from inflammation and damage to the epithelial cells lining the vessel walls. When these are damaged, the tight junctions between cells are also damaged. Water and proteinaceous fluid can leak from the vasculature into the interstitium.

**Part 4- Administration of Fluid Therapy, Venous Access and Monitoring**

There are many conditions for which fluids are necessary. Typically there are only two major reasons to administer fluids; the patient has either lost water (dehydration) or has low blood pressure (hypotension, hypovolemia). Dehydration refers to a loss of water from the interstitial space. When a patient loses fluids, like excessive urination or diarrhea, interstitial water is transferred to the vasculature to maintain blood pressure and perfusion. This lasts to a point, and then initially manifests itself as an interstitial fluid deficit—and is what we mean when we discuss dehydration. If the fluid losses are severe, or continue on for a long period of time, the vasculature can no longer maintain its volume, and an intravascular deficit occurs. This is manifested as “shock,” in this case causing hypotension and hypoperfusion. A patient may also present with vomiting and diarrhea and can lose water through each of those processes.

The fluid plan must address the various deficits in a step-wise manner. Does the patient show signs of shock? Does the patient show signs of dehydration?

There are four parts to the fluid therapy plan:

1. Addressing intravascular loss quickly with a bolus
2. Addressing interstitial deficits over 12–24 hours
3. Replacing ongoing losses (vomiting, diarrhea, panting, polyuria)
4. Adding these to the patient’s maintenance rate
Some Important Numbers

- Canine blood volume: 90 ml/kg
- Feline blood volume: 60 ml/kg
- Dehydration formula: BW (kg) x % dehydration x 1000 = mL to replace in 24 hours
- Maintenance rate: 60 ml/kg/day
- Ongoing losses: 20–30 ml/kg/day OR estimated volume of loss (urine quantification, etc.)
- Free-water deficit: BW (kg) x 0.6 x [(Na-140)/140]

Fluids for various scenarios

Some case examples:

- 1- Dehydration
  
  A 14y MN DSH, 4 kg, presents for polyuria/polydipsia. The cat appears quite thin and has the following physical exam findings and initial testing:
  1- Tacky MM’s
  2- CRT of 3 seconds
  3- Prolonged skin tent
  4- PCV 56%
  5- HR= 190
  6- BP= 120/72 MAP = 79

  What would be this patient’s fluid plan?
  
  **First:** Assess the intravascular compartment:
  
  HR is slightly elevated but probably not tachycardic and blood pressure is acceptable.
  
  **Second:** Assess the interstitial component:
  
  Appears to be 10% dehydrated.
  
  **Third:** Add any additional losses that may be incurred (urinary, fecal, respiratory, burns/wounds, vomiting)

  1- Maintenance
     a. 60ml/kg/day = 60 x 4 / 24 = 10
  2- Dehydration
     a. 10% = 0.1 x 4 x 1000 = 400 mL/24 = 16.6
  3- Ongoing losses
     a. Estimate on urine pad loss of 5-6mL of urine in a 4 hour period
     b. 5/4 x 24 = 30mL per day ongoing loss
  4- TOTAL plan:
     a. 240mL (maintenance) + 400mL (rehydration) + 30mL ongoing loss = 670mL/day
     b. Fluid rate = 670/24 = 30ml/hr

- 2- Intravascular losses and dehydration

  A 5y MN Great Dane, 92 lbs., presents with intractable vomiting and you suspect a GI foreign body. The owner’s initially do not have finances for surgery but can only afford medical management. Below are the pertinent findings on physical exam and bloodwork:
  1- HR: 120 BPM
  2- BP: 82 Doppler
  3- Tacky MM’s
  4- CRT = 2.5 seconds
  5- PCV = 55%
  6- Pulses weak and thready

  What would be this patient’s fluid plan?
First: Assess the intravascular compartment:
    Tachycardic with mild hypotension. Consider hypovolemic.

Second: Assess the interstitial component:
    Appears to be 8% dehydrated.

Third: Add any additional losses that may be incurred (urinary, fecal, respiratory, burns/wounds, vomiting)

The plan: (92 / 2.2 = 42kg)

1- Intravascular deficit:
    a. Administer bolus therapy until perfusion parameters improve
    b. 20 mL/kg Plasmalyte x 2. HR dropped to 110. BP increased to 104 mmHg.

2- Maintenance
    a. 60ml/kg/day = 60 x 42 = 2500 mL/day

3- Dehydration
    a. 8% = 0.08 x 42 x 1000 = 3360 mL/24 hours

4- Ongoing losses
    a. Observe for vomiting. Patient has not vomited in hospital and anti-emetic medications will be started

5- TOTAL plan:
    a. 2500mL (maintenance) + 3360mL (rehydration) = 5860 mL/day
    b. Fluid rate = 5860/24 = 240 mL/hr

- 3- Need for free water

4y FS Border collie, 35 lb, presents with obtundation of unknown cause. Owners finally reveal they play paint-ball and a few balls were missing. On presentation this patient is very “shocky” and dehydrated. Parameters/tests of interest include:

1- HR: 160
2- BP 140mmHg Systolic
3- Tacky MM’s
4- CRT = 4 seconds
5- Skin tent present
6- Enophthalmos (sunken eyes)
7- PCV = 68%
8- Na+ = 185 meq/L (ref range = 148-151 meq/L)

Note: This case is tricky. This patient is hypovolemic, dehydrated, and has a solute-poor water deficit (free water)- because of the excessive salt ingestion and subsequent osmotic diuresis. A few things need to be addressed:

1- How do you bolus a patient such as this?
    a. Bolusing will drop the Na+ level quicker than a limit of 1meq/L/hr
    b. Replacement of free-water can be accomplished with 5% Dextrose in water
    c. Need to calculate the free-water deficit in this patient
    d. Also- need to create a fluid that is the same osmolarity as the patient’s blood (so a Na+ level of 185)
    e. Add 0.9% NaCl (x meq/mL) to 1L of Normosol/Plasmalyte/Lactated Ringer’s to raise it to the same osmolarity.

Administration of fluids- drip-sets/IV pumps

2 major drip set types
    Macro drip (15 drops or 10 drops/mL) OR micro drip (60 drops/mL)

Fluid calculation with drop sets:
    You want to administer fluids to a 15lb. patient at 30mL per hour. You have a 15 drop/mL set.
How many drops/minute will you administer?
    Solution: 30 ml/hr x 15 drops/mL = 450 drops/hr. 450 / 60 = 7.5 drops per minute. Practically:
You would try to administer 4 drops every 30 seconds.

1- Buretrol’s:
   - Buretrol’s allow for administration of a set amount of fluid (less than 1 liter) and also to add electrolytes or medications to this smaller amount of fluid.
   - Allow for titration of various medications like dopamine or potassium without ruining a whole bag of fluids
   - Are somewhat $$ so may need to add an additional charge.

**Administration of Fluids**

**SQ Route**
Administration of fluids into the subcutaneous space is appropriate for patients who are dehydrated but NOT hypovolemic. Administering SQ fluids in a shock state will result in no increase intravascular volume because the small vessels in the interstitium are vasoconstricted. Dose of SQ fluids is typically

**Intravascular Route**
This is considered the idea route of fluid administration in a severely hypovolemic and dehydrated patient. The goal of fluids are to reduce blood viscosity and enhance fluid dynamics to carry oxygen to tissues and organs. All other methods require some time before this occurs- as they either must travel from the interstitium to the vasculature (SQ) or from the marrow, through the bone capillaries and into systemic circulation (IO route). However, IV catheterization may not ALWAYS be possible. Although in the majority of patients it is.

**Intraperitoneal?** See SQ fluids above- Fluid will not be absorbed into the systemic circulation.

**Bolusing Tips**
Remember: A bolus means fluid that will be administered in 5-15 minutes or less. So a 1L bolus should be achieved as fast as possible. Prescribing a 1L bolus on an IV pump set at 999ml/hr means it is being infused over 30 minutes! Boluses should be delivered either via hand squeezing the fluids, large catheters capable of high flow rates, or pressure bags designed to infuse fluids rapidly. Alternatively, IV pumps can be used if the volume is 250mL or less. And the pump should be set to it’s highest setting. A word of caution: The “volume to be infused” on the pump SHOULD be set to the bolus volume- to avoid iatrogenic over-administration.

**Monitoring a patient receiving fluids**
Patients receiving IV fluids depend on two things:
1- A technician who knows possible complications and how to intervene
2- Proper monitoring during administration
   Patients on IV fluids should have several variables checked on a regular basis (every 4-6 hours)
      1- Respiratory rate. Ideally this is done every hour
      2- Hydration status: MM/CRT, Skin tent, lung auscultation

**Complications:**
1- Catheter- associated
   a. Catheter-associated complications include phlebitis (sterile) and catheter associated blood stream or catheter site infections.
   b. Proper monitoring of invasive devices is essential to prevent or catch these
   c. IV Catheters should be examined q24 hours for signs of inflammation
   d. Central lines should have their bandages removed and the site checked q24 hours
   e. Catheters showing signs of inflammation: swelling, redness, pain, should be
2. Fluid intolerance/overload
   a. In cases of over-administration or intolerance of fluids typical signs include:
      i. Chemosis - swelling of conjunctiva
      ii. Harsh lung sounds
      iii. “Gooey” skin texture
      iv. Tachypnea
      v. Nasal discharge
      vi. Coughing
   b. Typical interventions (prescribed by the DVM) include:
      i. Stopping IV fluids
      ii. Oxygen
      iii. Radiographs
      iv. Diuretics
      v. Often stopping fluids, and potentially administration of a diuretic (Furosemide) will halt any further compromise.

**Tech tip:** Remember when infusing colloids and crystalloids:
   1. Reduce the rate of crystalloids by about 1/3. The colloids add a volume expanding effect and do some work for the crystalloids.
   2. Once you start colloids - Urine specific gravity cannot be used for any information. Colloid molecules can leak through the kidneys and artificially raise and alter the USG.