

Intravenous Fluids: Composition & Uses

Srinidhi Jayaram, PGY1

Body Fluid Compartments

- Total Body Water (TBW): 50-70% of total body wt.
- Avg. is greater for males.
- Decreases with age. Highest in newborn, 75-80%. By first year of life TBW \sim 65%.
- Most in muscle, less in fat.
- $TBW = ECF + ICF$
- $ICF \sim 2/3$ & $ECF \sim 1/3$
- $ECF = \text{Intravascular } (1/3) + \text{Interstitial } (2/3)$

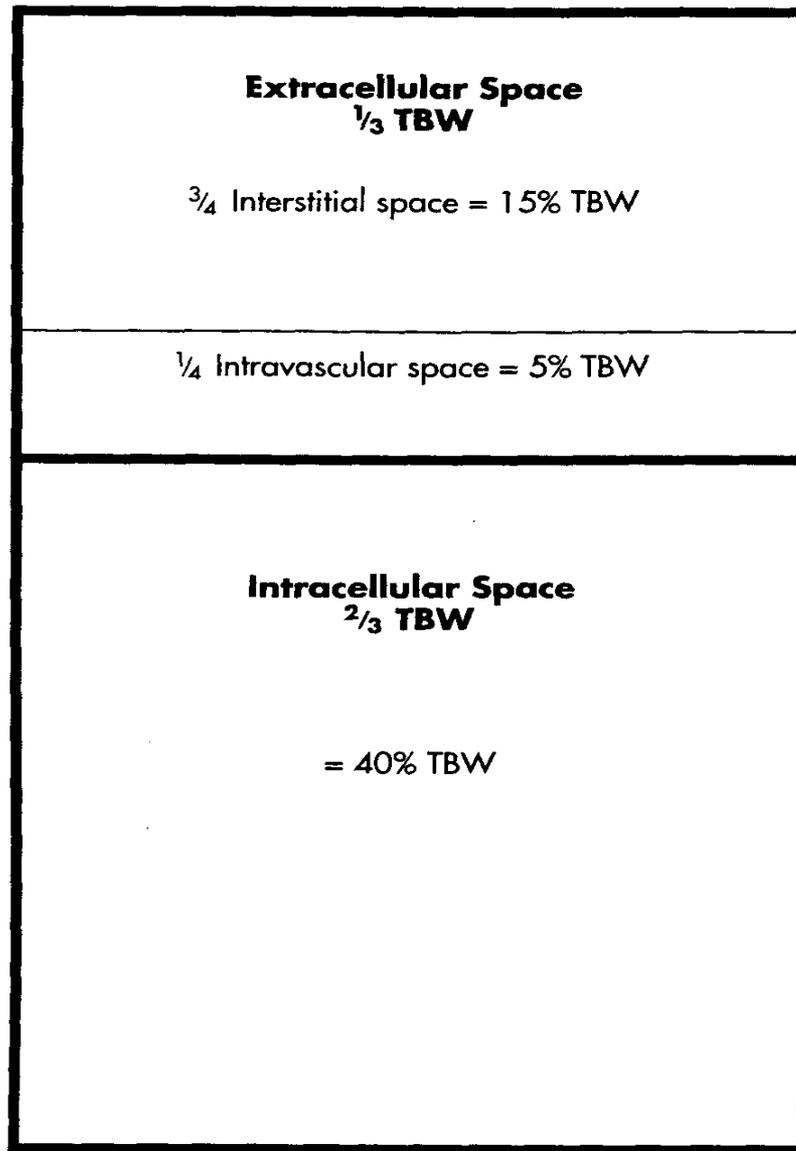


Figure 1
Distribution of body fluids. Total body water (TBW) = 50% to 70% of total body weight.

Electrolyte Physiology

- Primary intravascular/ECF cation is Na^+ . Very small contribution of K^+ , Ca^{2+} , and Mg^{2+} .
- Primary intravascular/ECF anion is Cl^- . Smaller contribution from HCO_3^- , SO_4^{2-} & PO_4^{3-} , organic acids, and protein.
- Primary ICF cation is K^+ . Smaller contribution from Mg^{2+} & Na^+ .
- Number of intravasc anions not routinely detected.

	ICF (mEq/L)	ECF (mEq/L)
Cations	K^+ (150-154) Na^+ (6-10) Mg^{+2} (40)	Na^+ (142) Ca^{+2} (5) K^+ (4-5) Mg^{+2} (3)
Anions	Organic PO_4^{-3} (100-106) protein (40-60) SO_4^{-2} (17) HCO_3^- (10-13) organic acids (4)	Cl^- (103-105) HCO_3^- (24-27) protein (15) PO_4^{-3} (3-5), SO_4^{-2} (4) Organic acids (2-5)

Basic Fluid and Electrolyte Losses

Table 2-1
Water Exchange (60- to 80-kg Man)

<i>Routes</i>	<i>Average Daily Volume (mL)</i>	<i>Minimal, (mL)</i>	<i>Maximal, (mL)</i>
H₂O gain:			
Sensible:			
Oral fluids	800–1500	0	1500/h
Solid foods	500–700	0	1500
Insensible:			
Water of oxidation	250	125	800
Water of solution	0	0	500
H₂O loss:			
Sensible:			
Urine	800–1500	300	1400/h
Intestinal	0–250	0	2500/h
Sweat	0	0	4000/h
Insensible:			
Lungs and skin	600	600	1500

Table 3 Composition of GI losses

SOURCE	DAILY LOSS (ML)	[Na ⁺]	[K ⁺]	[Cl ⁻]	[HCO ₃ ⁻]
Saliva	1,000	30-80	20	70	30
Gastric	1,000-2,000	60-80	15	100	0
Pancreas	1,000	140	5-10	60-90	40-100
Bile	1,000	140	5-10	100	40
Small Bowel	2,000-5,000	140	20	100	25-50
Large Bowel	200-1,500	75	30	30	0
Sweat	200-1,000	20-70	5-10	40-60	0

- Avg water loss in stool 150-400 ml.
- Avg loss in urine 800-1500 ml
- Avg insensible loss 8-12 ml/kg (60-75% resp + 25-40% skin)
- A pt deprived of all external access to water must still excrete a minimum of 500-800 ml urine/day in order to excrete products of catabolism in addition to mandatory insensible loss.
- These losses are increased in states of stress/dz
- Insensible losses increase with hypermetabolism, hyperventilation, and fever.

Basic Fluid and Electrolyte Requirements

Table 2 Daily Electrolyte Requirements

	DAILY REQUIREMENT	FOR 70-KG ADULT	FOR 10-KG CHILD
Sodium	1-2 meq/kg	70-140 meq/day	10-20 meq/day
Potassium	0.5-1.0 meq/kg	35-70 meq/day	5-10 meq/day
Calcium	0.2-0.3 meq/kg	1.4-2.1 meq/day	2.0-3.0 meq/day
Magnesium	0.35-0.45 meq/kg	24.5-31.5 meq/day	3.5-4.5 meq/day
Chloride	equal to sodium	equal to sodium	equal to sodium
Bicarbonate/Acetate	use with chloride to balance cations and help pH	use with chloride to balance cations and help pH	use with chloride to balance cations and help pH

- Daily fluid requirements of healthy children and adults can be estimated (100-50-20/4-2-1 or 35ml/kg/d for adults).
- This will vary depending on pt's renal and cardiac function.
- These requirements will increase in states of dz/stress as fluid losses increase.
- Requirements vary around what is necessary to maintain homeostasis and euvolemia.

IV Fluid/Electrolyte Therapy

- Three key concepts in consideration of fluid and electrolyte management:

cell membrane permeability

osmolarity

electroneutrality

- Cell membrane permeability refers to the ability of a cell membrane to allow certain substances such as water and urea to pass freely, while charged ions such as sodium cannot cross the membrane and are trapped on one side of it.

- Osmolarity is a property of particles in solution. If a substance can dissociate in solution, it may contribute more than one equivalent to the osmolarity of the solution. For instance, NaCl will dissociate into two osmotically active ions: Na and Cl. One millimolar NaCl yields a 2 milliosmolar solution.
- Electroneutrality means that the overall number of positive and negative charges balances. For instance, in conditions like renal tubular acidosis where HCO_3^- is lost, chloride is retained leading to a hyperchloremic state.

- Expected osmolarity of plasma can be calculated according to the following formula:

$$\text{Osmolarity (mOsm/kg)} = 2 \times [\text{mEq/L Na}^+] + \text{glucose} + \text{BUN}$$

- Concentration of sodium is the major determinant.
- Normal serum osmolarity ranges from about 280 to 295 mOsm/kg.
- Maintenance fluids must be determined for basic requirements, then existing volume or electrolyte deficits must be evaluated to determine the appropriate IV fluid to use and the volume to administer.

Types of IV Fluid

- **Crystalloid:** Balanced salt/electrolyte solution; forms a true solution and is capable of passing through semipermeable membranes. May be isotonic, hypertonic, or hypotonic.

Normal Saline (0.9% NaCl), Lactated Ringer's, Hypertonic saline (3, 5, & 7.5%), Ringer's solution.

However, hypertonic solutions are considered plasma expanders as they act to increase the circulatory volume via movement of intracellular and interstitial water into the intravascular space.

- **Colloid:** High-molecular-weight solutions, draw fluid into intravascular compartment via oncotic pressure (pressure exerted by plasma proteins not capable of passing through membranes on capillary walls). Plasma expanders, as they are composed of macromolecules, and are retained in the intravascular space.

Albumin, Hetastarch, Pentastarch (Pentaspán[®]), Plasma, Dextran.

- **Free H₂O solutions:** provide water that is not bound by macromolecules or organelles, free to pass through.

D5W (5% dextrose in water), D10W, D20W, D50W, and Dextrose/crystalloid mixes.

- **Blood products:** whole blood, packed RBCs, FFP, cryoprecipitate, platelets, albumin. Essentially all colloids.

Composition of common IV Fluids

Table 4 Commonly Used Intravenous Fluids

SOLUTION	pH	[Na ⁺]	[Cl ⁻]	[K ⁺]	[Ca ⁺²]	OTHER COMPONENTS	COMMENTS
Lactated Ringer's (LR)		130	109	4	3	Lactate 28 meq/L	Fluid choice for initial resuscitation
Normal saline (NS)		154	154	0	0		Alternative to LR; watch for hyperchloremic acidosis
D5LR	5	130	109	4	3	Dextrose 50 g, Lactate 28 meq/L	Initial postoperative maintenance; caution bolusing with dextrose
D5NS	4	154	154	0	0	Dextrose 50 g	Alternative to D5LR
D5.45NS	4	77	77	0	0	Dextrose 50 g	Hypotonic maintenance
D5.25NS	4	34	34	0	0	Dextrose 50 g	Hypotonic maintenance
7.5% NS	4	1,283	1,283	0	0	0	Hypertonic; further study
D5W	4.5	0	0	0	0	Dextrose 50 g	Free water; no role in resuscitation
6% hetastarch	3.5-7.0	154	154	0	0	30 g hydroxyethyl starch	Coagulation abnormalities
5% plasma protein (250 ml)	7.4	145	0	< 2	0	12.5 g protein	Colloid; expensive

TABLE 61-5 -- Fluids Used for Resuscitation

	NaCl (0.9%)	RINGER'S LACTATE	NaCl (3%)	ALBUMIN (5%)	HETASTARCH (6%)	DEXTRAN 70 + NaCl
Na(mEq/L)	154	130	513	130–160	154	154
Cl (mEq/L)	154	109	513	130–160	154	154
K(mEq/L)	0	4	0	0	0	0
Osmolarity (mOsm/L)	308	275	1025	310	310	310
Oncotic P (mm Hg)	0	0	0	20	30	60
Lactate (mEq/L)	0	28	0	0	0	0
Maximum Dose (mL/kg/24 hr)	None	None	Limited by serum Na ⁺	None	20	20
Cost (L)	\$1.26	\$1.44	\$1.28	\$100	\$27.30	\$35.08

- IVF can supply 3 things: fluid, electrolytes, & calories. In the nonstressed, fasting state, the 150g per day in D5W at 125ml/h can provide enough carbohydrate to limit proteolysis.

- The most common uses for IVF:

 - Acutely expand intravascular volume in hypovolemic states*

 - Correct electrolyte imbalances*

 - Maintain basal hydration*

Commonly used IV Fluids

- **Normal Saline (0.9% NaCl):** Isotonic salt water. 154 mEq/L Na⁺; 154 mEq/L Cl⁻; 308mOsm/L. Cheapest and most commonly used resuscitative crystalloid. High [Cl⁻] above the normal serum 103 mEq/L imposes on the kidneys an appreciable load of excess Cl⁻ that cannot be rapidly excreted. A dilutional acidosis may develop by reducing base bicarb relative to carbonic acid. Thus exist the risk of hyperchloremic acidosis. Only solution that may be administered with blood products. Does not provide free water or calories. Restores NaCl deficits.

- **Lactated Ringer's (RL):** Isotonic, 273 mOsm/L. Contains 130 mEq/L Na⁺, 109 mEq/L Cl⁻, 28 mEq/L lactate, and 4 mEq/L K⁺. Lactate is used instead of bicarb because it's more stable in IVF during storage. Lactate is converted readily to bicarb by the liver. Has minimal effects on normal body fluid composition and pH. More closely resembles the electrolyte composition of normal blood serum. Does not provide calories.

- **D5W/1/4NS:** Hypertonic, 406 mOsm/L. Provides 170 calories/L from 5% dextrose. Provides free water for insensible losses and some Na⁺ to promote renal function and excretion. With added K⁺ this is an excellent maintenance fluid in postop period. Prevents excess catabolism and limits proteolysis.
- **Hypertonic Saline (3% NaCl):** 1026 mOsm/L & 513 mEq/L Na⁺. Increases plasma osmolality and thereby acts as a plasma expander, increasing circulatory volume via movement of intracellular and interstitial water into the intravascular space. Risk of hypernatremia thus careful neuro-monitoring and VS.

Determining Fluid Deficit

Table 2-4
Extracellular Fluid Volume

<i>Type of Sign</i>	<i>Deficit</i>		<i>Excess</i>	
	<i>Moderate</i>	<i>Severe</i>	<i>Moderate</i>	<i>Severe</i>
Central nervous system	Sleepiness Apathy Slow responses Anorexia Cessation of usual activity	Decreased tension reflexes Anesthesia distal extremities Stupor Coma	None	None
Gastrointestinal	Progressive decrease in food consumption	Nausea, vomiting Refusal to eat Silent ileus and distention	At operation: Edema of stomach, colon, lesser and greater omenta, and small bowel mesentery	
Cardiovascular	Orthostatic hypotension Tachycardia Collapsed veins Collapsing pulse	Cutaneous lividity Hypotension Distant heart sounds Cold extremities Absent peripheral pulses	Elevated venous pressure Distention of peripheral veins Increased cardiac output Loud heart sounds Functional murmurs Bounding pulse High pulse pressure Increased pulmonary 2d sound Gallop	Pulmonary edema
Tissue	Soft, small tongue with longitudinal wrinkling Decreased skin turgor	Atonic muscles Sunken eyes	Subcutaneous pitting edema Basilar rales	Anasarca Moist rales Vomiting Diarrhea
Metabolic	Mild decrease temperature, 97-99° Rectal	Marked decrease temperature, 95-98° Rectal	None	None

Clinical Assessment of Severity of Dehydration

Percent Dehydration	Infant	Child	Clinical Signs and Symptoms
Mild	5%	3-4%	Increased thirst, tears present, mucous membranes moist, ext. jugular visible when supine, capillary refill > 2 seconds centrally, urine specific gravity > 1.020
Moderate	10%	6-8%	Tacky to dry mucous membranes, decreased tears, pulse rate may be elevated somewhat, fontanelle may be sunken, oliguria, capillary refill time between 2 and 4 seconds, decreased skin turgor
Severe	15%	10%	Tears absent, mucous membranes dry, eyes sunken, tachycardia, slow capillary refill, poor skin turgor, cool extremities, orthostatic to shocky, apathy, somnolence
Shock	>15%	>10%	Physiologic decompensation: insufficient perfusion to meet end-organ demand, poor oxygen delivery, decreased blood pressure.

- Volume deficits are best estimated by acute changes in weight. Less than 5% loss is very difficult to detect clinically and loss of 15+% will be associated with severe circulatory compromise.
- Mild deficit represents a loss of $\sim 4\%$ body wt.
- Moderate deficit --- a loss of $\sim 6-8\%$ body wt.
- Severe deficit --- a loss of $\sim >10\%$ body wt.
- Volume deficit may be a pure water deficit or combined water and electrolyte deficit.

- Pure water deficit is reflected biochemically by hypernatremia, increase in plasma osmolality, concentrated urine, and low urine $[Na^+]$ ($<15mEq/L$).
- Treatment involves replacement of enough water to restore plasma $[Na^+]$ to normal.
- The excess Na^+ for which water must be provided can be estimated from the following equation:

$$\Delta Na = (140 - \text{plasma Na}) \times TBW$$

(Recall --- $TBW = ECF + ICF = 50-70\%$ body wt.)

- ΔNa represents the total $mEq Na^+$ in excess of water. Divide ΔNa^+ by 140 to obtain the amount of water required to return serum Na^+ to $140mEq/L$.

- This fluid deficit must be corrected in addition to giving maintenance fluids for ongoing obligatory losses.
- Combined water and electrolyte deficit is commonly associated with GIT losses, diuretic therapy, adrenal insufficiency, excessive diaphoresis, burns, stomas, and 3rd spacing following trauma or surgery.
- Urine Na⁺ is often < 10mEq/L as a result of sodium conservation from aldosterone on renal tubules.
- Decreased blood vol diminishes renal perfusion and often produces prerenal azotemia: increased BUN & Cr with BUN increased greater relative to Cr.

- Normal BUN/Cr ratio is $\sim 10:1$. With prerenal azotemia it may increase to 20-25:1.
- These combined water and electrolyte deficits are corrected by choosing the appropriate IVF for the pt's electrolyte imbalance and the magnitude of the deficit may be estimated as in the previous tables, clinically.
- The composition of the correction fluid should take into account the plasma $[\text{Na}^+]$. If it is normal, fluid and lyte losses are probably isotonic, and the replacement fluid should be isotonic NS or its equivalent.

- Thus replacement therapy should be planned in 2 steps:
 1. Na^+ deficit should be calculated
 2. Volume deficit should be estimated from clinical S/S and change in body wt.
- However, avoid volume overload. Hormonal and circulatory responses to surgery result in postop Na^+ and water conservation by the kidneys that is independent of the status of the ECF volume.
- *BUT...consider replacement therapy vs resuscitation.*

Resuscitative IV Fluids

- Principle of trauma & surgery: Crystalloids; isotonic balanced salt solutions. *NS or RL.*
- Amount given based upon body wt, clinical picture, and vital signs. ?shock.
- Generally a bolus of 500-2000cc is given depending on the above, then rates are run at 1.5-2x maintenance or 10-20cc/kg/d on top of maintenance. Continuous clinical r/a of vitals and response to fluids already given is required for ongoing IVF therapy.
- Resuscitative IVF therapy is for initial stabilization and overlaps with further replacement therapy.

Crystalloids vs Colloids for Resuscitation

- Controversy exists over the use of colloids and hypertonic solutions as resuscitative fluids.
- The large volumes of crystalloid sometimes necessary to stabilize pts may lead to peripheral edema that may impair wound healing.
- Colloids offer the theoretical advantage of expanding the intravascular space with less volume, and have been shown to increase blood pressure more rapidly than crystalloids.
- 1 L of dextran increases intravasc vol by 800ml; 1 L of hetastarch by 750ml; 1 L 5% albumin by 500ml; and 1 L NS by 180 ml.

- Yet there is evidence that colloids may inhibit the coagulation system and cause anaphylactoid rxn's.
- Some studies have found an increased risk of ARF associated with hetastarch and pentastarch solutions when given for resusc of sepsis, possibly due to inadequate free water replacement.
- Overall meta-analyses of IVF therapy and mortality have not supported a benefit for colloids over crystalloids.
- Several meta-analyses have shown a trend toward increased mortality in heterogeneous groups of critically ill pt's resusc'd with colloids.

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- Given the available data, and potential risks of colloid solutions, crystalloids still remain the cornerstone of volume resuscitation, although pt's with profound volume deficits may benefit from colloids in addition to crystalloids.

Maintenance IV Fluids

- Can be calculated by three methods:
 1. Holliday-Segar method.
 2. Caloric method.
 3. Body surface area method.
- Most commonly used is Holliday-Segar method, most of you use it everyday and you probably don't even know it..... $4-2-1$ or $100-50-20$.
- In the Holliday-Segar method, fluid and electrolyte requirements are empirically based on caloric needs of the average hospital pt. This caloric expenditure is approximated based on body wt.

For each kilogram in this range	Daily caloric cost per kilogram	Daily Maintenance Fluid Requirements	Hourly Maintenance Fluid Requirements
1-10 kg (1 st 10kg)	100 kcal/kg/day	100ml	4ml
11-20 kg (2 nd 10kg)	50 kcal/kg/day	50ml	2ml
>20 kg (each kg over)	20 kcal/kg/day	20ml	1ml

Maintenance electrolyte requirements

Na	3-5 mEq per 100 kcal/day
K	2-4 mEq per 100 kcal/day
Cl	2 mEq per 100 kcal/day

- The Holliday-Segar method or 4—2—1 can only be applied to patients above 2 weeks of age.
- For every 100 kcal expended, a certain amount of fluid is lost either through "insensible water loss" or through renal function; a small amount is generated through oxidation of carbohydrates and tissue catabolism.
- This method does not take into consideration caloric expenditures above maintenance or take into account on-going fluid losses.
- This method is essentially a simplified/empiric application of the caloric method.

Monitoring endpoints for IVF therapy

- Endpoint should be maintenance or reestablishment of homeostasis.
- In order to reestablish homeostasis in a pt, IVF therapy must not only provide a balance of water and electrolytes, but must ensure adequate oxygen delivery to all organs and renal perfusion as evidenced by urine output.
- Endpoints: normalization of VS, $UO > 0.5 \text{ ml/kg/hr}$ (1 ml/kg/hr for a child) and restoration of normal mental status and lack of clinical signs of deficit.
- Other endpoints include normalization of labs, such as BUN:Cr ratio and electrolyte values.