

Fluid and Electrolyte Therapy

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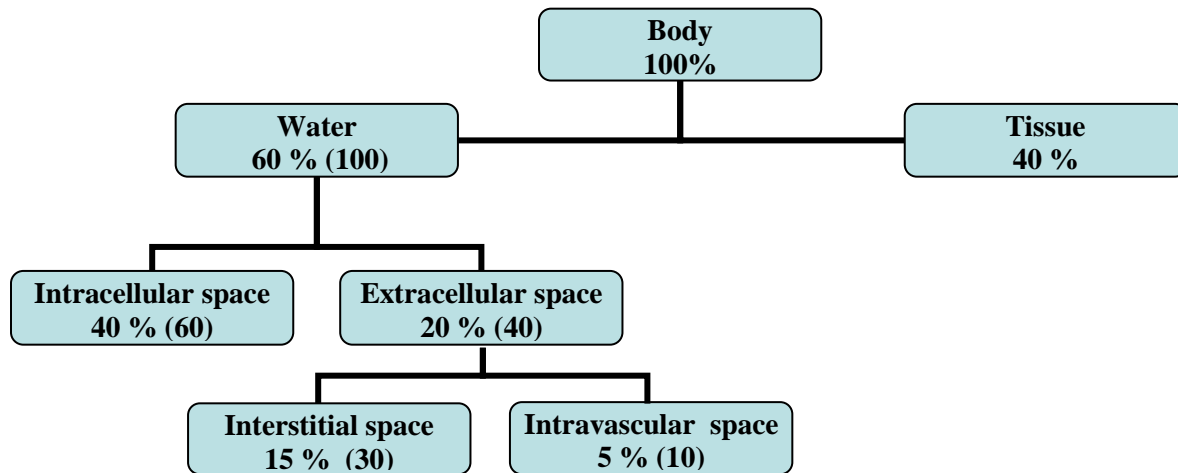
Purposes of fluid administration during the perianesthetic period

- Replace *insensible fluid losses* (evaporation, diffusion) during the anesthetic period
- Replace *sensible fluid losses* (blood loss, sweating) during the anesthetic period
- Maintain an *adequate and effective* blood volume
- **Maintain cardiac output and tissue perfusion**
- Maintain patency of an intravenous route of drug administration

Review normal body water distribution

- 1 gm = 1 ml; 1 kg = 1 liter; 1 kg = 2.2 lbs
- Total body water: 60% of body weight
- Intracellular water: 40% of body weight
- Extracellular water (plasma water + interstitial water): 20% of body weight
- Interstitial water: 20 % of body weight
- Plasma water: 5 % of body weight
- Blood volume: 9 % of body weight (blood volume = plasma water + red blood cell volume)
- Inter-compartmental distribution of water is maintained by hydrostatic, oncotic, and osmotic forces
- Daily water requirement: 1-3 ml/kg/hr (24-72 ml/kg/day)
 - 50 ml x body weight (kg) provides rough estimate for daily requirement
- Requirements vary with age, environment, disease, etc...

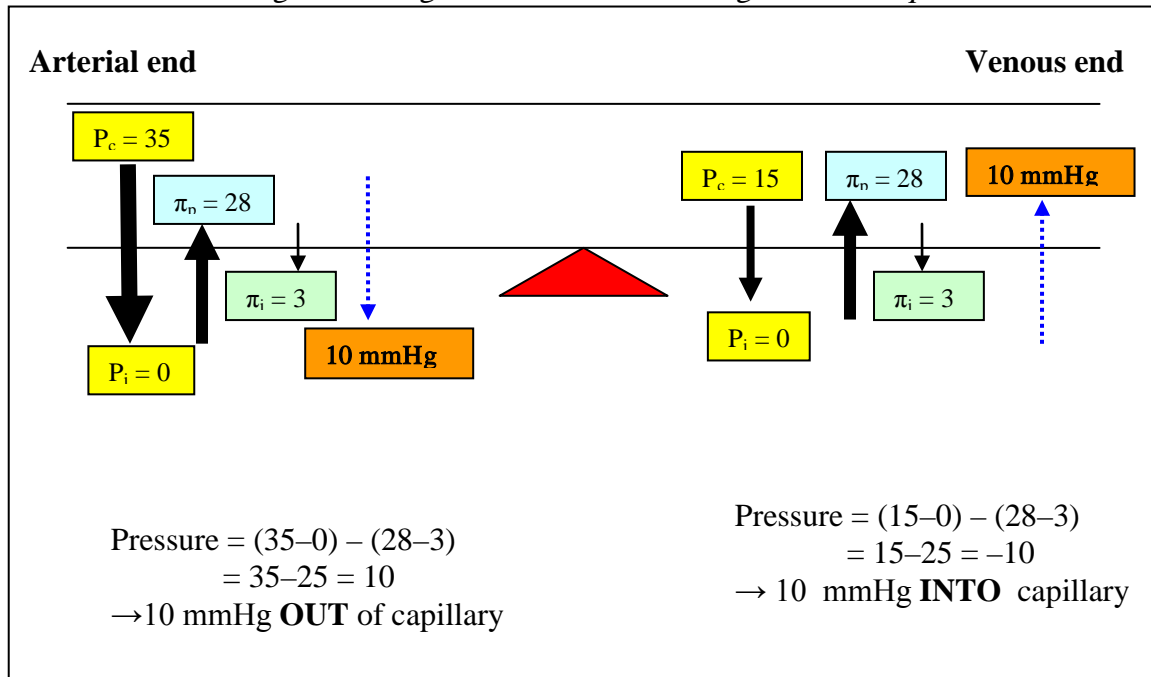
Figure 1. Normal body water distribution



Fluid movement across capillary membranes

- Filtration is governed by Starling's equation as below
- Net driving pressure into the capillary = $[(P_c - P_i) - (\pi_p - \pi_i)]$
 - P_c = capillary hydrostatic pressure (varies from artery to vein)
 - P_i = interstitial hydrostatic pressure (0)
 - π_p = plasma oncotic pressure (28 mmHg)
 - π_i = interstitial oncotic pressure (3 mmHg)
- If colloid osmotic pressure (COP) in the capillaries decreases lower than the COP in the interstitium, fluid will move out of the vessels and edema will develop.
- Plasma colloid osmotic pressure
 - Plasma proteins are primary determinant for the plasma colloid osmotic (oncotic) pressure
 - One gram of albumin exerts twice the colloid osmotic pressure of a gram of globulin
 - Because there is about twice as much albumin as globulin in the plasma, about 70 % of the total colloid osmotic pressure results from albumin.

Figure 2. Diagram to show the Starling forces in capillaries



- What happens if animal loses 500 ml of blood?
 - The capillary hydrostatic pressure (P_c) drops especially at the venous end. The net pressure into capillary increases and the balance is no longer maintained so fluid is retrieved into the circulation from the interstitium until P_c is restored.
 - However, this assumes there are enough interstitial (or intracellular) fluids available to shift into the circulatory space without compromising the patient, but when the cell is dehydrated already, only exogenous fluid administration can provide effective circulatory volume replacement in response to the blood volume loss.

Review of normal electrolyte distribution

Sodium

- The major component of ECF
- Osmotic concentration is regulated by maintaining sodium balance and provides osmotic forces to maintain water balance in interstitial fluid compartment
- Generally, water and sodium disturbances occur simultaneously
- Sodium levels indicate overall fluid balance
- Sodium levels are regulated by the kidney, through aldosterone and other related factors

Potassium

- The major component of ICF
- 98% of total body potassium is located intracellularly
- Provides osmotic forces to maintain water balance in intracellular fluid compartment

- Plasma potassium levels may not reflect total body potassium levels! Because it is indirect measure of intracellular K^+
- Potassium imbalances result in altered function of excitable membranes (e.g., heart, CNS)
- Normal renal function is required to prevent hyperkalemia
- Hypokalemia should be treated slowly: *do not exceed 0.5- 1 mEq K^+ /kg/hr, also maximum concentration 40 mEq/L.*

Calcium:

- Vital ion in normal neuromuscular activity, cardiac rhythm and contractility, cell membrane function, and coagulation
- Highly protein bound: total plasma calcium levels vary with plasma albumin levels, however ionized calcium levels may remain constant

Chloride

- The major component of ECF
- Renal regulation of electroneutrality usually results in an inverse relationship between Cl^- and HCO_3^-
- Tends to follow Na^+ , so chloride deranges, in general, do not need to be directly corrected

Bicarbonate

- Part of the major buffer system in the body
- Discussed previously (see Acid Base Physiology and Anesthesia)

Other Anions

- Plasma proteins, organic acids, sulphates
- Not routinely measured
- Constitute the “anion gap”

Changes in fluid and electrolyte balance in response to disease processes

- May vary widely
- Hypovolemia is common!
- Electrolyte changes are variable
- *Goal is to correct fluid and electrolyte imbalances before anesthesia, if possible*

Changes in fluid and electrolyte balance in response to anesthesia

- Many anesthetic agents produce *vasodilation and hypotension relative hypovolemia!*
- Results in alterations in sympathetic nervous system activity and the endocrine system
- Redistribution of blood flow with changes in vascular resistance
- Reduction in urinary flow rate, renal blood flow, and glomerular filtration rate seen with withholding water (fasting), anesthetic drug effects, and increased ADH levels
- *These effects can be eliminated or reduced by “filling the tank” with crystalloids*

General principles of fluid administration

Maintenance vs. replacement therapy

- Maintenance fluid therapy (plasmalyte 56, 0.45 NaCL with dextrose etc) is designed to meet the patient’s ongoing sensible and insensible fluid losses with normal fluid volume over 1 – 2 days; in the normal animal this is primarily water loss, with a lesser degree of electrolyte loss.
- Replacement fluid therapy (LRS, Plasmalyte A, Normosol, 0.9 NaCL, etc) is designed to replace existing fluid deficits; this usually requires replacement of both water and electrolytes
- The optimal fluid type for each of the above settings depends upon serum electrolytes, acid-base status, and concurrent administration of drugs and blood products.

Precautions for rapid fluid administration

- In dogs, maximum fluid administration rate is 90 ml/kg/hr (1 blood volume/hour)
- In cats, maximum fluid administration rate is 60 ml/kg/hr (1 blood volume/hour)
- Monitor cardiopulmonary status carefully.
- Monitor packed cell volume and total plasma protein levels: maintain PCV > 20% and TPP > 4 g/dl

Normal fluid administration rates during anesthesia

- Dogs, cats: 10 - 20 ml/kg/hr
- Horses, cattle: 5 - 10 ml/kg/hr

Table 1. Physiologic parameters useful for fluid therapy planning

Parameters	Less fluid required	Ideal	More fluid required
Central venous pressure	> 8 to 12 cm H ₂ O	3 to 8 cm H ₂ O	Negative to 5 cm H ₂ O
Pulmonary capillary wedge pressure	> 18 mmHg	5 – 18 mmHg	< 5 to 8 mmHg
Heart rate		< 120 / min	> 140 / min
Cardiac gallop	Gallop present		
Urine output	> 2 ml/kg/hr	1 – 2 ml/kg/hr	< 0.5 ml/kg/hr
BUN / Creatinine		Normal	Rising/ above normal
Urine SG			> 1.020 – 1.030
Thoracic radiograph	Edema, big heart, vessels, cava, or liver	Normal	Small heart, small vessels, collapsed cava
Echocardiography	Big LA, reduced LV function	Normal heart size and indexes	Small LA and/or LV size with enlarged LV walls
Plasma lactate (mmol/L)		< 2	> 2.5
PCV	20	35 - 45	> 45 (rising trends)
TP	< 3.0 g/dl	5 - 8	> 8 (rising trends)
Respiratory rate/effort	Rising trends	< 35 / min with minimal effort	
Peripheral edema	Colloid if albumin < 2.2 g/dl	CHF or vasculitis if albumin > 2	
Albumin	Colloid if < 1.5 – 1.8		> 3.5

Types of fluids available and general indications for their use

Crystalloid: a solution of crystalline solid dissolved in water

Colloids: a suspension of particles in a liquid ie, does not cross a semipermeable membrane, so exerts a colloid osmotic (oncotic) pressure

Crystalloids: Replacement fluids

- Generally are *polyionic isotonic fluids*
- Ringer's, Lactated Ringer's (LRS), PlasmaLyte 148, PlasmaLyte A are all polyionic isotonic crystalloid fluids that *closely mimic plasma electrolyte concentrations* (with or without bicarbonate precursors)
- 0.9% NaCl (normal saline) is an isotonic solution of Na, Cl, and water
- 5% dextrose is an isotonic solution of dextrose in water; the dextrose is rapidly metabolized, thus this essentially *results in the administration of free water*

- Commonly administered during general anesthesia to diminish the cardiovascular effects of anesthetic drugs and replace ongoing fluid losses
- Usually administered at 10-20 ml/kg/hr in small animal
- Usually administered at 5-10 ml/kg/hr in large animals
- May need to infuse 40 – 90 ml/kg/hr during shock using multiple catheters or fluid pumps
- *Replace acute blood loss by administering 3 volumes of crystalloid solution for each 1 volume of blood lost*

Crystalloids: Maintenance fluids

- Are hypotonic crystalloids that are low in sodium, chloride, and osmolality, but high in potassium compared to normal plasma compositions.
- May or may not contain dextrose
- Generally polyionic isotonic or hypotonic fluids
- Used for *long term fluid therapy*, such as the ICU setting; not generally used during anesthesia
- e.g., 0.45 % sodium chloride, 2.5 % dextrose with 0.45 % saline, 2.5 % dextrose with half strength LRS, Normosol M, Normosol M in 5 % dextrose, PlasmaLyte 56 in 5% dextrose, and Plasmalyte 56 (see Table 2).

Hypertonic fluids

- Hypertonic crystalloid saline (7.5% NaCl) has been indicated in some shock states to maintain cardiovascular function; pulls fluid into intravascular space by osmosis by creating transient hypernatremia. Dose is 4 ml/kg. Must follow with isotonic, polyionic fluids
- Generally used to treat particular deficits (e.g., 10% dextrose given to a hypoglycemic neonatal foal) or to treat edema (e.g., mannitol; colloid)
- Usually must be given cautiously

Table 2. Composition of Several Crystalloid Fluids

Solution	Type*	Na	Cl	K	Ca	Mg	Lact	Acet	Gluc	% Dex	pH	Osm
Plasma	-	144	107	5	5	1.5	-	-	-	-	7.5	290
2.5% Dextrose, 0.45% NaCl	M	77	77	-	-	-	-	-	-	2.5	4.0	280
2.5% Dextrose, 1/2 strength LRS	M	65.5	55	2	1.5	-	14	-	-	2.5	5.0	263
5% Dextrose	-	-	-	-	-	-	-	-	-	5	4.0	252
10% Dextrose	-	-	-	-	-	-	-	-	-	10	4.0	505
0.9% NaCl	R	154	154	-	-	-	-	-	-	-	5.0	308
Ringer's Soln	R	148	156	4	4.5	-	-	-	-	-	6.0	309
LRS	R	130	109	4	3	-	28	-	-	-	6.5	273
PlasmaLyte A	R	140	98	5	-	3	-	27	23	-	7.4	294
PlasmaLyte 148	R	140	98	5	-	3	-	27	23	-	5.5	294
PlasmaLyte 56 + 5% Dextrose	M	40	40	16	-	3	-	16	-	5	5.0	362
PlasmaLyte 56	M	40	40	13	-	3	-	16	-	-	5.5	110
7.5 % Hypertonic NaCl	R	1283	1283								5.0-5.7	2567

- Ions are presented as mEq/l
- *M = Maintenance; R = Replacement

Colloids

- Synthetic colloids are polydisperse (various molecular weight) and do not readily cross semipermeable membrane.
- Hypertonicity pulls fluids into the vascular space and increase blood volume which effect is longer lasting compared to crystalloid therapy.
- Solutions of starch or dextrans (of various molecular weights)
- Smaller volumes of colloids are as effective as larger volumes of crystalloids in maintaining intravascular fluid volume
- Historically have had a number of problems associated with their use, including allergic reactions, impaired coagulation, and renal damage; solutions available now have less problems associated with their use
- Expensive compared to crystalloids

Table 3. Composition of Several Colloidal Fluids

Solution	Na	Cl	K	Ca	Collid	COP (mmHg)	pH	Osm
Plasma	144	107	5	5		-	7.5	290
Hetastarch 6 % in 0.9 % NaCl (HEspan)	154	154			Hydroxyethylated amylopectic 60 g/L MW 450 KD	31	5.5	310
Dextran 40 in 0.9 % NaCl	154	154			Dextran 100 g/L MW 40 KD	>100	3.5- 7.0	310
Dextran 70 in 0.9 % NaCl	154	154			Dextran 60 g/L MW 70 KD	>100	5.0	309
6 % Albumin in 0.9 % NaCl	154	154			MW 69 KD	30	5.5	310
7.5 % NaCl-6% dextran 70	1283	1283				75	4-5	2567

Table 4. Fluid type and volume ratio for plasma volume restoration

Fluid Type	Examples	Volume needed to increase plasma volume by 1 liter	Distribution	Examples of clinical indication
Colloid	Starch Gelatin Dextrans	1 liter	Plasma volume	Hypovolemia, hypotension, normovolemic hemodilution, hypoalbuminemia
Hypertonic crystalloid	7.5 % saline	300 ml	Immediate plasma volume expansion causing ICFV reduction	Hypovolemic shock, cerebral edema
Hypotonic crystalloid	5 % dextrose	14 liters	Total body weight	Free water deficit, hypernatremia
Isotonic crystalloid	0.9 % NaCl, LRS	3 liters	ECFV (plasma volume and ISFV expansion)	Dehydration, hypovolemia, hypotension, normovolemic hemodilution

Blood and blood components

Whole blood

- Contains it all: colloids (plasma proteins), clotting factors including platelets, red blood cells for oxygen carrying capacity
- Relatively easy to collect and store
- *Indications*: acute blood loss, concurrent anemia and hypoproteinemia, clotting defects
- Stored blood is not quite as useful as fresh blood: reduced oxygen carrying capacity (review 2,3-DPG), platelets are inactive, clotting factors may be degraded
- A blood filter must be always used to sieve microthrombi from the blood product.
- 5 – 15 ml/kg/hr rate is used to treat acute hypovolemia, and 40-60 ml/kg/hr can be used in life-threatening emergency.
- In massive transfusion, defined as blood volume replacement greater than 1.5 times the recipient volume, abnormal bleeding may occur.
- This homeostatic defects is characterized by oozing from the operative wound, mucous membranes, and intravenous puncture sites.
- Blood types and crossmatching
 - Crossmatching between donor and recipient will minimize a fatal outcome.
 - There are about 12 types in dogs but DEA 1.1, 1.2, 1.7 are most antigenic.
 - Cats have AB blood group system; the most common being type A.
 - Always administer slowly in the beginning so as to allow adequate time to detect any adverse reactions, such as rashes, edema, vomiting, fever, DIC, dyspnea, hypotension, unconsciousness and tachycardia

Packed red blood cells

- Red cell fraction of separating plasma from whole blood
- Usually has a PCV of 70%
- Useful in treating *anemia*
- Reduces risk of fluid overload
- Reconstitute with equal volumes of 0.9% saline

Plasma

- Two types: fresh or frozen
- *Fresh plasma* contains colloids, active platelets, and clotting factors
 - Useful in treating coagulation defects
- *Frozen plasma* can be stored for periods up to a year; serve as a source of colloids (plasma proteins); often collected from stored whole blood when the red cell fraction is no longer viable
 - Useful in treating hypoproteinemia and maintaining normal colloidal osmotic pressure

Principles of blood and plasma transfusions

- Consider transfusion if PCV < 20% and/or TPP < 4 gm/dl
- Transfuse appropriate blood components
- Administration rate: < 10 ml/kg/hr (unless in crisis)

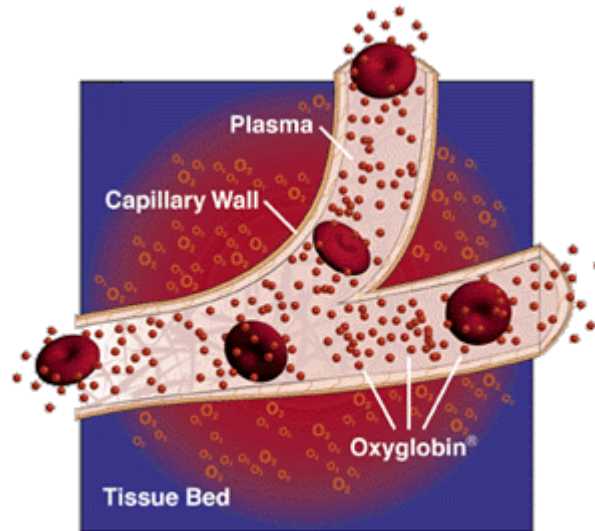
Complications of blood and plasma transfusions:

- Immune response to red cell antigens
- Immune response to white cell antigens
- In vitro (storage) changes
- Coagulation defects
- Citrate intoxication
- Hyperkalemia
- Hypothermia
- Sepsis

Blood substitutes - Oxyglobin®



- Purified bovine hemoglobin in lactated ringer's solution
- Doesn't contain red blood cells - instead contains crosslinked hemoglobin molecules
- Plasma half life is 30-40 hours
- Approved for use in dogs, but may also be used in other species
- Provides oxygen carrying capacity and oncotic pressure (consists of large protein molecules) - improves oxygenation and provides volume expansion



- Hemoglobin molecules disperse throughout the plasma and provide oxygen to the tissues, and oxyglobin molecules disperse throughout the small vessels more readily due to smaller size, and therefore provides better oxygenation at the microcirculatory ends (see figure above).
- Has several advantages over whole blood or packed red cells
 - Don't need to maintain donors
 - Long shelf life - 2 years
 - Doesn't require refrigeration
 - Doesn't require blood typing or cross matching
 - No risk of bacterial or viral contamination
 - Few reported adverse effects
 - Immediate availability a major advantage over blood products in crisis situations
- However, doesn't provide other components of whole blood that may be desired in some conditions – e.g. clotting factors
- Analogous product, **Hemopure®**, is undergoing FDA trials for use in human medicine