Fluid and Electrolytes & Renal Disorders

Topics for the Day
- Fluids and Electrolytes: review of normal physiology *
- Fluid imbalances *
- Electrolyte Disturbances *
- Beginning acid-base imbalance *
- Renal Disorders
- Fluid Types *

Electrolytes
- Solute that form ions (electrical charge)
  - Cation (+)
  - Anion (-)
- Major body electrolytes:
  - Na+, K+, Ca++, Mg++
  - Cl-, HCO\textsubscript{3}-, HPO\textsubscript{4}--

Fluid & Electrolytes
- Fluid: Water
- Electrolytes: ions dissolved in water
  - Sodium, potassium, bicarbonate, etc.
  - Also used medically for non ions (glucose)
- Osmolarity – osmols/kg solvent
- Osmolality – osmols/liter solution
  - In clinical practice are used interchangeably

Electrolyte Distribution
- Major ICF ions
  - \(K^+\)
  - \(HPO_{4}^-\)
- Major ECF ions
  - \(Na^+\)
  - \(Cl^-\), \(HCO_3^-\)
- Intravascular (IVF) vs Interstitial (ISF)
  - Similar electrolytes, but IVF has proteins
Mechanisms Controlling Fluid and Electrolyte Movement

- Diffusion
- Selective Permeability
- Facilitated diffusion
- Active transport
- Osmosis
  - \(2\times Na^+ + BUN + Glucose/18\)
- Hydrostatic pressure
- Oncotic pressure

Cells are selectively permeable

Sodium is the largest Determinant of Osmolality

- \(Na^+: 135 – 145\) mEq/L
- \(Ca^+: 8.5 – 10.5\) mEq/L
- \(K^+: 3.5 – 5\) mEq/L
- Osmolality~ \(2\times (Na^+) = 2\times (135 - 145)\) mEq/L

- Normal (Isotonic) 280 – 300
- Low (hypotonic) < 280
- High (hypertonic) > 300
Fluid Exchange Between Capillary and Tissue: Sum of Pressures

Fluid Shifts
- Plasma to interstitial fluid shift results in edema
  - Elevation of hydrostatic pressure
  - Decrease in plasma oncotic pressure
  - Elevation of interstitial oncotic pressure

Fluid Movement between ECF and ICF
- Water deficit (increased ECF)
  - Associated with symptoms that result from cell shrinkage as water is pulled into vascular system
- Water excess (decreased ECF)
  - Develops from gain or retention of excess water

Fluid Spacing
- First spacing: Normal distribution of fluid in ICF and ECF
- Second spacing: Abnormal accumulation of interstitial fluid (edema)
- Third spacing: Fluid accumulation in part of body where it is not easily exchanged with ECF (e.g. ascites)

Regulation of Water Balance
- Hypothalamic regulation
- Pituitary regulation
- Adrenal cortical regulation
- Renal regulation
- Cardiac regulation
- Gastrointestinal regulation
- Insensible water loss

F&E Balance

- Renin
- Angiotensin I
- Angiotensin II
- Atrial (ANP)
- Ventricles (BNP)
- Endothelium (CNP)
- Epinephrine
- Aldosterone
**Fluid Status Indicators**
- Physical exam
- Mucous membranes
- Turgor
- Blood
- Hematocrit
- Plasma
- BUN

**Urine**
- Output (volume)
- Specific Gravity
  - < 1.003: less conc
  - > 1.030: more conc

**Electrolytes**

**F&E Balance**
- Fluids
  - Normal
  - Contracted
  - Expanded
- Electrolytes (Sodium!!!)
  - Isotonic
  - Hypertonic
  - Hypotonic

**Extracellular Fluid Deficit**
- Causes
  - Inadequate intake, diuresis, excess sweating, burns, diarrhea, vomiting, hemorrhage
- Treatment
  - Stop underlying disorder
  - Replace fluids appropriately
  - Treat complications

**Volume Deficit**
- Isotonic Deficit
  - Electrolyte drinks
  - Isotonic saline (0.9%) injection
- Hypertonic Deficit
  - Drinking Water
  - Hypotonic saline (0.45%) injection, D5W
- Hypotonic Deficit
  - Isotonic Saline
  - Hypertonic saline (3%)
Extracellular Fluid Excess

- **Causes**
  - The Three failures: heart, liver, kidney
- **Treatment**
  - Remove fluid --> ????
  - Treat underlying disorder

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Electrolyte Disorders: Signs & Symptoms (most common*)

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Excess</th>
<th>Deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium (Na)</td>
<td>Hypernatremia&lt;br&gt;Thirst&lt;br&gt;CNS deterioration&lt;br&gt;Increased interstitial fluid</td>
<td>Hyponatremia&lt;br&gt;CNS deterioration</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>Hyperkalemia&lt;br&gt;Ventricular fibrillation&lt;br&gt;ECG changes&lt;br&gt;CNS changes&lt;br&gt;Weakness</td>
<td>Hypokalemia&lt;br&gt;Bradycardia&lt;br&gt;ECG changes&lt;br&gt;CNS changes&lt;br&gt;Fatigue</td>
</tr>
</tbody>
</table>

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Electrolyte Normal Values (memorize!!!!!)

- Sodium 135 – 145
- Potassium 3.5 – 5
- Chloride 106 – 106
- Calcium 9 – 11
- BUN 10 – 20
- Creatinine 0.7 – 1.2
- CO₂ (really bicarb) 22 – 26
- Magnesium: 1.5 – 2.5

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Electrolyte Disorders Signs and Symptoms

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<tr>
<td>Calcium (Ca)</td>
<td>Hypercalcemia&lt;br&gt;Thirst&lt;br&gt;CNS deterioration&lt;br&gt;Increased interstitial fluid</td>
<td>Hypocalcemia&lt;br&gt;Tetany&lt;br&gt;Chvostek’s, Trouseau’s signs&lt;br&gt;Muscle twitching&lt;br&gt;CNS changes&lt;br&gt;ECG changes</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>Hypermagnesemia&lt;br&gt;Loss of deep tendon reflexes (DTRs)&lt;br&gt;Depression of CNS&lt;br&gt;Depression of neuromuscular function</td>
<td>Hypomagnesemia&lt;br&gt;Hyperactive DTRs&lt;br&gt;CNS changes</td>
</tr>
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Hypernatremia

- **Manifestations**
  - Thirst, lethargy, agitation, seizures, and coma
  - Impaired LOC
  - Produced by clinical states
  - Central or nephrogenic diabetes insipidus
  - Reduce levels gradually to avoid cerebral edema

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Hypernatremia Treatment

- Treat underlying cause
- If oral fluids cannot be ingested, IV solution of 5% dextrose in water or hypotonic saline
- Diuretics if necessary
**Hyponatremia**

- Results from loss of sodium-containing fluids
  - Sweat, diarrhea, emesis, etc.
- Or from water excess
  - Inefficient kidneys
  - Drowning, excessive intake
- Manifestations
  - Confusion, nausea, vomiting, seizures, and coma

**Treatment**

- Oral NaCl
- If caused by water excess
  - Fluid restriction is needed
- If Severe symptoms (seizures)
  - Give small amount of IV hypertonic saline solution (3% NaCl)
- If Abnormal fluid loss
  - Fluid replacement with sodium-containing solution

**Hyperkalemia**

- High serum potassium caused by
  - Massive intake
  - Impaired renal excretion
  - Shift from ICF to ECF (acidosis)
- Drugs
- Common in massive cell destruction
  - Burn, crush injury, or tumor lysis
  - False High: hemolysis of sample

**Manifestations**

- Weak or paralyzed skeletal muscles
- Ventricular fibrillation or cardiac standstill
- Abdominal cramping or diarrhea

**Treatment**

- Emergency: Calcium Gluconate IV
- Stop K intake
- Force K from ECF to ICF
  - IV insulin
  - Sodium bicarbonate
- Increase elimination of K (diuretics, dialysis, Kayexalate)
**Hypokalemia**

- Low serum potassium caused by
  - Abnormal losses of K⁺ via the kidneys or gastrointestinal tract
  - Magnesium deficiency
  - Metabolic alkalosis

**Manifestations**
- Most serious are cardiac
- Skeletal muscle weakness
- Weakness of respiratory muscles
- Decreased gastrointestinal motility

<table>
<thead>
<tr>
<th>Hypokalemia</th>
<th>Calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td>KCl supplements orally or IV</td>
<td>Bones are readily available store</td>
</tr>
<tr>
<td>Should not exceed 10 to 20 mEq/hr</td>
<td>Blocks sodium transport and stabilizes cell membrane</td>
</tr>
<tr>
<td>To prevent hyperkalemia and cardiac arrest</td>
<td>Ionized form is biologically active</td>
</tr>
<tr>
<td>No Pee no Kay!!!!!!!!!!!!!!!!!!!!!!!!!!</td>
<td>Bound to albumin in blood</td>
</tr>
</tbody>
</table>

**Calcium**

- Obtained from ingested foods
- More than 99% combined with phosphorus and concentrated in skeletal system
- Inverse relationship with phosphorus
  - Otherwise...

**Functions**
- Transmission of nerve impulses
- Myocardial contractions
- Blood clotting
- Formation of teeth and bone
- Muscle contractions
**Calcium**
- Balance controlled by
  - Parathyroid hormone
  - Calcitonin
  - Vitamin D/Intake
  - Bone used as reservoir

**Hypercalcemia**
- High serum calcium levels caused by
  - Hyperparathyroidism (two thirds of cases)
  - Malignancy (parathyroid tumor)
  - Vitamin D overdose
  - Prolonged immobilization

**Hypercalcemia**
- Manifestations
  - Decreased memory
  - Confusion
  - Disorientation
  - Fatigue
  - Constipation

**Treatment**
- Excretion of Ca with loop diuretic
- Hydration with isotonic saline infusion
- Synthetic calcitonin
- Mobilization

**Hypocalcemia**
- Low serum Ca levels caused by
  - Decreased production of PTH
  - Acute pancreatitis
  - Multiple blood transfusions
  - Alkalosis
  - Decreased intake

**Hypocalcemia**
- Manifestations
  - Weakness/Tetany
  - Positive Trousseau's or Chvostek's sign
  - Laryngeal stridor
  - Dysphagia
  - Tingling around the mouth or in the extremities
## Treatment
- Treat cause
- Oral or IV calcium supplements
  - Not IM to avoid local reactions
- Treat pain and anxiety to prevent hyperventilation-induced respiratory alkalosis

### Phosphate
- Primary anion in ICF
- Essential to function of muscle, red blood cells, and nervous system
- Deposited with calcium for bone and tooth structure

### Phosphate
- Involved in acid–base buffering system, ATP production, and cellular uptake of glucose
- Maintenance requires adequate renal functioning
- Essential to muscle, RBCs, and nervous system function

### Hyperphosphatemia
- High serum \( \text{PO}_4^{3-} \) caused by
  - Acute or chronic renal failure
  - Chemotherapy
  - Excessive ingestion of phosphate or vitamin D
- Manifestations
  - Calcified deposition: joints, arteries, skin, kidneys, and corneas
  - Neuromuscular irritability and tetany

### Hyperphosphatemia
- Management
  - Identify and treat underlying cause
  - Restrict foods and fluids containing \( \text{PO}_4^{3-} \)
  - Adequate hydration and correction of hypocalcemic conditions

### Hypophosphatemia
- Low serum \( \text{PO}_4^{3-} \) caused by
  - Malnourishment/malabsorption
  - Alcohol withdrawal
  - Use of phosphate-binding antacids
  - During parenteral nutrition with inadequate replacement
### Hypophosphatemia

**Manifestations**
- CNS depression
- Confusion
- Muscle weakness and pain
- Dysrhythmias
- Cardiomyopathy

**Management**
- Oral supplementation
- Ingestion of foods high in $PO_4^{3-}$
- IV administration of sodium or potassium phosphate

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### Magnesium

- 50% to 60% contained in bone
- Coenzyme in metabolism of protein and carbohydrates
- Factors that regulate calcium balance appear to influence magnesium balance

- Acts directly on myoneural junction
- Important for normal cardiac function

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### Hypermagnesemia

- High serum Mg caused by
  - Increased intake or ingestion of products containing magnesium when renal insufficiency or failure is present

- Manifestations
  - Lethargy or drowsiness
  - Nausea/vomiting
  - Impaired reflexes***
  - Respiratory and cardiac arrest
Hypermagnesemia
- Management
  - Prevention
  - Emergency treatment
    - IV CaCl or calcium gluconate
  - Fluids to promote urinary excretion

Hypomagnesemia
- Low serum Mg caused by
  - Prolonged fasting or starvation
  - Chronic alcoholism
  - Fluid loss from gastrointestinal tract
  - Prolonged parenteral nutrition without supplementation
  - Diuretics

Hypomagnesemia
- Manifestations
  - Confusion
  - Hyperactive deep tendon reflexes
  - Tremors
  - Seizures
  - Cardiac dysrhythmias

Hypomagnesemia
- Management
  - Oral supplements (MgO, MgSO$_4$)
  - Increase dietary intake
  - Parenteral IV or IM magnesium when severe

Elementary Acid-Base balance
- Buffer systems
  - Carbonic Acid
  - Bicarbonate
- Metabolic: bicarb
  - low → metabolic acidosis
  - high → metabolic alkalosis
- Respiratory: carbon dioxide

Metabolic Panel and acid-base
- “CO2” on a BMP means bicarb!!!!!!
- normal 22 – 26
  - <22 = ?
  - >26 =?
**Metabolic Acidosis Manifestation**
- Acidosis causes HYPERKALEMIA!!!
- Neuro: Drowsiness, Confusion, H/A, coma
- CV: ↓BP, dysrhythmia (K+), dilation
- GI: NVD, abd pain
- Resp: increased resp (comp)

**Metabolic Alkalosis Manifestation**
- Alkalosis causes HYPOKALEMIA!!!
- Neuro: Dizziness, Irritability, Nervous, Confusion
- CV: ↑HR, dysrhythmia (K+)
- GI: NV, anorexia
- Neuromuscular: Tetany, tremor, paresthesia, seizures
- Resp: decreased resp (comp)

**MEMORIZE Arterial pH, PaCO2, HCO3−!!!!!!!**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Arterial</th>
<th>Venous</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.35-7.45</td>
<td>7.35-7.45</td>
</tr>
<tr>
<td>PaCO2</td>
<td>35-45 mm Hg</td>
<td>40-45 mm Hg</td>
</tr>
<tr>
<td>Bicarbonate (HCO3−)</td>
<td>22-26 mEq/L (mmol/L)</td>
<td>22-26 mEq/L (mmol/L)</td>
</tr>
<tr>
<td>PaO2</td>
<td>80-100 mm Hg</td>
<td>40-50 mm Hg</td>
</tr>
<tr>
<td>Oxygen saturation</td>
<td>90%-100%</td>
<td>60%-85%</td>
</tr>
<tr>
<td>Base excess</td>
<td>±2.0 mEq/L</td>
<td>±2.0 mEq/L</td>
</tr>
</tbody>
</table>

*Decreases above sea level and with increasing age.

**Interpretation of ABGs**
- Diagnosis in six steps
  - Evaluate pH
  - Analyze PaCO2
  - Analyze HCO3−
  - Determine if Balanced or Unbalanced
  - Determine if CO2 or HCO3− matches the alteration
  - Decide if the body is attempting to compensate

**Interpretation of ABG**
1. pH over balance
2. PaCO2 = “respiratory” balance
3. HCO3− = “metabolic” balance
4. If all three normal = balanced
5. Match direction. e.g., if pH and PaCO2 are both acidic, then primary respiratory acidosis
6. If other is opposite, then partial compensation; if pH normal, then fully compensated.

**Interpretation of ABGs**
- pH 7.36
- PaCO2 67 mm Hg
- PaO2 47 mm Hg
- HCO3 37 mEq/L
- What is this?
**Interpretation of ABGs**

- pH 7.18
- PaCO₂ 38 mm Hg
- PaO₂ 70 mm Hg
- HCO₃⁻ 15 mEq/L
- What is this?

**Interpretation of ABGs**

- pH 7.60
- PaCO₂ 30 mm Hg
- PaO₂ 60 mm Hg
- HCO₃⁻ 22 mEq/L
- What is this?

**Interpretation of ABGs**

- pH 7.58
- PaCO₂ 35 mm Hg
- PaO₂ 75 mm Hg
- HCO₃⁻ 50 mEq/L
- What is this?

**Interpretation of ABGs**

- pH 7.28
- PaCO₂ 28 mm Hg
- PaO₂ 70 mm Hg
- HCO₃⁻ 18 mEq/L
- What is this?

**Putting it all together**

- Always pay attention to
  - Patient history
  - Vital signs
  - Symptoms and physical exam findings
  - Lab Values
- Always ask:
  - What is causing this abnormal finding?
  - What can be done to fix it?

![Diagram of fluids and colloids]

- Fluids
  - DSW
  - ½ NS (0.45%)
  - Hypotonic
- Isotonic
  - NS (0.9%)
  - Lactated Ringer
- Hypertonic
  - 3% Saline
  - Plasmalyte
- Colloids
  - PRBCs
  - Albumin
  - Dextran
  - FFP
### IV Fluids

- **Purposes**
  1. **Maintenance**
     - When oral intake is not adequate
  2. **Replacement**
     - When losses have occurred

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### D5W (Dextrose = Glucose)

- Hypotonic
- Provides 170 cal/L
- Free water
  - Moves into ICF
  - Increases renal solute excretion
- Used to replace water losses and treat hyponatremia
- Does not provide electrolytes

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### Normal Saline (NS)

- **Isotonic**
- No calories
- More NaCl than ECF
- 30% stays in IVF
  - 70% moves out of IV space

- Expands IV volume
  - Preferred fluid for immediate response
  - Risk for fluid overload higher
- Does not change ICF volume
- Blood products
- Compatible with most medications

### Lactated Ringer’s

- **Isotonic**
- More similar to plasma than NS
  - Has less NaCl
  - Has K, Ca, PO₄³⁻, lactate (metabolized to HCO₃⁻)
    - CONTRAINDICATED in lactic acidosis
- Expands ECF

### D5 ½ NS

- Hypertonic
- Common maintenance fluid
- KCl added for maintenance or replacement

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<table>
<thead>
<tr>
<th><strong>D10W</strong></th>
<th><strong>Plasma Expanders</strong></th>
</tr>
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<tbody>
<tr>
<td>- Hypertonic</td>
<td>- Stay in vascular space and increase osmotic pressure</td>
</tr>
<tr>
<td>- Max concentration of dextrose that can be administered in peripheral IV</td>
<td>- Colloids (protein solutions)</td>
</tr>
<tr>
<td>- Provides 340 kcal/L</td>
<td>- Packed RBCs</td>
</tr>
<tr>
<td>- Free water</td>
<td>- Albumin</td>
</tr>
<tr>
<td>- Limit of dextrose concentration may be infused peripherally</td>
<td>- Plasma</td>
</tr>
<tr>
<td></td>
<td>- Dextran</td>
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Plasma Expanders:

- Stay in vascular space and increase osmotic pressure
- Colloids (protein solutions):
  - Packed RBCs
  - Albumin
  - Plasma
  - Dextran