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**Updates in Therapeutics® 2015: Critical Care Pharmacy Preparatory  
Review Course**

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**Fluids, Electrolytes, Acid-Base Disorders, and  
Nutrition Support**

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# Conflict of Interest Disclosures

- Nestlé Nutrition (consultant; speaker)
  - NPS Pharmaceuticals (consultant)
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# Learning Objectives

1. Assess hypo and hypernatremia and develop an appropriate treatment plan.
  2. Discuss causes and treatment of common intracellular electrolyte disorders.
  3. Differentiate causes for metabolic acidosis and alkalosis and construct a therapeutic treatment.
  4. Specify appropriate route for nutrition therapy, amounts, and component formulation.
  5. Identify markers for assessing tolerance, safety, and efficacy of enteral or parenteral nutrition.
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## Learning Objectives (continued)

5. Describe methods for ensuring glycemic control.
  6. Identify pertinent drug-nutrient interactions, and provide recommendations for the safe and effective delivery of medications to patients receiving enteral or parenteral nutrition therapy.
  7. Discuss current controversies regarding nutrition therapy for critically ill patients.
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# Lecture Outline

1. Fluid and Electrolyte Overview (pg 54-56)
  2. Water and Sodium Aberrations (pg 56-57)
  3. Intracellular Electrolytes (pg 57-68)
  4. Acid-Base Disorders (pg 68-74)
  5. Nutritional Assessment, Energy/Protein Requirements (pg 74-80)
  6. Enteral Nutrition (pg 80-82)
  7. Parenteral Nutrition (pg 82-85)
  8. Glycemic Control (pg 86-88)
  9. Controversies in Nutrition Support for Critically Ill Patients (pg 88-94)
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# Body Water and Fluids

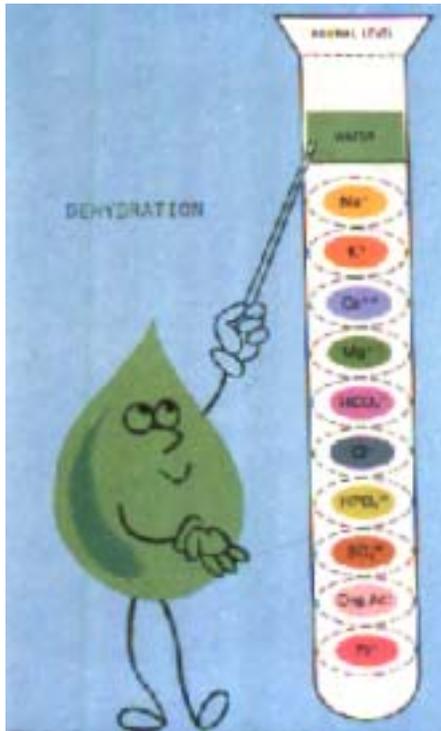
- Total body water: ~60% of weight for males; 55% for females – lower % for obese/elderly
  - Daily fluid requirements: 30 to 35 mL/kg/d (over-estimates obese, under-estimates small person). Alternative: ~1.4 to 1.5 L/m<sup>2</sup>/d BSA
  - 100 mL/kg for first 10 kg, 50 mL/kg for next 10 kg, and then 20 mL/kg for each kg thereafter
  - Insensible losses ~550 mL/m<sup>2</sup>/d BSA – increased ~10% to 15% per degree > 37°C
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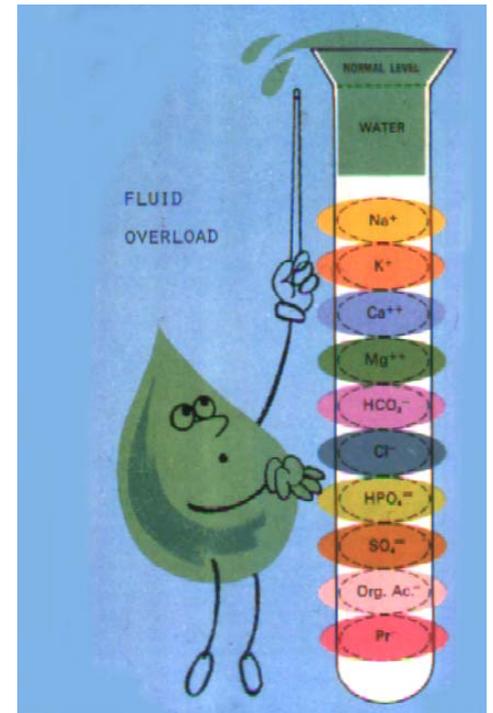
# Fluid Balance Assessment

- Recorded volume intake – volume output
  - “Normal” fluid balance ~ 600 to 800 mL/d
  - “Normal” fluid balance decreased with ventilator dependency (less humidified air lost)
  - “Normal” fluid balance increased with fever
  - Physical exam (mucous membranes, decreased skin turgor, edema)
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# Fluid Balance Assessment



- Hemodynamic markers (Swan-Ganz catheter measurements, CVP, tachycardia?)
- Urine output; I/Os, fever
- BUN, BUN/creatinine ratio
- Serum sodium change
- Alkalemia (“contraction alkalosis”)
- Glycemic control



## Electrolyte Content of GI Fluids (Table 4)

| Fluid           | Daily Volume (mL) | Na (mEq/L) | K (mEq/L) | CL (mEq/L) | HCO <sub>3</sub> (mEq/L) | Mag (mEq/L) |
|-----------------|-------------------|------------|-----------|------------|--------------------------|-------------|
| Stomach         | 1000 – 2000       | 60 –90     | 10 –15    | 100 –130   |                          | 0.9         |
| Duodenum        | 400 – 600         | 140        | 5 –10     | 90 –120    | 80                       |             |
| Small intestine | 2000 – 2500       | 140        | 5 –10     | 90 –120    | 30 – 40                  | 6 –12       |
| Colon           | < 300             | 60         | 20 –30    | 50         |                          | 6 –12       |
| Pancreas        | 600 – 800         | 140        | 5 –10     | 75         | 115                      | 0.4         |
| Bile            | 300 – 600         | 140        | 5 –10     | 100        | 30                       | 1.1         |

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## Self Assessment Question #2 (pg 52)

(from Tables 4 and 5):

**Which of the following would be the best replacement fluid for nasogastric losses?**

-  A. 0.9% sodium chloride and KCL 20 mEq/L
  -  B. 0.45% sodium chloride and KCL 20 mEq/L
  -  C. 5% dextrose in 0.225% sodium chloride and KCL 20 mEq/L
  -  D. Lactated ringers solution
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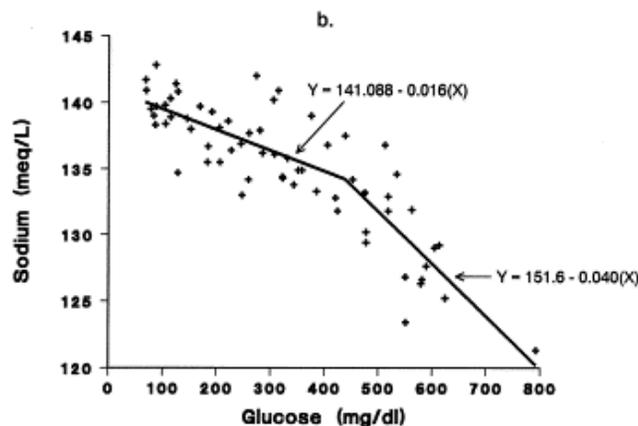
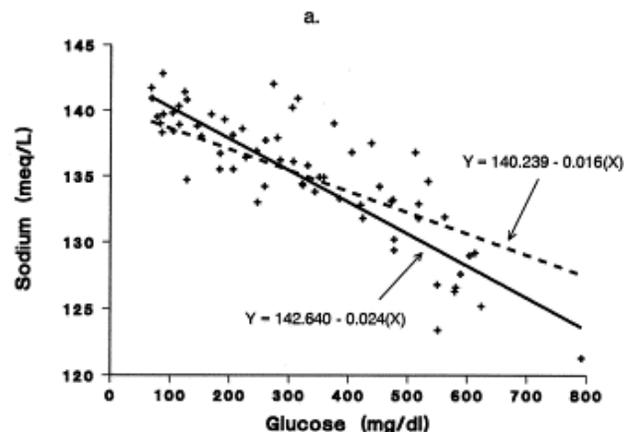
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# Evaluation of Hyponatremia

- Rule out pseudo or factitious hyponatremia (hyperproteinemia, hyperlipidemia, hypoglycemia)
  - Exclude mannitol, glycine for unmeasured osmoles
  - Evaluate ECF volume (American method) or urine sodium/osmolality (European method)
  - Evaluate urine sodium/osmolality (American method) or ECF volume (European method)
  - Consider patient conditions/diagnoses
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# Correcting Serum Sodium Concentration for Hyperglycemia

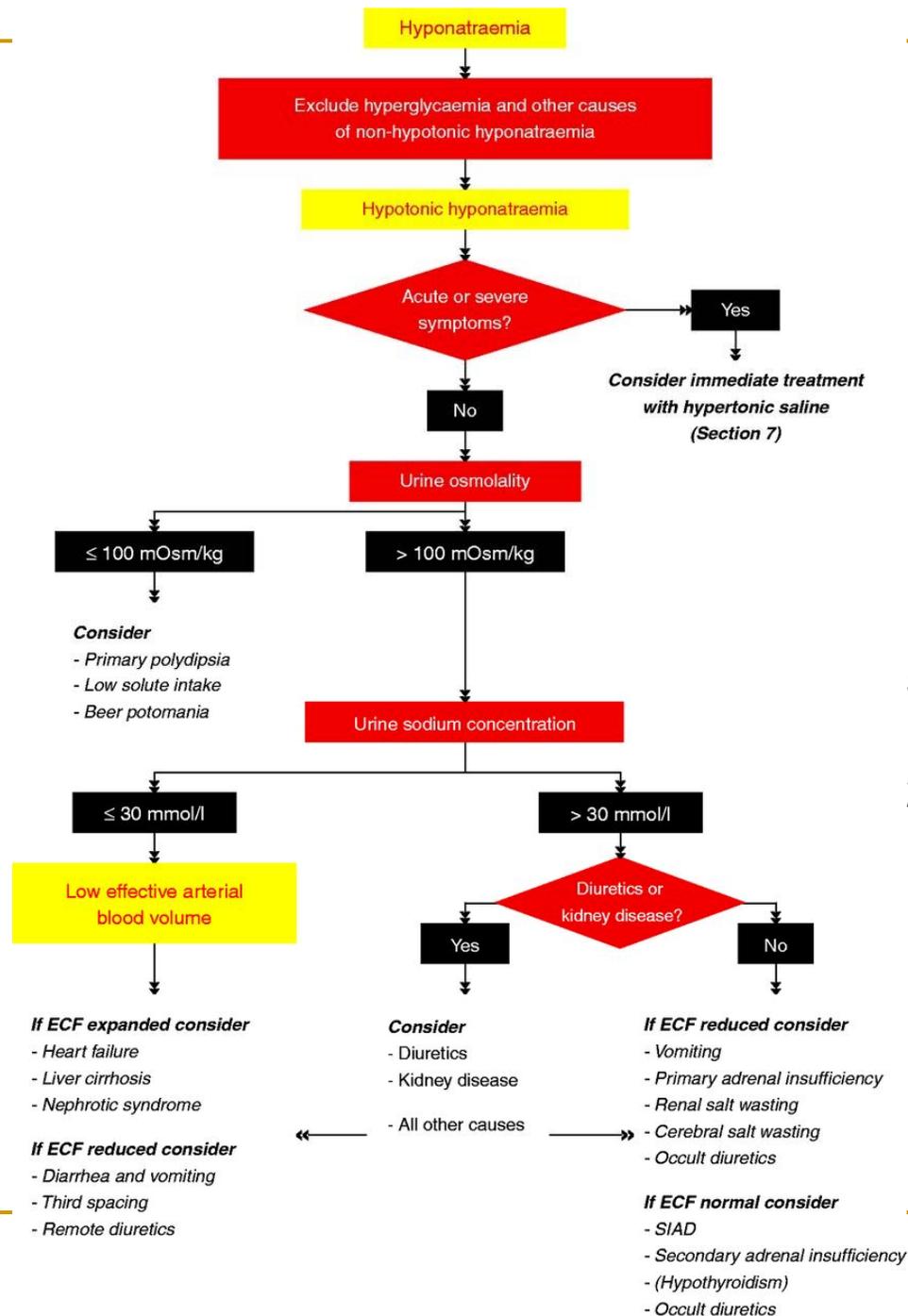
- For every 100 g/dL increase in BG > 100 mg/dL; serum Na will decrease by ~ 1.6 to 2.4 mEq/L
- Example: A patient with a serum glucose of 300 mg/dL and a Na of 130 mEq/L is given insulin therapy. What is the corrected serum Na once his BG is treated to normal?
- $300 - 100 = 200$ ;  $200/100 = 2$
- $2 \times (1.6 \text{ to } 2.4 \text{ mEq/L}) = 3 \text{ to } 5 \text{ mEq/L}$
- His “corrected” serum Na would be =  $130 + (3 \text{ to } 5) = 133 \text{ to } 135 \text{ mEq/L}$



# Hyponatremia

- Defined as a serum Na < 135 mEq/L (some clinicians are unconcerned unless serum Na < 130 mEq/L; severe: Na < 120 mEq/L)
- Sodium content within a defined volume of water
- MUST be interpreted with assessment of ECF status
- Patients can be hypovolemic, euvolemic, or hypervolemic (and have a low serum Na)





**Spasovski G et al.  
Eur J Endocrinol  
2014;170:G1-G47**

## Causes of Syndrome of Inappropriate Antidiuretic Hormone\*

### CNS Disorders

Trauma or stroke (subdural hematoma, subarachnoid or intracranial hemorrhage)

Infection (meningitis, encephalitis, brain abscess)

Malignancy (brain tumors)

### Malignancy

Small cell carcinoma of the lung

Pancreatic carcinoma

Lymphoma, Hodgkin's disease, sarcoma

### Pulmonary Infection

Pneumonia

Lung abscess

Tuberculosis

### Drugs

Carbamazepine

Nonsteroidal anti-inflammatory drugs

Chlorpropamide

Tricyclic antidepressants and selective serotonin reuptake inhibitors

Cyclophosphamide, vincristine, vinblastine

Narcotics

Angiotensin converting enzyme inhibitors

Clofibrate

Oxytocin

ADH analogs (desmopressin, vasopressin)

Antipsychotic agents

### Endocrine Disorders

Pituitary tumor

Hypothyroidism

Adrenal insufficiency

### Other conditions

Positive pressure ventilation

AIDS

Stress response (eg, surgery, trauma, thermal injury, sepsis)

## A Comparison of Clinical Findings in Cerebral Salt Wasting Syndrome (CSWS) vs Syndrome of Inappropriate Antidiuretic Hormone (SIADH)\*

| CSWS                                 | SIADH   |
|--------------------------------------|---|
| Hyponatremia                         | Hyponatremia                                  |
| Decreased extracellular fluid volume | Normal or expanded extracellular fluid volume |
| Negative sodium balance              | Variable sodium balance                       |
| Negative fluid balance               | Positive fluid balance or fluid equilibrium   |
| CVP/PCWP/EDVI decreased              | CVP/PCWP/EDVI normal or increased             |
| Decreased body weight                | Increased body weight                         |
| Serum osmolality increased or normal | Serum osmolality decreased                    |
| Urine osmolality increased           | Urine osmolality increased                    |
| Urine sodium concentration increased | Urine sodium concentration increased          |

CVP = central venous pressure  
 EDVI = end-diastolic volume index  
 PCWP = pulmonary capillary wedge pressure

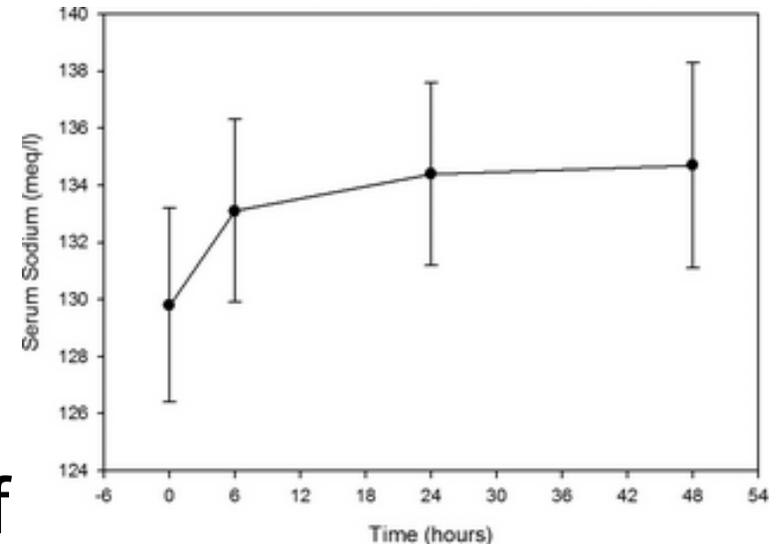
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# Treatment of Hyponatremia

- Acute vs severe symptoms – hypertonic saline vs. conivaptan
  - Do not increase serum Na  $> 10-12$  mEq/L/d (increased risk for central pontine myelinolysis); most clinicians prefer 6-8mEq/L/d change in absence of seizures, etc.
  - ECF expanded – fluid and Na restriction
  - ECF depleted – 0.9% NaCl
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# Treatment of Hyponatremia

- ECF normal – SIADH or adrenal insufficiency
- Fluid restriction first
- Consider conivaptan or tolvaptan if available
- Fluid restriction with use of 0.9% NaCL solution (make PN or EN solutions isonatremic); diuretic therapy may be needed



4.3 ± 2.6 mEq/L increase in serum Na 24 hrs after a single 20 mg bolus of conivaptan

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## Patient Case

- 55 yo 70 kg woman with pneumonia. Serum Na of 125 mEq/L on day 5 of hospitalization. BG is 167 mg/dL, BUN 20 mg/dL, creatinine 1.1 mg/dL
- Receiving EN (1kcal/mL, 62 g protein/L) @ 60 mL/hr + D5 ½ NS @ 25 mL/hr
- Fluid balance: + 300 to 600 mL/d for past 3 days. No edema.
- Serum osmolality 265 mOsm/kg, urine osmolality 490 mOsm/kg, urine Na 67 mEq/L

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# What is the most likely etiology for the patient's hyponatremia?

-  A. Factitious hyponatremia
-  B. Adrenal insufficiency
-  C. Cerebral salt wasting
-  D. SIADH

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# What would be the most appropriate treatment for this woman?

-  A. Sodium chloride tablets 1 g TID
-  B. Limit fluids (fluid restriction)
-  C. Change the intravenous fluid to 0.9% NaCl
-  D. Provide a short-term infusion of 3% NaCl

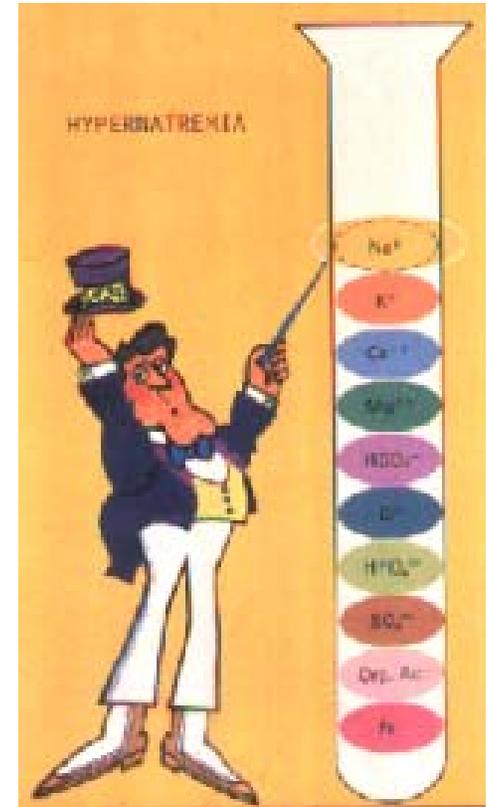
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# What change in the enteral feeding formula would be best?

-  A. Add NaCL 100 mEq/L to the EN formula
-  B. Change the formula to a fish oil enriched formula
-  C. Change the formula to a low carbohydrate, high fat formula
-  D. Change the formula to a 2 kcal/mL formula and decrease the rate

# Hypernatremia

- Hypervolemic: restrict water and Na, diuretics
- Hypovolemic: dehydration (water loss in excess of sodium)
- Euvolemic: primarily free water loss (fever, thermal injury, diabetes insipidous)
- Water deficit (L):  $\text{body weight(kg)} \times 0.6 \times [(\text{serum Na}/140) - 1]^*$



\*commonly reported but ? accuracy – usually underestimates total body water and free water losses.

Chevront SN et al. Am J Clin Nutr. 2013;97:79-85

# Hypernatremia

- Assess ECF volume status
- Do not decrease  $> 10-12$  mEq/L/d (cerebral edema)
- Hypervolemic: reduce Na and fluid intake
- Hypovolemic: hypotonic fluids (e.g.,  $\frac{1}{2}$  NS, D5  $\frac{1}{4}$  NS, D5W, water boluses per tube/po; delete Na in PN temporarily)
- Euvolemic: hypotonic fluids, (central DI: nasal desmopressin 10 mcg BID, IV desmopressin 1- 2 mcg BID), (nephrogenic DI: Na restriction, thiazides –paradoxical Tx)

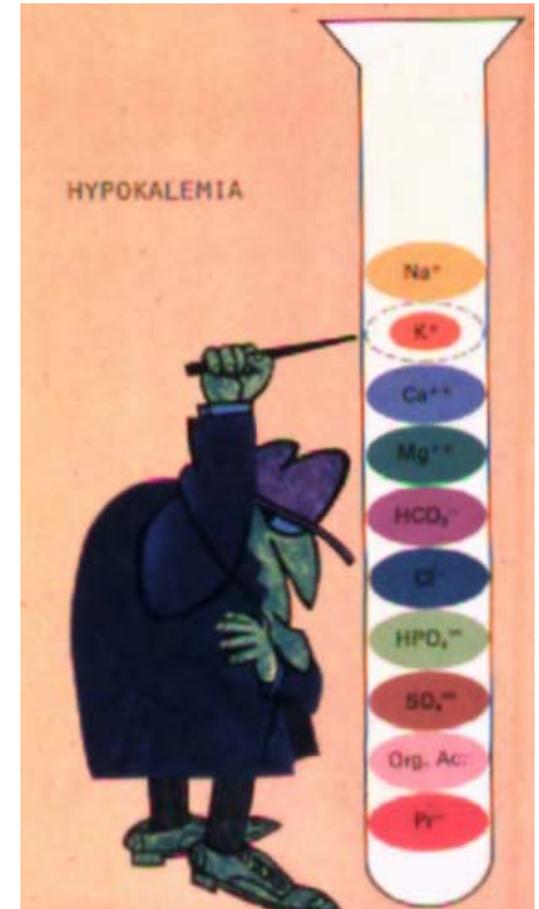
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# Potassium Homeostasis

- Total body stores 35 - 50 mEq/kg in normal healthy adults (25 – 30 mEq/kg if undernourished)
  - Serum K influenced by changes in pH (for every 0.1 increase in pH, serum K decreases by ~ 0.6 mEq/L and vice-versa)
  - Average requirement ~ 0.5 to 1.2 mEq/Kg/d
  - Kidney is primary route of elimination
  - Magnesium is required for normal potassium homeostasis
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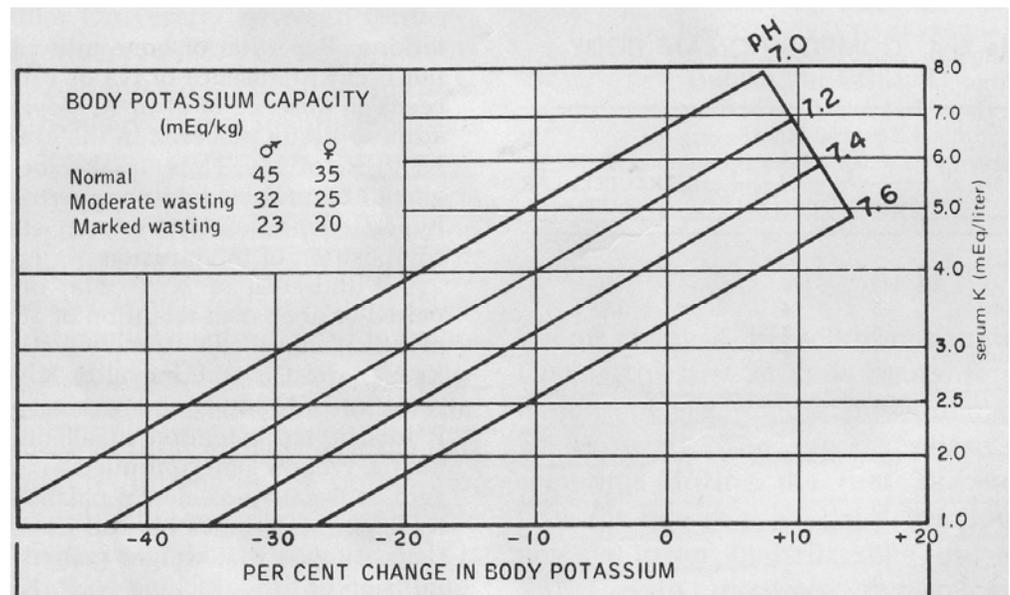
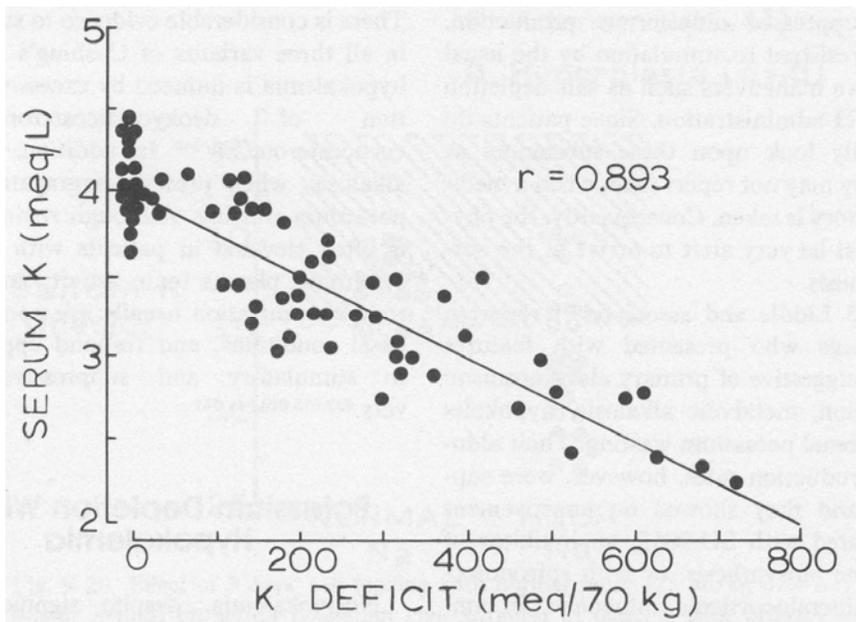
# Etiologies for Hypokalemia

- Increased requirements due to building of new muscle/tissue
- Increased gastrointestinal fluid losses
- Hypomagnesemia
- Medications –Beta agonists, catecholamines, insulin, amphotericin B, diuretics, bicarbonate
- Increased urinary losses (DI, DKA)



# Estimating Potassium Deficit

- Based on estimate of total body potassium
- Serum K = 3 mEq/L ~ 10% total body deficit
- Serum K = 2.5 mEq/L ~20% total body deficit

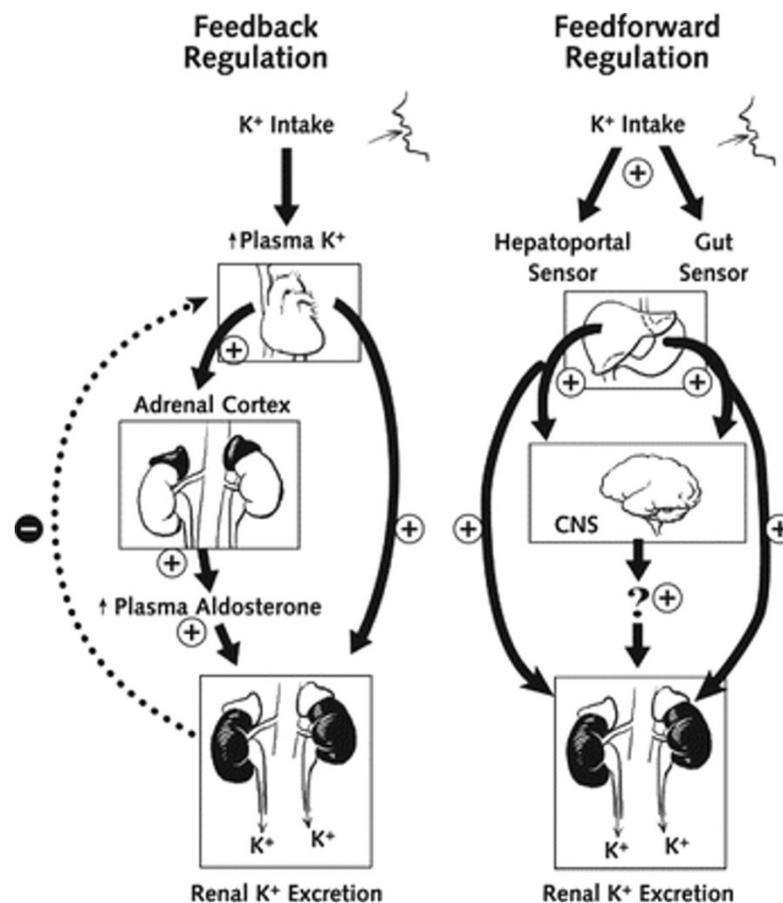


**Sterns RH et al. Medicine.1981;60:339.**

# Treatment of Hypokalemia

## Enteral vs Parenteral

- Enteral K is safer due to slower/controlled absorption rate
- Enteral K is safer due to feedforward regulation of K homeostasis
- Enteral K may be more difficult for some patients



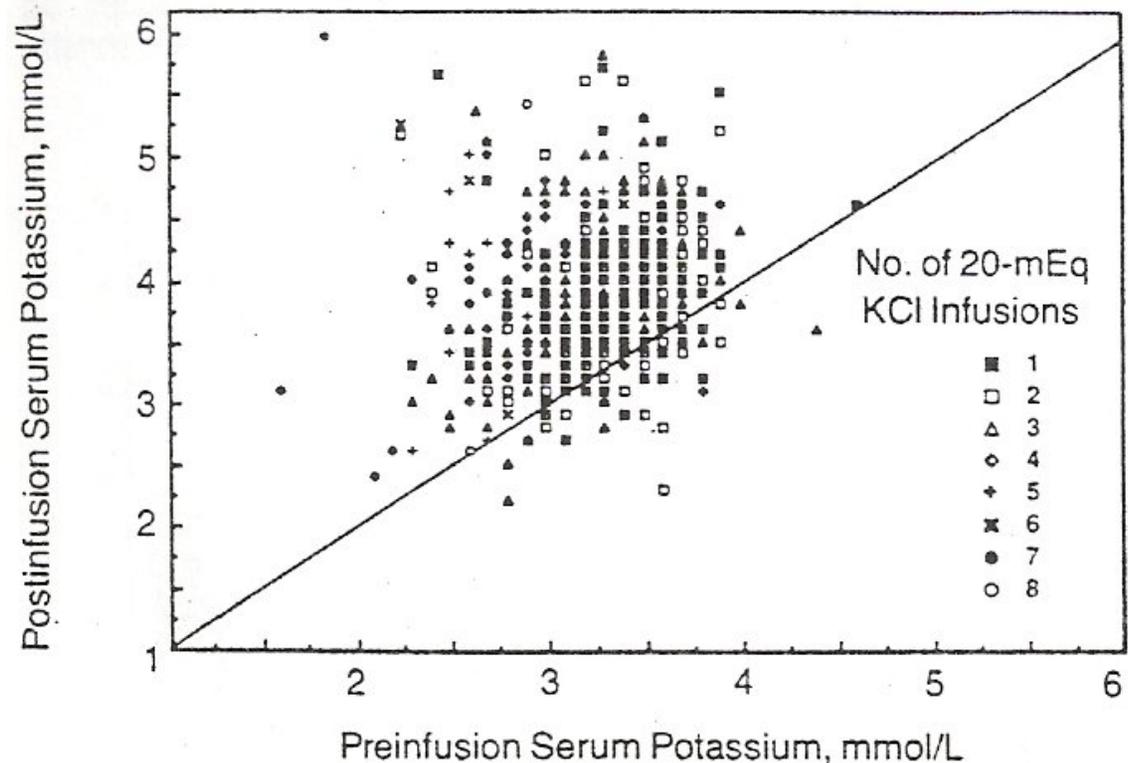
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# Intravenous Potassium Therapy

- When po potassium not possible or if patient has severe hypokalemia
  - Maximum concentration of 60 mEq/L of KCL for a peripheral IV.
  - “Boluses” (e.g., 40 mEq) cannot be given via peripheral IV: burning, phlebitis, pain. Must be given via central vein.
  - Maximum infusion rate of 10 mEq/hr (when pt is not on an ECG monitor); 20 mEq/hr if pt is being monitored.
  - 40 mEq/hr only if patient has paralysis or life-threatening arrhythmia.
-

# Intravenous Potassium Dosage

- For every 40 mEq IV KCL given, serum K increases by 0.5 to 0.6 mEq/L?
- 495 infusion sets in 190 patients
- KCL 20 mEq IV over 1 hour
- 0.25 mEq/L increased per 20 mEq dose



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# Potassium Dosing:

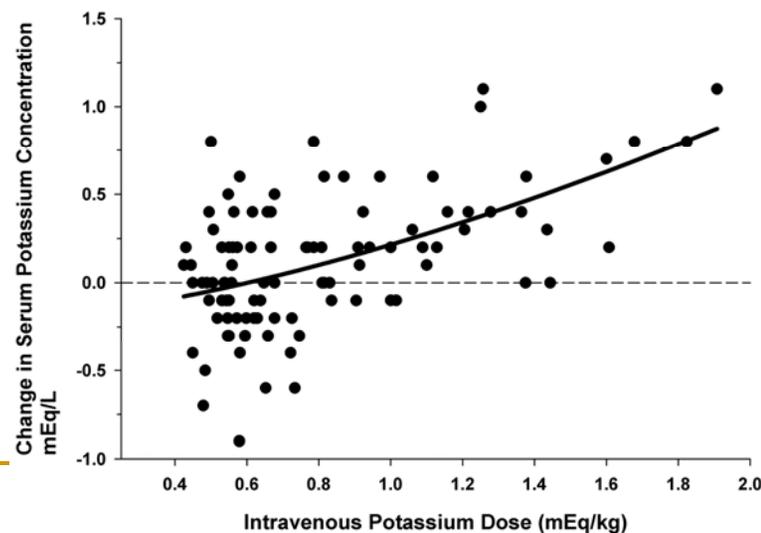
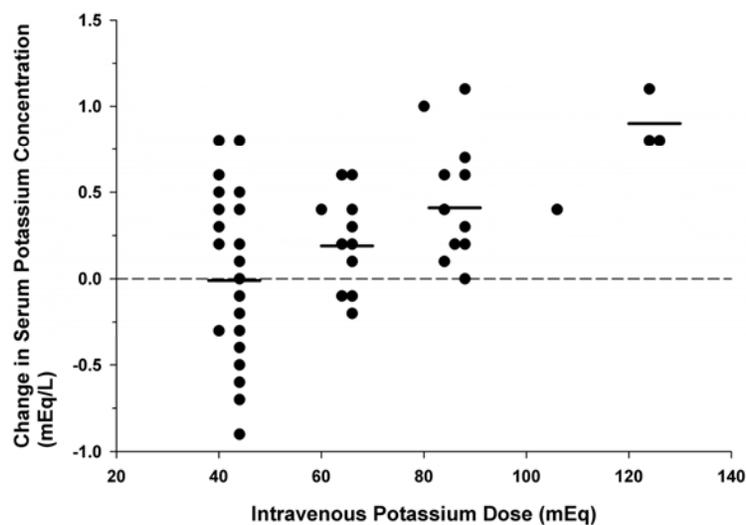
Effect of Body Size, Renal Function, Nutrition Therapy?

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# Empiric Dosing Guidelines for Potassium Chloride

| Serum K (mEq/L) | Potassium Dosage (mEq)* |
|-----------------|-------------------------|
| 3.5 – 3.9       | 40 mEq X 1 dose         |
| 3.0 – 3.4       | 40 mEq X 2 doses        |
| < 3             | 40 mEq X 3 doses        |

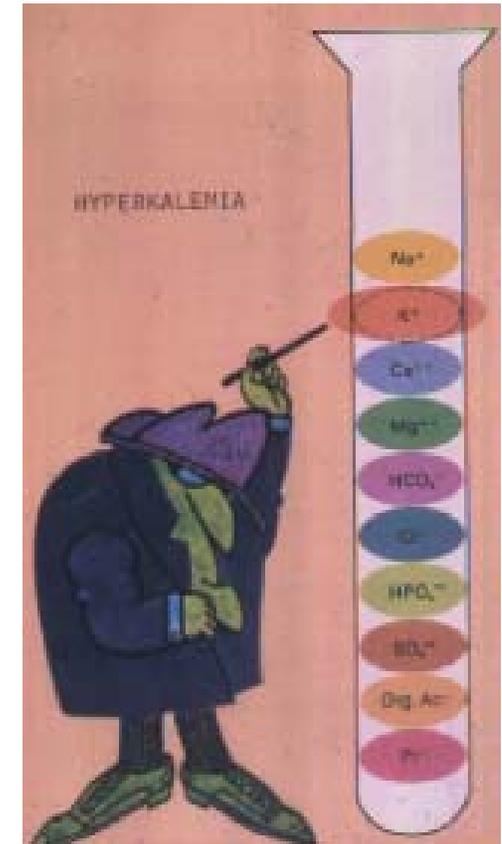
\*Use half dose for renal impairment; may need to be adjusted based on body size, nutrition therapy, and ongoing losses. Given at 10 mEq/hr.



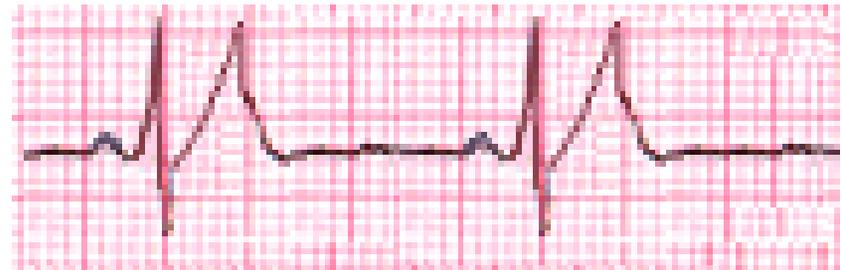
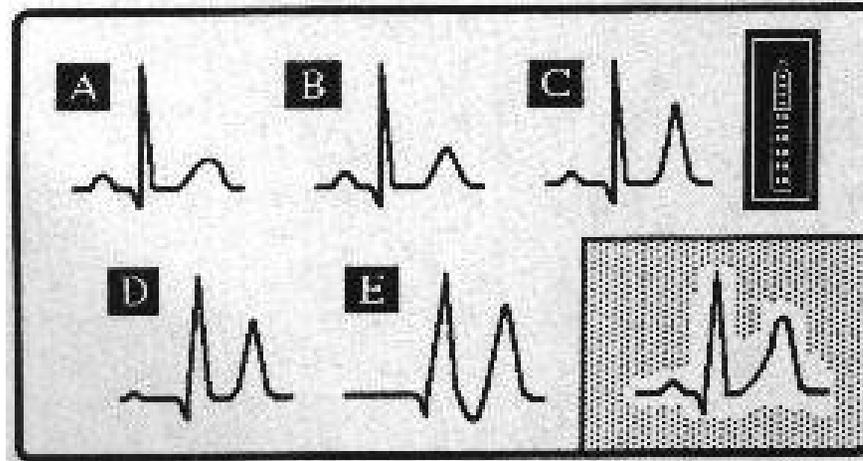
Johnston C et al. ASPEN meeting. February 2015.

# Hyperkalemia

- Rule out factitious hyperkalemia
- Etiologies: excessive intake, acidemia, renal impairment, tissue catabolism (chemotherapy, rhabdomyolysis), elderly are susceptible, hyporeninemic hypoaldosteronism, blood transfusion
- Etiologies – Drugs (K sparing diuretics, ACE and ARBs, NSAIDs, Heparin, Trimethoprim, Octreotide, Pen G (1.6 mEq K/million units)).



# Hyperkalemia



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# Treatment of Hyperkalemia

- Dextrose/Insulin 50 g / 15 units IV
  - Sodium bicarbonate 50 – 100 mEq IV
  - Calcium gluconate 2 g IV
  - Potent beta-2 agonist (albuterol)
  - Sodium polystyrene sulfonate 15 to 60 g up to every 6 hrs (in-vivo exchange capacity of ~ 1 mEq K per g).
  - Discontinue all sources of K intake
  - ? Loop diuretic therapy
  - Dialysis
-

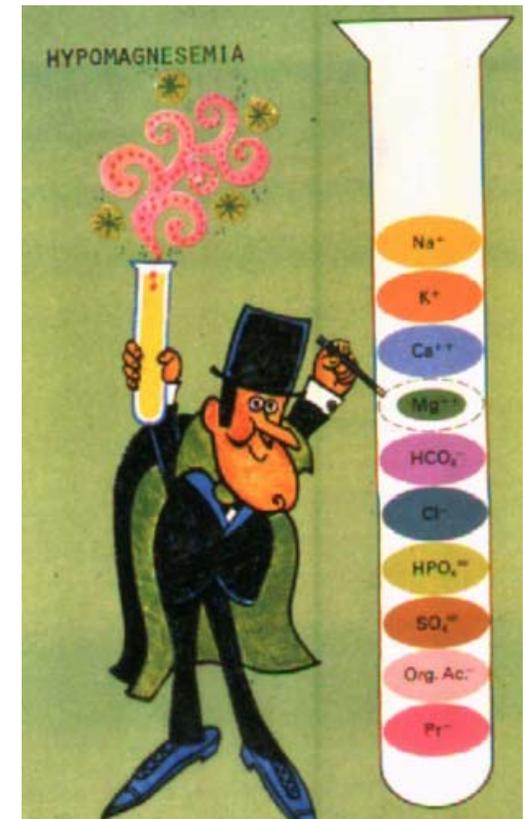
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# Magnesium Homeostasis

- 50% of magnesium is in bone; 1% of total body magnesium is in the ECF
  - Normal serum magnesium: 1.8 to 2.4 mg/dL
  - Serum: 60% ionized; 15% complexed; 25% protein bound.
  - Kidney is primary route of elimination
  - Influences potassium and calcium metabolism
-

# Hypomagnesemia

- Definition:  $< 1.8$  mg/dL
- Symptomatic:  $< 1.5$  mg/dL
- Causes hypokalemia
- Causes hypocalcemia
- Chvostek's/Trousseau's/QT prolongation, weakness, tetany
- Etiologies: diarrhea, alcohol, sepsis/critical illness, pancreatitis, burns, brain injury, drugs (see next slide)



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# Drug-Induced Hypomagnesemia

- Diuretics
  - Amphotericin B
  - Cyclosporin/tacrolimus
  - Foscarnet
  - Pentamidine
  - Cisplatin/Carboplatin/ifosfamide/Cetuximab
  - Lactulose/orlistat
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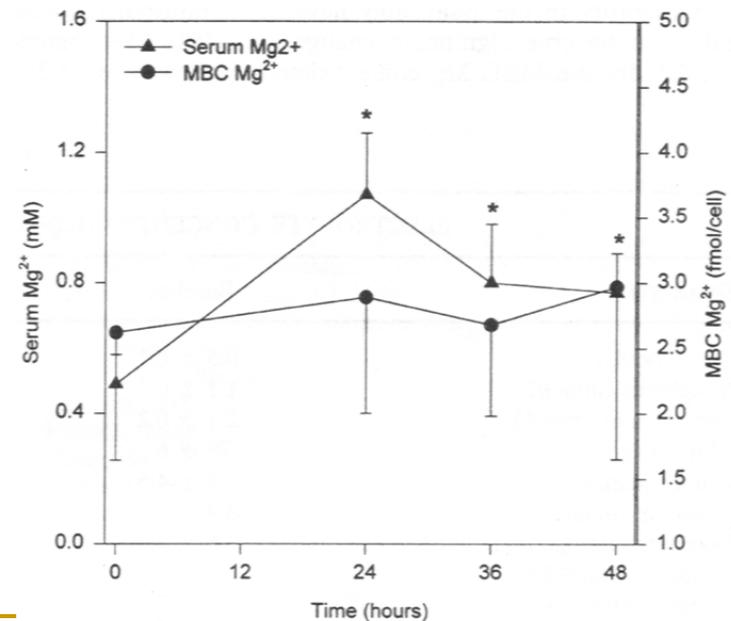
# Treatment of Hypomagnesemia

- 32 to 48 mEq/d (4-6 g/d) sufficient to maintain normal serum Mg concentrations
  - Estimated magnesium deficit: for a serum Mg concentration  $< 1.5$  mg/dL, a 1 to 2 mEq/kg deficit can be expected
  - Should be replaced over 4-5 days
  - Treat the etiology (ies)
  - Takes 48 hrs for the serum concentration to equilibrate following a short term infusion
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# Empiric Magnesium Dosing Guidelines

| Serum magnesium (mg/dL) | Intravenous Magnesium Sulfate dosage (g/kg)* |
|-------------------------|--|
| 1.6 to 1.8              | 0.05 g/kg                                    |
| 1.0 to 1.5              | 0.1 g/kg                                     |
| < 1.0                   | 0.15 g/kg                                    |

\*Use half dose for renal impairment; may need to be adjusted based on body size, nutrition therapy, and ongoing losses. Given at 1 g/hr.



Sacks et al. Nutrition.1997;13:303-8.

# Common Oral Magnesium Products and Dosing

| Salt Form | Strength (mg) | Elemental Mg (mEq) | Usual Dosing        |
|-----------|---------------|--------------------|---------------------|
| Oxide     | 400           | 19.8               | 1-2 tablets BID-TID |
|           | 100           | 6.9                |                     |
| Gluconate | 500           | 2.2                | 1-2 tablets BID-TID |
| Chloride  | 100           | 2.6                | 1-2 tablets BID-TID |
|           |               |                    |                     |

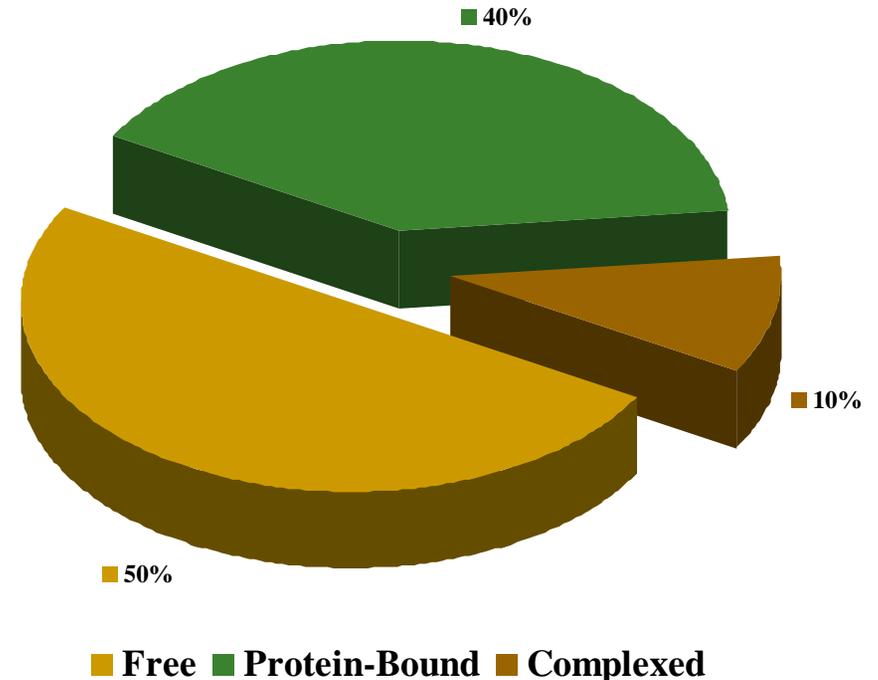
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# Calcium Homeostasis

- Ionized calcium (iCa): physiologically active fraction of serum total calcium
  - “Normal” serum calcium concentration is 8.5 to 10.5 mg/dL
  - “Normal” serum ionized calcium concentration is 1.12 – 1.32 mmol/L
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# Calcium Homeostasis

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# Calcium Homeostasis

- Average daily requirement with PN: 15 mEq/d calcium gluconate
  - Kidney is primary route of elimination
  - Magnesium can influence calcium homeostasis (**end organ resistance to PTH** +/- impaired secretion of PTH)
  - Mild hypocalcemia will correct within ~ 48 hrs after correction of hypomagnesemia
-

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## Correcting Serum Calcium Conc for a Low Serum Albumin Conc

- For every 1 g/dL decrease in serum albumin concentration, serum calcium concentration will decrease by 0.8 mg/dL- Endres, 1999; Orrell, 1971;35:483-489
  - Only use in NON-ICU patients!
  - Use of the modified Orrell equation (above) correctly identified 1 out of 21 hypocalcemic patients (from a total of 100 NSS trauma patients) - Dickerson RN. JPEN. 2004;28:133-41.
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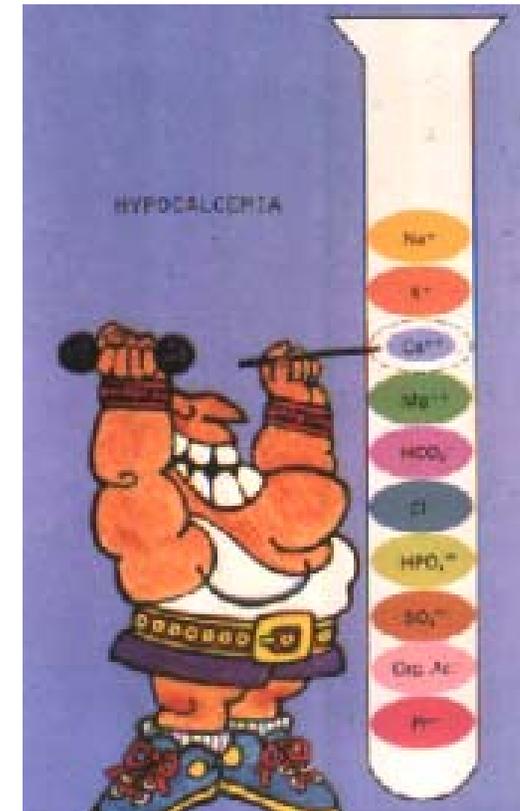
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## Correcting Serum Calcium Conc for a Low Serum Albumin Conc

- Example: A patient with a serum albumin 2 g/dL, serum calcium 7 mg/dL
  - Normal serum albumin = 4 g/dL
  - $4 - 2 = 2$
  - $2 \times 0.8 = 1.6$
  - “Corrected” serum calcium =  $7 + 1.6 = 8.6$  mg/dL
-

# Hypocalcemia

- Prolonged QTc, parasthesias, Chvostek's and Trousseau's signs, PVCs, seizures, tetany, torsades des pointes
- Mild: iCa 1 – 1.12 mmol/L
- Moderate to severe: iCa < 1 mmol/L
- Multiple causes: critical illness, CRRT, massive blood transfusion, alkalemia, hypomagnesemia, hyperphosphatemia, pancreatitis, drugs (see hypoMg drugs)



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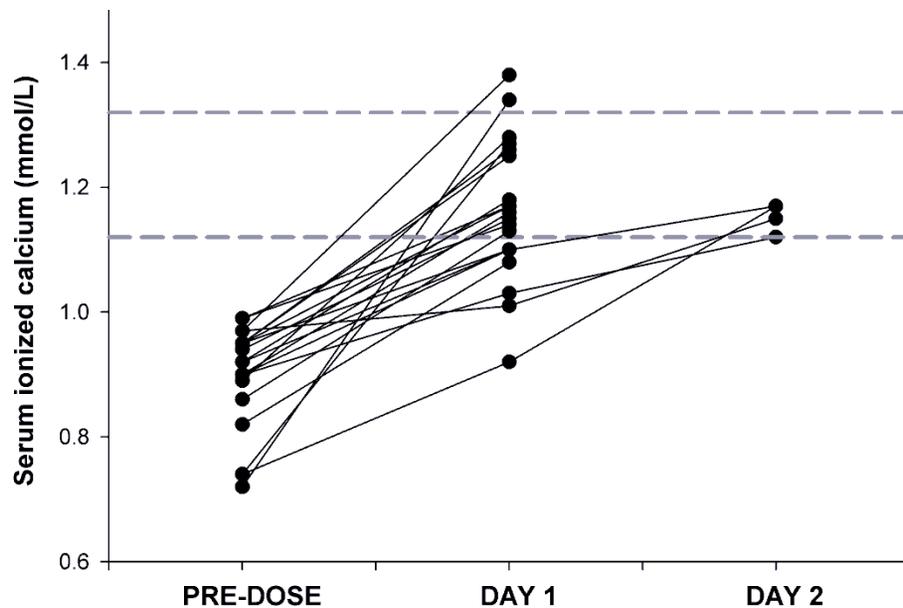
## When Should Hypocalcemia be Treated?

- Significant or symptomatic hypocalcemia
  - Massive blood transfusion with pre-existing myocardial disease
  - Calcium channel blocker overdose
  - Receiving inotropic agents and/or vasopressors
  - Adjunct to emergent management of severe hyperkalemia
  - Coagulopathy?
  - Prevention of worsening hypocalcemia?
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# Treatment of Hypocalcemia

Treat the cause if possible!

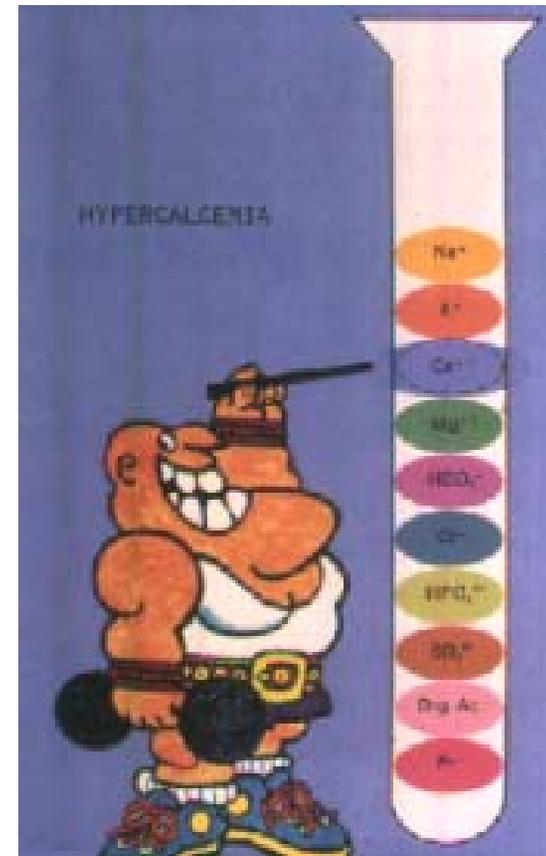
| iCa (mmol/L) | IV calcium gluconate dose |
|--------------|---------------------------|
| 1 – 1.12     | 2 g in 100 mL over 2 hrs  |
| < 1          | 4 g in 100 mL over 4 hrs  |



Dickerson. JPEN.2005;29:436-431.  
Dickerson. JPEN.2007;31:228-233.  
Dickerson. Nutrition.2007;23:9-15.

# Etiologies for Hypercalcemia

- Immobilization
- Metabolic bone disease
- Immobility
- Excessive intake
- Malignancy
- Drugs (vitamin D)
- Dehydration
- Granulomatous diseases (TB, sarcoidosis)



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# Treatment of Hypercalcemia

- IV fluids/Rehydrate! Add furosemide if necessary.
  - Mobilize the patient
  - Calcitonin
  - Pamidronate
-

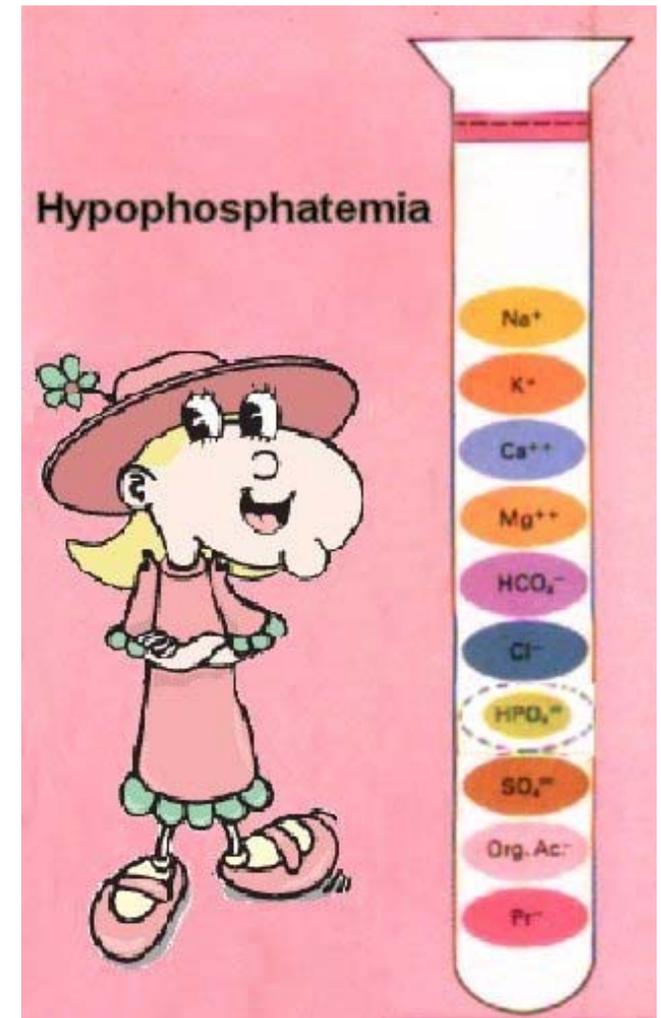
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# Phosphorus Homeostasis

- Regulated by vitamin D and PTH
  - Normal serum concentration: 2.5 – 4.5 mg/dL
  - During critical illness, goal is to achieve ~ 4 mg/dL (based on Zazzo and Aubier studies)
  - Kidney is primary route of elimination
  - Mean Renal Phosphate Threshold Conc (T<sub>m</sub>P/GFR) is ~ 3 – 3.3 mg/dL (trauma and thermally injured patients – Dickerson, 2001)
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# Etiologies of Hypophosphatemia

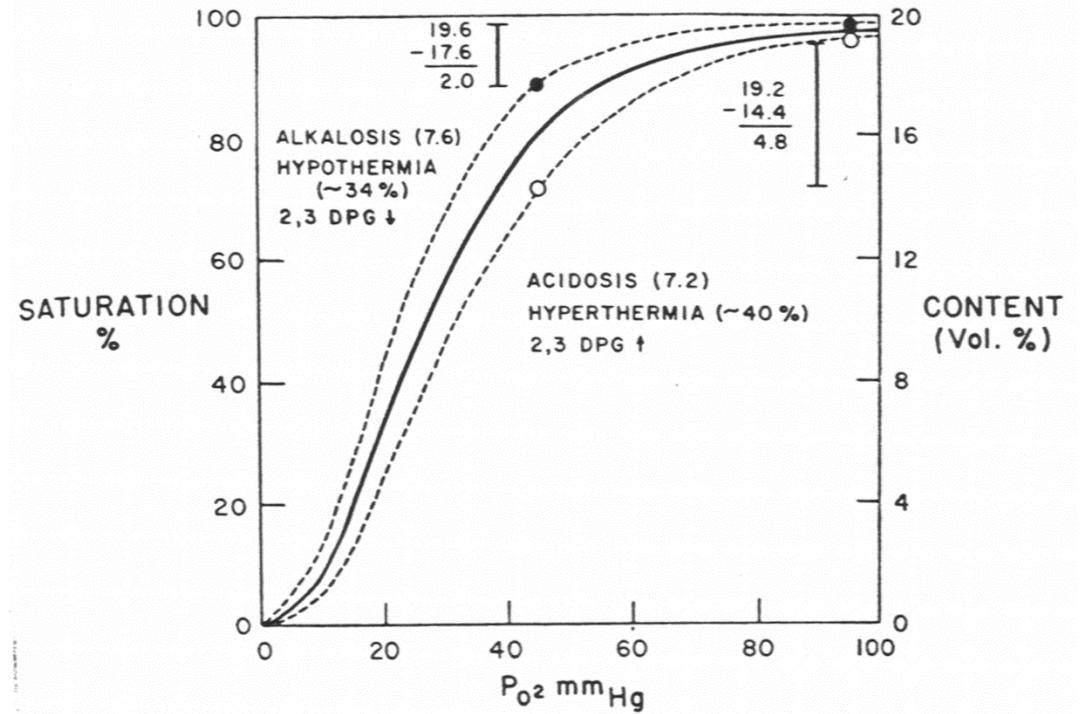
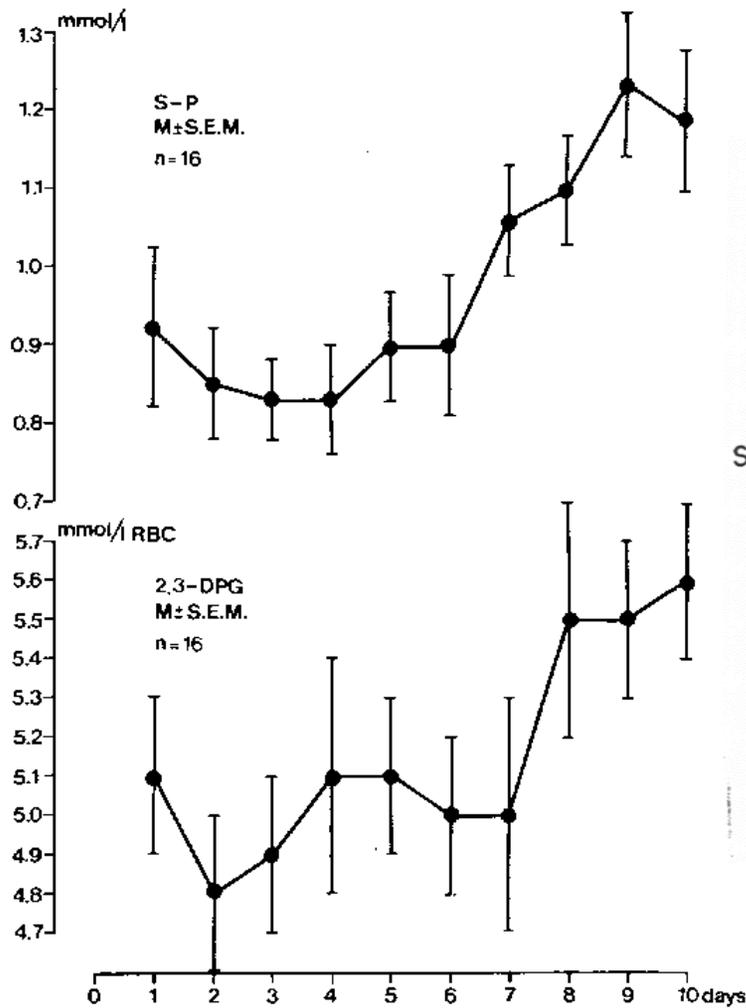
- Malnourishment
- Alcoholism
- Refeeding syndrome
- Drugs (insulin, catecholamines)
- Critical Illness/TBI/Thermal injury/DKA/alkalemia
- Hepatic Resection
- Hyperparathyroidism
- Cancer (fibroblast growth factors)



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# Hollywood and Refeeding Syndrome

- HBO's Band of Brothers. Easy Company, 101st Airborne, US Army during WWII.
  - Liberation of Landsberg Concentration Camp.
-

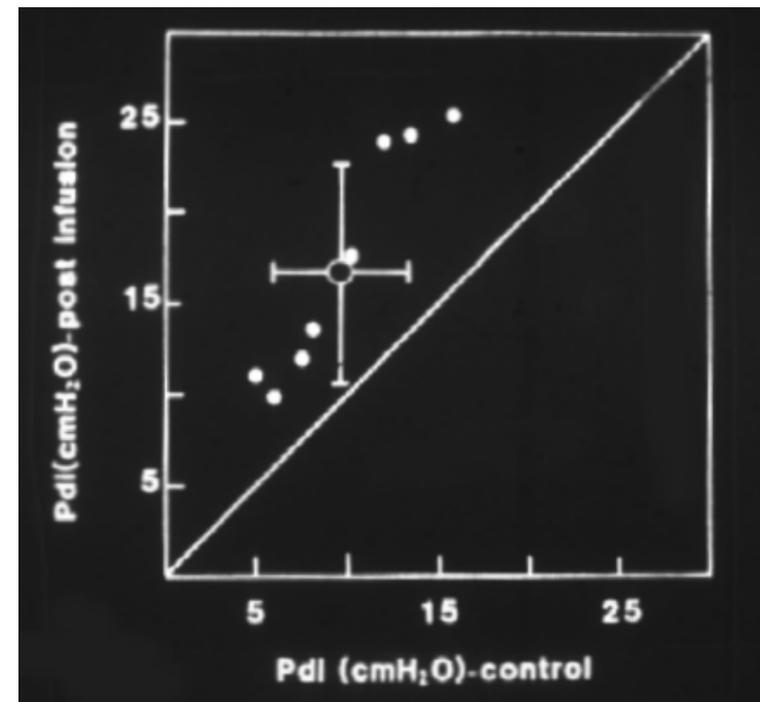


Loven L. J Trauma.1986;26:348-52. Sheldon GF. J Trauma.1973;15:971-9.

# Effect of Phosphorus Supplementation on Organ Function

| Variable | Before    | After     | P <  |
|----------|-----------|-----------|------|
| Phos     | 1.0 ± 0.4 | 3.8 ± 1.4 | 0.01 |
| HR       | 102 ± 17  | 105 ± 13  | NS   |
| CI       | 3.8 ± 1.9 | 4.5 ± 1.8 | 0.01 |

Zazzo. Inten Care Med.1995;21:826-31.



Aubier. NEJM.1995;313:420-4.

# IV Phosphorus Dosing for Hospitalized Patients

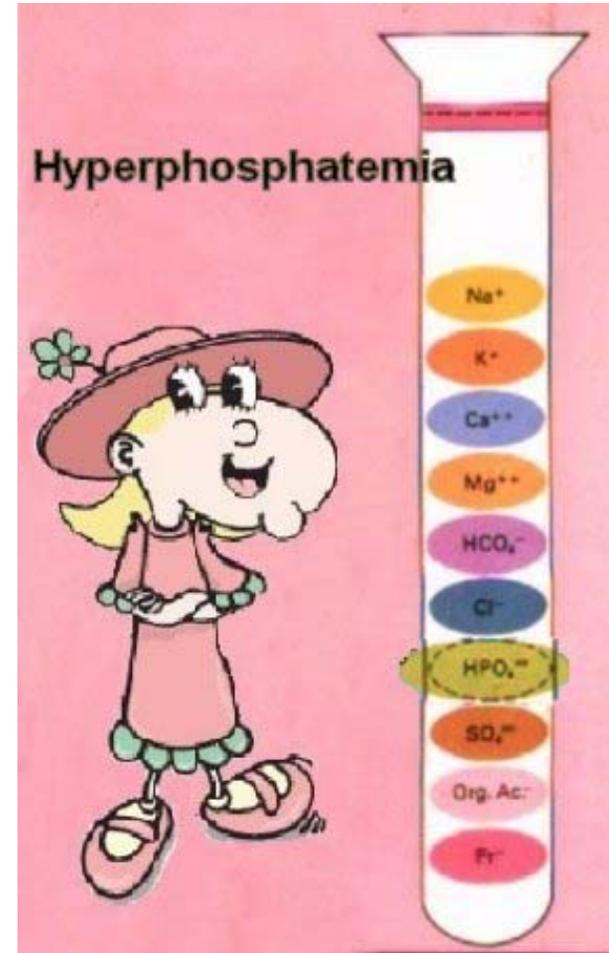
| Serum Phosphorus<br>Conc (mg/dL) | Dosage<br>(mmol/kg) |             |
|----------------------------------|---------------------|-------------|
|                                  | General/ICU         | Trauma/Burn |
| ■ 2.3 to 3 mg/dL                 | ■ 0.16              | ■ 0.32      |
| ■ 1.6 to 2.2 mg/dL               | ■ 0.32              | ■ 0.64      |
| ■ $\leq 1.5$ mg/dL               | ■ 0.64              | ■ 1         |

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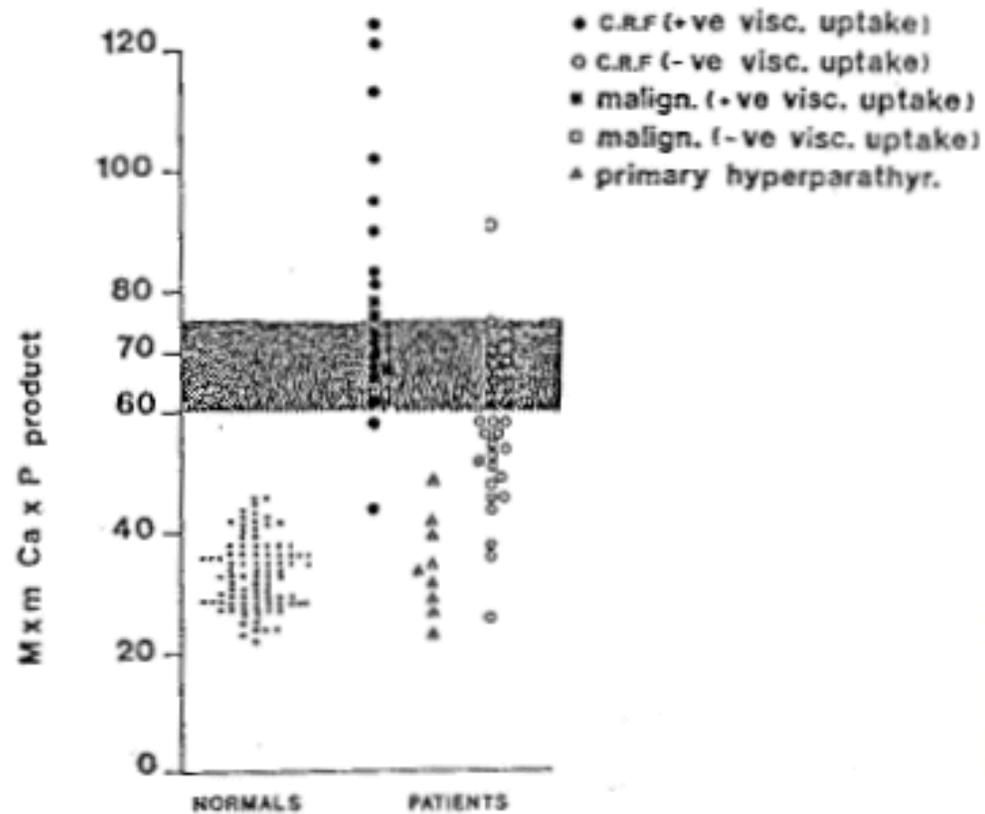
Infuse intravenous phosphorus at 7.5 mmol/hr

# Hyperphosphatemia

- Renal failure
- Immobility/chronic critical illness-associated metabolic bone disease
- Vitamin D toxicity
- Excessive phosphorus intake



# Hyperphosphatemia



Velentzas. Adv Exper Med Biol. 1978;103:195-201.

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# Treatment of Hyperphosphatemia

## Phosphate Binders

| <b>Drug</b>  | <b>P-binding capacity</b>   | <b>Initial Dose</b>        |
|--|-----------------------------|----------------------------|
| <b>Aluminum hydroxide</b><br>(not recommended in renal failure)                      | <b>22.3 mg/ 5 ml</b>        | <b>30 ml Q6hr</b>          |
| <b>Calcium carbonate</b><br>(less effective at higher gastric pH; higher Ca content) | <b>43 mg/ g calcium</b>     | <b>1 g QID</b>             |
| <b>Calcium acetate</b><br>(lower in calcium content than Ca carbonate)               | <b>106 mg/ g calcium</b>    | <b>1334 to 2001 mg TID</b> |
| <b>Sevelamer</b><br>(Maximal binding at pH 7; powder or capsule)                     | <b>800 mg/cap or packet</b> | <b>800 mg TID</b>          |
| <b>Lanthanum</b>   | <b>data not available</b>   | <b>500 mg TID</b>          |

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## Patient Case

- 55 yo 70 kg man, s/p total colectomy and hepatic resection for stage IV colon Ca. Twenty pound unintentional weight loss. Frequent ETOH. NG output > 2 L/d. PN initiated.
- Na 140 mEq/L, K 3.2 mEq/L, CL 102 mEq/L, tot CO2 25 mEq/L, BUN 14 mg/dL, creat 0.9 mg/dL, Ca 8.1 mg/dL, phos 2 mg/dL, mag 1.4 mg/dL, albumin 2.5 g/dL.

---

## Which potassium-phosphorus dosing regimen is best for this patient?

-  A. KCL liquid 40 mEq per NGT X 2 doses, 2 Neutra-Phos capsules in water per NGT
-  B. Kphos 30 mmol IV X 1 dose, 2 doses of KCL liquid 40 mEq per NGT
-  C. KCL 40 mEq IV X 1, Kphos 45 mmol IV X 1
-  D. KCL 40 mEq IV X 1, Kphos 30 mmol IV X 1

---

The patient is also given Mag Sulfate 6 g IV over 6 hrs. His repeat serum Mag the next day is 1.9 mg/dL. Which next therapeutic option is best?

-  A. Magnesium oxide 500 mg BID X 4-5days
-  B. Magnesium sulfate 2-4 g IV daily X 4-5 days
-  C. Give a second dose of 6 g of Mag Sulfate IV
-  D. No additional treatment is necessary

---

## Patient Case

- 24 yo 70 kg man s/p GSW abdomen with multiple abdominal injuries. He received 10 units of PRBC.
- Serum iCa is 0.86 mmol/L, K 4.6 mEq/L, Mag 1.8 mEq/L.
- Good renal function (sCr 0.8 mg/dL and UOP > 0.5 mL/kg/hr).

---

# What is the most likely etiology for his hypocalcemia?

-  A. Hypomagnesemia
-  B. Excessive urinary diuresis
-  C. Blood transfusion
-  D. Critical illness

---

# Which therapeutic regimen would be best for this patient?

-  A. Calcium gluconate 2 g IV over 2 hrs
-  B. Calcium gluconate 4 g IV over 4 hrs
-  C. Calcium chloride 1 g IV push over 5 to 10 min
-  D. No calcium therapy necessary

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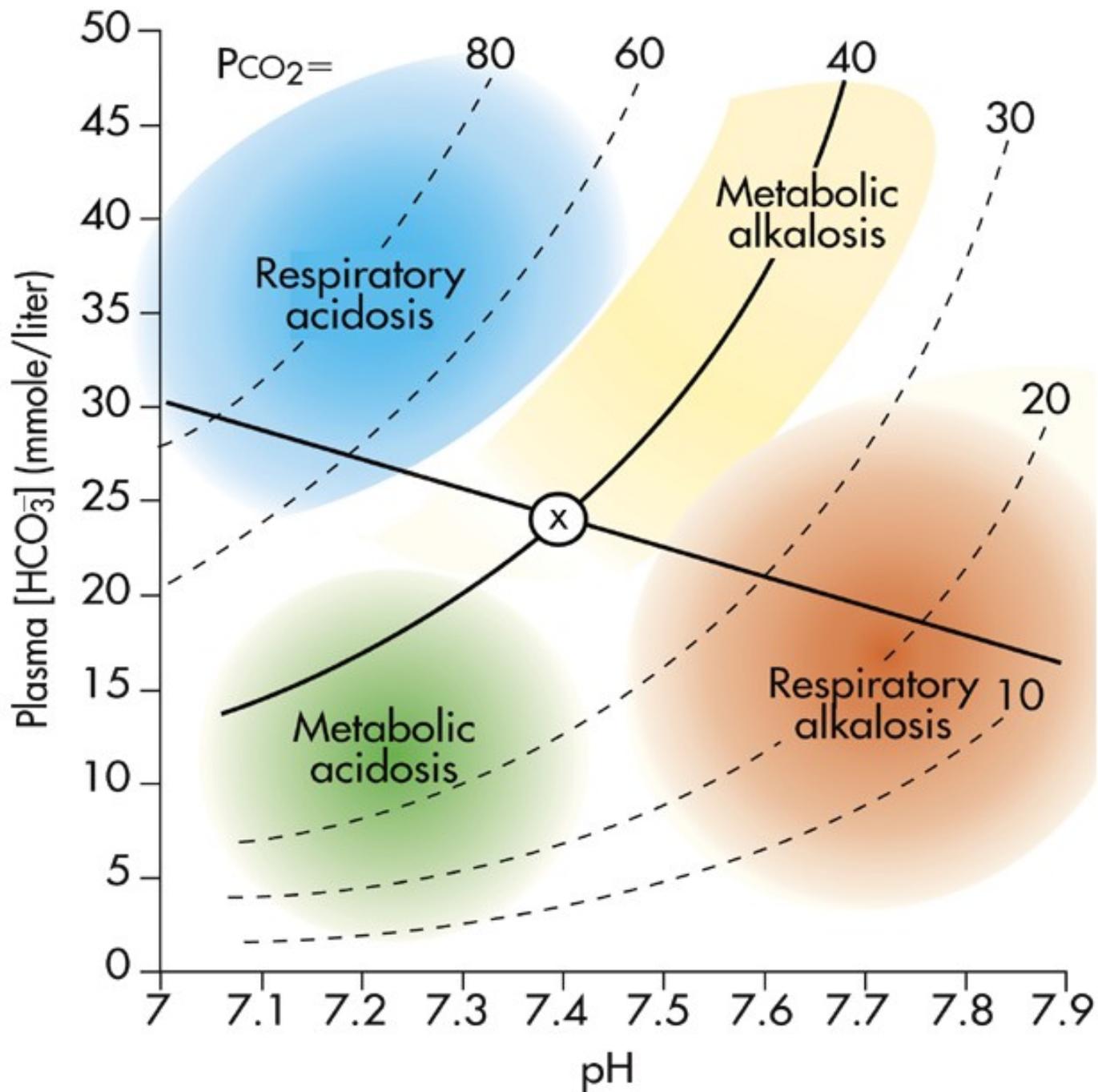
# Lecture Outline

1. Fluid and Electrolyte Overview (pg 54-56)
  2. Water and Sodium Aberrations (pg 56-57)
  3. Intracellular Electrolytes (pg 57-68)
  4. **Acid-Base Disorders (pg 68-74)**
  5. Nutritional Assessment, Energy/Protein Requirements (pg 74-80)
  6. Enteral Nutrition (pg 80-82)
  7. Parenteral Nutrition (pg 82-85)
  8. Glycemic Control (pg 86-88)
  9. Controversies in Nutrition Support for Critically Ill Patients (pg 88-94)
-

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# Acid-Base Disorders

- Severe Acidemia ( $\text{pH} \leq 7.25$ )
  - Severe Alkalemia ( $\text{pH} \geq 7.55$ )
  - Metabolic acidosis
  - Metabolic alkalosis
  - Compensatory response to A-B disorders
  - Base Excess – freedom from memorizing acid-base correction formulas?
-



---

# Metabolic Acidosis: Anion Gap

$$\text{Anion Gap} = \text{Na} - \text{Cl} - \text{HCO}_3$$

Normal range: ~3 – 11 or 12 mEq/L

- Every 1 g/dL decrease in serum Alb < 4 g/dL contributes to an unmeasured ~2.5 mEq/L in gap
  - Example: Na 145 mEq/L, Cl 110 mEq/L, HCO<sub>3</sub> 20 mEq/L, albumin 2 g/dL
  - Anion Gap = 145 - 110 - 20 = 15
  - Correction Factor = 4 - 2 = 2 X 2.5 = 5
  - Corrected Anion Gap = 15 + 5 = 20
-

---

# **Causes of an Anion Gap Acidosis**

## **A MUD PIE**

- **Aspirin (salicylates)**
  - **Methanol**
  - **Uremia (renal failure) including rhabdomyolysis**
  - **Diabetes (Diabetic Ketoacidosis)**
  - **Paraldehyde**
  - **Infection or Ischemia (Lactic acidosis)**
  - **Ethylene Glycol or Ethanol toxicity**
-

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# **Causes of a Non-Anion Gap Acidosis ACCRUED**

- **Ammonium Chloride or Acetazolamide (urine bicarbonate loss)**
  - **Chloride intake (sources: PN, IVs, etc.)**
  - **Cholestyramine (GI bicarbonate loss)**
  - **Renal Tubular Acidosis- Type I, II, IV**
  - **Urine diverted into the bowel**
  - **Endocrine disorders (e.g., aldosterone deficiency)**
  - **Diarrhea (also enterocutaneous fistulas)**
-

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# Anion Gap Metabolic Acidosis

## Use of the Delta Ratio

- sometimes used in the assessment of elevated anion gap metabolic acidosis to determine if a mixed acid base disorder is present.
  - Delta ratio =  $\Delta$  Anion gap/ $\Delta$  [HCO<sub>3</sub><sup>-</sup>] or  $\uparrow$  anion gap/ $\downarrow$  [HCO<sub>3</sub><sup>-</sup>]
  - DR = 
$$\frac{\text{Measured anion gap} - \text{Normal anion gap}}{\text{Normal [HCO}_3^-] - \text{Measured [HCO}_3^-]}}$$
  - DR = 
$$\frac{(\text{AG} - 14)}{(24 - [\text{HCO}_3^-])}$$
-

## Evaluating Metabolic Acidosis: the Delta Ratio

| <b>Delta Ratio</b> | <b>Assessment Guidelines</b>  |
|--------------------|---|
| <b>&lt; 0.4</b>    | <b>Hyperchloremic normal anion gap acidosis</b>   |
| <b>&lt; 1</b>      | <b>High anion gap acidosis and normal anion gap acidosis</b>  |
| <b>1 to 2</b>      | <b>Anion gap acidosis</b>   |
| <b>&gt; 2</b>      | <b>High anion gap acidosis and concurrent metabolic alkalosis OR a pre-existing compensated respiratory alkalosis</b> |

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## Determining Extent of Compensation and Mixed Acid-Base Disorders (see Table 17)

**Chronic Respiratory Acidosis:** For every 10 mm Hg increase in pCO<sub>2</sub>, serum HCO<sub>3</sub> should increase by ~ 4 mEq/L

- **Chronic Respiratory Alkalosis:** For every 10 mm Hg decrease in pCO<sub>2</sub>, serum HCO<sub>3</sub> should decrease by ~ 5 mEq/L
  - **Metabolic Acidosis:**  $p\text{CO}_2 = \sim (1.5 \times \text{HCO}_3) + 8$
  - **Metabolic Alkalosis:** widely variable increase in pCO<sub>2</sub>  $p\text{CO}_2 = \sim (0.7 \times \text{HCO}_3) + 21$
-

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## **Evaluating Acid-Base Disorders at the Bedside**

- **Know the clinical details of the patient**
  - **Is the “snap-shot” reflective of the current clinical situation**
  - **Find the cause for the acid-base disorder**
  - **Is compensation appropriate?**
  - **Is the pH severe enough to warrant therapy?**
  - **Plan a therapeutic treatment regimen**
-

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# **Treatment of Metabolic Acidosis**

## **Intravenous sources of alkali**

- **Sodium bicarbonate**
  - **Sodium acetate**
  - **Sodium citrate**
  - **THAM (0.3 N Tromethamine)**
  - **Lactate**
-

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# Treatment of Metabolic Acidosis

## Use of bicarbonate

- Total dose of bicarbonate =  
 $0.5 \times \text{Wt (kg)} \times (24 - [\text{HCO}_3])$
  - Give one half to one third (OR 1 to 2 mEq/kg) over several hours (avoid boluses) to get pH > 7.25
  - Once pH > 7.25, slower correction without increasing  $\text{HCO}_3 > 4$  to 6 mEq/L to avoid overalkalinization
  - Serial ABGs (e.g., Q6h)
-

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# Treatment options for Metabolic Alkalosis depends on:

- **Sodium Chloride Responsive (urinary Cl < 25 mEq/L)**
  - **Sodium Chloride Resistant (urinary Cl > 40 mEq/L)**
-

---

# **Causes of Sodium Chloride Responsive Metabolic Alkalosis**

- **Excessive gastric fluid losses**
  - **Diuretic therapy (especially loop)**
  - **Dehydration (contraction alkalosis)**
  - **Hypokalemia**
-

---

## Causes of Sodium Chloride Resistant Metabolic Alkalosis

- **Excessive mineralocorticoid activity (hyperaldosteronism, glucocorticoid excess/Cushing's disease, glycyrrhizic acid)**
  - **Massive blood transfusion**
  - **Milk alkali syndrome**
  - **Large doses of large penicillins**
-

---

# Treatment of Saline Responsive Alkalemia

- **Treat the etiology**
  - **0.9% NaCl + KCL to replenish deficits**
  - **Acetazolamide 250 – 375 mg QD-TID**
  - **HCL therapy**
-

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# Hydrochloric Acid Therapy

- **Only if NaCl and KCl not possible**
  - **Central venous administration only**
  - **Glass bottle**
  - **0.1 or 0.2 N HCL (0.2 N for fluid restricted patients)**
-

---

# Hydrochloric Acid Therapy

## Calculating the Dose

- **Chloride deficit method**

**mEq HCL= 0.2 X WT (kg) X (103 – serum Cl)**

- **Bicarbonate excess method**

**mEq HCL= 0.5 X WT (kg) X (serum HCO<sub>3</sub> - 24)**

- **Give ~ 1/2 of the above calculated dose over 12 hrs and reassess. ABGs Q6h.**

- **Stop infusion at ~ pH 7.45 to avoid over-correction**

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# Patient Case

- 70 yo, 40 kg female s/p radical cystectomy with ileal conduit, post-op ileus, NG output 1.5 L/d, and requires PN.
- 0.45% NaCl + KCL 20 mEq/L @ 50 mL/hr
- PN electrolyte daily intake: NaCL 60 mEq, K Acetate 40 mEq, Na Phos 15 mmol, Mg sulfate 24 mEq, calcium gluconate 10 mEq.
- After a few days of PN, her ABG was pH7.29, pO2 95, pCO2 35, HCO3 21. Serum Na 141, K 3.9, CL 117, total CO2 content 22

---

# Which best describes her acid-base disorder?

-  A. Hyperchloremic, normal AG acidosis
-  B. AG acidosis
-  C. AG acidosis with hyperchloremia
-  D. Respiratory acidosis with concurrent metabolic alkalosis

---

# Which is the most appropriate treatment algorithm?

-  A. Substitute the NaCl in the PN solution with Na Acetate
-  B. Sodium bicarbonate 100 mEq IV
-  C. Change the IV solution to Lactated Ringers solution
-  D. Add 100 mEq of sodium bicarbonate to the PN solution

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-

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# Nutritional Assessment

- ASPEN definitions vs “Classic” definitions
  - Mild, moderate, severe based on IBW
  - Underweight BMI  $\leq 18.5$  (kg/m<sup>2</sup>)
  - Obese BMI  $\geq 30$  (kg/m<sup>2</sup>)
  - Serum proteins – albumin/prealbumin – decreased with stress
  - Weight loss is significant when  $> 10\%$  unintentional wt loss within 6 months
-

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# Caloric Content of Macronutrients

- Glucose 3.4 kcal/g
  - Carbohydrate 4 kcal/g
  - Protein/Amino acids 4 kcal/g
  - Fat 9 kcal/g
  - IV Fat ~10 kcal/g (IV fat emulsion contains glycerol and phospholipids; 10% = 1.1 kcal/mL, 20% = 2 kcal/mL, 30% = 3 kcal/mL)
  - Propofol: administered in 10% lipid emulsion!
-

---

# Recommended Caloric Intake

## An Over-Simplification

- Critically ill patients: 25 to 30 kcal/kg/d
  - MICU patients: 25 to 27 kcal/kg/d (no more than 30 kcal/kg/d)
  - SICU: 25 to 30 kcal/kg/d (no more than 35 kcal/kg/d)
  - Trauma: 25 to 32 kcal/kg/d (no more than 35 kcal/kg/d)
  - Burns: Other formulas used; hypermetabolic.
-

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# Recommended Caloric Intake

## An Over-simplification

- Weight based caloric intakes are erroneous in small (~50 kg), older (> 65 to 70 yrs), or obese patients (BMI  $\geq$  30 kg/m<sup>2</sup>)
  - Small/Elderly = ~1.2 to 1.3 X BEE (Harris-Benedict equations), no more than 1.5 X BEE
  - Obese =  $\leq$  25 kcal/kg IBW/d (in conjunction with a high protein intake)
-

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# Avoid Overfeeding

- Do not exceed:
    - Glucose/carbohydrate: 5 mg/kg/min**
    - Fat (IV): 2.5 g/kg/d (keep  $\leq$  1.5 g/kg/d)
  - Hypercapnia (an excess in total kcals are more likely to cause hypercapnia vs. % CHO vs. % fat)
  - Hyperglycemia
  - Fatty infiltration of the liver/hepatic steatosis/cholestasis
-

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# Protein Requirements

- Critically ill patients: 1.5 to 2 g/kg/d - requirements greater for surgical/trauma vs. medical ICU patients
  - European vs American guidelines
  - SCCM-ASPEN: 1.2 to 2 g/kg/d; higher amounts likely needed for multiple trauma or burns
-

---

# Protein Requirements

- Trauma/Burns: 2 – 2.5 g/kg/d
  - Renal Failure:
    - AKI/CKD: 0.6 – 1 g/kg/d
    - Hemodialysis: 1 – 1.5 g/kg/d
    - **CRRT: 2 – 2.5 g/kg/d**
  - Obese: 2 – 2.5 g/kg IBW/d
    - BMI < 40: 2 g/kg IBW/d
    - BMI  $\geq$  40: 2.5 g/kg IBW/d
-

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# Patient Case

- 40 kg woman admitted to the trauma ICU receives a PN solution containing 350 g dextrose, 160 g amino acids, and 80 g of lipid daily.
- Her most ABG revealed: a pH of 7.30, pCO<sub>2</sub> of 55, PO<sub>2</sub> of 96, and HCO<sub>3</sub> of 31.
- Her BGs from the past 24 hours range from 150 to 180 mg/dL.

---

Which change would be best to recommend concerning her PN?

-  A. Decrease dextrose to 175 g/d, increase lipid to 120 g/d.
-  B. Add 20 units of regular human insulin.
-  C. Decrease all the macronutrients by about one-half.
-  D. Increase the acetate content.

# Assessing Protein Requirements

## Nitrogen Balance

- $NB \text{ (g/d)} = N_{in} - N_{out}$
- $NB > +4 \text{ g/d} = \text{anabolic}$
- $NB -4 \text{ to } +4 \text{ g/d} = \text{nitrogen equilibrium}$
- $NB \text{ worse than } -4 \text{ g/d} = \text{catabolic}$
- Classic NBAL equation
  - $NB = \text{Protein in (g/d)}/6.25 - \text{UUN (g/d)} - 4 \text{ g/d}$
  - If BUN change  $\geq 5 \text{ mg/dL}$ , add to losses (see chapter pg 30)
- Highly catabolic patients may use different NB calculation (pg 30)

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## Patient Case

- A 24 hr urine collection was done to determine nitrogen balance for a 45 yo obese man with pancreatitis and sepsis receiving hypocaloric, high protein (24 kcal/kg IBW/d, 2 g/kg IBW or 150 g/d of protein) PN.
- The urine urea nitrogen (UUN) concentration was 900 mg/dL and urine volume output was 3000 mL. The BUN was unchanged during the NB determination.

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Using the classic NB equation, what was his nitrogen balance?

 A. + 4 g/d

 B. - 4 g/d

 C. - 7 g/d

 D. -10 g/d

---

# What changes would be best to make to the PN regimen?

-  A. Increase the protein and non-protein energy content
-  B. Increase the protein content, decrease the non-protein energy content
-  C. Increase the protein content
-  D. Increase the non-protein content

---

# Indications for EN

- If the patient is unable to ingest adequate amounts to achieve goal nutritional intake
  - Early EN is beneficial for critically ill patients (ESPEN 2006; SCCM/ASPEN 2009)
  - Definition of early? – 24 hrs to 48 hrs post admission to ICU (max 72 hrs)
  - How much EN is necessary for a beneficial effect? controversial
-

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# Which EN formula?

- See Table 22 pg 32 highlighting different commercially available EN formulas that are indicated for different clinical conditions.
-

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# Important EN-Medication Interactions

- Whereby TF may be held 1 hr prior to and after medication administration:
  - **Warfarin**
  - **Phenytoin**
  - Levothyroxine\*
  - Fluroquinolones\*
  - Itraconazole\*

\*Interaction may be overcome by providing a higher dosage; readjust doses when EN d/c'd

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# Indications for PN

- ESPEN 2009: Patients not expected to receive EN within 3 days should receive PN within 24-48 hrs if EN contraindicated
  - SCCM-ASPEN 2009: PN indicated only after first 7 days of hospitalization when EN not possible
  - Depends on state of malnourishment, catabolic state of patient; outcomes more variable for medical vs surgical patients
-

---

# Central vs. Peripheral PN

- Peripheral PN requires low concentrations of macronutrients and high volume of fluid to keep osmolality tolerable (e.g.,  $< \sim 800$  mOsm/kg)
- Approx Osmol = (dextrose g/L X 5) + (% amino acids X 100) + (% lipid X 15) + 200\*

\*estimate of electrolyte, vitamins, minerals contribution to osmolality

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# Glucose

- Obligatory requirements: 130 g/d
  - Surgical wound: 80 to 150 g/d
  - Don't exceed 5 mg/kg/min
  - Glucose 3.4 kcal/g
  - Provides the majority of non-protein kcals
-

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# Lipid Emulsion

- 10%=1.1 kcal/mL; 20%=2 kcal/mL;30%=3 kcal/mL
  - To prevent EFAD in adults: at least 100 to 150 g/weekly (e.g., 1 – 1.5 g/kg weekly)
  - Preferably give < 1.5 g/kg/d and definitely not > 2.5 g/kg/d (adults)
  - Do not allow triglycerides to exceed 400 mg/dL
-

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# Predisposing Conditions to Impaired IV Triglyceride Clearance

Excessive lipid intake (propofol!)

Acute pancreatitis

Uncontrolled diabetes

Kidney failure

End-stage sepsis

Obesity

HIV

Hyperlipidemia

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Pregnancy

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# Vitamins and Trace Minerals

- Additional zinc may be indicated for patients with intractable diarrhea, intestinal fistulae, critical illness
  - Copper and manganese should be withheld in patients with significant hepatobiliary/cholestatic liver disease
  - Supplemental thiamine indicated for ETOHics and severely malnourished patients
-

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-

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# Glycemic Control

- SCCM: keep BG < 150 mg/dL for most patients and absolutely < 180 mg/dL
  - ASPEN: target BG 140 to 180 mg/dL
  - ADA: target BG 140 to 180 mg/dL lower BG target may be appropriate in select patients.
  - “Select patients”: trauma, thermal injury, CT surgery (e.g., BG < 140 to 150 mg/dL)
  - Avoid BG < 70 mg/dL; definitely avoid < 40 mg/dL
-

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