Fluid and Electrolyte Abnormalities

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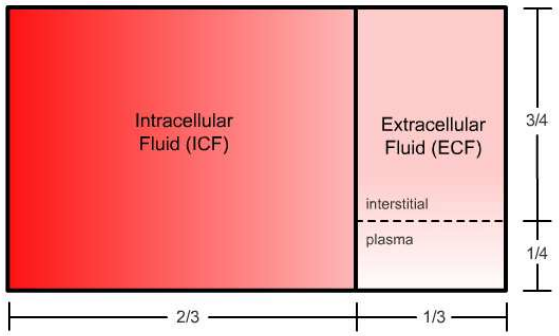
Fluid & Electrolytes

Approximately 60% of typical adult's weight is water (> 40L)

- Factors that influence amount of body fluid are: *age, gender, and body fat*
- Body fluids located in two compartments:

1. Intracellular fluid (ICF) 2/3 of body fluid

2. Extracellular fluid (ECF)



Fluid & Electrolytes

ECF might be further divided into:

- **Intravascular fluid**: 5L within the vessels. About 3L of blood is plasma, the other 2L is made up of erythrocytes, leukocytes, and platelets.

- **Interstitial fluid**: surrounding cells (about 9L in adults). Lymph is an example of interstitial fluid

- **Transcellular fluid**: about 1L in total, the smallest division of ECF (cerebrospinal, pleural, and digestive secretions)

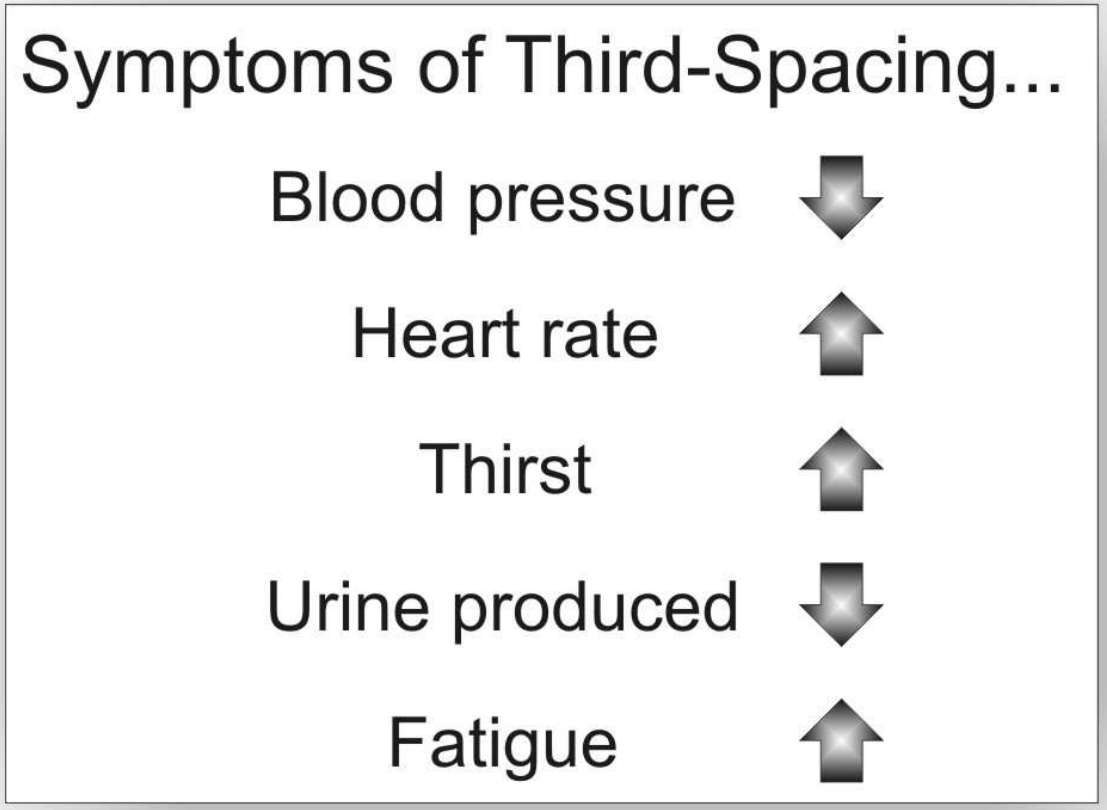
Fluid & Electrolytes

Body fluid moves between ICF and ECF to maintain equilibrium

Loss of ECF into a space that doesn't contribute to equilibrium status is referred as **Third-Space fluid shift.** Early clue of third space fluid shift is *the decrease in urine output despite fluid intake*

Intravascular fluid --- ►**Third space** ►↓Kidney input ► Compensatory ↓urine output ►↑pulse ↓B Press ↑B Weight ► Input/Output imbalance

Fluid & Electrolytes



Fluid & Electrolytes

Route of Gain & Loss

H2O and electrolytes are gained by drinking and eating or via intravenous, sub-cutaneous, and enteral feeding

Loss by:

1. Kidneys:

Urine output is approximately: 1-2000 ml (1ml/kg/h)

2. Skin:

Sensible = visible, insensible = non-visible sweating vary from 0-1000 ml or more every hour. ***Fever and exercise*** evaporate an excess of liquids

3. Lungs :

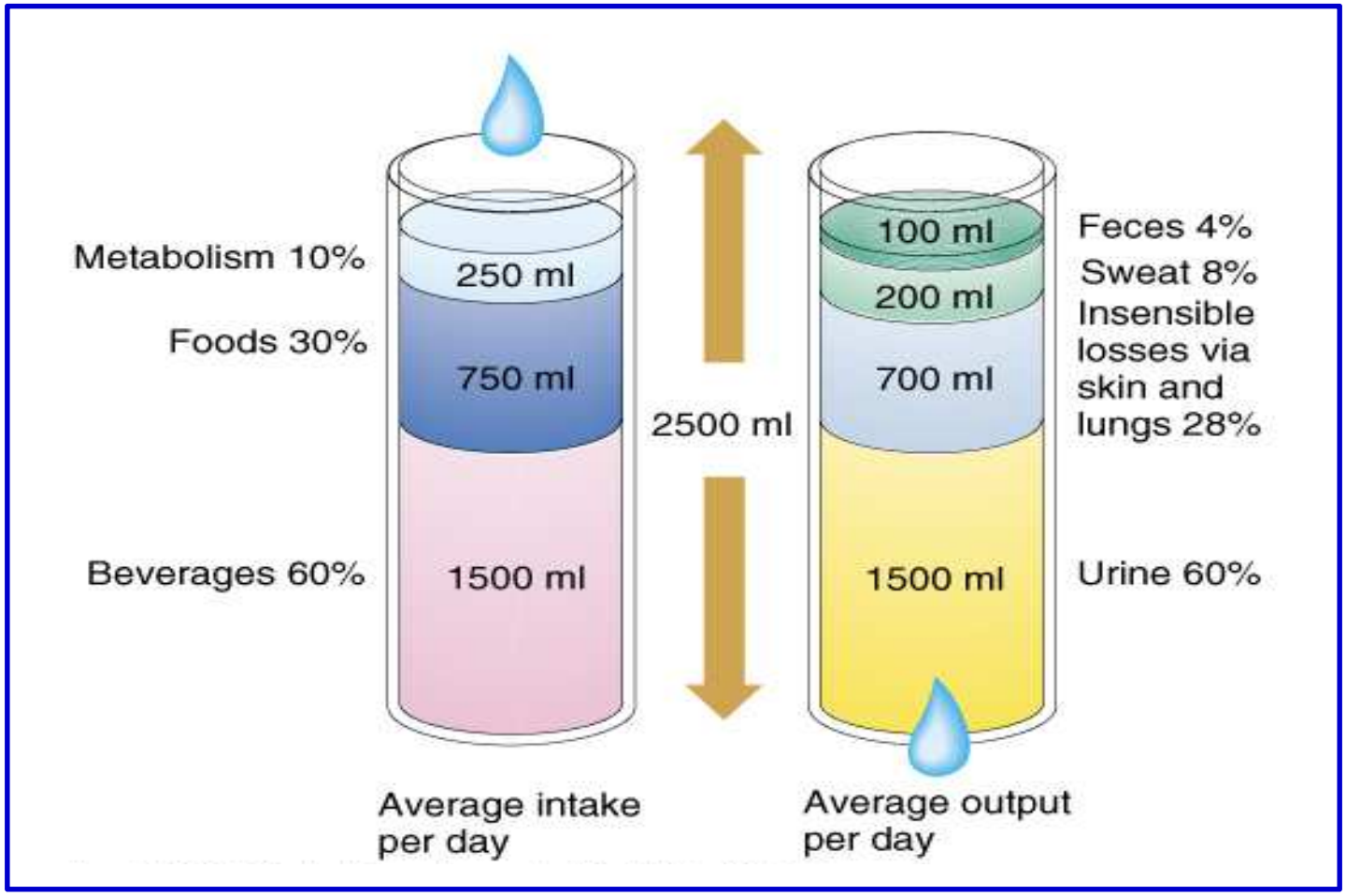
Loss ↑ with ***high respiratory rate and depth or both***

500-1000 ml/ day (insensible)

4. G.I. tract

Usual loss: about 200 ml/day

Daily Water Balance (liters)



Urine Specific Gravity

Measure the kidneys ability to excrete or conserve water. Normal specific gravity is: **1.005-1.030**
Specific gravity is inversely related with urine volume.
Gravity > 1035: frank dehydration!

Blood Urea Nitrogen (BUN) = azotemia/2.14

End products of protein metabolism from both muscle & dietary intake. Normal range is: **10-30 mg/dl**
BUN increased with: GI bleeding, dehydration, fever, and sepsis
BUN decrease with: end stage liver diseases, reduced protein intake, and starvation

Creatinine

The end products of muscle metabolism
Is a specific indicator of renal function
Normal serum creatinine is: **0.8-1.3 mg /dl**

Hematocrit

Measure volume percentage of RBCs in whole blood: 44%-52% for male, 39%-47% for female
↑ in cases of dehydration (and policythemia)
↓ in cases of over-hydration and anemia

Urine Sodium

Changes with sodium intake
Affected by circulating blood volume
Normal range is 50-220 mEq/24hrs

Fluid Volume Disturbances

1. Fluid volume deficit: Hypovolemia

- **Hypovolemia:** usually results when water and electrolytes are lost in the same proportion as they exist in the normal body fluids

- **Dehydration:** usually refer to loss of water alone with increased serum Na+ level

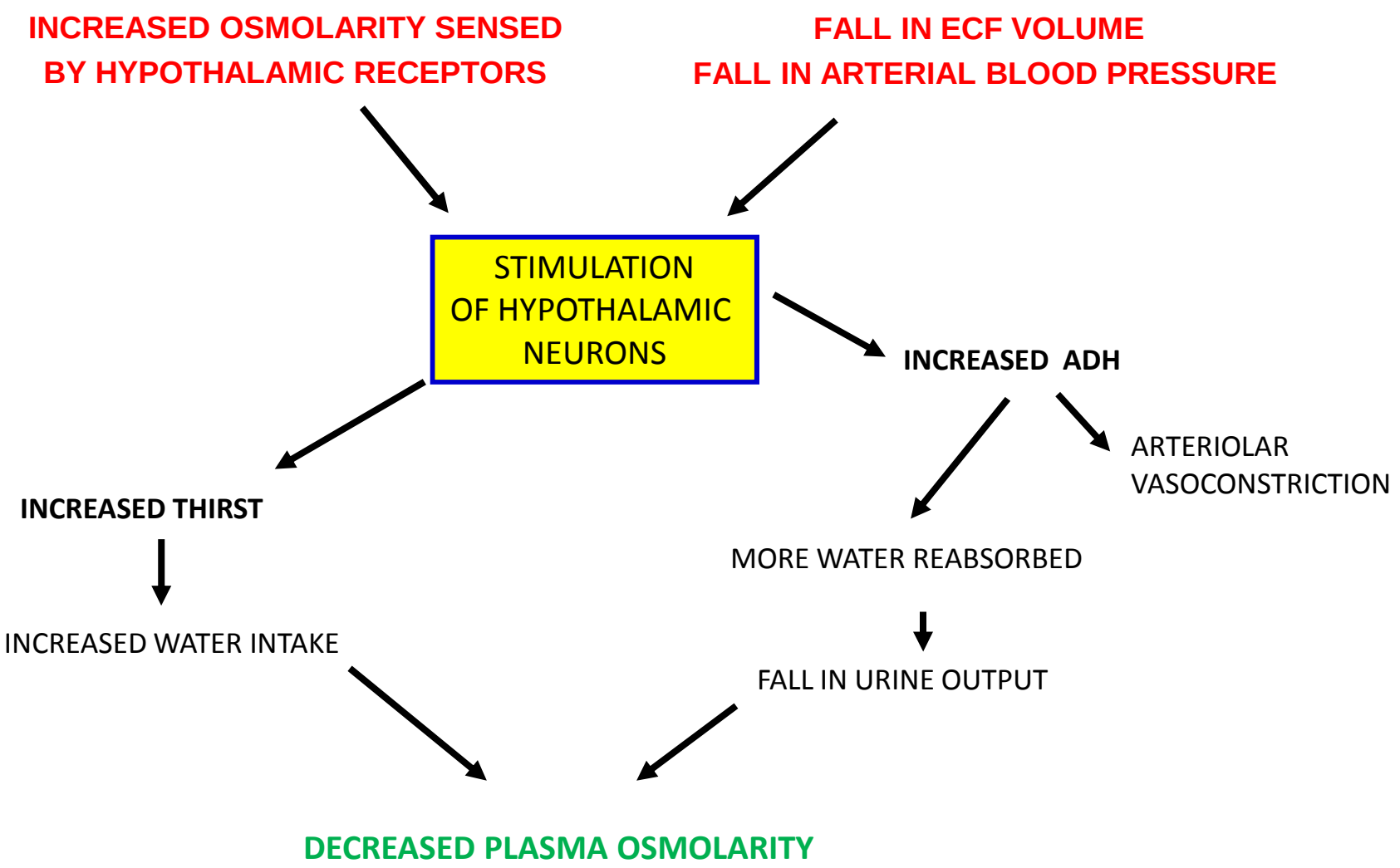
Fluid Volume Disturbances

Hypovolemia Clinical Manifestations

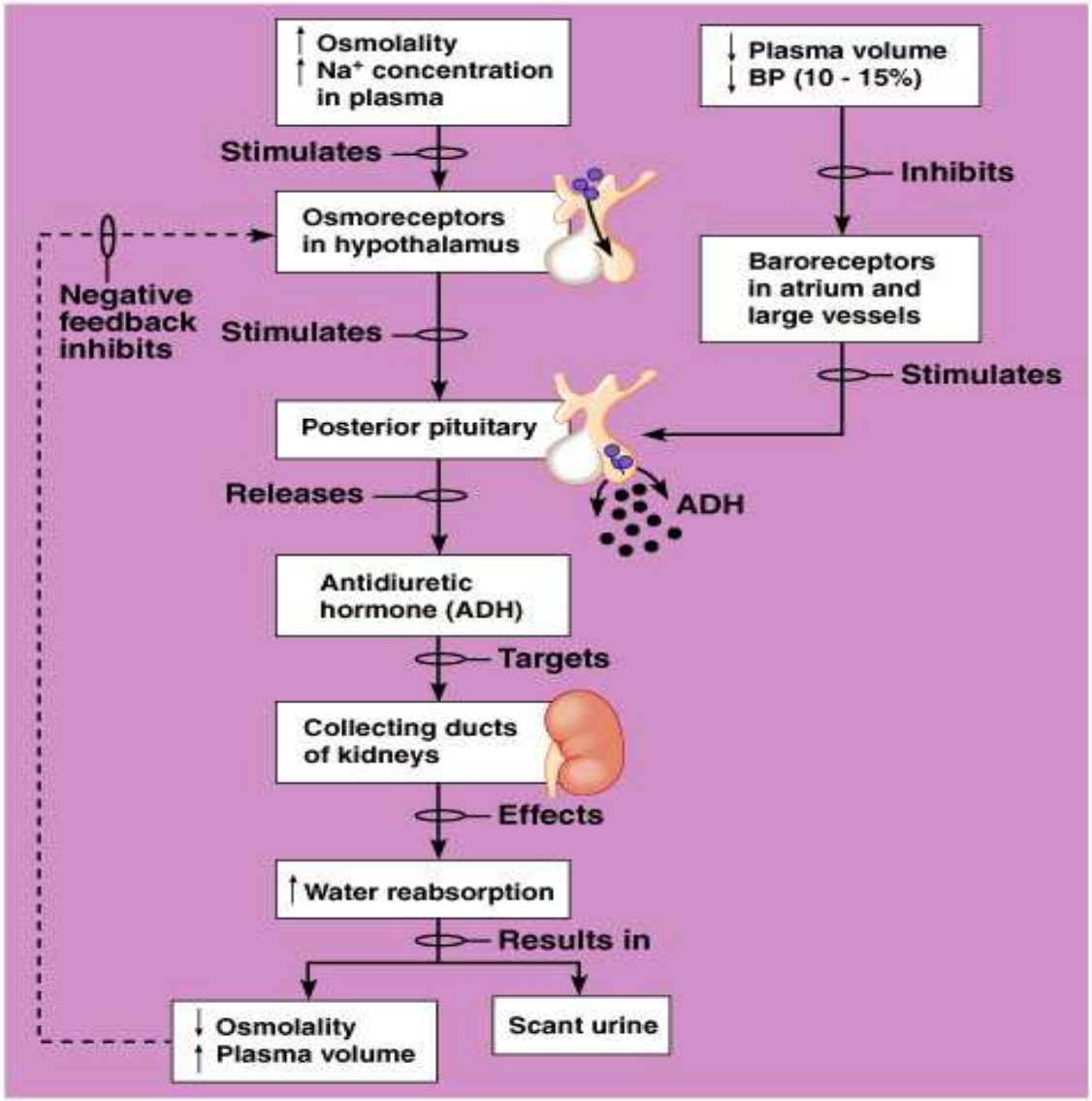
Hypovolemia

Signs & Symptoms	Signs & Symptoms
Weight Loss	Increased Temp
Decreased Skin Turgor	Cool, clammy skin
Oliguria	Thirst
Concentrate Urine	Anorexia
Postural Hypotension	Nausea
Weak, rapid pulse	Muscle Weakness
Flattened Neck Veins	Muscle Cramps

Regulation of Water Output



Regulation of Water Output



Fluid Volume Disturbances

Hypovolemia diagnostic evaluation

– Physical examination
– Serum BUN and Creatinine (↑↑ ratio B/C)
– Hematocrit level *"great than normal/expected"*
– Urine specific gravity ↑↑
– Serum electrolytes level:
  - Hypokalemia: in case of GI or renal loss
  - Hyperkalemia: in case of adrenal insufficiency
  - Hypernatremia: in case of ***Dehydration*** (or diabetes insipidus)

Fluid Volume Disturbances

2. Fluid volume excess: Hypervolemia

Hypervolemia is an isotonic expansion of ECF caused by abnormal retention of water and Na in approximately the same proportion as normal

Clinical Manifestations:

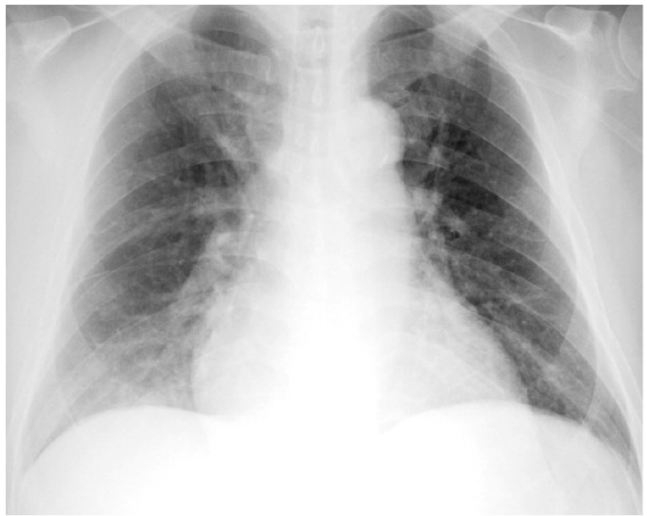
- ***Edema***
- ***Distended neck veins***
- ***Increased BP, Central Vein Pressure, pulse rate***
- ***Crackles over the lungs, shortness of breath, and wheezing, dyspnea***
- ***Increased body weight (and urine output)***

Fluid Volume Disturbances

Hypervolemia Diagnostic Evaluation

- Decreased BUN, creatinine, serum osmolality and hematocrit because of plasma dilution, and ↓ protein intake

- CXR may disclose pulmonary congestion



1. Assess the patient

Euvolaemic: veins are well filled, extremities are warm, blood pressure and heart rate are normal (depending on other pathology).

Hypovolaemic:The patient may have cold hands and feet, absent veins, hypotension, tachycardia, oliguria and confusion. History of fluid loss or low intake.

Hypervolaemic: Patient is oedematous, may have inspiratory crackles; history of poor urine output or fluid overload.

2. Does my patient need IV fluid?

NO: he may be drinking adequately, may be receiving adequate fluid via NG feed or TPN, or may be receiving large volumes with drugs or drug infusions (or a combination of these). ALLOW PATIENTS TO DRINK IF AT ALL POSSIBLE.

Hypervolaemic: may need fluid restriction or gentle diuresis.

YES: not drinking, has lost, or is losing fluid

So WHY does the patient need fluid?

Maintenance fluid only – patient does not have excess losses above insensible loss. If no other intake he needs approximately 30ml/kg/24hrs. He may only need part of this if receiving other fluid. Patients having to fast for over 8-12 hours should be started on IV maintenance fluid.

Replacement of losses, either previous or current. If losses are predicted it is best to replace these later rather than give extra fluid in anticipation of losses which may not occur. This fluid is in addition to maintenance fluid. Check blood gases.

Resuscitation: The patient is hypovolaemic as a result of dehydration, blood loss or sepsis and requires urgent correction of intravascular depletion to correct the deficit

4. What type of fluid does my patient need?

MAINTENANCE FLUID

IV fluid should be given via volumetric pump if a patient is on fluids for **over 6 hours or if the fluid contains potassium. Always prescribe as ml/hr not 'x hourly' bags.**

Never give maintenance fluids at more than 100ml/hour.

Weight kg	Fluid Requirement in mls/day	Rate in ml/hour
35-44	1200	50
45-54	1500	65
55-64	1800	75
65-74	2100	85
≥75	2400	100 (max)

NHS Fife

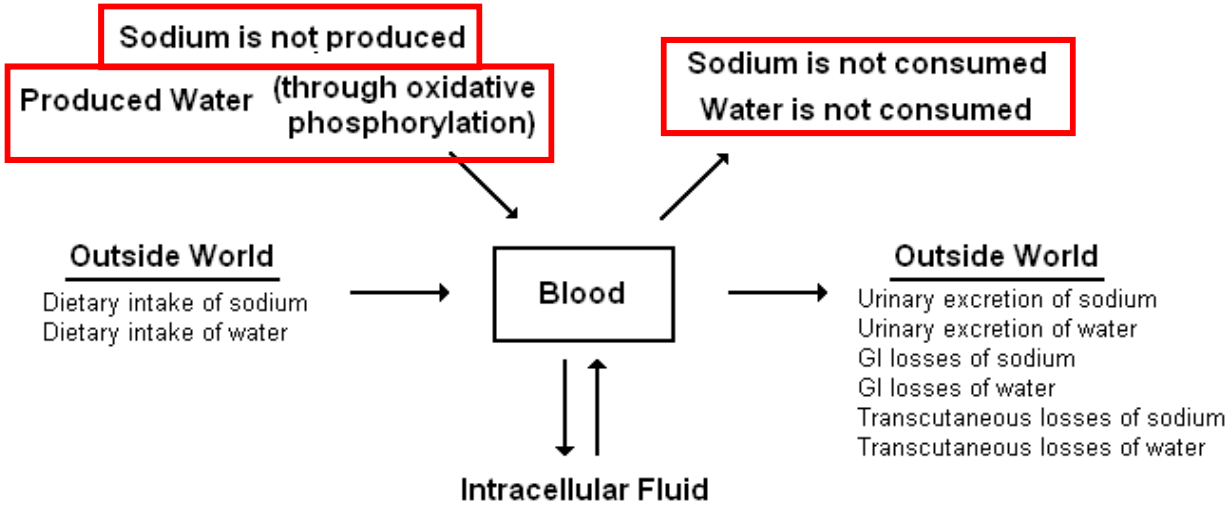
GUIDANCE FOR INTRAVENOUS FLUID AND ELECTROLYTE PRESCRIPTION IN ADULTS

REPLACEMENT FLUID

Fluid losses may be due to diarrhoea, vomiting, fistulae, drain output, bile leaks, high stoma output, ileus, blood loss or excessive sweating. Inflammatory losses in the tissues are hard to quantify and are common in pancreatitis, sepsis, burns and abdominal emergencies.

It is vital to replace high gastro-intestinal (GI) losses. Patients may otherwise develop severe metabolic derangement with acidosis or alkalosis and hypokalaemia. Hypochloraemia occurs with upper GI losses.

Overview of Sodium Balance



Hyponatremia

Primary sodium loss
Poor intake of sodium
Increased urinary loss of sodium
Increased GI loss of sodium
Transcutaneous loss of sodium
Transmembrane shift of sodium

Primary water excess
Excessive intake of water
Excessive oxidative phosphorylation
Decreased urinary loss of water
Decreased GI loss of water
Decreased transcutaneous loss of water
Transmembrane shift of water

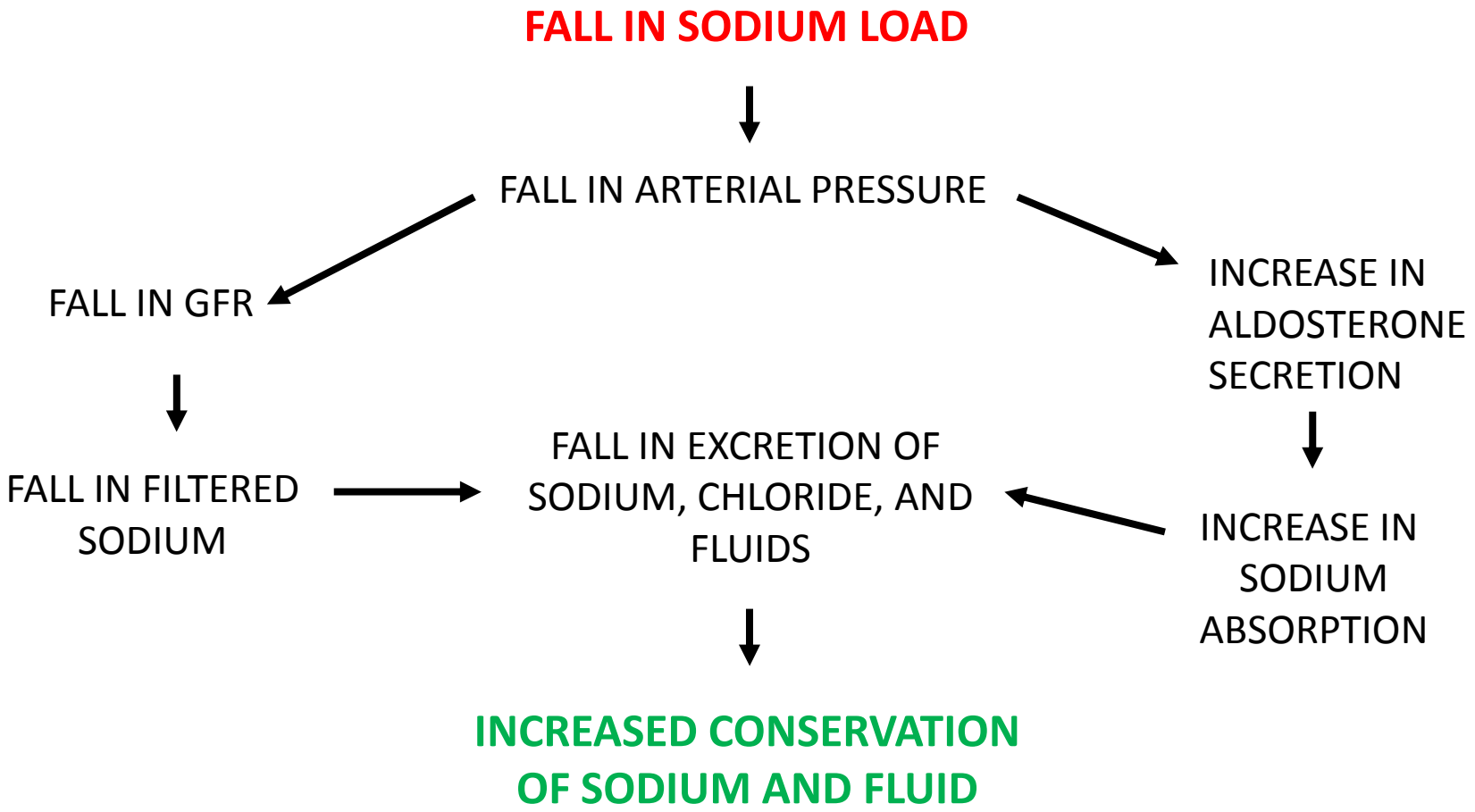
Hypernatremia

Primary sodium excess
Increased intake of sodium
Decreased urinary loss of sodium
Decreased GI loss of sodium
Decreased transcutaneous loss of sodium
Transmembrane shift of sodium

Primary water loss
Decreased intake of water
Diminished oxidative phosphorylation
Increased urinary loss of water
Increased GI loss of water
Increased transcutaneous loss of water
Transmembrane shift of water

Italics Physiologic state which either does not occur, or does not lead to significant pathologic abnormality.

Blood pressure and renal handling of sodium



Osmolarità sierica = [(2 Na) + (Azotemia/2,8) + (Glucosio/18)]

Hyponatremia

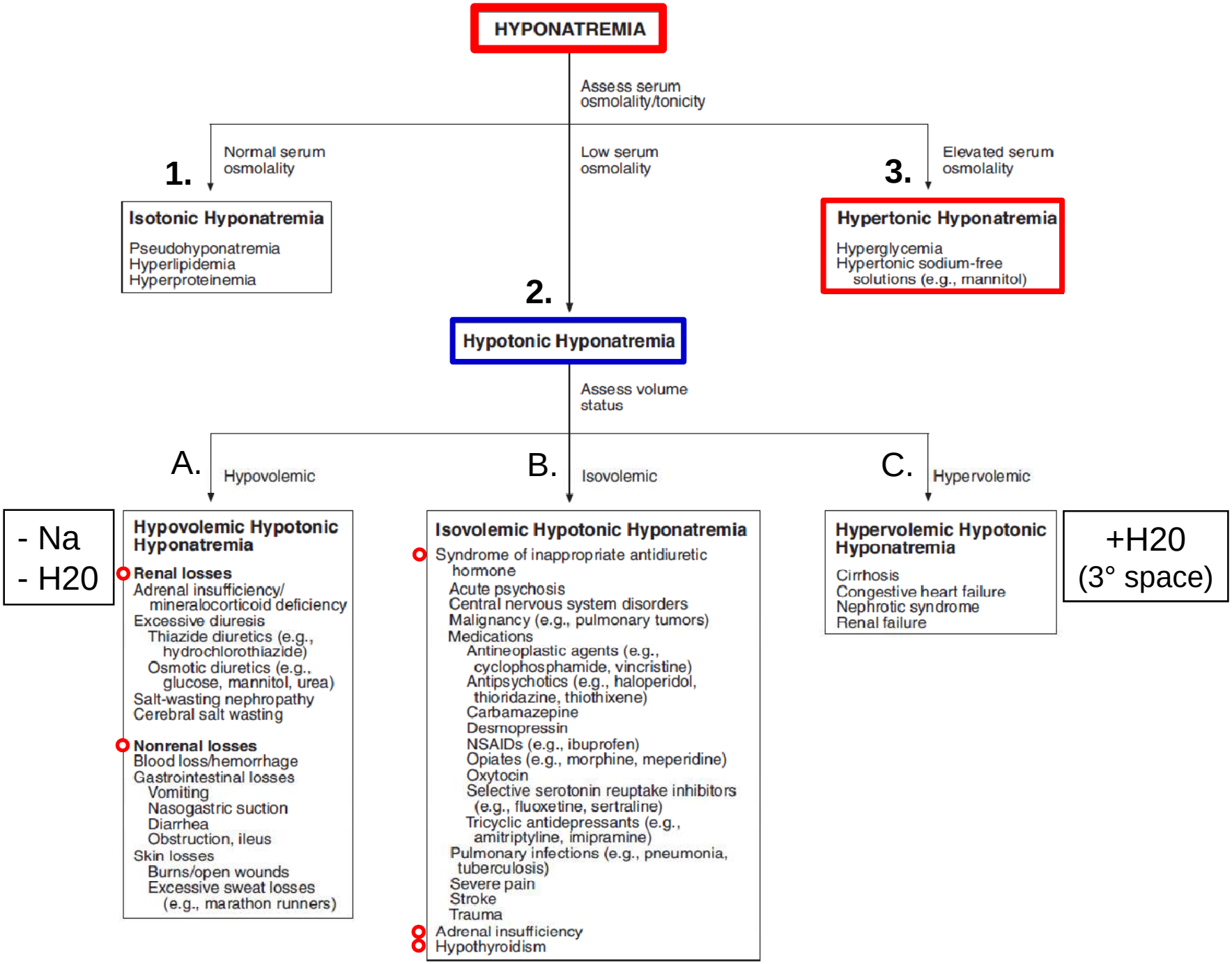
Decreased serum sodium

Na+ <135 mEq/L

Hyponatremia

- Loss of salt (and water)
  - Diuretics
  - Addison's disease
  - Osmotic diuresis (DKA)
  - Diarrhea
  - Diaphoresis
  - Vomiting
- Increased body water (dilutional hyponatremia)
  - Excess water intake (water intoxication)
  - CHF
  - Renal failure
  - Cirrhosis

Figure 1. Classification and common etiologies of hyponatremia.[1,3,6,8,9] NSAIDs = nonsteroidal antiinflammatory drugs.



Hyponatremia

- Signs/Symptoms
  - Often asymptomatic if slow or until below 120 mEq/L (130 mEq/L if acute)
  - Neurologic: ***lethargy, apathy secondary to cerebral edema, headache, muscle twitching, hyper-reflexia, seizures*** (Na^+ <110 mEq/L)
  - Salivation, lacrimation, diarrhea
- Treatment: *correct the underlying condition:*
  - Hyperv: fluid restrict, ± diuretics
  - Hypov: hypertonic saline to increase level 2-3 mEq/L/hr at max rate 100cc of 5% saline/hr

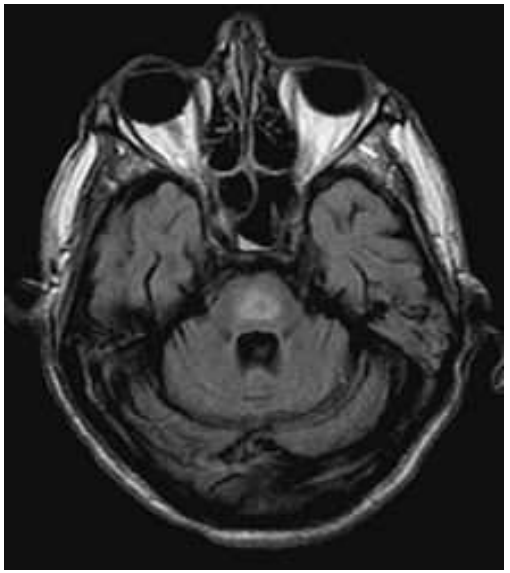
Mielinolisi Pontina Centrale

Conosciuta anche con il nome di ***sindrome da demielinizzazione osmotica***, è una patologia neurologica causata da un grave danno a carico della guaina di mielina delle cellule nervose nel tronco encefalico, più precisamente nel ponte.

La causa della malattia è prevalentemente iatrogena: ***correzione troppo veloce di una iposodiemia.***

Si caratterizza per l'insorgenza di: *paralisi acuta, disfagia, disartria e altri sintomi neurologici.*

Può verificarsi anche in altre zone cerebrali esterne al ponte e per questo alcuni autori ritengono più corretto il termine ***sindrome da demielinizzazione osmotica***



Osmolarità sierica = [(2 Na) + (Azotemia/2,8) + (Glucosio/18)]

Hypernatremia

Elevated serum sodium

Na^+ >150 mEq/L

Hypernatremia

- Free water deficit or water loss are greater than salt loss. **Always associated with hyper osmolar state. *High mortality rate (>40% if severe)***
- Forms:
  - **Hypovolemic: *the true dehydration***
  - **Isovolemic:** seen in diabetes insipidus (↓ ADH)
  - **Hypervolemic:** loss of hypotonic fluids with inadequate replacement with hypertonic fluids. Hypervolemic is usually iatrogenic! May see also in Cushing's and Conn's diseases

Hypernatremia

Classification and Common Etiologies of Hypernatremia

Classification	Etiology
Hypovolemic	Loss of hypotonic fluids (vomiting, diarrhea, nasogastric suctioning, osmotic diuresis, burns and open wounds, sweat, lungs)
Isovolemic	Diabetes insipidus (central diabetes, nephrogenic diabetes insipidus)
Hypervolemic	Hypertonic saline solutions, sodium bicarbonate solutions, mineralocorticoid excess (hyperaldosteronism)

Hypernatremia

- Signs/Symptoms
  - Neurologic: restless, ***seizure, coma, delirium***
  - Sticky mucus membranes, poor salivation and lacrimation, hyperpyrexia, red swollen tongue
  - ***Thirst, weakness***

- Treatment: correct underlying disorder
  - ***Free water replacement in dehydration.*** Slow infusion of glucose 5%: give ½ over first 24 hrs, then rest over next 24 hrs to avoid cerebral edema.

Hypernatremia

water deficit = (total body water) x [1-(Na/140]

(total body water = correction factor x weight)

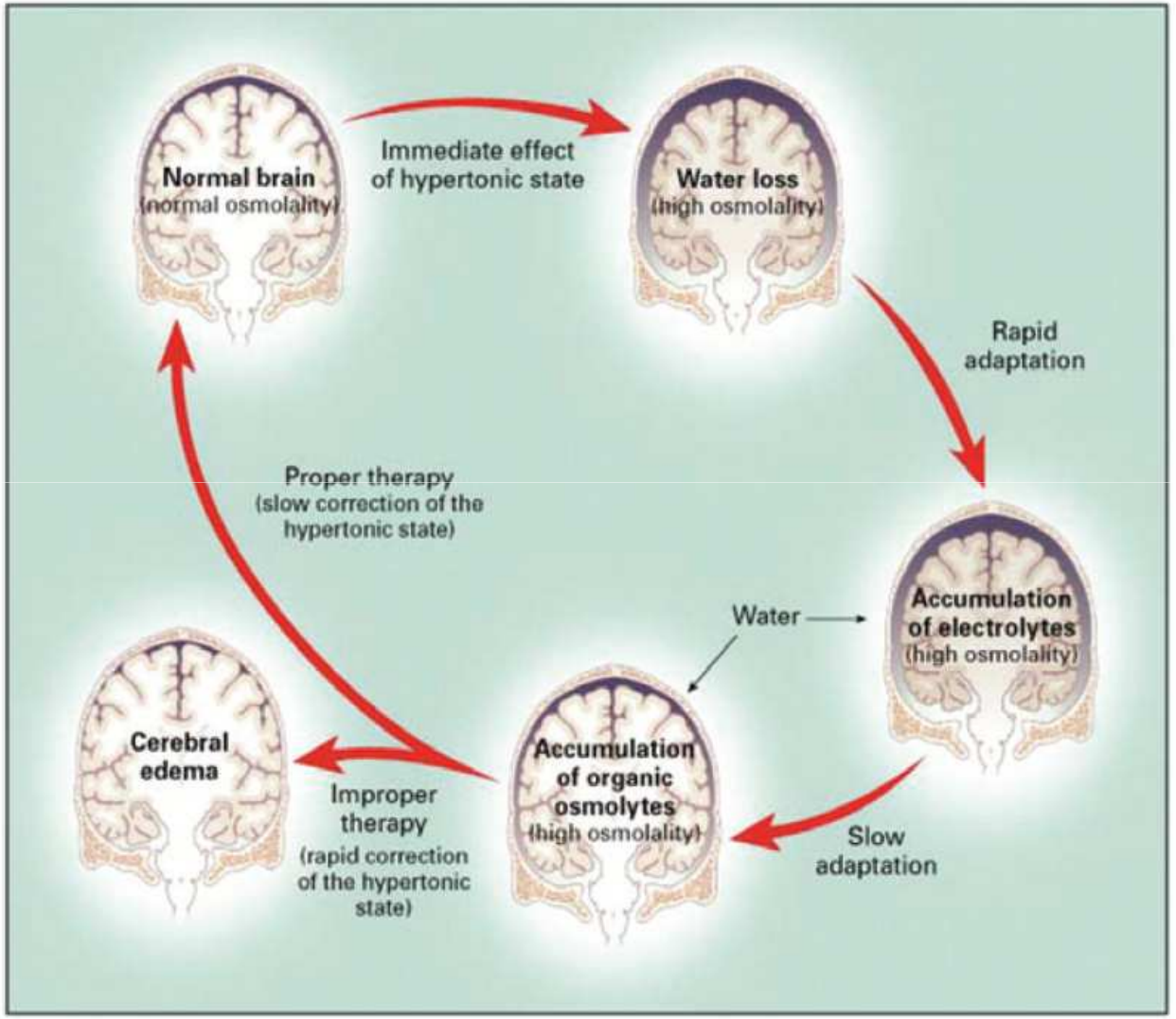
The correction factor is 0.6 for men, 0.5 for women and elderly men, and 0.45 for elderly women.

$$\text{Deficit idrico} = \frac{(\text{Na attuale} - \text{Na desiderato}) \times \text{peso attuale} \times 0{,}6}{\text{Na desiderato}}$$

Esempio: il deficit idrico in un uomo che pesa 70 kg con sodiemia di 156 mEq/L è:

$$\frac{(156 - 140) \times 70 \times 0{,}6}{140} = 4{,}8 \text{ L}$$

Too fast correction : risk of Brain Edema



Fonte: Adrogue HJ, et al. N Engl J Med 2000; 342(20):1493-9.

Overview of Potassium Balance

Potassium is not produced

Potassium is not consumed

Outside World

Dietary intake of potassium

Blood

Outside World

Urinary excretion of potassium
GI losses of potassium
Transcutaneous losses of potassium via sweat

Intracellular Fluid

Hyperkalemia

Excessive intake
Decreased urinary excretion
Decreased GI loss
Decreased transcutaneous loss
Transmembrane shift

Hypokalemia

Poor intake
Increased urinary excretion
Increased GI loses
Increased transcutaneous losses
Transmembrane shift

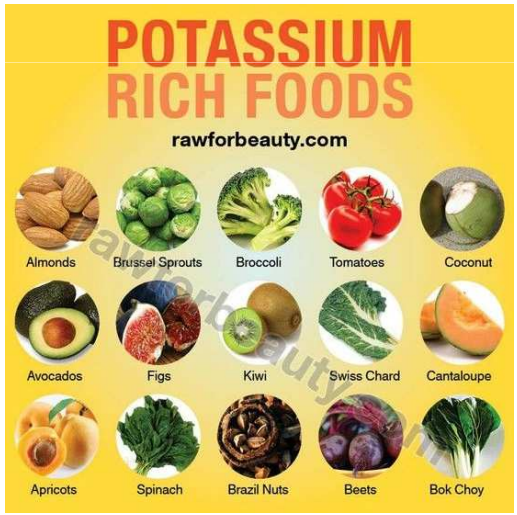
Hypokalemia

Decreased serum potassium

$K^+ < 3.5$ mEq/L

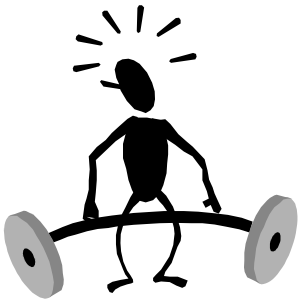
Hypokalemia can only occur for four reasons:

1. **Decreased intake of K**
2. **K shifts inside the cells**
3. **Extra-renal losses of K**
4. **Renal losses of K**

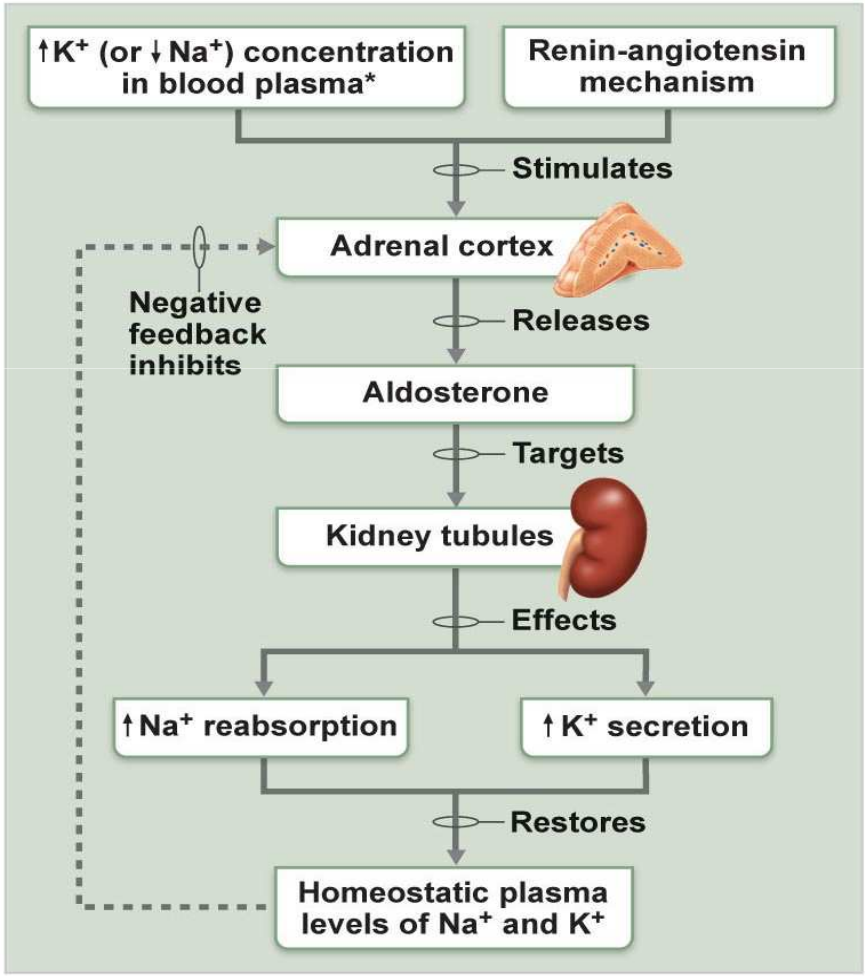


Hypokalemia

- **Etiology:**
  - Intracellular uptake with redistribution: seen in ***acute alkalosis, insulin therapy,*** and anabolism state
  - Depletion: due to ***GI losses, renal/diuretics, steroids***, and renal tubular acidosis
- **S/Sx:**
  - ***Clinical***: ***muscle weakness/fatigue, decreased tendon reflexes, ileus.*** Insulin resistance in DM
  - EKG: low, flat T-waves, ST depression, and U waves

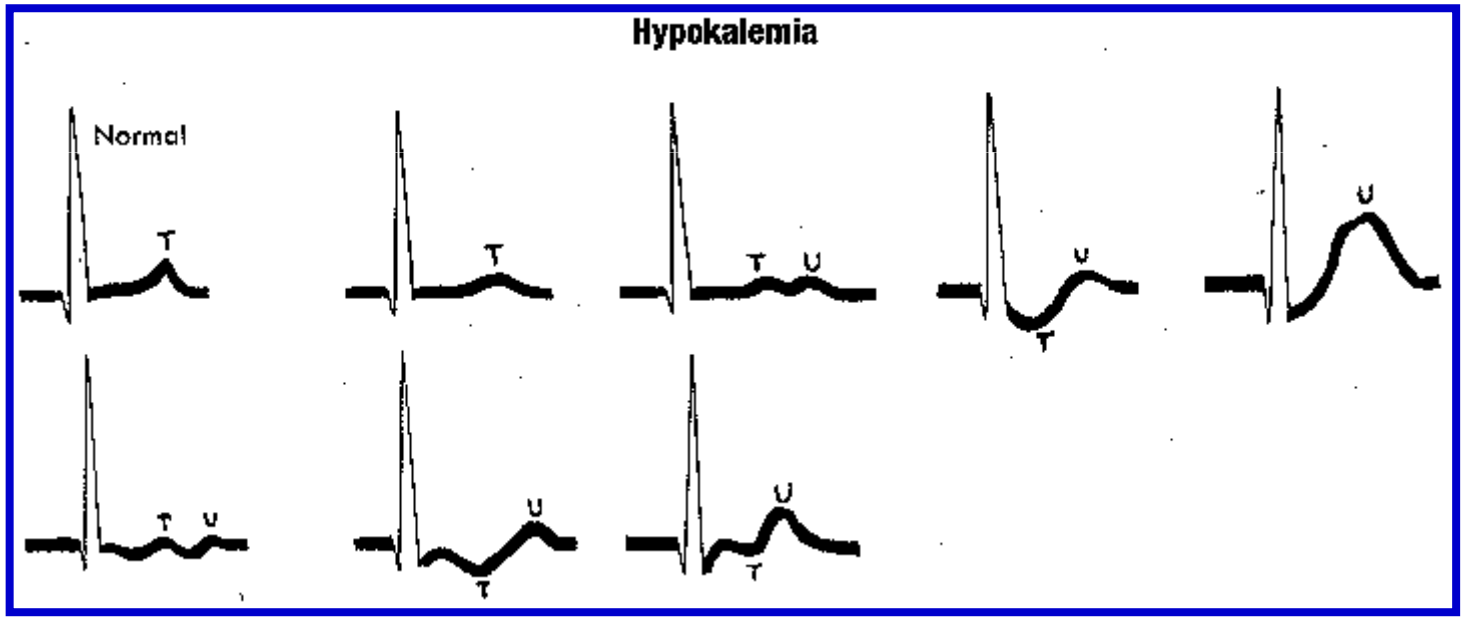


Hypokalemia in Hyperaldosteronism



Hypokalemia

- ECG changes in hypokalemia (↓)



Low, flat T-waves, ST depression, and U waves

Hypokalemia

Oral K:

- KCL cp: e.g. retard 600 mg 1 cp x 2 die
- K aspartate: e.g. 10-30 mEq in a glass of water

IM K: NO

EV K: big vein, small catheter, diluted (e.g. 60 mEq in 500 ml saline in1h)

Hypokalemia

Empirical Treatment of Hypokalemia

Severity	Serum Potassium Concentration (meq/L)	I.V. Potassium Replacement Dose (meq)[a]
Mild to moderate	2.5–3.4	20–40
Severe	<2.5	40–80

[a]In patients with normal renal function; patients with renal insufficiency should receive ≤50% of the initial empirical dose. Rate of infusion = 10–20 meq potassium per hour; maximum infusion rate = 40 meq potassium per hour. Continuous cardiac monitoring and infusion via a central venous catheter are recommended for infusion rates >10 meq potassium per hour. Maximum potassium = 80 meq/L via a peripheral vein; up to 120 meq/L via a central vein (admixed in 0.9% or 0.45% sodium chloride injection).

Hyperkalemia

Elevated serum potassium

$K^+ > 5.5$ mEq/L

$K^+ > 6$ mEq/L - **Emergency**

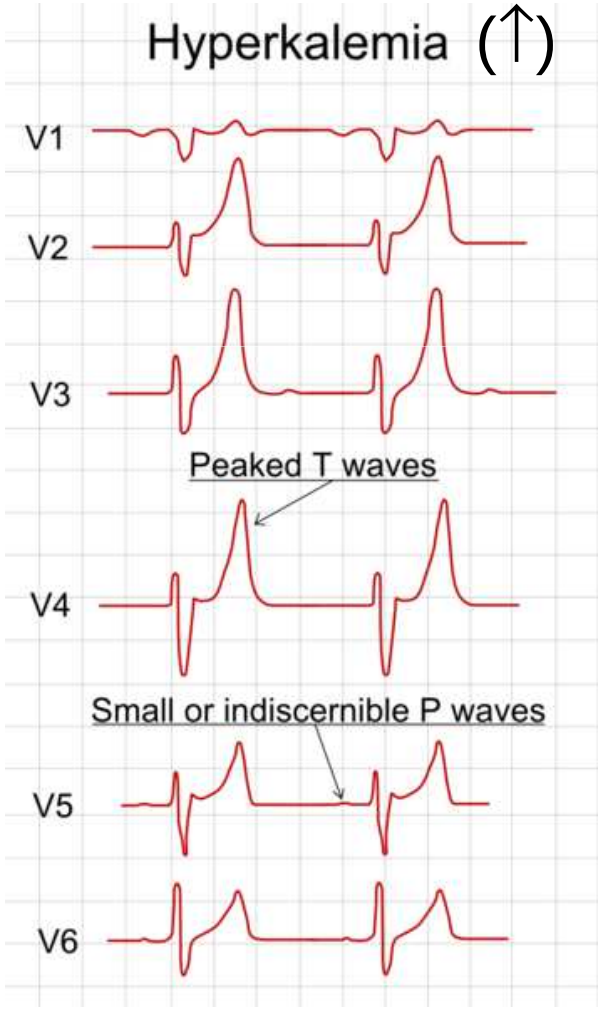
$K^+ > 7$ mEq/L - **Life Threat**

Hyperkalemia

- Etiology:
  - Renal insufficiency, spironolactone, ACE-inhibitors, diabetes, mineralcorticoids deficiency
  - Redistribution in acidosis, hypo-insulinism, tissue necrosis, digoxin poisoning, severe hemolysis
  - Psuedo-hyperkalemia in leukocytosis, and thrombocytosis

Hyperkalemia

- S/Sx:
  - Clinical: nausea/vomiting, colic, weakness diarrhea
  - EKG: (↑)
  - early peaked T waves; then flat P waves, depressed ST segment, widened QRS progressing to sine wave and V fibrillation
  - Cardiac arrest occurs in diastole



Hyperkalemia

- Treatment:
  1. Remove iatrogenic causes (ACEs, spironolattone)
  2. Acute: if > 7.5 mEq/L or EKG changes
     - ***Ca-gluconate: 1 mg over 2 min IV***
     - ***Glucose 5% + regular insulin***
     - Sodium bicarbonate
     - ***Emergent dialysis***
  3. ***Hydration*** (saline) and ***diuretics*** (furosemide)
  4. ***Kayexalate*** (ionic exchange resins) x OS or enema

Hyperkalemia

Treatments for Hyperkalemia

Treatment	Dose	Route	Time to Onset	Duration of Effect	Mechanism of Action and Effects
Calcium gluconate[a,b]	1–2 g (4.56–9.12 meq cacium)	I.V. over 5–10 min	1–2 min	10–30 min	Antagonizes cardiac conduction abnormalities
Sodium bicarbonate[a]	50–100 meq	I.V. over 2–5 min	30 min	2–6 hr	Increases serum pH; redistributes potassium into cells
Insulin (regular)[a] (with dextrose)	5–10 units	I.V. with 50 mL of 50% dextrose injection	15–45 min	2–6 hr	Redistributes potassium into cells
50% dextrose	50 mL (25 g)	I.V. over 5 min	30 min	2–6 hr	Increases insulin release; redistributes potassium into cells; prevents hypoglycemia when insulin is given
10% dextrose	1000 mL (100 g)	I.V. over 1–2 hr	30 min	2–6 hr	Increases insulin release; redistributes potassium into cells; prevents hypoglycemia when given with insulin
Furosemide	20–40 mg	I.V.	5–15 min	4–6 hr	Increases renal potassium loss
Sodium polystyrene sulfonate[c]	15–60 g	Oral or rectal	1 hr	4–6 hr	Resin exchanges sodium for potassium; increases fecal potassium elimination
Albuterol	10–20 mg	Nebulized over 10 min	30 min	1–2 hr	Stimulates sodium–potassium pump; redistributes potassium into cells
Hemodialysis	2–4 hr	NA[d]	Immediate	Variable	Removes potassium from plasma

[a]First-line therapies in hyperkalemic emergencies.
[b]Repeat dose in five minutes if abnormal electrocardiogram persists. Calcium chloride may also be used, but calcium gluconate is preferred over calcium chloride for peripheral venous administration because it causes less venous irritation. Calcium chloride (1000 mg = 13.6 meq calcium) provides three times more calcium than calcium gluconate (1 g = 4.56 meq calcium).
[c]Can be used to treat acute hyperkalemia, but the effects may not be seen for several hours. Removes 0.5–1 meq of potassium per 1 g of sodium polystyrene sulfonate.
[d]NA = not applicable.

Hypocalcemia

Decreased serum calcium

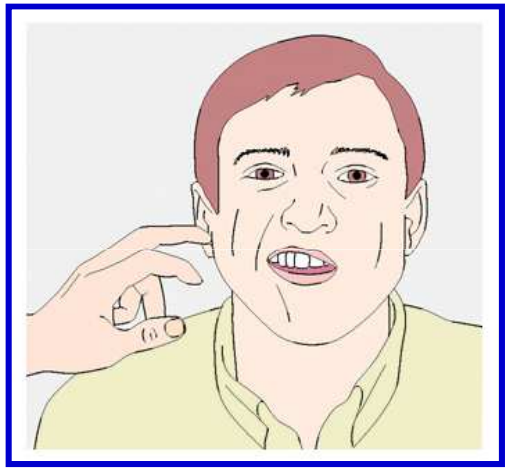
$Ca^{2+} < 8.5$ mg/100ml

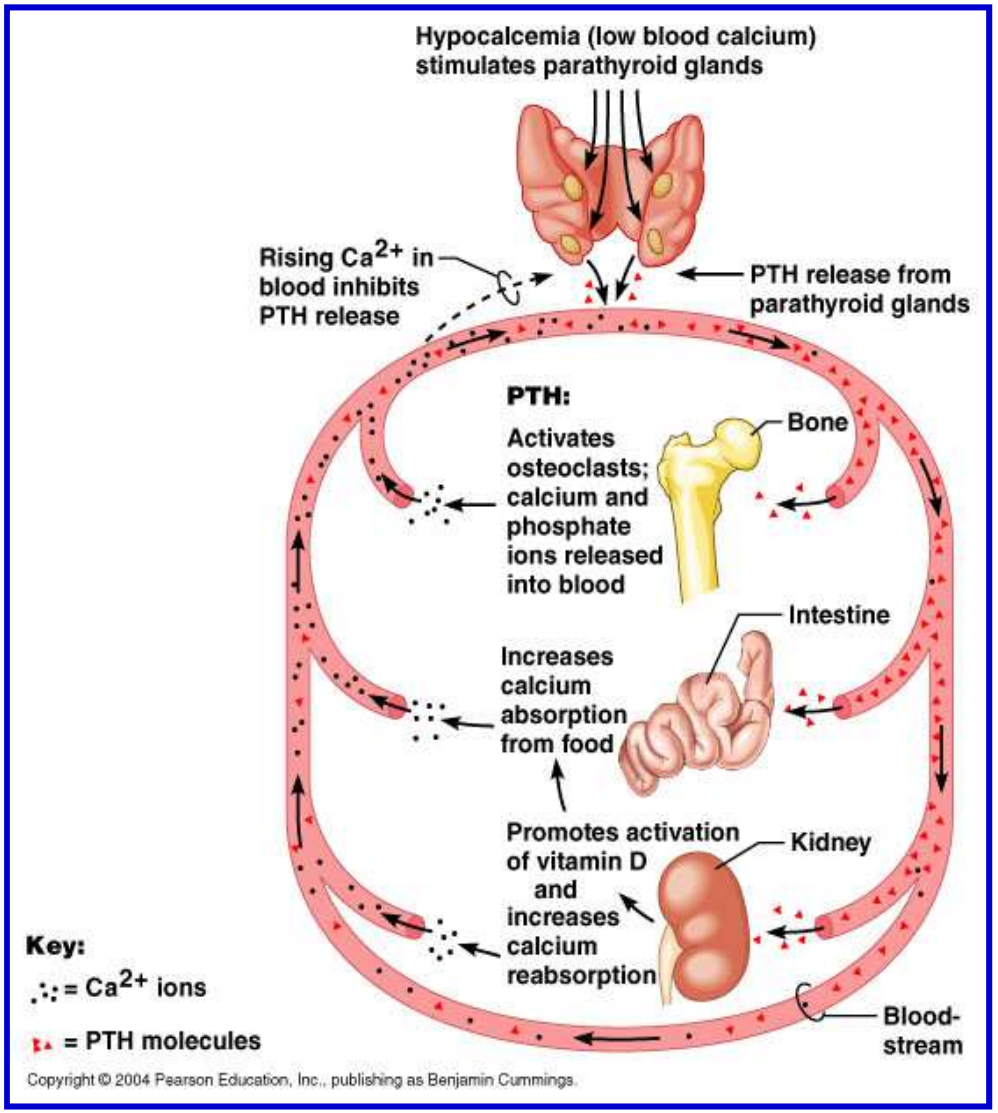
Hypocalcemia

- Seen in hypoalbuminemia (*need to correct for!*). Check ionized Ca. Often symptomatic below 8 mEq/dL
- ***Check PTH:***
  - **High:** ***low Vitamin D, renal insufficiency*****,** pancreatitis, hyperPO4, pseudohypoparathyroidism, massive blood transfusion (citrate), drugs (e.g. gentamicin)
  - **S/Sx:** ***numbness, tingling, circumoral paresthesia***, ***cramps tetany, increased tendon reflexes,*** Chvostek's sign, Trousseau's sign
  - EKG has prolonged QT interval

Hypocalcemia

Chvostek's sign -
Trousseau's sign





Hypocalcemia

Treatment:

- **Acute:** (IV) CaCl 10 cc of 10% solution = 6.5 mmol Ca or Ca.Gluconate 10cc of 10% solution = 2.2 mmol Ca
- **Chronic:** (OS) 0.5-1.25 gm $CaCO_3$ = 200-500 mg Ca.
- **Vit D (calciferol):** must have normal serum PO4. Start 50.000 – 200.000 units/day

Hypocalcemia

Calcium Supplements

Calcium Salt	Elemental Calcium (meq/g)	Elemental Calcium (%)	Administration Route[a]
Calcium chloride	13.6	27	I.V.
Calcium gluconate	4.56	9	I.V. or oral
Calcium acetate	12.7	25	I.V. or oral
Calcium carbonate	20	40	Oral
Calcium citrate	10.5	21	Oral

[a]Maximum rate of i.v. infusion = 1.5 meq/min.

Empirical Dosages of I.V. Calcium[5,32,142]

Degree of Hypocalcemia	Preferred Calcium Salt[a]	Intermittent Bolus Dosage	Continuous Infusion Dosage[b]
Mild to moderate, asymptomatic	Gluconate	1–2 g calcium gluconate over 30–60 minutes; may repeat every 6 hours as needed	4.56–9.12 meq calcium over 30–60 minutes; may repeat every 6 hours as needed
Severe, symptomatic	Chloride or gluconate	1000 mg calcium chloride or 3 g calcium gluconate over 10 minutes; may repeat as needed	13.6 meq calcium over 10 minutes; may repeat as needed
Severe, symptomatic; refractory to intermittent bolus doses	Chloride or gluconate	Not applicable	0.8–1.5 meq calcium per minute; monitor serum calcium every 6 hours or more frequently

[a]Calcium chloride should be administered via a central venous catheter to avoid extravasation and tissue necrosis; 1000 mg calcium chloride = 13.6 meq calcium; 1 g calcium gluconate = 4.56 meq calcium.

[b]Maximum rate of intravenous infusion = 1.5 meq calcium per minute.

Hypercalcemia

Increased serum calcium

Ca^{2+} > 10.5 mg/100ml

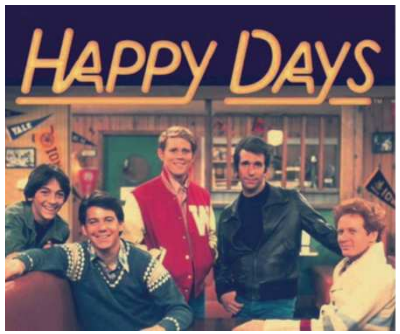
Hypercalcemia

- Usually secondary to **hyperparathyroidism** or **malignancy.**
- Other causes are: ***thiazides,*** milk-alkali syndrome, granulomatous disease, acute adrenal insufficiency
- Acute crisis is serum Ca> 12mg/dL. Critical at 16-20mg/dL
- S/Sx: ***anorexia, abdominal pain, confusion, lethargy, coma***

Milk-alkali syndrome

- In ***"milk-alkali syndrome"*** patients take excessive amounts of **milk and antacids** to control dyspepsia, leading to overingestion of two key ingredients that lead to the disorder: excess calcium and excess base.

- Ingesting over two grams of elemental calcium per day produces this disorder in susceptible individuals. Gastrointestinal absorption of such a large amount of calcium leads to hypercalcemia



Hypercalcemia

Treatment:

- ***Hydration with saline solution (dilution)***
- ***Loop diuretic (furosemide)***
- ***Biphosphonates IV (stop osteoclasts activity)***
- ***Steroids for:*** lymphoma, multiple myeloma, adrenal insufficiency, bone mets, Vit D intoxication. May need Hemodialysis.

Hyperphosphatemia

– ***Renal insufficiency*****,** hypoparathyroidism, may produce “metastatic” calcification

Pharmacologic Treatment of Hyperphosphatemia

Medication	Dosage Forms	Initial Recommended Dosage[a]	Maximum Recommended Dosage[a]
Calcium acetate	Tablet: 667 mg Gelcap: 667 mg	2 tablets or gelcaps three times daily with meals	4 tablets or gelcaps with each meal daily; avoid hypercalcemia
Calcium carbonate	Tablet, capsule, liquid, and powder; various strengths	1–2 g three times daily with meals	7 g/day; avoid hypercalcemia
Aluminum hydroxide	Tablets: 300 and 600 mg Suspension: 320 mg/5 mL	1–2 tablets or 15–30 mL three or four times daily with meals and at bedtime	1800 mg (3–6 tablets) or 30 mL every 4 hr
Magnesium hydroxide	Tablets: 300 and 600 mg Liquids: 400 and 800 mg/5 mL	1–2 tablets or 5–15 mL three times daily with meals	2–4 tablets four times daily with meals or 15 mL four times daily with meals and at bedtime
Sevelamer	Tablets: 400 and 800 mg Capsule: 403 mg	800–1600 mg three times daily with meals	4000 mg three times daily with meals

[a]May require higher doses in rare situations or in some patients with chronic renal insufficiency and severe hyperphosphatemia. The dosage should be adjusted to achieve the goal serum phosphorus level in these situations.

Hypomagnesemia

Hypomagnesemia

- ***Malnutrition (most elderly), burns***, pancreatitis, SIADH, after parathyroidectomy, primary hyperaldosteronism

- S/Sx: ***weakness, fatigue, hypereflexia, seizure, arrhythmia***

- Treatment: IV replacement of 2-4 g of $MgSO_4$ per day or oral replacement