جامعة الملك سعود
King Saud University

Principles of fluid and electrolyte balance in surgical patients

Surgery Team
MED 433

MED 433

Objectives :

I. Normal water and electrolyte balance

II. Assessing losses in the surgical patient
- ✓ Insensible fluid losses.
- ✓ Effect of surgery.

III. Intravenous fluid administration
- ✓ Types of intravenous fluid.
- ✓ Maintenance fluid requirements
- ✓ Treating Hypovolemia and or hypotension.

IV. Specific water and electrolyte abnormalities
- ✓ Water and sodium imbalance.
- ✓ Potassium imbalance.
- ✓ Other electrolyte disturbances.

V. Acid-base balance
- ✓ Metabolic acidosis.
- ✓ Metabolic alkalosis
- ✓ Respiratory acidosis
- ✓ Respiratory alkalosis
- ✓ Mixed patterns of acid-base imbalance

Sources : **Slides, Raslan's Notebook, Principles & Practice of Surgery by: O. James Garden**

Color Index : Slides & Raslan's | Textbook | Doctor's Notes | Extra Explanation

Terminologies & Introduction

A solvent	is the liquid where particles dissolves in (e.g. Water) that can be measured in liters and milliliters
Solutes	are the dissolving particles
A molecule	is the smallest unit with chemical identity (e.g. Water consist of one oxygen and two hydrogen atoms = water molecule)
Ions	are dissociated molecule into parts that have electrical charges (e.g. NaCl dissociates into Na+ and Cl-)
Cations	are positively charged ions (e.g. Na+) due to loss of an electron (e-)
anions	are negatively charged ions (e.g. Cl-) due to gain of an electrone (e-)
Electrolytes	are interacting cations and anions (e.g. H+ + Cl- = HCL [hydrochloric acid])
Univalent	ion has one electrical charge (e.g. Na+)
divalent	ion has two electrical charges (e.g. Ca++)
Molecular weight	is the sum of atomic weights of different parts of a molecule (e.g. H+ [2 atoms] + O2 [16 atoms] = H2O [18 atoms])
A mole	is a measuring unit of the weight of each substance` in grams (e.g. 1 mole of Na+ = 23 grams, 1 mole of Cl- = 35 grams, 1 mole of NaCl = 58 grams). It can be expressed in moles/L, millimoles x 10-3/L, micromoles x 10-6/L of the solvent.
Equivalence	refers to the ionic weight of an electrolyte to the number of charges it carries (e.g. 1 mole of Na+ = 1 Equivalent, whereas 1 mole of Ca++ = 2 Equivalents). Like moles, equivalence can also be expressed in milliequivalent/L and microequivalent/L of the solvent.
Osmosis	is the movement of a solution (e.g. water) through a semi permeable membrane from the lower concentration to the higher concentration.

Osmole/L or milliosmole/L	**is a measuring unit for the dissolution of a solute in a solvent**
Osmotic coefficient	means the degree of dissolution of solutes (molecules) in a solvent (solution). For example the osmotic coefficient of NaCl is 0.9 means that if 10 molecules of NaCl are dissolved in water, 9 molecules will dissolve and 1 molecule will not dissolve.
Osmolarity	is the dissolution of a solute in plasma measured in liters,
Osmolality	is the dissolution of a solute in whole blood measured in kilograms. Therefore, Osmolality is more accurate term because dissolution of a solute in plasma is less inclusive when compared to whole blood that contains plasma (90%) and Proteins (10%).
Gibbs – Donnan Equilibrium	refers to movement of chargeable particles through a semi permeable membrane against its natural location to achieve equal concentrations on either side of the semi permeable membrane. For example, movement of Cl- from extra cellular space (natural location) to intracellular space (unusual location) in case of hyperchloremic metabolic acidosis because negatively charged proteins (natural location in intravascular space) are large molecules that cannot cross the semi permeable membrane for this equilibrium.
Tonicity	of a solution means effective osmolality in relation to plasma (=285 milliosmol/L). Therefore, isotonic solutions [e.g. 0.9% saline solution] have almost equal tonicity of the plasma, hypotonic solutions [e.g. 0.45% saline solution] have < tonicity than plasma, and hypertonic [e.g. 3% saline solution] solutions have > tonicity than plasma.

Fluid and electrolyte balance may be altered in the surgical patient for several reasons:

- ✓ ADH and aldosterone secretion
- ✓ Loss from the gastrointestinal tract (e.g. bowel preparation, ileus, stomas, fistulas)
- ✓ Insensible losses (e.g. sweating secondary to fever)
- ✓ Third space losses
- ✓ Surgical drains
- ✓ Medications (e.g. diuretics)
- ✓ Underlying chronic illness (e.g. cardiac failure, portal hypertension).

Note:

- ➡ 1 mEq/L = 1 mmol/L
- ➡ 1 cc = 1 ml

I. Normal water and electrolyte balance

- ✓ Intravenous fluid is the giving of fluid and substances directly into a vein.
- ✓ Water forms about 60% of total body weight in men and 55% in women.
- ✓ Men will therefore contain about 42 litres, and a 70 kg. woman nearer 38 litres. The reason for this difference between the sexes is that women contain an extra 5% adipose tissue
- ✓ Extracellular water is distributed between the plasma and the interstitial space.
- ✓ Influenced by age, gender and lean body mass. Older age and female sex is less percent.

➲ Distribution of fluid between the intra- and extravascular compartments is dependent upon:

- ➥ The oncotic pressure of plasma (which is determined by albumin primarily) and the permeability of the endothelium
- ➥ Size of compartment available.
- ➥ Tonicity (mainly): water balance is adjusted to maintain osmolality.

➲ Distribution of fluid and electrolytes between the intracellular and extracellular fluid compartments. (figure 1.1)

	Intracellular	Extracellular	
Water containment (total of 60%)		interstitial space	intravascular space
	40%	15%	5%
	30 Liters	9 Liters	3 Liters
	two-thirds (0.66)	**one-third** (0.34)	
Principal ions (electrolytes)	Potassium(K^+), magnesium(Mg^+), phosphate(HPO_3^-) and sulphate	Sodium(Na^+), chloride (Cl^-), Calcium (Ca^{++}), albumin and bicarbonate	
Main +ve	Potassium(K^+)	Sodium(Na^+)	
Main –ve	phosphate(HPO_3^-)	chloride (Cl^-)	

- ✓ in our day to day use, fluids can only be given into, or taken from the vascular space (5%) which is the most important compartment for physicians.
- ✓ Fluid losses occur mainly from the vascular compartment as well. We lose water through our renal and gastrointestinal tracts, and this can be seen and measured.
- ✓ The water we lose from our skin and respiratory tract can not be measured with ease, and makes up our insensible losses. These amount to 500 ml a day in health, and increase in sickness, particularly when febrile (200 cc/day for each degree)

To calculate total body water (TBW) need:

- Male TBW = body weight (BW) × 0.6
- Female TBW = body weight (BW) × 0.5

Example 1:

70 kg male:

TBW= 70x 0.6 = 42 L

Intracelular volume = 0.66 x 42 = 28 L

Extracelular volume = 0.34 x 42 = 14 L

- Interstitial volume = 0.75 x 14 = 10.5 L
- Intravascular volume = 0.25 x 14 = 3.5 L

serum	Na^+	K^+	Cl^-	HCO_3^-	Ca^{+2}
Normal value (mmol/L)	135-147	3.5-5	98-108	20-28	2.2-2.6

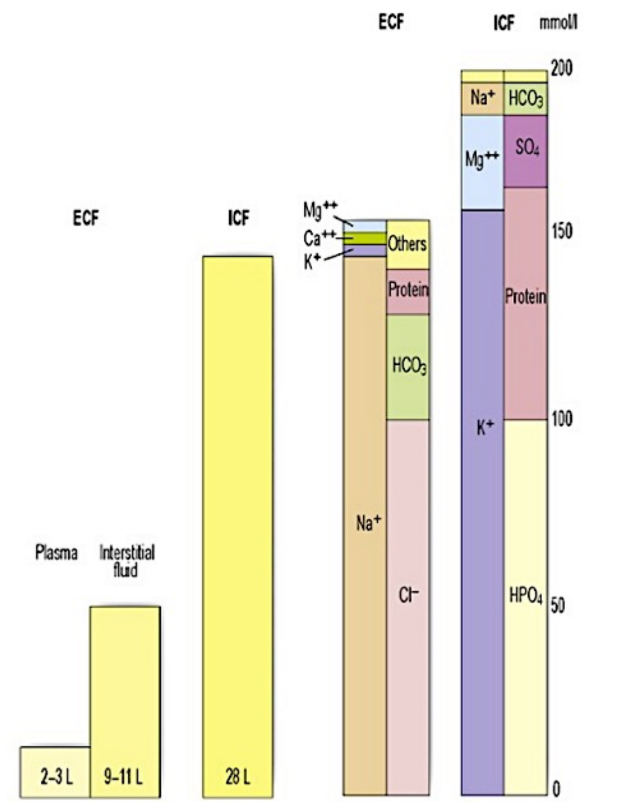


Figure 1.1

➲ Requirements of fluid and electrolytes

First: Fluid requirements

- ✓ the normal daily fluid requirement is ~30–35 ml/kg (~2500 ml/day).
- ✓ Normal adult requires approximately 35 cc/kg/d
- ✓ After the first month of life, fluid requirements decrease and the '4/2/1'formula can be used to estimate maintenance fluid requirements:
  - ➥ the first 10 kg of body weight requires 4 ml/kg/h
  - ➥ the next 10 kg 2ml/kg/h
  - ➥ thereafter each kg of body requires 1ml/kg/h.

The estimated maintenance fluid requirements of a 35 kg child would therefore be: (10 x 4) + (10 x 2) + (15 x 1) = 75 ml/hr

- Hypovolemia, when TBW is deficit, it's not compatible with normal organ perfusion. Its causes are:
  - ➥ GI: diarrhoea, vomiting, etc.
  - ➥ renal: diuresis
  - ➥ vascular: haemorrhage
  - ➥ skin: burns
- Hypervolemia, when TBW is in excess it's necessary for organ perfusion, but usually harmful. Its causes are:
  - ➥ Iatrogenic.
  - ➥ Heart / Liver / Kidney failure.

➲ How to calculate fluid requirements (total requirement of fluids for a patient per day):

Fluid requirements =
normal requirement + amount of lost fluids per day + insensible loss

- ✓ **Normal fluid needed =** body weight x 35
- ✓ **Lost fluids:** Know if the patient has diarrhea, any disease or abnormal GI loss (e.g nasogastric tube suctioning) to measure the lost fluids
- ✓ **Insensible water loss** makes up about 500 ml a day. It is the amount of fluids lost on a daily basis from the lungs, skin, respiratory tract and water excreted in the faeces.
  - ➥ Pyrexia increases water loss from the skin by approximately 200 ml/day for each 1°C rise in temperature.
  - ➥ sweating and use of non-humidified oxygen increase insensible water loss as well.

➲ Normal daily losses and requirements for fluids and electrolytes

	Volume (ml)	Na+ (mmol)	K+ (mmol)
Urine	2000	80	60
Insensible losses (skin and respiratory tract)	700	--	--
Faeces	300	--	10
Minus endogenous water	300	--	--
Total	2700	80	70

➲ How to measure fluid requirements per hour: (3 methods)

1. Find out the normal fluid requirement and divide it by 24 hours.
2. Apply the '4/2/1'formula (mentioned earlier page 7)
3. Body weight (kg) + 40 = IVF rate

- ✓ Assumes no significant renal or cardiac disease and NPO {nil per os (nothing by mouth)}
- ✓ This is the maintenance IVF rate, it must be adjusted for any dehydration or ongoing fluid loss.
- ✓ Conversely, if the patient is taking fluids PO (by mouth), the IVF rate must be decreased accordingly.
- ✓ Daily electrolytes, BUN (Blood urea nitrogen) ,Creatinine , Input/Output, and if possible, weight should be monitored in patients receiving significant IVF.

Example 2
Fluid requirements of a 70kg man = 70 + 40 = 110 cc/hr

Second: Electrolytes requirement

Sodium	**Potassium**
✓ **1-3 meq/kg/day** ✓ 70 kg male requires 70-210 meq NaCl in 2600 cc fluid per day. ✓ 0.45% saline contains 77 meq NaCl per liter. ✓ 2.6 L x 77 = 200 meq ✓ Thus, 0.45% saline is usually used as maintenance of IV fluid assuming no other volume or electrolyte issues.	✓ **1 meq/kg/day** ✓ K can be added to IV fluids. Remember this increases osm load. ✓ 20 meq/L is a common IVF additive. ✓ This will supply basal needs in most patients who are NPO. ✓ If significantly hypokalemia, order separate K supplementation. ✓ Oral potassium supplementation is always preferred when feasible. ✓ Should not be administered at rate greater than 10-20 mmol/hr

➲ Calculation of osmolality

- ➡ Difficult: measure and add all active osmoles (molecules)
- ➡ Easy = [sodium in blood x 2] + urea + glucose [1]
- ➡ Normal = 280 - 290 mosm / kg

✓ We measure it to know if the fluid is isotonic, hypotonic or hypertonic

✓ In conditions such as hypernatremia, renal failure (raised urea) or hyperglycemia, osmolality is raised.

Example 3
70 kg male requires 70 - 210 mEq NaCl in 2600 cc fluid per day. ✓ In such case, you give the patient half normal saline. Why? ✓ The patient needs 70 – 210 mEq NaCl in 2.6 L a day, The half normal saline contains 77 mEq NaCl per liter When you measure it: 77 x 2.6 = 200 mEq, It meets the daily requirement of the patient. ✓ Unlike giving normal saline which contains 154 mEq NaCl per liter.

(1) As sodium is the major extracellular cation, the majority of extracellular anions will be equal to its concentration. Urea and glucose make up the remaining significant osmoles,

- ✓ Intravenous fluid is the giving of fluid and substances directly into a vein.

Substances that may be infused intravenously

- Volume expanders (crystalloids and colloids)
- Blood-based products (Whole blood, fresh frozen plasma, cryoprecipitate)
- blood substitutes.
- medications.

Types of intravenous fluid:

A. Colloid solutions:

- ✓ Containing water and large proteins and molecules, so tend to stay within the vascular space and increase intravascular pressure.
- ✓ Used for volume expanding (in hypotension), or protein replacement (low albumin)
- ✓ Very expensive.
- ✓ Examples: Dextran, hetastarch, albumin

B. Crystalloid solutions:

- ✓ Containing water and electrolytes (sodium, potassium, calcium, chloride).
- ✓ Do not contain large proteins and molecules.
- ✓ crystalloid's osmolality related to the blood's.
- ✓ Classified according to their "tonicity:
  1. Isotonic (0.9% NaCl 'normal saline' and Lactated Ringer's)
  2. Hypotonic (2.3 % dextrose)
  3. Hypertonic (D5 NaCl)

Type of fluid	Sodium mmol/L	Potassium mmol/L	Chloride mmol/L	Osmolority mmom/L
plasma	**136 -145**	**3.5 – 5.0**	**98 -105**	**280 - 300**
5% Dextrose	0	0	0	278
Dextrose 0.18% saline	30	0	30	283
0.9% “normal” saline	154	0	154	308
0.45%”half normal” saline	77	0	77	154
Ringer’s lactate	130	4	109	273
Hartmann’s	131	5	111	275
Gelatine 4%	145	0	145	290
5% albumin	150	0	150	300
20% albumin	-	-	-	-
Hes 6% 130/0.4	154	0	154	308
Hes 10% 200/0.5	154	0	154	308
Hes 6% 450/0.6	154	0	154	308

Normal saline fluid (NS 0.9%)

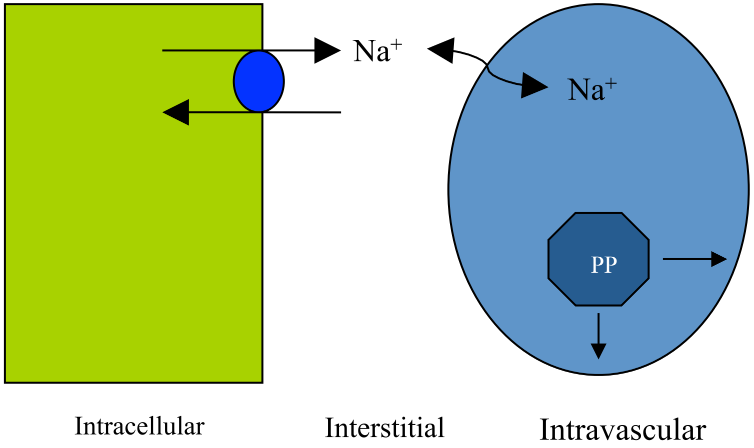
- ✓ (NS) is the commonly used term for a solution of 0.90% weight/volume of NaCl, about 300 mOsm/L or 9.0 g per liter
- ✓ 1 liter of normal saline contains 154 mmol/L of Na and 154 mmol/L of Cl only.

Hartmann's fluid	Ringer lactate fluid
One litre of Hartmann's solution contains: • 131 mEq of sodium ion = 131 mmol/L. • 111 mEq of chloride ion = 111 mmol/L. • 29 mEq of lactate = 29 mmol/L. • 5 mEq of potassium ion = 5 mmol/L. • 4 mEq of calcium ion = 2 mmol/L .	One litre of lactated Ringer's solution contains: • 130 mEq of sodium ion = 130 mmol/L • 109 mEq of chloride ion = 109 mmol/L • 28 mEq of lactate = 28 mmol/L • 4 mEq of potassium ion = 4 mmol/L • 3 mEq of calcium ion = 1.5 mmol/L

*NS is used more than Ringer lactate because it's less expensive

Osmotic / oncotic pressure
Gibbs – Donnan Equilibrium

Sodium moves freely between the vascular and interstitial spaces, but is actively extruded from the intracellular space; it is therefore the principle extracellular cation. It is also the cation that we most frequently administer by giving intravenous saline (NaCl). When we do this, we increase extracellular tonicity and water must move from the intracellular space to normalise osmolality.



1. Water imbalance

	Water Excess H_2O ⬆
Causes	✓ inappropriate use of hypotonic solutions (e.g. D5%Water) leading to hypo-osmolar hyponatremia ✓ Syndrome of inappropriate anti-diuretic hormone secretion (SIADH) **SIADH causes** :malignant tumors, CNS diseases, pulmonary disorders, medications, and severe stress.
Symptoms	develop slowly and if not recognized and treated promptly, they become evident by convulsions and coma due to cerebral edema
Signs	Hypertension, Tachycardia, Raised JVP / gallop, edema, Pleural effusions, Pulmonary edema, Ascites, Organ failure
Diagnosis	of SIADH secretion is established when **urine sodium > 20 mEq/L when there is no renal failure, hypotension, and edema**.
Treatment	✓ water restriction and infusion of isotonic or hypertonic saline solution ✓ use of ADH- Antagonist (Demeclocycline 300-600 mg b.i.d).

Antidiuretic Hormone (ADH):

- ✓ ADH is released from the posterior pituitary gland in response to high osmolality in plasma or in response to low volume.
- ✓ ADH secretion is influenced by volume receptors so that hypovolemia stimulates ADH secretion and water reabsorption. In the paradoxical situation where hypovolemia is accompanied by a fall in osmolality, ADH secretion will increase because the major stimulant is hypovolemia

Role of ADH: to maintain normovolemia and the osmolality of plasma by changes in ADH secretion from the posterior pituitary.

Anti-diuretic hormone secretion results in:

- ✓ Pure water reabsorption from the collecting duct of the nephron via a pathway that involves the V2 receptor and aquaporin 2.
- ✓ It increases the urine's concentration

1. Water imbalance

	Water Deficit H_2O ⬇
Causes	✓ the most encountered derangement of fluid balance in surgical patients. ✓ Bleeding, third spacing (1), gastrointestinal losses, increase insensible loss (normal ≈ 10ml/kg/day), and increase renal losses (normal ≈ 500-1500 ml/day).
Symptoms	Feeling thirsty, dryness, lethargy, and confusion.
Signs	✓ dry tongue and mucous membranes, sunken eyes, dry skin, loss of skin turgor, collapsed veins ✓ depressed level of consciousness, and coma. ✓ postural hypotension, Tachycardia, absence of JVP at 45o
Diagnosis	Increase serum sodium (>145mEq/L) and Increase serum osmolality (>300 mOsmol/L)
Treatment	✓ Bleeding should be replaced by IVF initially then by whole blood or packed red cells depending on hemoglobin level. Each blood unit will raise the hemoglobin level by 1 g. ✓ If fluid loss was caused by diarrhea or vomiting you give IVF (crystalloid usually). ✓ If sodium is low, give a solution that contains sodium (e.g. 0.9% NaCl) ✓ If sodium is >145 mEq/L give 0.45% hypotonic saline solution ✓ If sodium is >160 mEq/L give D5% water cautiously and slowly (e.g. 1 liter over 2-4 hours) in order not to cause water excess. ✓ You should treat anything that causes further water loss. ✓ Third spacing replacement can be estimated within a range of 4-8 ml/kg/h. ✓ Gastrointestinal and intraoperative losses should be replaced 1 cc/cc loss ✓ IVF maintenance can be roughly estimated by 4/2/1 rule.

(1) Third spacing is the shift of fluid from the intravascular space to a nonfunctional space,

2. Sodium imbalance

	HYPERNATREMIA Na^{+} ↑
Causes	1. Excessive sodium load (excessive normal saline (0.9%) or hypertonic solutions e.g. 3% NaCl - >145 of Na) **2. Hyperaldosteronism**; aldosterone promotes water & Na+ retention (rare) 3. Reduced water intake by fasting, nausea and vomiting, or reduced consciousness as in Alzheimer's patient/elderly (they forget to drink) 4. Increased water loss by sweating (pyrexia, hot environment), respiratory tract loss (increased ventilation, administration of dry gases) or burns. 5. Inappropriate urinary water loss by diabetes insipidus (pituitary or nephrogenic) or diabetes mellitus 6. Patients with CHF, cirrhosis, and nephrotic syndrome are prone to this complication
Symptoms	Similar to water excess symptoms, includes coma, convulsions and confusion.
Diagnosis	It is established when serum sodium >145 mEq/L
Treatment	✓ Water intake ✓ Decrease sodium infusion in IVF (e.g. 0.45% NaCl or D5%Water).

	HYPONATREMIA Na^+ ⬇
Causes	1. Hyperglycemia (it could be Pseudohyponatremia; diabetic) ➡ Corrected Na+ = BS mg/dl x 0.016 + P (Na) (BS = blood sugar) 2. Excessive IV sodium-free fluid administration (hypotonic solutions) 3. Hyponatremia with volume overload "hypervolemic hyponatremia" usually indicates impaired renal ability to excrete sodium.
Treatment	✓ Administering the calculated sodium needs in isotonic solution ✓ In severe hyponatremia (Na+ <120 mEq/L) you give a hypertonic solution ✓ Serum Na+ administration shouldn't be given at a rate > 10-12 mEq/L/hr (because rapid correction may cause permanent brain damage due to the osmotic demyelination syndrome) ✓ Before treating hyponatremia, you should check if it's true hyponatremia or pseudohyponatremia by checking the glucose levels. ➡ The glucose levels should be corrected in case of pseudo-hyponatremia, no further treatment is needed.

3. Potassium imbalance

	HYPERKALEMIA K^+ ↑
Causes	✓ Increase K+ infusion in IVF ✓ Tissue injury, surgery, Rhabdomyolysis ✓ Metabolic acidosis (causes a shift of potassium from intracellular space into extracellular space) ✓ Renal failure (↓excretion) ✓ Blood transfusion (RBCs contain high concentrations of K+) ✓ Hemodialysis
Signs & Symptoms	Arrhythmia
Diagnosis	Increase serum $K^+ > 6$ mEq/L and ECG changes (bradycardia and peaked T wave)
Treatment	✓ Insulin: 10 IU (shifts K+ back into intracellular compartment) + glucose: 1 ampule of Dextrose 50% (prevent hypoglycemia from insulin) – over 15 minutes ✓ Calcium oxalate enemas (can also be given orally) ✓ Lasix 20-40 mg IV ✓ Dialysis (if needed)

HYPOKALEMIA K^+ ↓	
Causes	✓ The most common surgical abnormality ✓ Inadequate replacement (e.g. during surgery) ✓ Diuretics (e.g. Lasix) ✓ Metabolic alkalosis (shifts K+ to intracellular compartment) ✓ Hyperaldosteronism (promotes K+ excretion in kidneys) ✓ Gastrointestinal tract losses: (Vomiting, Gastric aspiration/drainage, Fistulae, Diarrhea , Ileus (disruption of the normal propulsive gastrointestinal track that causes obstruction which prevents bowel contents, such as stool, fluid and gas, from moving through the intestine, which becomes distended), Intestinal obstruction, Potassium-secreting villous adenomas ✓ Urinary loss ✓ Renal tubular disorders (e.g. Bartter syndrome, renal tubular acidosis, amphotericin-induced tubular damage)
Signs & Symptoms	Weakness and fatigue (most common), muscle cramps and pain (severe cases), altered level of consciousness, arrhythmias
Diagnosis	Occurs when serum K^+<3 mEq/L.
Treatment	✓ K+ replacement (KCl solution) infusion or orally. ✓ Should not be administered at rate greater than 10-20 mmol/hr

4. Calcium disturbances

HYPERCALCEMIA (Ca^{++} ↑)	
Causes	hyperparathyroidism and malignancy.
Symptoms	confusion, weakness, lethargy, anorexia, vomiting, epigastric abdominal pain (due to pancreatitis), and polyuria (nephrogenic diabetes insipidus)
Diagnosis	by measuring the **free** Ca++ >10mg/dl
Treatment	includes normal saline infusion ➥ If Ca >14mg/dl with ECG changes: additional diuretics, calcitonin, and mithramycin (antineoplastic antibiotic that has been discontinued) might be necessary.

HYPOCALCEMIA (Ca^{++} ↓)	
Causes	✓ from low parathyroid hormone after thyroid or parathyroid surgeries. ✓ low vitamin D. ✓ Pseudohypocalcemia (low albumin and hyperventilation). ✓ Other less common causes include: pancreatitis, necrotizing fascitis, high output G.I. fistula, and massive blood transfusion.
Symptoms	✓ Numbness and tingling sensation circumorally or at the fingers' tips. ✓ Tetany and seizures may occur at a very low calcium level.
Signs	Tremor, hyperreflexia, carpopedal spasms and positive Chvostek sign.
Diagnosis	serum Ca < 8.5 mg/dl (2.1 mmol/L)
Treatment	✓ Should start by treating the cause. ✓ Calcium supplementation with calcium gluconate or calcium carbonate i.v. or orally. ✓ Vitamin D supplementation especially in chronic cases.

5. Magnesium imbalance

HYPERMAGNESEMIA	Mg^{++} ↑
Causes	✓ Mostly occurs in association with renal failure, when Mg+ excretion is impaired. ✓ The use of antacids containing Mg+ may aggravate hypermagnesaemia. ✓ Hypermagnesemia and hypophosphatemia are all conditions of renal failure
Treatment	Treatment includes rehydration and renal dialysis

HYPOMAGNESAEMIA	Mg^{++} ↓
Causes	✓ Magnesium is important for neuromuscular activities. (cannot correct K nor Ca) ✓ It happens from inadequate replacement in depleted surgical patients with major GI fistula and those on TPN.
Symptoms	Usually there are no symptoms but when you want to correct Ca or K levels they don't get corrected.
Treatment	When Mg decreases the Ca and K will decrease as well even though they were in their normal levels. But when correcting the magnesium everything will go back to normal The majority of magnesium is intracellular with only <1% in the extracellular space.

6. Phosphate imbalance

HYPERPHOSPHATEMIA	HPO_3^- ⬆
Causes	Mostly associated with renal failure and hypocalcaemia due to hypoparathyroidism, which reduces renal phosphate excretion.

HYPOPHOSPHATEMIA	HPO_3^- ⬇
Causes	✓ Inadequate intestinal absorption. ✓ Increased renal excretion, ✓ Hyperparathyroidism ✓ Massive liver resection ✓ Inadequate replacement after recovery from significant starvation and catabolism.
Symptoms	Muscle weakness and inadequate tissue oxygenation due to reduced 2, 3- bisphosphoglycerate levels.
Treatment	Early recognition and replacement will improve these symptoms.

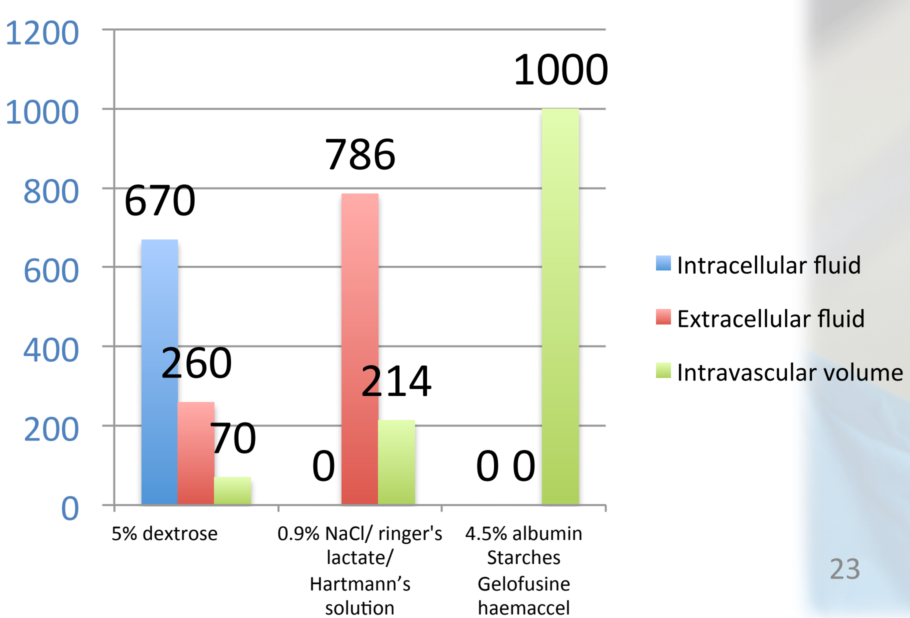
Mg and phosphate abnormalities occur with chronic diseases, before replacing them check the renal system, caused all the time by renal failure

➲ Prescribing fluids:

- ✓ 2 basic types. Crystalloids are simple solutions of small solutes, whilst colloids are suspensions of macromolecules, or in the case of blood, cells.
- ✓ most commonly used crystalloids are saline and dextrose
  - ➡ The standard saline solution is 0.9% saline, often referred to as " normal saline ”being slightly hypertonic, and hypernatraemic.
  - ➡ Dextrose is usually given as 5% dextrose, which means that it contains 5 grams of glucose per 100 ml of water. This solution is roughly isotonic to serum, but the glucose is rapidly utilised, leaving behind pure water.
- ✓ Multiple colloid preparations are available, but the essential ones are either:
  - ➡ natural, such as blood, human albumin or plasma.
  - ➡ or synthetic, where the macromolecule is manufactured. Common synthetic colloids are haemaccel and gelofusine, in which hydrolysed gelatin is suspended in saline.

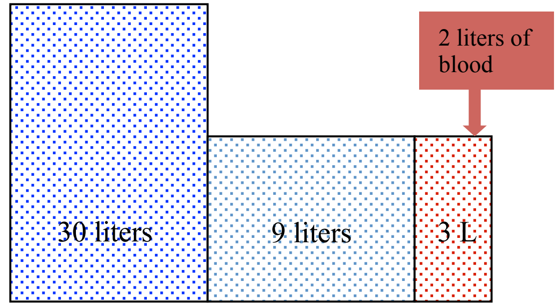
➲ The rules of fluid replacement:

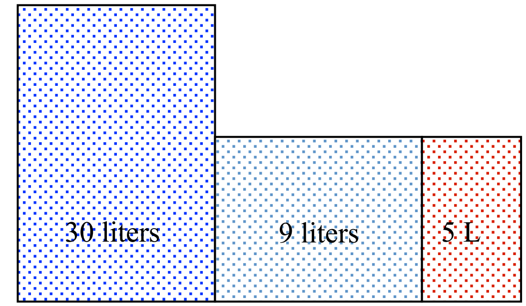
- ✓ Replace blood with blood
- ✓ Replace plasma with colloid
- ✓ Resuscitate with colloid
- ✓ Replace ECF depletion with saline
- ✓ Rehydrate with dextrose



Colloids

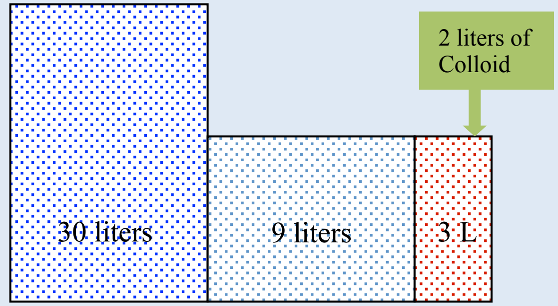
Giving 2 litres of blood, will expand their intravascular compartment. None of this fluid will escape across the blood vessel walls (in the short term at least) and the other compartments are unaffected. **This is the right treatment for blood loss.**

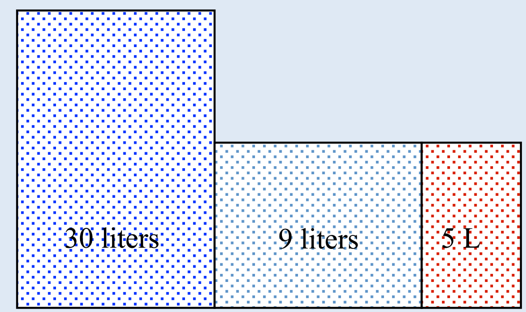


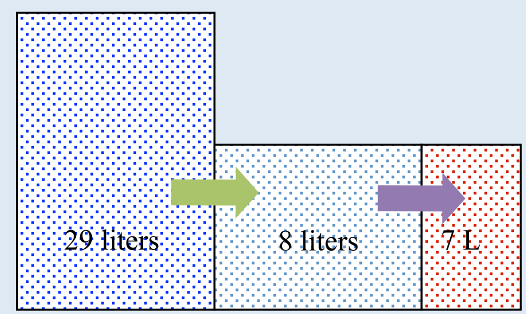


Giving 2L colloid into the vascular space results in an immediate expansion of the intravascular compartment by 2 litres, as does blood.

- ✓ Colloid does not escape from the vascular space, but does increase oncotic pressure markedly causing water to be drawn into the vascular space from the interstitial and intracellular reservoirs. Giving colloid therefore not only expands the vascular space itself, but does so by moving water from other spaces.

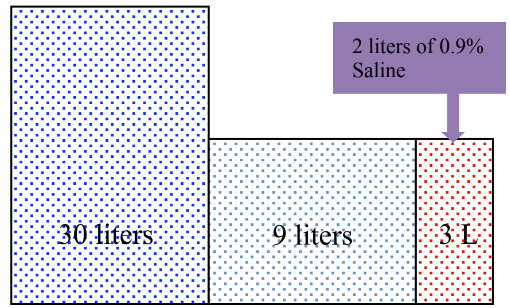


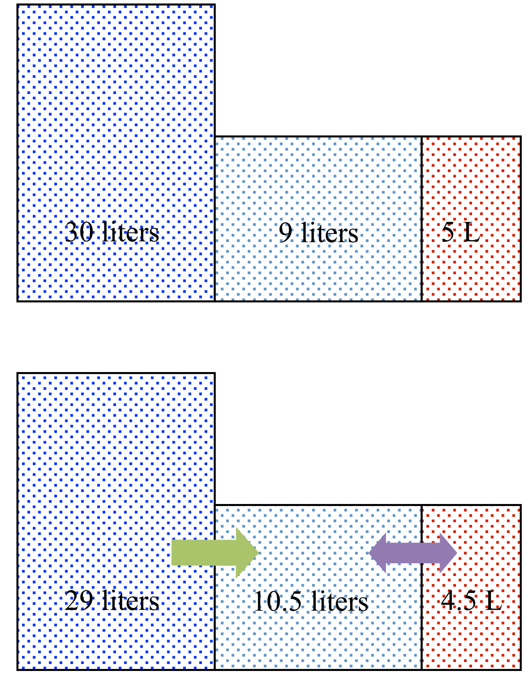




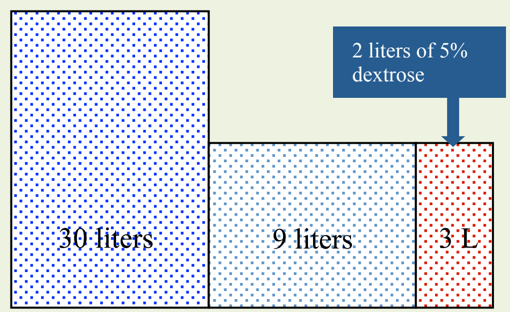
Crystalloids

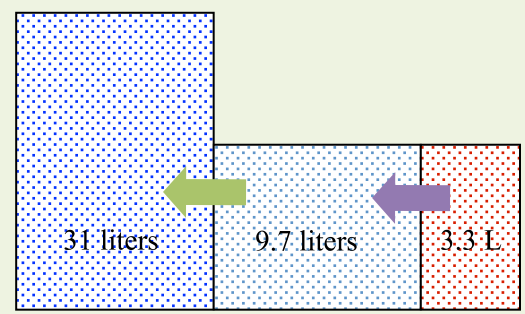
Saline, does not remain within the vascular space, will diffuse into the interstitial space.
The sodium it carries will not enter the intracellular space. Saline will therefore cause immediate expansion of the intravascular volume, followed by equilibration between the vascular and interstitial spaces, the osmolality of which are equal, but are now slightly greater than that of the intracellular space, due to the increased sodium load water movement from the intracellular space in order to equalise osmolality throughout all three compartments.





5 Dextrose is isotonic to plasma. Giving 2 litres of 5% dextrose will cause the immediate expansion of the vascular compartment, but, as its glucose content is rapidly metabolised, the remaining water will distribute itself between all compartments and very little will remain within the blood space. For this simple reason, dextrose is not a fluid of resuscitation.





Normal physiology

- Hydrogen ion is generated in the body by:
  - Protein and CHO metabolism (1meq/kg of body weight)
  - Predominant CO_2 production
- Mechanisms to maintain the normal value of pH:

Normal values:
pH = 7.36 – 7.42
H^+ concentration = 36 –40 mmol/L
PCO_2 ~ 40 mmHg
Bicarbonate concentration [HCO3-] = 20- 28, average 24 mmol/L

In the intracellular fluid:	In the extracellular fluid:
1. **Proteins which include hemoglobin :** Protein buffers include basic group, and acidic protein buffer groups, that act as hydrogen ion depletors or donors to maintain the pH level at 7.4 2. **Phosphate:** when H concentrations increase, it binds to H ions and is excreted in the urine with sodium	1. **The buffer system**: bicarbonate/carbonic acid system: pH levels depend on CO_2 and HCO_3 mainly $H^+ + HCO_3^- \leftrightarrow H_2CO_3 \leftrightarrow CO_2 + H_2O$ ✓ Hydrogen ions and the bicarbonate form carbonic acid which forms CO_2 and water under the enzyme **carbonic anhydrase.** ✓ So if hydrogen ions increase in the plasma, CO_2 production will increase therefore the pH will decrease.

- **Respiratory compensation:** In acidosis, pH changes will stimulate the respiratory center in the brain stem → hyperventilation → PCO_2 will decrease and the pH levels will get back to normal.
- **Metabolic compensation:** when acid accumulates: the kidneys increase urinary excretion of acids and reabsorption of bicarbonate (in the proximal tubules in the kidneys).

Acid Base Disorders

Metabolic acidosis:

- ✓ Low pH due to H^+ ions accumulation and HCO_3 ions decrease.
- ✓ To know the **cause** of metabolic acidosis you have to calculate the anion gap:

AG = Cations (Na + K) – Anions (Cl + HCO_3) Normal value is 12 mmol (8-16)	
High anion gap (AG >16):	**Non-aniongap(AG=8-12):**
✓ **Lactic acidosis** caused by shock (any cause), severe hypoxemia, severe hemorrhage/anemia, liver failure ✓ **Diabetic ketoacidosis** ✓ Acute or chronic renal failure ✓ Poisoning (ethylene glycol, methanol, salicylates)	Increased bicarbonate loss by diarrhea, intestinal fistulae, renal tubular acidosis (types I-IV)

Metabolic alkalosis:

- ✓ High HCO_3 → high pH
- ✓ **Causes:**
  - H^+ ions loss (vomiting, NGT, Lasix)
  - Hypokalemia
  - HCO_3 retention.

➥ If you lose K, you will get alkalosis. If you gain you will get acidosis.

Acid Base Disorders

Respiratory acidosis:	Respiratory alkalosis:
Causes: (anything that causes hypoventilation) ✓ Common surgical causes of respiratory acidosis ✓ Central respiratory depression ✓ Opioid drugs ✓ Head injury or intracranial pathology ✓ Pulmonary disease ✓ Severe asthma ✓ COPD ✓ Severe chest infection	Causes: (anything that causes hyperventilation): ✓ Pain ✓ Apprehension/hysterical hyperventilation ✓ Pneumonia ✓ Central nervous system disorders (meningitis, encephalopathy) ✓ Pulmonary embolism ✓ Septicemia ✓ Salicylate poisoning ✓ Liver failure

Type of A- B disorder	Acute (Uncompensated)			Chronic (Partially compensated)		
	PH	**PCO2**	**HCO3**	**PH**	**PCO2**	**HCO3**
Respiratory acidosis	↓↓	↑↑	Normal	↓	↑↑	↑
Respiratory alkalosis	↑↑	↓↓	Normal	↑	↓↓	↓
Metabolic acidosis	↓↓	Normal	↓↓	↓	↓	↓
Metabolic alkalosis	↑↑	Normal	↑↑	↑	↑	↑

Clinical cases

Case 1:
A 62 year old man is 2 days post-colectomy. He is euvolaemic, and is allowed to drink 500ml. His urine output is 63 ml/hour:

1. How much IV fluid does he need today ?

This man has a normal total body water content, and you aim is to maintain that.
A urine output of 63 ml / hr gives him a total daily urine loss of 1.5 litres.
His insensible losses are likely to be 500 ml. He therefore needs a total fluid intake of 2 litres to balance his losses. He is only allowed to drink 500 ml.
He therefore needs 1.5 litres of fluid IV today.

2. What type of IV fluid does he need ?

As he is euvolaemic, this man does not need resuscitation, so he should only receive crystalloid. His losses will include water and electrolytes. Giving him just 5% dextrose will cause osmolality to fall and hyponatraemia to follow. Giving him just 0.9% saline will cause gradual hypernatraemia and hypertonicity.
This man needs a mixture of crystalloids. He is getting water orally which might help to offset the sodium load of saline. Even so, it is reasonable to use saline and dextrose in a 2:1 ratio; this proportion can be changed in response to changes in his clinical state and serum sodium.

Case 2:
3 days after her admission, a 43 year old woman with diabetic ketoacidosis has a blood pressure of 88/46 mmHg & pulse of 110 bpm. Her charts show that her urine output over the last 3 days was 26.5 litres, whilst her total intake was 18 litres:

1. How much IV fluid does he need to regain a normal BP?

The hyperglycaemia of diabetic ketoacidosis causes glycosuria which results in an osmotic diuresis. This causes high losses of water and dehydration occurs if fluid balance is not attended to.
In this case, the lady has lost 26.5 litres of urine plus at least 1.5 litres insensible losses over the last 3 days; her input has been 18 litres. This equals a deficit of 10 litres, and it is not surprising that she appears to be hypovolemic with hypotension and tachycardia.
Assuming that she was euvolaemic to start with, she needs to gain 10 litres in order to regain a normal BP.

2. What type of IV fluid would you use?

As she has a low BP, we can assume that her blood volume is low, and that organ perfusion is at risk. She therefore needs to be resuscitated. The initial fluids to use would be colloid in order to normalise BP and pulse. There is no need to use only colloid; indeed, this would cause intravascular overload and heart failure. After using perhaps 1 or 2 litres of colloid, her remaining fluids should be crystalloid. As she has lost mainly water, a large part of this should be dextrose, and serum [Na+] should be monitored in order to assess the need for IV saline.

Case 3:
An 85 year old man receives IV fluids for 3 days following a stroke; he is not allowed to eat. He has ankle oedema and a JVP of +5 cms; his charts reveal a total input of 9 l and a urine output of 6 litres over these 3 days.

1. How much excess fluid does he carry ?

This man has become hypervolaemic with interstitial oedema and intravascular excess, because he has received 3 litres more fluid than he has passed out in his urine. Remember however that he loses 500 ml / day insensible losses.
His total fluid excess is therefore around 1.5 litres.

2. What would you do with his IV fluids ?

Although he is not drinking, he is overloaded and his IV fluids should be stopped. After a day without IV fluids, he should be euvolaemic, and IV fluids can be recommenced at 2.5 litres a day without overloading him.

Case 4:
5 days after a liver transplant, a 48 year old man has a pyrexia of 40.8oC. His charts for the last 24 hours reveal:

urine output:	2.7 litres
drain output:	525 ml
nasogastric output:	1.475 litres
blood transfusion:	2 units (350 ml each)
IV crystalloid:	2.5 litres
oral fluids:	500 ml

Continue case 4:
On examination he is tachycardic; his supine BP is OK, but you can't sit him up to check his erect BP. His serum [Na+] is 140 mmol/l.

1. How much IV fluid does he need?

As is often the case with complex surgical patients, this man has multiple sources of luid loss. In each case, urine, drain or tube, the fluid lost will be a mixture of fluid and solutes. Indeed, drain fluid will have an electrolyte content very similar to plasma.
His obvious losses (urine + drain + NG tube) total 4.7 litres.
His insensible losses are higher than normal because of his fever, and will be about 800 ml, giving a total loss of 5.5 litres.
His total intake was 3.7 litres, and he is therefore deficient by 1.8 litres.
Assuming that his total losses for this day are similar to those of the day before, he will need about 7.3 litres in order to become euvolaemic.

2. What fluid would you use?

He will almost undoubtedly need a mixture of fluids. He will need colloid or further blood in order to fill the intravascular compartment and maintain organ perfusion. He will need saline to replace water and solute losses, and will need some dextrose in order to prevent hypernatraemia.
In practice, a case of this complexity will require repeated re-evaluation, adjustment of his fluids throughout the day with serial blood tests in order to guide you.

Thank You..

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