Objectives: Electrolyte Abnormalities

- Recognize the most common signs and symptoms of electrolyte abnormalities
- Understand and implement a standard approach to management of electrolyte abnormalities
- Identify and avoid pitfalls in the management of electrolyte abnormalities
- Recognize and anticipate clinical scenarios when electrolyte abnormalities can become dangerous

Remember...
Taking Care of Patients & Managing Electrolytes is a Team Sport!
(RN, PharmD, MD & Patient)
Electrolytes: General Principles

• Goal = Electroneutrality
  - Inside cell = outside cell

• Context matters
  - Medications
  - Hemodynamics
  - Vitals
  - Symptoms

Electrolytes: General Principles

• Clinical manifestations determine urgency of treatment, NOT absolute laboratory values

• Speed and magnitude of correction dependent on clinical circumstances

• Frequent reassessment of electrolytes required

Case Presentation

Mr. E is a 55 yo man admitted after 2 day history of nausea, vomiting, diarrhea and generalized weakness. His wife found him lethargic and confused and called 911. D-stick was > 500. History obtained from the patient’s wife...

• Past Med Hx: insulin dependent diabetes, hypertension and depression

• Social Hx: 2-3 drinks per day, 1 pack per day tobacco

• Meds: “a water pill”, “a pill for my blood pressure”, and insulin
Question 1:
Which of the following electrolyte abnormalities are you likely to find?

1) Hypophosphatemia
2) Hypomagnesemia
3) Hyperkalemia
4) Hypocalcemia
5) All of the above

Question 2:
His BP is 80/50, HR 110, pH on VBG is 7, blood sugar on lab draw still > 500 and serum K is 3.4. Which of the following is the most important next intervention (IVF already infusing)

1) IV magnesium
2) IV bicarbonate
3) IV potassium
4) Insulin
5) None of the above

Question 3:
All of the following contribute to Mr. E's hypokalemia except

1) Alcohol withdrawal (DT's)
2) Diarrhea
3) Malnutrition (poor PO intake)
4) Medications
5) DKA
Electrolyte Abnormalities

• Nonspecific
• Each electrolyte abnormality can have multiple clinical manifestations
• Each clinical manifestation can be caused by multiple different electrolyte abnormalities

Electrolyte Abnormalities: Risk Factors

• Age
• Malnutrition
• Medications (e.g. diuretics, antidepressants)
• Diabetes
• Renal function (acute or chronic kidney disease)
• Volume status (too MUCH or too LITTLE)
• Iatrogenesis (meds, fluid choice, diuretics...)
• Acute illness (e.g. DKA, sepsis, bowel obstruction, diarrheal illness, DTs)
• Etc...

Potassium (K⁺)
Potassium (K⁺): Fast Facts

• Intracellular ion
  - Only ~1% extracellular space (Tip of the iceberg)
• Essential to maintain electrical membrane potential
• Tightly regulated
  - Short term plan* (inside/outside cell)
  - Long term plan** (inside/outside body)
  - Na⁺-K⁺-ATPase pump
    - Membrane protein on all cells (Na⁺ out, K⁺ in)
• Makes up 2.6% of the earth’s crust

K⁺ Regulation: “Short” Term Plan

• Shift (intracellular/extracellular)
• Na⁺-K⁺-ATPase pump
• Intracellular shift (drives K⁺ inside cells)
  - Catecholamines (endogenous or exogenous)
    - Via β₂ activation of Na⁺-K⁺-ATPase pump
  - Insulin
  - pH
    - Acidemia – H⁺ into cells, K⁺ out of cells
    - Alkalemia – H⁺ out of cells, K⁺ into cells
• Plasma K⁺

K⁺ Regulation: “Long” Term Plan

• GOAL -> K⁺ in = K⁺ out
Even the kidney needs goals!
• Tools
  - KIDNEY (ok... stool helps out a bit too – normally 10-15meq/day)
    - Proximal tubule (irrespective of K⁺ status)
    - Loop of Henle (Na⁺-K⁺-2Cl⁻ pump)
    - Collecting tubule – primary site of K⁺ regulation
      - Distal flow or Na⁺ delivery
      - Plasma K⁺
      - Mineralocorticoid
      - Non re-absorbable anions (phos, bicarb, anion X)
Serum K⁺: Tip of the Iceberg

Example:
80 Kg person, 60% H₂O = ~ 48L
1/3 extracellular = 16L
2/3 intracellular = 32L

Serum K⁺ = 4 meq/L (extracellular value)
= 140 meq/L (intracellular value)

16L x 4 = 64 meq, 32L x 140 = 4480 meq
45 (1%) + 64 = 109, 109/16L = 6.81 (K 4→6.8!!)

1% shift inside to outside cell (~45 meq) enough to STOP the heart!!!
Hypokalemia: Causes

- **Decreased intake** (not enough in...)
  - Malnutrition, alcoholism, anorexia

- **Increased losses** (too much out...)
  - Renal
    - Meds (diuretics), metabolic alkalosis (bicarb is a non-reabsorbable anion), hypoMg++, hyperaldosteronism
  - Extra-renal
    - Diarrhea, sweating, NG suction, vomiting

- **Shift** (“hiding”)
  - Acute alkalosis, hyperventilation, sudden stress (catecholamine surge), insulin, β agonist, hypothermia (therapeutic)

Hypokalemia: Signs & Symptoms

- **Cardiac**
  - Arrhythmias (SVT, VT, bradycardia, conduction delays)
  - Abnormal EKG findings (u waves, prolonged QT, flat or inverted t waves)

- **Neuromuscular**
  - Weakness, paraesthesias, paralysis
  - Encephalopathy in cirrhosis
    - Hypokalemia stimulates production of ammonia

- **GI**
  - Ileus, constipation, cramps, nausea, vomiting

- **Renal**
  - Polyuria - hypokalemia inhibits Na⁺-K⁺-2Cl⁻ pump, unable to produce concentrated urine, large volume to excrete daily load, kind of a nephrogenic DI

Treatment: Hypokalemia

- **How Much? Rule of Thumb** Goal K - current K x 100
  - Example 4 - 3.2 x 100 = 80 meq

- **How fast?**
  - Consider symptoms - i.e. how urgent
  - Limitations: need insulin to shift K into cells, relative hypoglycemia may suppress insulin, consider renal function
    - Oral replacement not > 40meq at a time
    - Allowable maximum IV dose per hour controversial
      - 10meq/hr peripherally and 20meq/hr centrally generally accepted

- **What Route?**
  - Route & rate of K+ admin depends on level & clinical status
    - Enteral preferred IF tolerating PO
    - IV if < 2.5 and/or symptomatic or unable to take PO
Treatment: Hypokalemia

- Why isn’t it working?
  - What’s the mag?
  - Review meds
    - Diuretics, lactulose, enemas, bicarb, IV penicillins…
    - K+ in dextrose triggers insulin and K shifting
  - Not enough in? too much out?
    - Increased losses in polyuric state (ATN or post obstructive recovery, DI…)
    - Undiagnosed hyperaldo state - what’s the urine K
  - Consider scheduled replacement if ongoing losses or ongoing need for diuretics

Hypokalemia: Key Considerations

- What signs and symptoms are present?
- What is the serum magnesium?
- What is the urine potassium?
  - Don’t forget to check when the serum K is still low!
- What is the pH?
  - K replacement more urgent in setting of acidemia
- Place on telemetry
- Consider transfer to ICU if symptomatic, K < 2.5 and/or requires administration through central line

Hypokalemia: Key Considerations

- REMEMBER: Serum potassium is a poor reflection of total body potassium
- Treat hypokalemia urgently in setting of digoxin
- Avoid iatrogenesis: STOP/HOLD offending meds (e.g. diuretics, enemas, bicarbonate, lactulose)
- Treat hypokalemia urgently in acidosis
  - BEFORE correcting acidosis!

  ALARM BELLS should sound for hypok in setting of acidemia!
Hyperkalemia

- Uncommon without AKI or CKD
- Red Flag for something else going on (i.e. tumor lysis, rhabdomyolysis...)
- With normal renal function need ~ 150 meq FAST to exceed protective mechanisms (shift/excretion)
- Hidden K+ loads:
  - Transfusion (old RBC, intracellular K leaks)
  - PCN G - ~ 1.7meq per 1 million units
  - LR or IVF w/KCl

Hyperkalemia: Causes

- Increased intake (too much in...)
  - Exogenous
  - Oral supplements in setting of acute or chronic kidney dysfunction
  - Iatrogenic (e.g. in IV fluids, LR or NS with KCl)
  - Endogenous
  - Cell death (rhabd, tumor lysis, hemolysis)
- Decreased losses (not enough out...)
  - Renal dysfunction
  - Hypoaldosteronism
  - RTA
- Shift (extracellular)
  - Acidosis (e.g. DKA), rapid rewarming after therapeutic hypothermia
- Drugs
  - Succinylcholine, NSAIDS, ACE-I, Bactrim, beta blockers, heparin, supplements
Hyperkalemia: Kidney
Goal K⁺ in = K⁺ out
IF persistently hyperkalemic, blame the
- Should be able to excrete
• Acute kidney injury, chronic kidney disease...
  - Loss of functioning nephrons
• Volume depletion: True or Effective
  - Need distal flow (Na⁺ delivery) for potassium excretion
• Hypoaldosteronism
  - Aldo SHOULD be upregulated with increased serum potassium

Hyperkalemia in DKA
• Common
• Acidemia - K⁺ shifts extracellular
  - H⁺ goes in and K⁺ goes out for electroneutrality
• Insulin not available to shift K inside cell
• Solute drag
  - Hyperglycemia increases H₂O loss from cells and K⁺ “dragged” along
• Acute kidney injury
• Drugs: Ace-Inhibitors/ARB/K⁺ sparing diuretics, continued potassium supplements

Drugs and Hyperkalemia
• Interfere with K⁺ into cells
  - Digoxin - blocks Na⁺-K⁺-ATPase pump
    - Dose dependent increase in K
  - Beta Blockers
    - Block β₂ activation of Na⁺-K⁺-ATPase pump
• Other drugs, other mechanisms...
  - Succinylcholine
  - Trimethoprim
  - Heparin
  - Spironolactone, Epleronone
  - ...
Hyperkalemia: Treatment

IMPORTANT!!: often asymptomatic

• **Step 1: STABILIZE heart**
  - Calcium IV - Remember this does NOT change K⁺ level
  - Repeat lab and check EKG
  - Make sure patient on telemetry!

• **Step 2: SHIFT K⁺ -- (short term plan)**
  - Options include: glucose/insulin, β-agonists, bicarbonate

• **Step 3: REMOVE K⁺ -- (long term plan)**
  - Kidney: IV fluid (if hypovolemic), lasix, dialysis
    - Need distal flow (Na⁺ delivery) to excrete K⁺
  - GI: kayexalate or other agent

Hypomagnesemia

Hypomagnesemia: Signs & Symptoms

• **Cardiovascular:**
  - QT prolongation, arrhythmias, vasospasm, cardiac ischemia

• **Neuromuscular:**
  - Weakness, tremor, seizures, tetany, obtundation, coma

• **Electrolytes:**
  - Hypokalemia, hypocalcemia
Hypomagnesemia: Causes

- **Decreased intake (not enough in...)**
  - Malnutrition, alcoholism
- **Increased loss (too much out...)**
  - Renal
    - Diuretics, hypokalemia, drugs (aminoglycosides, amphotericin), renal tubular dysfunction (common in alcoholics)
  - GI
    - Diarrhea, NG suction, malabsorption
- **Shift ("hiding")**
  - Refeeding, hypothermia

Treatment: Hypomagnesemia

- **How Much?**
  - Determine target (nl range vs >2 depending on clinical scenario)
  - Protocols work best for patient safety
- **How fast?**
  - Consider symptoms – i.e. how urgent
  - Oral replacement: example 128mg Mg Chloride q8hr
  - IV replacement: example 1g/hr (8.1meq/gram)
  - Recheck more frequently for severe (<1) or ongoing loss
- **What Route?**
  - Route & rate of Mag admin depends on level & clinical status
    - Enteral preferred IF tolerating PO
    - IV if <1 and/or symptomatic or unable to take PO

Treatment: Hypomagnesemia

- **Why isn’t it working?**
  - Review meds
    - Diuretics, lactulose, enemas
    - Not enough in? too much out?
    - Increased losses in polyuric state (ATN or post obstructive recovery, DL...)
  - Consider scheduled replacement if ongoing losses or ongoing need for diuretics
Hypomagnesemia

- Stop offending meds (diuretics, lactulose...)
- Replace enterally if taking PO
- Replace IV if symptomatic or unable to take PO
- Always check in patients with arrhythmias
- Always check in patients with chronic alcohol use
- Always check in patients with ICH, SAH...
- Always check in hypokalemic patients
- Always check in patients with neurological complaints
- Do not need to check every day in every patient!

Phosphorous

- Intracellular ion
  - Extracellular level is only "tip of the iceberg"
- Extracellular shift
  - acidemia
  - rewarming
- Intracellular shift
  - Alkalemia
  - Therapeutic hypothermia
- Watch for severe hypophosphatemia in refeeding syndrome
Hypophosphatemia

Hypophosphatemia: Causes
- Decreased intake (not enough in...)
  - Malnutrition (includes alcoholics)
- Increased loss (too much out...)
  - Renal
    • Diuretics, hypokalemia, hypomag, steroids, hyperparathyroid
  - GI
    • Diarrhea, antacids, malabsorption
- Shift ("hiding")
  - Acute alkalosis, refeeding, drugs (insulin, epi)

Hypophosphatemia: Signs & Symptoms
- CNS
  - Altered mental status, obtundation, coma, seizures
- Neuromuscular
  - Weakness, respiratory failure, rhabdomyolysis, paresthesias, lethargy
- Other
  - Hemolysis, impaired platelet function, impaired oxygen delivery, impaired renal tubular function

Critical for ALL cellular functions
Treatment: Hypophosphatemia

• How Much?
  - Target normal range (no data for higher target)
  - Protocols work best for patient safety
• How fast?
  - Consider symptoms - i.e. how urgent
  - Oral replacement: example Kphos 2-3 tab q4 hr
    - Each tablet contains 11meq K+, 3.6 mmol phos
  - IV replacement: example 15-30 mmol over 4 hrs
    - Note: 460mg Na in every 15mmol IV NaPhos
  - Recheck more frequently for severe (< 1) or ongoing loss

Treatment: Hypophosphatemia

• What Route?
• Route & rate of Phos admin depends on level & clinical status
  - Enteral preferred IF tolerating PO
  - IV if < 1 and/or symptomatic or unable to take PO
• Why isn’t it working?
  - Review meds
  - Consider scheduled replacement if ongoing losses or severe malnutrition
  - REMEMBER: Serum phos is a poor reflection of total body phosphorous

Hyperphosphatemia
Hyperphosphatemia

- Abnormal but not usually “critical”
- Generally not an “acute” concern
- Can lead to calciphylaxis in setting of hypercalcemia
- Careful not to replace calcium unless ABSOLUTELY necessary – risk of calciphylaxis
  - Life threatening hyperkalemia
  - Symptomatic or clinically significant hypocalcemia

Hyperphosphatemia: Causes

- **Increased intake** (too much in...), relative
  - Exogenous
    - Oral supplements in setting of acute or chronic kidney dysfunction
  - Endogenous
    - Cell death (rhabdo, tumor lysis, hemolysis)
- **Decreased losses** (not enough out...)
  - Renal dysfunction
  - Hypoaldosteronism
- **Shift** (extracellular)
  - Acidosis (e.g. DKA), rapid rewarming after therapeutic hypothermia

Treatment: Hyperphosphatemia

- Removal?
  - Decrease intake
  - Oral: phos binders
  - Dialysis
- Why isn’t it working?
  - Unidentified or untreated source of phosphorous
    - Endogenous (ongoing cell destruction)
    - Exogenous (dietary intake)
Hypocalcemia

Hypocalcemia: Causes
- Sepsis**
- Burns
- Rhabdomyolysis**
- Pancreatitis**
- Malabsorption
- Liver & kidney disease
- Hypomagnesemia**
- Massive transfusion**
- CRRT with citrate**
- Hypoparathyroidism
** more common in ICU patients

Hypocalcemia: Signs & Symptoms
- Cardiovascular
  - Hypotension, bradycardia, arrhythmias, cardiac arrest, digitalis insensitivity, conduction delays
- Neuromuscular
  - Weakness, muscle spasm, laryngospasm, hyperreflexia, seizures, tetany, paraesthesias
Hypocalcemia: What is Critical?

- DEPENDS on Signs & Symptoms
- Check ionized calcium (affected by pH (falls with alkalosis) and albumin)
- Replace if clinical symptoms
  - e.g. shock, hyperkalemia
- Replace if EKG changes
- Don’t need to replace in rhabdomyolysis or pancreatitis (shifts)
- Watch closely and replace with ongoing losses (e.g. multiple transfusions or CRRT), particularly in setting of hypotension

Hypocalcemia: Treatment

- Calcium Chloride (should be given via central vein)
  - 1g of 10% CaCl in 10mL has 272 mg calcium
- Calcium Gluconate
  - 1g of 10% CaGlu in 10mL has 90mg calcium
- Monitor frequently if clinically symptomatic
- Adverse effects
  - Hypercalcemia, bradycardia, nausea/vomiting, flushing, tissue necrosis, dig toxicity

Hypercalcemia
Hypercalcemia: Causes

- Malignancy
- Hyperparathyroidism
- Immobilization
- Excess vitamin A or D
- Thyrotoxicosis
- Granulomatous Disease

Hypercalcemia: Signs & Symptoms

- **Cardiovascular**
  - Hypertension, ischemia, arrhythmias, conduction abnormalities, hypotension (volume depletion)

- **Neuromuscular**
  - Weakness, altered mental status, coma, seizures

- **GI**
  - Nausea/vomiting, anorexia, abdominal pain, constipation, pancreatitis

- **Other**
  - Bone pain, kidney stones, acute kidney injury, nephrogenic DI

Hypercalcemia: Treatment

- Treat underlying disease
- IV normal saline to restore volume
  - Saline decreases calcium reabsorption
- Diuresis AFTER volume repletion can increase renal calcium loss
  - Diuresis + IVF (exception to rule NO diuretics with IVF)
  - Can be precipitated or worsened by diuretics if not volume replete
- Careful in setting of hyperphosphatemia
- Dialysis and bisphosphonates are other options
Electrolyte Replacement: Caution

- Serum Cr > 2
- Patient weight < 45 kg
- Patient on any form of renal replacement therapy
- Urine output < 20cc/hr, 175cc/8hr or < 250cc/hr 12 hour shift

Electrolytes: Summary

- Treat the electrolyte change, but DON'T FORGET to search for the cause
- Clinical manifestations are usually not specific to a particular electrolyte change
- Clinical circumstances determine urgency of treatment rather than electrolyte concentration
- Frequent reassessment of electrolyte abnormalities required
Electrolytes: Summary

- Administer K\(^+\) using central venous catheter during life threatening hypokalemia
- Use calcium first line to stabilize myocardium during severe hyperkalemia followed by interventions to shift potassium
- Treat hypokalemia before hyperglycemia to avoid worsening of hypokalemia with shift
- Anticipate electrolyte changes
  - Consider rewarming, acid/base status, meds...

Electrolytes: Summary

- Abnormal ≠ Critical
- Clinical context is critical!
- Critical thinking is fun, expected and “critical”!
  Remember that taking care of patients and managing electrolytes is a team sport.
- Consider medications (including fluids), hemodynamics, urine output, symptoms
- Remember that “critical” nature “depends” on patient
- Consider electrolyte protocol development if not already at your hospital

Case Presentation

Mr. E is a 55 yo man admitted after 2 day history of nausea, vomiting, diarrhea and generalized weakness. His wife found him lethargic and confused and called 911. D-stick was > 500. History obtained from the patient’s wife...

- Past Med Hx: insulin dependent diabetes, hypertension and depression
- Social Hx: 2-3 drinks per day, 1 pack per day tobacco
- Meds: “a water pill”, “a pill for my blood pressure”, and insulin
Question 1:
Which of the following electrolyte abnormalities are you likely to find?
1) Hypophosphatemia
2) Hypomagnesemia
3) Hyperkalemia
4) Hypocalcemia
5) All of the above

Question 2:
His BP is 80/50, HR 110, pH on VBG is 7, blood sugar on lab draw still > 500 and serum K is 3.4. Which of the following is the most important next intervention (IVF already infusing)
1) IV magnesium
2) IV bicarbonate
3) IV potassium
4) Insulin
5) None of the above

Question 3:
All of the following contribute to Mr. E’s hypokalemia except
1) Alcohol withdrawal (DTs)
2) Diarrhea
3) Malnutrition (poor PO intake)
4) Medications
5) DKA
Questions?????

Questions are guaranteed in life; Answers aren’t.