Parenteral Nutrition Primer: Balancing Acid-Base, Fluids and Electrolytes

Phil Ayers, PharmD, BCNSP, FASHP
Todd W. Canada, PharmD, BCNSP, FASHP, FTSHP
Michael Kraft, PharmD, BCNSP
Gordon S. Sacks, Pharm.D., BCNSP, FCCP
Disclosure

- The program chair and presenters for this continuing education activity have reported no relevant financial relationships, except:

- **Phil Ayers** - ASPEN: Board Member/Advisory Panel; B Braun: Consultant; Baxter: Consultant; Fresenius Kabi: Consultant; Janssen: Consultant; Mallinckrodt: Consultant

- **Todd Canada** - Fresenius Kabi: Board Member/Advisory Panel, Consultant, Speaker's Bureau

- **Michael Kraft** - Rockwell Medical: Consultant; Fresenius Kabi: Advisory Board; B. Braun: Advisory Board; Takeda Pharmaceuticals: Speaker’s Bureau (spouse)

- **Gordon Sacks** - Grant Support: Fresenius Kabi
Sodium Disorders and Fluid Balance

Gordon S. Sacks, Pharm.D., BCNSP

Professor and Department Head
Department of Pharmacy Practice
Harrison School of Pharmacy
Auburn University
Learning Objectives

Upon completion of this session, the learner will be able to:

1. Differentiate between hypovolemic, euvolemic, and hypervolemic hyponatremia
2. Recommend appropriate changes in nutrition support formulations when hyponatremia occurs
3. Identify drug-induced causes of hypo- and hypernatremia
No sodium for you!
Presentation Outline

- Overview of sodium and water
- Dehydration vs. Volume Depletion
- Water requirements & Equations
- Hyponatremia
  - Hypotonic
    - Hypovolemic
    - Euvolemic
    - Hypervolemic
- Hypernatremia
  - Hypovolemic
  - Euvolemic
  - Hypervolemic
Sodium and Fluid Balance

- Helpful hint: total body sodium determines volume status, not sodium status
- Examples of this concept
  - Hypervolemic – too much volume
  - Hypovolemic – too little volume
  - Euvolemic – normal volume
Water Distribution

- Total body water content varies from 50-70% of body weight
  - Dependent on lean body mass: fat ratio
    - Fat water content is ~10% compared to ~75% for muscle mass
- Water is “held” within each compartment primarily by one major solute
  - Sodium & extracellular space
  - Potassium & intracellular space
  - Plasma proteins & intravascular space
FLUID COMPARTMENTS AND THEIR MEMBRANES

EXTRACELLULAR 30%

INTRACELLULAR 35%

INTERSTITIAL 16%

INTRAVASCULAR 7%

CELLULAR MEMBRANE
PASSIVELY PERMEABLE ONLY TO WATER, FOLLOWING OSMOTIC PRESSURE GRADIENTS

CAPILLARY MEMBRANE
PASSIVELY PERMEABLE TO ALL, EXCEPT CELLS AND PROTEIN, FOLLOWING PRESSURE GRADIENTS
Serum Osmolality

- The number of osmoles (particles) acting to hold fluid within the ECF

\[ S_{\text{osm}} = (2 \times \text{Na}) + (\text{glucose}) + (\text{BUN}) \]

\[ 18 \quad 2.8 \]
Volume Regulation and Na\(^+\) Metabolism

Circulating blood volume

Pituitary gland

ADH (arginine vasopressin)

AG II

adrenal gland

aldosterone
## Composition of Gastrointestinal Fluids

<table>
<thead>
<tr>
<th></th>
<th>Sodium (mEq/L)</th>
<th>Potassium (mEq/L)</th>
<th>Chloride (mEq/L)</th>
<th>Bicarbonate (mEq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastric</td>
<td>60</td>
<td>10</td>
<td>130</td>
<td>--</td>
</tr>
<tr>
<td>Small bowel</td>
<td>140</td>
<td>5</td>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>Bile</td>
<td>145</td>
<td>5</td>
<td>100</td>
<td>35</td>
</tr>
<tr>
<td>Pancreatic</td>
<td>140</td>
<td>5</td>
<td>75</td>
<td>115</td>
</tr>
<tr>
<td>Colon</td>
<td>60</td>
<td>30</td>
<td>40</td>
<td>--</td>
</tr>
</tbody>
</table>
Etiologies of **Hypotonic** Hyponatremia

- **Hypovolemic**
  - $\downarrow$ Na $>$ $\downarrow$ TBW

- **Isovolemic**
  - $\leftrightarrow$ Na TBW

- **Hypervolemic**
  - $\uparrow$ Na $<$ $\uparrow$ TBW
Causes of Hypotonic Hypovolemic Hyponatremia

\[ \text{Na} > \text{TBW} \]

Extra Renal
- GI losses
- 3rd spacing

Renal
- Diuretics
- Adrenal ds
- Kidney ds
Signs and Symptoms of Hypovolemic Hyponatremia

- **Symptoms**
  - Lethargy, dizziness, nausea, vomiting
  - Muscle cramps, decreased reflexes

- **Signs**
  - Flat jugular veins
  - Low blood pressure
  - Tachycardia
  - Poor skin turgor
Management of Volume Depletion

- Volume replacement with 0.9% NaCl in H₂O
  - Hypertonic saline (3% or 5% NaCl) is used for patients having seizures or in a coma due to euvolemic or hypervolemic hyponatremia
    - Severe symptoms: 50-100 mL bolus and/or 1 mL/kg/hr until serum Na has increased by 4-6 mEq/L
    - Mild symptoms: 0.2-0.4 mL/kg/hr
- Stop any diuretics
- Replace water and sodium via PN, EN, IVF, enterostomy, or PO intake to match losses and maintain euvolemia
- Treat underlying cause, such as diarrhea, vomiting
# Characteristics of Infusates

<table>
<thead>
<tr>
<th>Infusate</th>
<th>Na content (mEq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% NaCl in H₂O</td>
<td>855</td>
</tr>
<tr>
<td>3% NaCl in H₂O</td>
<td>513</td>
</tr>
<tr>
<td>0.9% NaCl in H₂O</td>
<td>154</td>
</tr>
<tr>
<td>Ringer’s lactate solution</td>
<td>130</td>
</tr>
<tr>
<td>0.45% NaCl in H₂O</td>
<td>77</td>
</tr>
<tr>
<td>0.2% NaCl in 5% dextrose</td>
<td>34</td>
</tr>
<tr>
<td>5% dextrose</td>
<td>0</td>
</tr>
</tbody>
</table>
Formulas for H$_2$O & Na Disorders

Water Deficit = Total Body Water (Liters) × \( \left( \frac{\text{Current Serum Sodium (mEq/L)}}{\text{Desired Serum Sodium}} - 1 \right) \)

Water Excess = Total Body Water (Liters) × \( \left( 1 - \frac{\text{Current Serum Sodium (mEq/L)}}{\text{Desired Serum Sodium}} \right) \)

Sodium Requirement = Total Body Water × (Desired Serum Sodium - Current Serum Sodium (mEq/L))

Change in Serum Na (mEq/L) =

\( \frac{\text{Na (mEq/L) content of infusate} - \text{Current Serum Na (mEq/L)}}{\text{Total Body Water (L) + 1}} \)

Example Calculation

- 65 yo male (70 kg); Serum Na\(^+\) 128
- Total body water = 0.6 (70 kg) = 42 L
- Change in serum sodium with 0.9% NaCl (NS)
  - \((154 \text{ mEq/L} - 128 \text{ mEq/L})/(42L +1) = 0.6 \text{ mEq Na}^+ \text{ per 1L of NS}\)
Wesley is an 8-year-old Razorback Musk Turtle from Palatine, IL.

Wesley always dreamed of marauding on the high seas, wreaking havoc on unsuspecting boaters...waiting patiently, ready to strike, says Pet Parents Craig and Melanie. Fortunately for us, his dream only comes true once a year on Halloween. The rest of the year he is content in fulfilling his role as a peaceful turtle.
Causes of Hypotonic **Euvolemic** Hyponatremia

- Glucocorticoid Insufficiency
- SIADH
- Psychogenic polydipsia
- Hypothyroidism
Drug-induced Hyponatremia

- Clonidine

- Anti-Cancer Agents
  - Cyclophosphamide
  - Cisplatin
  - Carboplatin

- Tri-Cyclic Antidepressants
  - Amitriptyline
  - Desipramine

- Chlorpropamide
- Tolbutamide

- Carbamazepine
- Lamotrigine

- SIADH
  - Na+
  - TBW
## Signs and Symptoms of SIADH

<table>
<thead>
<tr>
<th>Signs</th>
<th>Laboratory Indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal BP</td>
<td>↑ Urine Na</td>
</tr>
<tr>
<td>No edema</td>
<td>↑ Urine Osmolality (&gt; 100 mOsm/kg)</td>
</tr>
<tr>
<td>No orthostasis</td>
<td>↓ Serum Na</td>
</tr>
<tr>
<td>No tachycardia</td>
<td>↓ Serum Osmolality (&lt; 275 mOsm/kg)</td>
</tr>
</tbody>
</table>
Self-Assessment Questions

1. Which of the following medications has been associated with causing SIADH?
   a. Phenytoin
   b. Lithium
   c. Carbamazepine
   d. Amphotericin B
Treatment of Symptomatic Acute Hyponatremia

- Fluid Restriction Strategies
  - Restrict all intake that is consumed by drinking, not just water
  - Aim for a fluid restriction that is 500 mL below the 24-hr urine volume
  - Do not restrict sodium or protein intake

- For severe symptoms
  - 100 mL of 3% NaCl infused over 10 min x 3 as needed

- For mild to moderate symptoms with a low risk of herniation
  - 3% NaCl infused at 0.5 mL/kg/hr
  - avoid correction by more than 12 mEq/L/day
  - Rule of 6’s: “6 a day makes sense for safety”

Osmotic Demyelination Syndrome (ODS)

- Patients at High Risk for ODS
  - Serum Na ≤ 105 mmol/L
  - Hypokalemia
  - Alcoholism
  - Undernutrition
  - Advance liver disease

- Tips for Avoiding ODS
  - Lower goal of correction for serum Na by 4-6 mmol/L/day with high risk of ODS
  - Do not exceed 8 mmol/L within any 24-hour period


Hyponatremia, Hypothyroidism, & Adrenal Insufficiency

Hypothalamus
CRH & TRH

Anterior Pituitary
ACTH & TSH

Adrenal gland
Cortisol & Aldosterone

Inability to reabsorb Na/H$_2$O
Impaired renal free H$_2$O excretion

Check Cortisol, ACTH, and TFT’s to address low Na$^+$
Causes of Hypotonic Hypervolemic Hyponatremia

- Cirrhosis
- CHF

\[ \uparrow \text{Na} < \uparrow \text{TBW} \]

Nephrotic Syndrome
Hypotonic Hypervolemic Hyponatremia - Treatment

- Reduce fluid intake (begin with restriction of 1 L/day)
- Eliminate sodium intake (PN and IVF)
- May require diuretic therapy (with loop diuretics) combined with 3% NaCl if patient is severely symptomatic
- If fluid restriction unsuccessful, start either conivaptan or tolvaptan and discontinue restriction
- For tolvaptan, it may be titrated up from 15 to 30 to 60 mg/day as necessary to achieve desired Na correction
- Follow serum concentrations of sodium carefully; continue therapy until serum Na has normalized, symptoms improve, or when serum Na is no longer preventing use of diuretic therapy

Hypernatremia

Hypovolemic: \( \downarrow \text{Na}^+ < \downarrow \text{TBW} \)

Euvolemic: \( \leftrightarrow \text{Na}^+ < \downarrow \text{TBW} \)

Hypervolemic: \( \uparrow \text{Na}^+ > \uparrow \text{TBW} \)
Signs and symptoms of hypernatremia

Central Nervous System
Mild: restlessness, lethargy, headache
Moderate: disorientation, confusion
Severe: stupor, coma, seizures

Increased muscle tone
Increased deep tendon reflexes

Signs and symptoms of hypernatremia
Causes of Hypernatremia

\[ \downarrow \text{Na} < \downarrow \text{TBW} \]

- Loss of hypotonic fluids
- Drugs
  - Diuretics
  - Laxatives
- Hypovolemic
Hypovolemic Hypernatremia Treatment

- Initially, patients need salt and water replacement to perfuse vital organs (NS is usually treatment of choice initially)

- Once volume status has been corrected, hypotonic solutions are appropriate (D5W, ½ NS, ¼ NS)
Causes of Hypernatremia

- Diabetes Insipidus
- Central Nephrogenic
- Nonrenal Losses
  - Thermal injury
  - Fever
- Euvolemic
- Drugs
  - Lithium
  - Amphe B
  - Phenytoin
Euvolemic Hypernatremia

- Caused by loss of primarily free water (thermal injury, fever, diabetes insipidus)
- Hypotonic fluids are the treatment of choice
  - IV – D5W, ½ NS, ¼ NS
  - PO/ Tube – water
- Delete sodium in PN temporarily
- Add water boluses to EN
Euvolemic Hypernatremia – diabetes insipidus

- **Central DI**
  - Absolute deficiency in ADH
  - Often associated with neurosurgery/ head trauma
  - Replacement is the cornerstone of treatment

- **Nephrogenic DI**
  - Impaired response to ADH at the nephron/collecting duct
  - Genetic causes and drug-induced causes
  - Lithium treatment is the #1 cause of acquired nephrogenic DI
Euvolemic Hypernatremia – diabetes insipidus

- Treatment of central DI
  - Nasal or oral desmopressin for chronic care
  - Nasal desmopressin 10 mcg daily (titrate to 10 mcg BID is common)
  - Intravenous desmopressin can be used in acute care (ICU) – 1 mcg IV
Euvolemic Hypernatremia – diabetes insipidus

- Treatment for nephrogenic DI
  - Sodium restriction
  - Thiazide diuretics (paradoxical treatment)
  - Amiloride is effective for lithium-induced nephrogenic DI
  - Induce a mild state of hypovolemia which stimulates proximal tubule reabsorption of water
Hypervolemic Hypernatremia

- ↑ Na > ↑ TBW
- Caused by an excess of both water and sodium; however, sodium excesses are greater
- This is usually iatrogenic (i.e., too much NS)
- Minimize fluid/ eliminate sodium/ diuretics
- Concentrate PN formulation – eliminate Na
- Concentrate EN formulation (e.g. 2 kcal/mL formula)
Cautions with Management

- Correction of HYPERnatremia should aim to reduce the serum Na at a maximal rate of 0.5 mEq/liter/hr to prevent cerebral edema and convulsions.
- A targeted fall in the serum Na of 6 mmol/liter/day should be the goal, until the Na < 145 mEq/liter.
- 0.9% NaCl should only be used in cases of frank circulatory compromise.
Cerebral Edema

Free H$_2$O for Hypernatremia

- “Free H$_2$O” is often ordered for treatment
- “Free H$_2$O” refers to water not associated with organic or inorganic ions
- H$_2$O can be replaced orally, however it should NEVER be given IV as “Sterile H$_2$O for Injection”
- 5% Dextrose in H$_2$O is appropriate choice for “Free H$_2$O” given IV
Sodium and Fluid Balance Conclusions

- Disorders of sodium and water balance are common in patients
- The nutrition support formulation is often the major component of fluid intake
- Proper diagnosis of a sodium disorder requires an accurate assessment of volume status
- An effective clinician must be well grounded in disorders of sodium and water
Self-Assessment Questions

2. Which one of the following intravenous fluids would be most appropriate for INITIAL therapy in a patient with hypovolemic hypernatremia and hypotension?
   a. D5W
   b. ¼ NS
   c. D5 ½ NS
   d. NS
Answers to Self-Assessment Questions

1. Answer = c; carbamazepine is associated with inappropriate release of ADH. Phenytoin, lithium, and amphotericin B are associated with diabetes insipidus and hypernatremia.

2. Answer = d; The first priority in a dehydrated state is to perfuse the vital organs. This is accomplished most effectively by giving an IVF that will stay in the intravascular space, i.e., NS would be given first in this situation.
References

References

References

Parenteral Nutrition Management – Focus on Potassium & Magnesium

Todd W. Canada, PharmD, BCNSP, FASHP, FTSHP
University of Texas MD Anderson Cancer Center
Houston, Texas
Disclosure

- Fresenius Kabi
  - Advisory Board
  - Consultant
  - Speakers Bureau
- I hate electrolyte abnormalities
Objective

- Describe the importance of potassium and magnesium and provide key management strategies in patients receiving nutrition support
Patient Case

- 35-year-old Caucasian male with ulcerative colitis and recurrent seminoma admitted for salvage chemotherapy with paclitaxel, ifosfamide and cisplatin, now with typhilitis on hospital day 8
  - Pale, ill appearing male with distended abdomen, nasogastric tube draining ~ 2 L/day, loose BM x 3
  - Labs

<table>
<thead>
<tr>
<th>Value</th>
<th>Normal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>100</td>
</tr>
<tr>
<td>16</td>
<td>0.38</td>
</tr>
<tr>
<td>75</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>26.3</td>
</tr>
<tr>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

Ion Ca 1.13 / Phos 1.9 / Mg 1.5
Room Air 7.46 / 27 / 97 / 19 / BE -4

- TBili: 1.3
  - Alk Phos: 95
  - AST / ALT: 26 / 15
  - Alb: 2.3
  - Triglycerides: 99

- Weight 60 kg, Height 66 inches
  - Ideal body weight 63.8 kg (94% of IBW)
Patient Case

- Medications
  - Acyclovir 400 mg IV q12h
  - Caspofungin 50 mg IV q24h
  - Cefepime 2 g IV q8h
  - Hydrocortisone 50 mg IV q8h
  - Pantoprazole 40 mg IV q24h
  - Hydromorphone PCA 0.2 mg q8min

- IV Fluids
  - 0.9% NaCl at 75 mL/hr
1. Which is the most appropriate assessment of hypokalemia prior to initiating PN?

- A. Mild with uncompensated respiratory alkalosis
- B. Moderate with compensated metabolic acidosis
- C. Severe with uncompensated respiratory alkalosis
- D. Moderate with uncompensated respiratory acidosis

Answer = A
What Constitutes **Serious** $K^+$ & $Mg^{++}$ Abnormalities?

<table>
<thead>
<tr>
<th>Decreased</th>
<th>Serum Electrolyte</th>
<th>Elevated</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 3.5$ mEq/L</td>
<td>Potassium</td>
<td>$&gt; 5.5$ mEq/L</td>
</tr>
<tr>
<td>$&lt; 1.2$ mg/ dL*</td>
<td>Magnesium</td>
<td>$&gt; 4.8$ mg/ dL</td>
</tr>
</tbody>
</table>

* To convert Magnesium to mEq/L, multiply above numbers by 0.833

<table>
<thead>
<tr>
<th>Decreased</th>
<th>Serum Electrolyte</th>
<th>Elevated</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 3.5$ mEq/L</td>
<td>Potassium</td>
<td>$&gt; 5.5$ mEq/L</td>
</tr>
<tr>
<td>$&lt; 15$ mEq/L</td>
<td>$CO_2$ Content*</td>
<td>$&gt; 40$ mEq/L</td>
</tr>
</tbody>
</table>
## Definitions of K⁺ Abnormalities

<table>
<thead>
<tr>
<th>Definition</th>
<th>Serum K⁺ (mEq/L = mmol/L)</th>
<th>Intensive Care Unit Prevalence in 1st week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe Hypokalemia</td>
<td>&lt; 3</td>
<td>3.3 – 4%</td>
</tr>
<tr>
<td>Mild Hypokalemia</td>
<td>3 – 3.4</td>
<td>18.2 – 20.2%</td>
</tr>
<tr>
<td>Normokalemia</td>
<td>3.5 – 5</td>
<td></td>
</tr>
<tr>
<td>Mild Hyperkalemia</td>
<td>5.1 – 6</td>
<td>16.2 – 17%</td>
</tr>
<tr>
<td>Severe Hyperkalemia</td>
<td>&gt; 6</td>
<td>3.6 – 4%</td>
</tr>
</tbody>
</table>

N = 10,451  
Mean Age 59.4 yrs, 61% Male  
27% Medical / 73% Surgical ICU

Effect of $K^+$ Depletion on Serum $K^+$

Data from 7 balance studies (6 were in normal volunteers) of 24 subjects.

Each fall in serum $K^+$ of 0.27 mEq/L corresponded to a 100 mEq deficit.

## Correlation between Serum K⁺ & Arterial pH

<table>
<thead>
<tr>
<th>pH Range</th>
<th>Serum K⁺ (mEq/L) – Mean ± Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.14 – 7.36</td>
<td>5.1 ± 0.89</td>
</tr>
<tr>
<td>7.37 – 7.46</td>
<td>4.66 ± 0.5</td>
</tr>
<tr>
<td>7.47 – 7.6</td>
<td>3.58 ± 1.04</td>
</tr>
</tbody>
</table>

For every 0.1 unit change in pH, the change in serum K⁺ is approximately 0.5 mEq/L.
For every 0.1 unit change in pH, the change in serum $K^+$ is approximately 0.5 mEq/L.
Correcting Electrolyte Disorders

- Identify the etiology of the electrolyte abnormality
- Characterize it as either acute or chronic
- Evaluate the therapeutic index for the electrolyte

If acute (< 48 hours) – supplemental infusion
If chronic (> 48 hours) – use with maintenance solutions

Etiologies of Hypokalemia

- Inadequate dietary $K^+$ intake
- Hypomagnesemia
  - Cisplatin, Caspofungin
- Diarrhea
  - Typhilitis
- Vomiting or nasogastric losses
  - 2 Liters/day
- High dose corticosteroids
  - Hydrocortisone
- Insulin
- Proximal renal tubular acidosis
  - Ifosfamide
Dextrose & Insulin Effects on Serum K$^+$

PN provides 5 – 15 g dextrose/hr in most adults

2. What would be the most appropriate dose of potassium for his PN in mEq/day?

A. 60
B. 100
C. 150
D. 200

Answer = B
Management of Hypokalemia

- $K^+ \text{ administration is most common cause of hyperkalemia}$
  - $10 \text{ mEq } K^+ \text{ intravenously increases serum } \sim 0.1 \text{ mEq/L}$

N = 190 (MICU with 32 oliguric)  
77% central / 23% peripheral administration

Management of Hypokalemia

- $\text{K}^+$ administration is most common cause of hyperkalemia
  - 10 mEq $\text{K}^+$ intravenously increases serum $\sim$0.1 mEq/L

<table>
<thead>
<tr>
<th>Serum Potassium</th>
<th>20 mEq</th>
<th>30 mEq</th>
<th>40 mEq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline K</td>
<td>2.7</td>
<td>3.4</td>
<td>3.5</td>
</tr>
<tr>
<td>Post-infusion K</td>
<td>3.8</td>
<td>4.1</td>
<td>4.3</td>
</tr>
<tr>
<td>1 hr Post-infusion K</td>
<td>3.5</td>
<td>4.0</td>
<td>4.1</td>
</tr>
</tbody>
</table>

$\text{N} = 48$ (Mixed ICU with Mean Age 59, 62, 41 yrs)
100% central venous catheter administration over 1 hour

Management of Hypokalemia

- $K^+$ administration is most common cause of hyperkalemia
  - 10 mEq $K^+$ intravenously increases serum $\sim 0.1$ mEq/L

<table>
<thead>
<tr>
<th>Baseline K</th>
<th>Peak K</th>
<th>Post-infusion K</th>
<th>1 hr Post-infusion K</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.9</td>
<td></td>
<td></td>
<td>3.2</td>
</tr>
</tbody>
</table>

Mean Change in K / 20 mEq = 0.25 mEq/L

N = 40 (MICU with Mean Age 59 yrs)
65% central / 35% peripheral administration

Management of Hypokalemia with Consideration of Hypomagnesemia

N = 48 (Mixed ICU with Mean Age 59, 62, 41 yrs)
100% central venous catheter administration over 1 hour

## Potassium

\[ K^+ = \text{Kevorkian (It’s a Killer)} \]

### Table: Potassium Levels and Clinical Implications

<table>
<thead>
<tr>
<th>K^+ Concentration</th>
<th>Clinical Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.5 mEq/kg/day</td>
<td>Anuric Acute Renal Failure</td>
</tr>
<tr>
<td>1-2 mEq/kg/day</td>
<td>Normal</td>
</tr>
<tr>
<td>&gt; 2 mEq/kg/day</td>
<td>Metabolic alkalosis</td>
</tr>
<tr>
<td>Anuric Acute Renal Failure</td>
<td>K^+ shifters</td>
</tr>
<tr>
<td>Chronic Kidney Disease</td>
<td>K^+ sparing drugs</td>
</tr>
<tr>
<td>K^+ Sparing Drugs</td>
<td>K^+ wasting drugs</td>
</tr>
<tr>
<td>- Spironolactone</td>
<td>- Catecholamines</td>
</tr>
<tr>
<td>- Amiloride</td>
<td>- Insulin</td>
</tr>
<tr>
<td>ACE Inhibitors (Vasotec)</td>
<td>- Furosemide, Torsemide</td>
</tr>
<tr>
<td>Trimethoprim (Bactrim)</td>
<td>- Hydrocortisone</td>
</tr>
<tr>
<td></td>
<td>- Amphotericin B</td>
</tr>
</tbody>
</table>

### Notes:

- **Narrow therapeutic index**
- Clinical judgment and monitoring must be used when determining the most appropriate dose with evaluation of renal function and acid/base status.

3. What would be the most appropriate dose of magnesium for his PN in mEq/day?

A. 16
B. 32
C. 64
D. 96

Answer = C
# Prevalence of Hypomagnesemia

<table>
<thead>
<tr>
<th>Reference</th>
<th>Patient Population</th>
<th>Definition of Hypomagnesemia</th>
<th>Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salem (1991)</td>
<td>Emergency Department</td>
<td>$&lt; 1 \text{ mEq/L}$</td>
<td>9%</td>
</tr>
<tr>
<td>Wong (1983)</td>
<td>University Hospital-Medical</td>
<td>$&lt; 1.2 \text{ mEq/L}$</td>
<td>11%</td>
</tr>
<tr>
<td>Whang (1987)</td>
<td>VA Hospital</td>
<td>$&lt; 1.25 \text{ mEq/L}$</td>
<td>6.9%</td>
</tr>
<tr>
<td>Whang (1977)</td>
<td>VA Hospital</td>
<td>$&lt; 1.25 \text{ mEq/L}$</td>
<td>9%</td>
</tr>
<tr>
<td>Rubeiz (1993)</td>
<td>University Hospital-Medical</td>
<td>$&lt; 1.25 \text{ mEq/L}$</td>
<td>18%</td>
</tr>
<tr>
<td>Whang (1984)</td>
<td>2 University &amp; 1 VA Hospital</td>
<td>$&lt; 1.25 \text{ mEq/L}$</td>
<td>26%</td>
</tr>
<tr>
<td>England (1992)</td>
<td>Surgical Pre-op</td>
<td>$&lt; 1.5 \text{ mEq/L}$</td>
<td>16%</td>
</tr>
<tr>
<td>Salem (1991)</td>
<td>Emergency Department</td>
<td>$&lt; 1.5 \text{ mEq/L}$</td>
<td>22%</td>
</tr>
<tr>
<td>Whang (1990)</td>
<td>Hospitalized</td>
<td>$&lt; 1.48 \text{ mEq/L}$</td>
<td>47%</td>
</tr>
<tr>
<td>Chernow (1989)</td>
<td>Post-op SICU</td>
<td>$&lt; 1 \text{ mEq/L}$</td>
<td>9%</td>
</tr>
<tr>
<td>Desai (1988)</td>
<td>University Hospital-MICU</td>
<td>$&lt; 1.2 \text{ mEq/L}$</td>
<td>19%</td>
</tr>
<tr>
<td>Rubeiz (1993)</td>
<td>University Hospital-MICU</td>
<td>$&lt; 1.25 \text{ mEq/L}$</td>
<td>20%</td>
</tr>
<tr>
<td>Fiaccadori (1988)</td>
<td>Pulmonary ICU</td>
<td>$\leq 1.4 \text{ mEq/L}$</td>
<td>9.4%</td>
</tr>
<tr>
<td>Reinhart (1985)</td>
<td>Community Hospital-MICU</td>
<td>$&lt; 1.4 \text{ mEq/L}$</td>
<td>20%</td>
</tr>
<tr>
<td>Zaloga (1987)</td>
<td>ICU</td>
<td>$&lt; 1.4 \text{ mEq/L}$</td>
<td>33%</td>
</tr>
<tr>
<td>Chernow (1989)</td>
<td>Post-op SICU</td>
<td>$&lt; 1.5 \text{ mEq/L}$</td>
<td>61%</td>
</tr>
<tr>
<td>Ryzen (1985)</td>
<td>University Hospital-MICU</td>
<td>$&lt; 1.5 \text{ mEq/L}$</td>
<td>44%</td>
</tr>
<tr>
<td>Ryzen (1985)</td>
<td>University Hospital-MICU</td>
<td>$&lt; 1.5 \text{ mEq/L}$</td>
<td>65%</td>
</tr>
<tr>
<td>England (1992)</td>
<td>Post-op SICU (Mg Treated)</td>
<td>$&lt; 1.5 \text{ mEq/L}$</td>
<td>68%</td>
</tr>
</tbody>
</table>
Etiologies & Effects of Hypomagnesemia

- Inadequate dietary Mg++ intake
- Medication-related losses
  - Cisplatin, Ifosfamide
  - Caspofungin
- Diarrhea
  - Typhilitis

- Reduces insulin sensitivity
  - Decreases autophosphorylation of B-subunit of insulin receptor
- Reduces glucose cellular uptake
  - Decreases translocation of glucose transporter protein
- Impairs insulin secretion
  - Decreases affinity of insulin binding to its receptor
- Reduces lipoprotein lipase
Magnesium Replacement Effects on $K^+$

- Serum Mg$^{++}$ at 30 hrs significantly higher with less $K^+$ excretion
- Serum $K^+$ significantly higher after 6 hrs of Mg$^{++}$ treatment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control (n=15)</th>
<th>Magnesium Sulfate (n=17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium Given (mEq)</td>
<td>344</td>
<td>245</td>
</tr>
<tr>
<td>Potassium Excreted (mEq/48 hrs)</td>
<td>72</td>
<td>74</td>
</tr>
<tr>
<td>Magnesium Given (mEq)</td>
<td>418</td>
<td>173</td>
</tr>
<tr>
<td>Magnesium Excreted (mEq/48 hrs)</td>
<td>2</td>
<td>62</td>
</tr>
</tbody>
</table>

$N = 32$ (SICU with Mean Age 52 vs. 60 yrs) with Serum $K^+ < 3.5$ mEq/L
Baseline Serum $K^+ 3.3$ vs. $3.4$ mEq/L; Baseline Serum Mg$^{++} 2.1$ vs. $1.9$ mg/dL

Management of Hypomagnesemia

- Mg\(^{++}\) administration is most common cause of hypermagnesemia
  - 8 mEq (1 g) Mg\(^{++}\) IV increases serum ~0.1 mg/dL

![Graph showing response to Mg\(^{++}\) IVPB infused over 24 hr]

## Magnesium in PN

Mg = “May give” more

<table>
<thead>
<tr>
<th>Magnesium Intake (mEq/kg/day)</th>
<th>Acute Renal Failure</th>
<th>Normal</th>
<th>Alcohol abuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.25</td>
<td>Renal replacement therapy may increase need depending on mode of dialysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25 – 0.5</td>
<td>Normal</td>
<td></td>
<td>Magnesium wasters</td>
</tr>
<tr>
<td>&gt; 0.5</td>
<td></td>
<td></td>
<td>- Loop diuretics (furosemide, torsemide, bumetanide)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Hydrochlorothiazide &gt; 50 mg/day</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Amphotericin B</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Aminoglycosides</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Cisplatin, carboplatin, oxaliplatin, ifosfamide, cetuximab</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Cyclosporine, tacrolimus</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Foscarnet</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Proton pump inhibitors (e.g., omeprazole)</td>
</tr>
</tbody>
</table>

## Chronic Kidney Disease

- Severe diarrhea (any cause)

## Hypermagnesemia

- Renal Replacement Therapy
K⁺ & Mg⁺⁺ Considerations in Compounding PN

- Considerations for adding fat emulsion to PN (3-in-1)
  - Phospholipid emulsifier is anionic
  - Dependent on cations:
    - Trivalent (Iron > 2 mg/L)
    - Divalent (Mg + Ca > 20 mEq/L)
    - Monovalent (Na + K > 150 mEq/L)
  - Emulsion cracking more likely to occur at pH ≤ 5
    - Fat emulsions do not possess pH buffering capacity
      - Hydrolytic degradation of triglycerides forming free fatty acids can lower the pH over the course of its shelf life
      - Minimal hydrolysis occurs at a pH of 6.5 – 7


Amino acids 2.5 – 7%
Dextrose 5 – 20%
Fat emulsion 2 – 5%
Electrolyte Dosages in PN

<table>
<thead>
<tr>
<th>Low Dose†</th>
<th>Electrolyte</th>
<th>High Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.5 mEq/kg/day</td>
<td>Potassium</td>
<td>&gt; 2 mEq/kg/day</td>
</tr>
<tr>
<td>&lt; 0.5 mEq/kg/day</td>
<td>Acetate*</td>
<td>&gt; 3 mEq/kg/day</td>
</tr>
<tr>
<td>&lt; 0.25 mEq/kg/day</td>
<td>Magnesium</td>
<td>&gt; 2 mEq/kg/day</td>
</tr>
</tbody>
</table>

† Although considered a low dose, this may be appropriate given any degree of renal impairment

* Evaluate the blood gas for actual serum pH (< 7.2 severe acidemia; > 7.6 severe alkalemia)
Key Takeaways

- Key Takeaway #1
  - Magnesium treatment alone augments potassium retention.

- Key Takeaway #2
  - Potassium and magnesium replacement in 3-in-1 PN is limited by their effect on the anionic emulsifier in fat emulsions.

- Key Takeaway #3
Importance of Phosphorus and Calcium in Patients Receiving Parenteral Nutrition

Michael D. Kraft, Pharm.D., BCNSP
Clinical Associate Professor – University of Michigan College of Pharmacy
Assistant Director, Education & Research – University of Michigan Hospitals and Health Centers
Ann Arbor, MI
Learning Objectives

Upon completion of this session, the learner will be able to:

1. List common causes of phosphorus and calcium abnormalities in adult patients receiving nutrition support.

2. Recommend empiric treatment options for phosphorus and calcium abnormalities in adult patients receiving nutrition support.

3. Identify approaches to prevent phosphorus and calcium abnormalities in select adult patients receiving nutrition support.
General Principles

- Mild disorders, asymptomatic: may not require immediate treatment
- Severe disorders: can be urgent/emergent
- Must assess the whole patient, don’t just “treat the numbers”
  - Provide appropriate maintenance requirements, anticipate potential abnormalities
  - Dose adjustments in PN ~ 10 – 25% (with some exceptions)
  - Treat the underlying cause
  - Treat and/or prevent symptoms
  - Normalize serum concentrations, avoid overcorrection
  - Avoid/decrease morbidity, mortality
  - Patient safety!
Phosphorus (P) and Calcium (Ca) Homeostasis

Phosphorus (P)

- Majority in bones and intracellular compartment, ~1% in extracellular fluid
- Many essential functions
  - ATP
  - 2,3-Diphosphoglycerate (2,3-DPG)
  - Bone and cell membrane phospholipids
- Adequate stores needed for glucose utilization/glycolysis, protein synthesis, neurologic function, muscle function
- Normal serum [P] ~ 2.7 – 4.5 mg/dL
- Unstressed, well-nourished adults require ~ 20 – 40 mmol/day, or ~ 10 – 15 mmol per 1000 kcals
- Increasing total caloric load → decreased serum [P]
- Inadequate maintenance dosing → severe hypophosphatemia and sequelae

Phosphorus (P) – Altered Requirements

- Some patients have higher daily P requirements
  - Severely malnourished/risk for refeeding syndrome
  - Critically ill, trauma, traumatic brain injury
  - Thermal injury, liver resection
- Patients with impaired renal function → likely require P restriction (possible exception: renal replacement therapy)
- Typically monitor serum [P] daily in non-stressed, well-nourished adult inpatients receiving nutrition support
- Closer monitoring in special patients listed above, especially when initiating nutrition support (e.g., every 12 hours)

Calcium (Ca)

- **Key roles**
  - Bone structure, coagulation, platelet adhesion
  - Neuromuscular activity, Endocrine & exocrine secretory functions

- **Vast majority (~99%) in bones, <1% in serum**
  - ~40 – 50% blood Ca bound to proteins (albumin)
  - Ionized [Ca] closely regulated, better indicator of functional Ca status

- **Normal serum concentrations**
  - Total [Ca] ~ 8.6 – 10.2 mg/dL
  - Ionized [Ca] ~ 1.12 – 1.3 mmol/L

- **Adult patients receiving PN (normal renal function) require**
  ~10 – 15 mEq/day for maintenance

- **Adjusting maintenance doses**
  - Depends on daily Ca dose, clinical condition
  - Response to dose changes/supplemental doses

Phosphorus and Calcium Considerations in Specific Conditions

- Chronic Kidney Disease
  - Hyperphosphatemia, Vitamin D deficiency
  - Renal osteodystrophy, soft-tissue calcification
  - Acid-base abnormalities (e.g., metabolic acidosis)

- Intestinal Failure
  - Malabsorption, Short Bowel Syndrome (SBS), Inflammatory Bowel Disease (IBD)
  - Malabsorption $\rightarrow$ vitamin D deficiency
  - Chronic corticosteroid therapy $\rightarrow$ bone demineralization
  - Large GI losses $\rightarrow$ dehydration, metabolic alkalosis, magnesium deficiency

- Long-term PN/PN-dependence $\rightarrow$ Metabolic Bone Disease

Phosphate and Calcium Compatibility in Parenteral Nutrition Admixtures
Ca and P Compatibility in PN Admixtures

- $\text{Ca}^{2+} + \text{HPO}_4^{2-} \rightarrow \text{CaHPO}_4$

- Deaths associated with Ca-Phos precipitation in PN admixtures (FDA 1994, JPEN 1996)

- Factors affecting Ca-Phos solubility in PN admixtures:
  - Final pH
  - Amino Acid brand and final concentration
  - Dextrose concentration
  - Ca salt
  - Order of mixing
  - Temperature
  - Time

Ca and P Compatibility in PN Admixtures

- Must follow safe PN practices when compounding PN Admixtures!
  - Use established Ca-Phos solubility curves
  - Consider PO₄ from ALL sources
  - Use Ca Gluconate, avoid Ca Chloride
  - Add PO₄ salts early in sequence, Ca toward end
  - Consider admixture volume at time Ca is added
  - Periodically agitate, check for precipitation
  - Use appropriate in-line filter (0.22-micron or 1.2-micron)
  - Store at appropriate temperature

- Recommended **minimum** final concentrations: dextrose 10%, amino acids 4%, IV Lipid Emulsion 2% (admixture stability)

Hypophosphatemia
Hypophosphatemia

- Serum [P] < 2.7 mg/dL; ~2 – 3% of inpatients, 28 – 80% of critically ill patients
- Associated with higher mortality, longer LOS, longer duration of mechanical ventilation
- Critically ill may be predisposed to hypophosphatemia
- Severe symptoms with serum [P] < 1 mg/dL (~0.3 mmol/L)
  - Hypoxia, respiratory failure
  - Weakness, paresthesias, mental status changes
  - Seizures, coma, death
- General causes: inadequate intake/increased demand, altered distribution, altered excretion

Refeeding Syndrome

- Constellation of electrolyte abnormalities and symptoms associated with rapid re-introduction of nutrition (especially carbohydrates) after prolonged starvation

- **The Minnesota Experiment**: 36 conscientious objectors of war
- Prisoners of War (WWII)
- Hallmark Sign: hypophosphatemia

- Other S/Sx:
  - Hypokalemia, hypomagnesemia
  - Thiamine deficiency, fluid/sodium intolerance, possibly hyperglycemia

- Can lead to severe sequelae: paresthesias, mental status changes, seizures, coma, and death

Refeeding Syndrome - Pathophysiology

Prolonged Starvation / Severe Malnutrition

- Re-introduction of CHO → ↑ metabolic rate, ↑ insulin secretion, ↑ glycolysis, anabolism
- ↑ Glucose uptake, ↑ demand for ATP and $O_2$, ↑ uptake of Phos, K+, Mg++, ↑ utilization of thiamine

Nutrient depletion → glycogen, gluconeogenesis/protein catabolism, fatty acid catabolism → ketone production
- Electrolyte, vitamin depletion; salt/water intolerance
- ↓ metabolic rate, ↓ insulin secretion

Hypophosphatemia
Hypokalemia
Hypomagnesemia
Thiamine deficiency
Na+/water retention
+/− Hyperglycemia

REFEEDING SYNDROME

Refeeding Syndrome / Refeeding Hypophosphatemia

- Review of 27 patient cases since 2000
  - **Hypophosphatemia = 96%**
  - At least 1 other e-lyte abnormality = 71%
  - Hypomagnesemia = 51%; hypokalemia = 46%
  - Hypocalcemia = 27%; hyponatremia = 8%
  - One documented thiamine deficiency (4%), one with S/Sx of possible thiamine deficiency
  - Paresthesias = 15%, tachycardia/bradycardia = 8% each
  - Edema/excessive wt gain = 22%
  - One pt with heart failure, one with ventricular ectopy
  - Hyperglycemia not reported
Refeeding Syndrome/Hypophosphatemia

- Prevention is key!
- "Start low, go slow", AVOID OVERFEEDING
- Correct electrolyte abnormalities before initiating nutrition support
- Provide adequate PO₄ (e.g., may require increased maintenance doses by ~ 25 – 50% (or higher) for first several days of PN therapy)
- May require increased monitoring (e.g., serum [P] ~ twice a day)
- Most cases develop in first 3 – 5 days, but some reported > 5 – 7 days

Management of Refeeding Syndrome in Critically Ill Adults

- Multicenter, randomized, single-blind, parallel-group study, 339 critically ill adults
- Serum [P] < 0.65 mmol/L (~ 2 mg/dL) (and > 0.16 mmol/L (~ 0.5 mg/dL) decrease) w/in 72-hrs of starting nutrition support
- Randomized to standard vs. caloric restriction (20 kcal/hr x ≥ 2 days)
- Gradual return to goal over 2 – 4 days (40 kcal/hr, 60 kcal/hr, 80% goal, 100% goal)
- If serum [P] < 0.71 mmol/L (~ 2.2 mg/dL) → start over

Management of Refeeding Syndrome in Critically Ill Adults

Fewer patients required insulin on days 2 – 6

# Empiric Treatment of Hypophosphatemia

<table>
<thead>
<tr>
<th>Degree of Hypophosphatemia</th>
<th>Suggested IV phosphate dose*†</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3 – 2.7 mg/dL (~ 0.75 – 0.9 mmol/L) Mild hypophosphatemia, asymptomatic</td>
<td>0.08 – 0.16 mmol/kg</td>
</tr>
<tr>
<td>1.5 – 2.2 mg/dL (~ 0.5 – 0.75 mmol/L) Moderate hypophosphatemia, asymptomatic</td>
<td>0.16 – 0.32 mmol/kg</td>
</tr>
<tr>
<td>&lt; 1.5 mg/dL (~ &lt; 0.5 mmol/L) Severe hypophosphatemia, symptoms present, possibly severe</td>
<td>0.32 – 0.64 mmol/kg†</td>
</tr>
</tbody>
</table>

* In patients with normal renal function; patients with renal insufficiency should receive ≤ 50% of the initial empiric dose. Maximum infusion rate = 7.5 mmol phosphate/hour; Suggest using adjusted body weight (AdjBW) in patients who are significantly obese (weight > 130% of IBW or BMI ≥ 30 kg/m²): AdjBW (males) = (\([\text{wt (kg)} - \text{IBW(kg)}]\) x 0.3) + IBW; AdjBW (females) = (\([\text{wt (kg)} - \text{IBW(kg)}]\) x 0.25) + IBW

† Doses up to 1 mmol/kg have been used in adult critically ill trauma patients

**IV Phosphate**

- Sodium (NaPhos) or Potassium (KPhos) salt
  - 1 mmol NaPhos $\sim 1.33$ mEq Na$^+$
  - 1 mmol KPhos $\sim 1.47$ mEq K$^+$
- Infuse doses over $\sim 4 - 6$ hours, max $\sim 7 - 7.5$ mmol/hour
- Limited data for rates up to 15 mmol/hour, however:
  - No difference in serum [P] vs. 7.5 mmol/hour
  - More patients developed hyperkalemia
  - Trend toward increased fractional PO$_4^-$ excretion
- Caution with KPhos, may require central line

Treatment/Prevention of Hypophosphatemia

- Provide adequate maintenance doses in PN, some may require daily supplement or ↑ maintenance dosing in PN
- Deficits typically require several days to fully correct → especially critically ill, malnourished/risk of refeeding
- Consider ALL sources of Na+ and K+ in PN admixtures
- No data/protocols to guide dose adjustments → reasonable to consider adjusting daily doses in PN by ~ 10 – 25%, monitor for response
- Critically ill adults → decrease nutrition to ~ 20 kcal/hr, advance over ~ 4 days
- Further adjustments based on response and clinical condition

Monitoring

- Data lacking on optimal time to recheck serum [P] after supplementation
  - Some protocols and guidelines suggest ~ 2 – 6 hours after a dose
  - Several studies have rechecked ~ 12 – 24 hours after supplementation, or on a daily basis

- Reasonable to monitor once-twice daily if actively treating
  - Potentially more frequently in severe/symptomatic cases until resolved
# Example Protocol

## Empiric Treatment of Hypophosphatemia

<table>
<thead>
<tr>
<th>Serum Phos Concentration (Goal 2.7 – 4.6 mg/dL)</th>
<th>IV Phosphate Dose</th>
<th>Recommended Serum Phos Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 – 2.6 mg/dL</td>
<td>15 mmol over 2 hrs</td>
<td>With next AM labs</td>
</tr>
<tr>
<td>1.5 – 1.9 mg/dL</td>
<td>30 mmol over 4 hrs</td>
<td>Within 12 hrs of completing dose or with AM labs</td>
</tr>
<tr>
<td>&lt; 1.5 mg/dL</td>
<td>45 mmol over 6 hrs and notify MD</td>
<td>Within 4 – 6 hrs of completing dose</td>
</tr>
</tbody>
</table>

- Only for patients with normal renal function (e.g., est GFR > 60 mL/min)
- Maximum phosphate infusion = 7.5 mmol/hr
- Doses provided as NaPhos; if serum [K+] < 4 mEq/L, contact MD to enter separate order for KPhos replacement
Hyperphosphatemia
Hyperphosphatemia

- Serum [P] > 4.5 mg/dL (~ 1.45 mmol/L)
- Most common cause → impaired kidney function
  - Tumor lysis, hemolysis, rhabdomyolysis
  - Hypoparathyroidism, vitamin D intoxication
  - Immobility, Acidosis (metabolic, respiratory)
- Severe hyperphosphatemia, acute kidney injury, and dehydration reported after treatment with oral and rectal P-containing laxatives (especially in patients with impaired kidney function)
- Risk of metastatic calcification may increase with serum Ca x P > 55-60 mg$^2$/dL$^2$

Treatment of Hyperphosphatemia

- Complete assessment of the patient, remove underlying cause(s)

- Adjust/restrict P intake (i.e. reduce phosphate dose in PN), especially patients with impaired kidney function
  - Empirically → reduce maintenance dose ~ 50%?
  - No data, need to use clinical judgment, adjust based on response

- Patients receiving Renal Replacement Therapy → variable requirements depending on form of RRT, native kidney function

- Can consider phosphate binder therapy (e.g., calcium carbonate, sevelamer)

Monitoring

- Most therapies have delayed onset → frequent monitoring of serum [P] likely not needed
- Every 24 – 48 hours likely appropriate in most patients
- Critically ill, symptomatic, or receiving CRRT may require more frequent monitoring
- Goal to normalize serum [P], maintain the serum Ca x P < 55 mg^2/dL^2, avoid calcification
Hypocalcemia
Hypocalcemia

- Serum total [Ca] < 8.6 mg/dL (~2.15 mmol/L), ionized [Ca] < 1.1 mmol/L
- May occur in 15 – 88% of hospitalized patients, ~ 21% of critically ill patients
- Often associated with hypoalbuminemia
  - Sepsis, Pancreatitis, kidney dysfunction, hypoparathyroidism, Vitamin D deficiency
  - Hypomagnesemia, Hyperphosphatemia, Citrated blood
  - Medications: loop diuretics, calcitonin
- Hallmark sign → tetany
  - Muscle cramps, paresthesias, seizures
  - Prolonged QT, heart block, ventricular fibrillation

“Corrected” Calcium

- Poor correlation between total serum [Ca] & free/ionized [Ca] in:
  - Critically ill
  - Hypoalbuminemia, acid-base disorders
- Monitor ionized [Ca], especially critically ill
- “Corrected” [Ca]: Modified Orrell equation (Developed in non-critically ill patients)

Corrected serum [Ca] (mg/dL) = Serum [Ca] (mg/dL) + [0.8 x (4 – albumin (g/dL))]

- Dickerson, et. al., 22 methods for correcting [Ca]
  - Sensitivity = 25%, FN = 75%; Specificity = 90%, FP = 10%
  - 85% of crit ill trauma patients with total [Ca] < 7 mg/dL had ionized hypocalcemia (ionized [Ca] < 1.12 mmol/L)
  - Other high-risk: albumin < 2 g/dL, pH > 7.45

Treatment of Hypocalcemia

- Remove underlying cause(s), correct hypomagnesemia
- Critically ill, severe cases → IV treatment
  - 1000 mg Ca Chloride ~ 13.6 mEq Ca^{++}
  - 1 g Ca Gluconate ~ 4.65 mEq Ca^{++}
  - Watch for dosing errors, do not use term “amp”
- DO NOT infuse via the same IV line as PO_{4}-containing products
- Ca Gluconate for routine supplementation
- Calcium Chloride via central line only!

Risk of extravasation → soft-tissue calcification, ulceration, necrosis (calcinosi cutis)

## Empiric Treatment of Hypocalcemia

<table>
<thead>
<tr>
<th>Degree of Hypocalcemia</th>
<th>Preferred Calcium Salt*</th>
<th>Suggested IV Dose+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serum ionized [Ca] ~ 1 – 1.12 mmol/L</td>
<td>Gluconate</td>
<td>1 – 2 g calcium gluconate, infused over 1 – 2 hrs</td>
</tr>
<tr>
<td>Mild – moderate, asymptomatic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serum ionized [Ca] &lt; 1 mmol/L</td>
<td>Gluconate</td>
<td>3 – 4 g calcium gluconate, infused over 3 – 4 hours</td>
</tr>
<tr>
<td>Severe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe, symptomatic hypocalcemia (with serum ionized [Ca] &lt; 1 mmol/L)</td>
<td>Gluconate or chloride</td>
<td>1 – 3 g calcium gluconate, or 500 – 1000 mg calcium chloride, infused over 10 min, may repeat ~ every 60 min as needed until stabilized, then supplement as suggested above based on serum ionized [Ca] and patient symptoms/ clinical status</td>
</tr>
</tbody>
</table>

* Calcium chloride should be administered via a central venous catheter to avoid extravasation and tissue necrosis; 1,000 mg calcium chloride = 13.6 mEq Ca, 1 g calcium gluconate = 4.65 mEq Ca
+ Typically a calcium gluconate dose of 1 – 2 g (4.65 – 9.3 mEq Ca) is mixed in 100 mL of D5W or NS and infused at a maximum rate of 1 g/hour for routine supplementation (non-emergent situations).

Empiric Treatment of Hypocalcemia

- Serum [Ca] < 7 mg/dL → Measure ionized [Ca] (could empirically treat (1 – 2 g Ca Gluconate) if ionized [Ca] not available)
- No apparent correlation between weight-based dose and change in serum [Ca]
- Reasonable to check serum ionized [Ca] ~ 10 – 12 hours after a dose, possibly more frequent if symptomatic/severe

## Example Protocol – Treatment of Hypocalcemia

<table>
<thead>
<tr>
<th>Serum Ionized [Ca]</th>
<th>IV Calcium Gluconate Dose</th>
<th>Recommended Serum [Ca] Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.05 – 1.11 mmol/L</td>
<td>1 g IV over 60 minutes</td>
<td>With next AM labs</td>
</tr>
<tr>
<td>0.99 – 1.04 mmol/L</td>
<td>2 g IV over 120 minutes</td>
<td>~ 12-hrs after completing dose</td>
</tr>
<tr>
<td>0.93 – 0.98 mmol/L</td>
<td>3 g IV over 180 minutes</td>
<td>~ 12-hrs after completing dose</td>
</tr>
<tr>
<td>&lt; 0.93 mmol/L</td>
<td>4 g IV over 120 – 240 minutes and notify MD</td>
<td>~ 12-hrs after completing dose, within 4 – 6-hrs after dose if symptomatic</td>
</tr>
</tbody>
</table>
Hypercalcemia

- Total serum [Ca] > 10.2 mg/dL (~2.55 mmol/L), ionized [Ca] > 1.3 mmol/L
  - Mild-moderate: total [Ca] 10.3-12.9 mg/dL, ionized [Ca] 1.3-1.6 mmol/L
  - Severe: total [Ca] > 13 mg/dL, ionized [Ca] > 1.6 mmol/L

- Most common causes: malignancy and primary hyperparathyroidism
  - Adrenal insufficiency, Paget’s disease, Immobilization, rhabdomyolysis, Vitamin A or Vitamin D toxicity
  - Medications: thiazide diuretics, lithium

- Can lead to Ca-Phos precipitation, metastatic calcification, renal failure

- Mild hypercalcemia: Remove underlying cause(s), reduce dose in PN, hydration and ambulation

Treatment of Severe Hypercalcemia

- Hypercalcemic crisis: emergency requiring immediate treatment, can lead to acute kidney injury, ventricular arrhythmias, coma, death
- Aggressive hydration $\rightarrow$ IV normal saline $\sim$ 200 – 300 mL/hr
- +/- IV loop diuretic (furosemide) $\rightarrow$ rigorous data lacking, consider if not responding to fluid (ensure adequate resuscitation first)
- Consider calcitonin 4 units/kg q 12 hrs if inadequate response $\rightarrow$ usually limited to a few days (tachyphylaxis)
- Bisphosphonates:
  - Pamidronate 60 – 90 mg IV over 2 – 24 hrs
  - Chronic critical illness: 30 mg IV daily x 3 days (with calcitriol)
  - Zoledronic acid 4 – 8 mg IV over 15 minutes
  - Assess renal function/dosing

Summary

- Phosphorus and Calcium are vital components of nutrition support therapy
- Influenced by several factors, including clinical condition and medications
- Provide appropriate maintenance doses, be proactive in preventing abnormalities
- Important safety considerations when prescribing and compounding PN admixtures, and when treating abnormalities
Patient Case

WS, 36-year-old woman, CC of constipation, abdominal pain, distention, nausea, vomiting, decreased appetite and decreased PO intake x 4 days.

- Gradual unintentional weight loss of ~10 pounds (4.5 kg) over the past month
- PMHx: chronic constipation, chronic abdominal pain, recurrent bowel obstructions, severe malnutrition
- PSHx: Multiple abdominal surgeries, including colon resection with colostomy and mucus fistula s/p takedown, SBR x 2 with LOA
- FH/SH: N/C, non-smoker, occ EtOH, endorses chronic prescription opioid Rx for chronic abd pain
- NKDA
- Medications: Hydrocodone/APAP 5mg/325mg 1 tab q 4 – 6 hrs (states taking 1 tab q 4 – 5 hrs ATC); Docusate 100 mg PO twice daily; Polyethylene glycol 3350, 17 g PO daily

PE: 162 cm (~ 5’ 4’’), 41 kg, IBW 54.5 kg
Patient Case

\[\begin{array}{ccc}
136 & 96 & 9 \\
3.2 & 27 & 0.5 \\
\end{array}\]

\[\begin{array}{c}
79 \\
10.1 \\
7.7 \\
29.5 \\
\end{array}\]

Ca = 7.9 mg/dL  
Mg = 1.2 mg/dL  
Phos = 2 mg/dL  
Alb = 2.7 g/dL  
25-OH vitamin D = 9 ng/mL (20-50)

Placed NG, conservative management

Failed several attempts at PO and enteral nutrition, NG replaced, PICC placed, plan to initiate PN
Learning Assessment

Which of the following is a potential cause of hypophosphatemia in this patient?

A. Hypervitaminosis D
B. Severe Malnutrition
C. Respiratory alkalosis
D. Constipation
Learning Assessment

Which of the following treatments for hypophosphatemia would you recommend at this time for this patient (PN therapy has not started)?

A. Initiate PN at goal, increase maintenance dose of phosphate by ~ 25%
B. Administer IV sodium phosphate 30 mmol x 1 over 2 hours
C. Administer oral Na-K phosphate 2 packets (16 mmol) dissolved in water x 1
D. Administer IV potassium phosphate 12 mmol IV x 1 over 2 hours
Learning Assessment

What would you recommend regarding this patient’s serum calcium concentration?

A. Check serum ionized calcium concentration
B. Administer IV calcium gluconate 2 g x 1 dose over 1 hour
C. Administer IV calcium chloride 1 g x 1 dose over 1 hour
D. Administer PO calcium carbonate 1,000 mg (20 mEq) x 1 dose
Acid Base Disorders

Phil Ayers, Pharm.D., BCNSP, FASHP
Baptist Health Systems, Jackson, MS
Associate Clinical Professor
School of Pharmacy
University of Mississippi
Objectives

1. Review the role of the kidneys and lungs in acid-base balance.
2. Describe the various acid-base disorders and discuss common causes.
3. Review acid-base disorders that may be seen with the use of parenteral nutrition.
Acid-Base Definitions

• Within cells, the major buffers are
  o Carbonic acid/Bicarbonate
  o Proteins
  o Phosphate
• Within erythrocytes, hemoglobin is major buffer
• Importance of carbonic anhydrase

\[
\text{H}_2\text{O} + \text{CO}_2 \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-
\]
  o Carbohydrate & fat metabolism generate ~15,000 mmol of CO\textsubscript{2} daily
  ➢ Respiration prevents the accumulation of endogenously produced CO\textsubscript{2}
Acid-Base Definitions

- Henderson-Hasselbalch equation (37 °C plasma)

\[
pH = 6.10 + \log \left( \frac{[\text{HCO}_3^-]}{0.03 \times \text{PaCO}_2} \right)
\]

- 2 types of HCO$_3^-$
  - Calculated from arterial pH & PaCO$_2$
    - arterial blood gas
  - Measured as total CO$_2$ content
    - serum determination
5 Basic Acid Base Disorders

- Metabolic Acidosis
- Metabolic Alkalosis
- Respiratory Acidosis
- Respiratory Alkalosis
- Mixed Disorders
ABG Analysis

pH

• 7.35-7.45
  • Acidemia, compensated or mixed
    • Respiratory Acidosis $\uparrow$PCO$_2$
    • Metabolic Acidosis $\downarrow$HCO$_3$^{-}

<7.35

• Alkalemia
  • Respiratory Alkalosis $\downarrow$PCO$_2$
  • Metabolic Alkalosis $\uparrow$HCO$_3$^{-}
Kidneys

- Regulate the concentration of bicarbonate in the blood
- 90% of reabsorption of bicarbonate occurs in the proximal tubules and is catalyzed by carbonic anhydrase
- Excrete 50-100 mEq/day of nonvolatile acids
Metabolic Acidosis

- Arterial pH less than 7.35 (7.35-7.45)
- Low bicarbonate (22-31mEq/L)
- Compensates by hyperventilating to increase carbon dioxide excretion (low PCO$_2$)
- **Calculate the Anion Gap**
Metabolic Acidosis

- Anion Gap = $\text{Na}^+ - (\text{Cl}^- + \text{HCO}_3^-)$
  - 3-11 mEq/L or 12 ± 4 mEq/L
- Normal Anion Gap (Hyperchloremic Acidosis)
- Elevated Anion Gap
Normal Anion Gap

- **Hypokalemic**
  - Diarrhea
  - Fistulous Disease
  - RTA-Type 1 (Distal)
  - RTA-Type 2 (Proximal)
  - Carbonic Anhydrase Inhibitors

- **Hyperkalemic**
  - Hypoaldosteronism
  - HCl
  - RTA-Type 4
  - K⁺ Sparing Diuretics
Elevated Anion Gap

- Severe Renal Failure
- Lactic Acidosis
- Ketoacidosis
  - Starvation, Ethanol, DM
- Drug Intoxications
  - Ethylene Glycol, Methanol, Salicylates
Mnemonics for Metabolic Acidosis

- Elevated Anion Gap
  - M- Methanol
  - U- Uremia
  - D- DKA
  - P- Paraldehyde
  - I- Isoniazid
  - L- Lactic Acidosis
  - E- Ethylene Glycol
  - S- Salicylates

- Normal Anion Gap
  - U- Ureteral diversion
  - S- Saline infusion
  - E- Exogenous Acid
  - D- Diarrhea
  - C- CA inhibitors
  - A- Adrenal insufficiency
  - R- RTA
Metabolic Alkalosis

- Elevated pH greater than 7.45 (7.35-7.45)
- Elevated bicarbonate (22-31mEq/L)
- Some respiratory compensation as a result of hypoventilation (minor)
Metabolic Alkalosis

- Saline Responsive
  - Urine Chloride < 10mEq/L
- Diuretics
- Gastric Loss (vomiting, NG suction)
- Exogenous alkali administration (PN salts, bicarbonate, lactated ringers)
- Alkalosis associated with hypokalemia
Metabolic Alkalosis

- Saline-Resistant
  - Urine Chloride > 10mEq/L
  - Normotensive (K⁺ depletion, hypercalcemia)
  - Hypertensive (Mineralcorticoids)
Lungs

- Regulate \( \text{paCO}_2 \)
- Resting RR 14-18 BPM
- TV apx 500ml
- Oxygenation of blood
- Chemoreceptors
- 90% arterial \( \text{O}_2 \) is oxy-Hgb
# Normal Blood Gas Values

<table>
<thead>
<tr>
<th></th>
<th>Arterial Blood</th>
<th>Venous Blood</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH</strong></td>
<td>7.40 (7.35-7.45)</td>
<td>7.36 (7.31-7.41)</td>
</tr>
<tr>
<td><strong>PCO&lt;sub&gt;2&lt;/sub&gt;</strong></td>
<td>35-45 mm Hg</td>
<td>42-55 mm Hg</td>
</tr>
<tr>
<td><strong>PO&lt;sub&gt;2&lt;/sub&gt;</strong></td>
<td>80-100 mm Hg</td>
<td>30-50 mm Hg</td>
</tr>
<tr>
<td><strong>HCO&lt;sub&gt;3&lt;/sub&gt;⁻</strong></td>
<td>22-26 mEq/L</td>
<td>24-28 mEq/L</td>
</tr>
<tr>
<td><strong>Base Excess</strong></td>
<td>-2.4 to +2.3 mEq/L</td>
<td>-2.4 to 2.3 mEq/L</td>
</tr>
<tr>
<td><strong>O₂ Saturation</strong></td>
<td>&gt; 90%</td>
<td>60-85%</td>
</tr>
</tbody>
</table>
Respiratory Acidosis

- pH less than 7.35 (7.35-7.45)
- Elevated PCO₂ (35-45mmHg)
- Hypoventilation
- Compensation via kidney
Respiratory Acidosis-Acute

- Acute CNS depression
  - Drug overdose (BDZ’s, narcotics, propofol)
  - Head trauma
  - CVA
  - CNS infection (encephalitis)
Respiratory Acidosis-Acute

- Acute NM disease
  - Guillain-Barre syndrome
  - Spinal cord injury
  - Botulism
  - Organophosphate poisoning
Respiratory Acidosis-Acute

- Acute airways disease
  - Status asthmaticus
  - Upper airway obstruction
  - Exacerbation of COPD
Respiratory Acidosis-Acute

- Acute parenchymal and vascular disease
- Massive PE
- Acute pleural or chest wall disease
  - Pneumothorax
  - Hemothorax
  - Flail chest
Respiratory Acidosis-Chronic

- Central sleep apnea
- Primary alveolar hypoventilation
- Obesity hypoventilation syndrome
- Spinal Cord Injury
- Diaphragmatic paralysis
- Amyotrophic lateral sclerosis
- Myasthenia gravis
Respiratory Acidosis-Chronic

- Muscular dystrophy
- Multiple sclerosis
- Poliomyelitis
- Hypothyroidism
- Kyphoscoliosis
- COPD
- Severe chronic interstitial lung disease
Respiratory Alkalosis

- Elevated pH greater that 7.45
- Low PCO$_2$ (35-45mmHg)
- Hyperventilation
Respiratory Alkalosis

- Hypoxia
- Parenchymal lung disease
  - Pneumonia
  - Bronchial asthma
  - Diffuse interstitial fibrosis
  - PE
Respiratory Alkalosis

- Medications and mechanical ventilation
  - Salicylate
  - Nicotine
  - Xanthine
  - Catecholamines
  - Analeptics
Respiratory Alkalosis

- CNS disorders
  - Meningitis, encephalitis
  - Cerebrovascular disease
  - Head trauma
  - Anxiety
## Compensation

<table>
<thead>
<tr>
<th>Disorder</th>
<th>pH</th>
<th>Primary alt.</th>
<th>Compensatory alt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Met. Acidosis</td>
<td>↓</td>
<td>↓HCO₃⁻</td>
<td>↓PaCO₂</td>
</tr>
<tr>
<td>Met. Alkalosis</td>
<td>↑</td>
<td>↑HCO₃⁻</td>
<td>↑PaCO₂</td>
</tr>
<tr>
<td>Resp. Acidosis</td>
<td>↓</td>
<td>↑PaCO₂</td>
<td>↑HCO₃⁻</td>
</tr>
<tr>
<td>Acute</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resp. Acidosis</td>
<td>↓</td>
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<td>Chronic</td>
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<td>Chronic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disorder</td>
<td>pH</td>
<td>Normal Level of Compensation</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>-----</td>
<td>-------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Met. Acidosis</td>
<td>↓</td>
<td>↓PaCO₂ = 1.2 x ↓HCO₃⁻</td>
<td></td>
</tr>
<tr>
<td>Met. Alkalosis</td>
<td>↑</td>
<td>↑PaCO₂ = 0.6 x ↑HCO₃⁻</td>
<td></td>
</tr>
<tr>
<td>Resp. Acidosis</td>
<td>↓</td>
<td>↑HCO₃⁻ = 0.1 x ↑PaCO₂</td>
<td></td>
</tr>
<tr>
<td>Acute</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resp. Acidosis</td>
<td>↓</td>
<td>↑HCO₃⁻ = 0.4 x ↑PaCO₂</td>
<td></td>
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</table>
Case Study

77 yo female with PMH significant for COPD. Pt is admitted to ICU with SOB. ABG’s and Lab on arrival:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (Normal Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>146 (135-145mEq/l)</td>
</tr>
<tr>
<td>Potassium</td>
<td>4 (3.5-5mEq/l)</td>
</tr>
<tr>
<td>Chloride</td>
<td>104 (98-107mEq/L)</td>
</tr>
<tr>
<td>CO₂</td>
<td>34 (22-31mEq/L)</td>
</tr>
<tr>
<td>BUN</td>
<td>27 (7-20mg/dl)</td>
</tr>
<tr>
<td>Cr</td>
<td>1.2 (0.7-1.5mg/dl)</td>
</tr>
<tr>
<td>pH</td>
<td>7.38 (7.35-7.45)</td>
</tr>
<tr>
<td>pCO₂</td>
<td>62.9 (35-45mmHg)</td>
</tr>
<tr>
<td>PO₂</td>
<td>72 (80-100mmHg)</td>
</tr>
<tr>
<td>HCO₃</td>
<td>36.5 (24-30 mEq/L)</td>
</tr>
<tr>
<td>BE</td>
<td>10.0</td>
</tr>
</tbody>
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What disorder is present
Case Study

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<tr>
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<td>1.2 (0.7-1.5mg/dl)</td>
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</table>

**Level of Compensation**

\[
\text{HCO}_3^- = 0.4 \times \uparrow \text{pCO}_2 = \uparrow \text{HCO}_3^- = 0.4 \times (62.9-40)
\]

\[
= 0.4 \times 22.9 = 9.16 \text{ (27 + 9.16 = 36.2)}
\]

Compensated Respiratory Acidosis
Compensation

- Higher 10% predicted
  - Met Alk + Resp Acid
  - Met Acid + Resp Alk

- Lower 10% predicted
  - Met + Resp Acidosis
  - Met + Resp Alkalosis
Mixed Acid-Base Disorders

- Metabolic Acidosis and Respiratory Acidosis
  - Cardiopulmonary arrest
  - Respiratory failure with anoxia

- Metabolic Alkalosis and Respiratory Alkalosis
  - Congestive heart failure and vomiting
  - Diuretic therapy and hepatic failure
  - Diuretic therapy and pneumonia
Mixed Acid-Base Disorders

- Metabolic Alkalosis and Respiratory Acidosis
  - Diuretic Therapy and COPD
  - Vomiting and COPD
- Metabolic Acidosis and Respiratory Alkalosis
  - Salicylate overdose
  - Septic Shock
  - Sepsis and renal failure
Mixed Acid-Base Disorders

- Metabolic Alkalosis and Metabolic Acidosis
  - Diuretic Therapy and ketoacidosis
  - Vomiting and renal failure
  - Vomiting and lactic acidosis/ketoacidosis
- Mixed Hyperchloremic and High AG Metabolic Acidosis
  - Diarrhea and Lactic/ketoacidosis
  - RTA and chronic renal failure
Parenteral Nutrition

- Metabolic acidosis - excessive chloride in PN
- Metabolic alkalosis - excessive acetate in PN
- Respiratory Acidosis - overfeeding (uncommon)
Parenteral Nutrition/IV Therapy

- Know your IV nutritional therapy (Amino Acids)
- Primary IV
- Medication profile
- Determine loss from tubes, drains, ostomy, renal
Parenteral Nutrition

- HPN Study
  - Retrospective observational cohort
  - 39 patients (1989-2006)
  - 10/39 (25.6%) patients showed evidence of acid-base disturbance (4 severe)
  - 8 patients-metabolic acidosis

- PN Error
  - 69yoF (44kg)-bowel resection-short gut syndrome
  - Accidental bolus of PN and IVFE (lipids)
  - 1200mL of 1800mL PN and 200mL of IVFE <1 hour
  - 6.99/64/78/15, lactate 11.8 mmol/L, Glucose 775mg/dl
  - Combined metabolic and respiratory acidosis
  - Hyperviscosity syndrome
  - Plasma exchange

- e-SPEN, the European e-Journal of Clinical Nutrition and Metabolism 6 (2011) e31ee35
Case Study 1

A.A. 44-year-old with past medical history significant for lupus is admitted via the ED. The patient has a two-day history of acute severe diarrhea. Patient is dx with RTA-Type 1 by nephrology. Day 8 of hospital stay, patient develops respiratory failure is intubated and transferred to ICU. Pt is placed on MV and sedated with lorazepam.

Current Medication Regimen:

<table>
<thead>
<tr>
<th>Drug</th>
<th>Dosage</th>
</tr>
</thead>
<tbody>
<tr>
<td>½ NS</td>
<td>50ml/h</td>
</tr>
<tr>
<td>TPN</td>
<td>75ml/h</td>
</tr>
<tr>
<td>Lorazepam</td>
<td>2mg/h</td>
</tr>
<tr>
<td>Enoxaparin</td>
<td>30mg SubQ Daily</td>
</tr>
<tr>
<td>Famotidine</td>
<td>20mg IV Daily</td>
</tr>
<tr>
<td>Levofloxacin</td>
<td>250mg IVPB Daily</td>
</tr>
</tbody>
</table>
## Case Study 1

<table>
<thead>
<tr>
<th>Electrolytes:</th>
<th><em>abg</em></th>
<th><strong>ABG</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>134</td>
<td>(135-145mEq/l)</td>
</tr>
<tr>
<td>Potassium</td>
<td>2.9</td>
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<td>62</td>
<td>(7-20mg/dl)</td>
</tr>
<tr>
<td>Cr</td>
<td>4.5</td>
<td>(0.7-1.5mg/dl)</td>
</tr>
<tr>
<td>pH</td>
<td>7.31</td>
<td>(7.35-7.45)</td>
</tr>
<tr>
<td>pCO₂</td>
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<td>(35-45mmHg)</td>
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</tr>
<tr>
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<td>16</td>
<td></td>
</tr>
<tr>
<td>BD</td>
<td>-9</td>
<td>(±2)</td>
</tr>
</tbody>
</table>
Case Study 1

Electrolytes: ABG

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<td>BUN</td>
<td>62 (7-20mg/dl)</td>
<td>BD -9 (+2)</td>
</tr>
<tr>
<td>Cr</td>
<td>4.5 (0.7-1.5mg/dl)</td>
<td></td>
</tr>
</tbody>
</table>

Metabolic Acidosis:

1. RTA-1
2. Diarrhea
3. PN
4. Lorazepam
Case Study 1

P.T. 65 yo male admitted to SICU s/p MVC. Currently on mechanical ventilation, sedation with midazolam infusion. Patient’s abdomen is distended with no bowel sounds c/w ileus. Nasogastric tube to suction with 300-400cc out per 8 hour shift.

Current Medication Regimen:

Piperacillin/Tazobactam 3.375 IV q 8h
Esomeprazole 40mg IV daily
A.A.5/15 multi-chamber 60ml/h
LR 30ml/h (KVO)
Furosemide/Albumin/Chlorothiazide 10ml/h
240mg 5% 240mg
## Case Study 1

<table>
<thead>
<tr>
<th>Electrolytes</th>
<th>ABG</th>
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</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>144 (135-145mEq/l)</td>
</tr>
<tr>
<td>Potassium</td>
<td>3.1 (3.5-5mEq/l)</td>
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<tr>
<td>Chloride</td>
<td>94 (98-107mEq/L)</td>
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<tr>
<td>CO₂</td>
<td>40 (22-31mEq/L)</td>
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<tr>
<td>BUN</td>
<td>45 (7-20mg/dl)</td>
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<tr>
<td>Cr</td>
<td>2.5 (0.7-1.5mg/dl)</td>
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<tr>
<td>pH</td>
<td>7.52 (7.35-7.45)</td>
</tr>
<tr>
<td>pCO₂</td>
<td>48 (35-45mmHg)</td>
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<tr>
<td>PO₂</td>
<td>70 (80-100mmHg)</td>
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<tr>
<td>HCO₃</td>
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</tr>
<tr>
<td>BE</td>
<td>14.1 (+ 2)</td>
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Case Study 1

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Metabolic Alkalosis

1. Acetate in PN
2. LR
3. NG to suction
4. Diuretic/Albumin infusion
The commercially available (multi chamber) parenteral nutrition products are balanced equally with chloride/acetate:

A  TRUE
B  FALSE
The commercially available (multi chamber) parenteral nutrition products are balanced equally with chloride/acetate:

FALSE
Parenteral nutrition is a common cause of respiratory acidosis:

A  TRUE
B  FALSE
Parenteral nutrition is a common cause of respiratory acidosis:

B  FALSE
Key Takeaways

- **Key Takeaway #1**
  - Acid-base balance involves kidneys, lungs and other buffers.

- **Key Takeaway #2**
  - Parenteral nutrition (PN) does play a role in acid-base balance and patients should be stable before initiating PN.

- **Key Takeaway #3**
  - Determination of acid-base abnormalities requires a review and understanding of disease states and/or medications that may influence acid-base disorders.
References: