Fluid, Volume, Electrolyte, and Blood Product Replacement

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Choose the best IV solution for a diabetic patient with chest pain being transferred to the coronary care unit. VS unstable. Pt is hypotensive w/rapid pulse.
A) D5W
B) NS = 0.9% saline
C) ½ NS = 0.45% saline
D) Ringer’s lactate = LR
E) 3% saline
F) B or D
Choose the best IV solution for a 40 yo patient w/septic shock.

A) D5W
B) NS = 0.9% saline
C) ½ NS = 0.45% saline
D) Ringer’s lactate = LR
E) 3% saline
F) B or D
Choose the best IV solution for a diabetic patient with glucose 1300 mg/dL, Na 150 mEq/L, BP 60/40, pulse 120 bpm.

A) D5W
B) NS = 0.9% saline
C) ½ NS = 0.45% saline
D) Ringer’s lactate = LR
E) 3% saline
F) B or D
Choose the best IV solution for the same diabetic patient with glucose 1300 mg/dL, Na 150 mEq/L who is now hemodynamically stable.

A) D5W
B) NS = 0.9% saline
C) ½ NS = 0.45% saline
D) Ringer’s lactate = LR
E) 3% saline
F) B or D
Distribution of Body Water

- Blood/Plasma
- Interstitial Fluid
- Cell Membrane
- Intracellular Fluid

Extracellular Fluid
Distribution of Body Water (Volume)

Total Body Water
(60% body weight)
42 L for 70 kg man

- ICF
  (2/3 body water)
  27 - 29 L

- ECF
  (1/3 body water)
  13 L

  - Interstitial Fluid
    (3/4 ECF)
    10 - 11 L

  - Intravascular Fluid
    (1/4 ECF)
    3 - 4 L
Maintenance of Body H$_2$O Distribution - Osmolality

• 3 principles to keep in mind:
  – there is no active (energy consuming) movement of H$_2$O between body compartments
  – all membranes in the body are freely permeable to H$_2$O
    • EXCEPT: TAL, distal convoluted tubule, collecting tubule
  – movement of H$_2$O between body compartments follows osmolar forces
What is the most abundant anion or cation that regulates the size of the ECF?

A) Na
B) K
C) Cl
D) $\text{HCO}_3$
E) BUN/SCR
F) Glucose
Start: **D5 1/2NS+20 meq K @ Wt+40/hr**

- A reasonable approach is to start **1/2 normal saline to which 20 meq of potassium chloride is added per liter.**
  
  
  
  \((1/2NS+20 \text{ K } @ \text{ Wt+40/hr})\)

- Glucose in the form of dextrose (D5) can be added to provide some calories while the patient is NPO.

- The normal kidney can maintain sodium and potassium balance over a wide range of intakes.

- So, start: **D5 1/2NS+20 meq K**

  at a rate equal to their weight + 40ml/hr, but no greater than 120ml/hr. then adjust as needed, see next page.
Start D5 1/2NS+20 meq K, then adjust:

- If sodium falls, increase the concentration (eg, to NS)
- If sodium rises, decrease the concentration (eg, 1/4NS)
- If the plasma potassium starts to fall, add more potassium.
- If things are good, leave things alone.
Fluid Volume Disturbances

- Fluid Volume Excess (Hypervolemia)
Fluid Volume Excess

- Pathophysiology – may be related to fluid overload or diminished function of the homeostatic mechanisms responsible for regulating fluid balance
- Contributing factors – HF, renal failure, cirrhosis
Fluid Volume Excess 2

• Clinical manifestations – edema, distended neck veins, crackles, tachycardia, increased blood pressure, increased weight
Electrolyte Imbalances

Sodium!

Normal range – 135 to 145 mEq/L

- Primary regulator of ECF volume (a loss or gain of sodium is usually accompanied by a loss or gain of water)
Hyponatremia

• Sodium level less than 135 mEq/L
• May be caused by vomiting, diarrhea, sweating, diuretics, etc.
Hyponatremia

• Clinical manifestations
- Poor skin turgor
- Dry mucosa
- Decreased saliva production
- Orthostatic hypotension
- Nausea/abdominal cramping
- Altered mental status
Hyponatremia

• **Medical management**
  - Sodium Replacement
  - Water Restriction
Hypernatremia

- Sodium level is greater than 145 mEq/L

- Can be caused by a gain of sodium in excess of water or by a loss of water in excess of sodium
Hypernatremia

• Pathophysiology
  - Fluid deprivation in patients who cannot perceive, respond to, or communicate their thirst
  - Most often affects very old, very young, and cognitively impaired patients
Hypernatremia

- Clinical manifestations
  - Thirst
  - Dry, swollen tongue
  - Sticky mucous membranes
  - Flushed skin
  - Postural hypotension
Hypernatremia

• Medical Management
  – Preventing Hypernatremia
  – Correcting Hypernatremia
Hyponatremia: Na⁺ less than 130 mEq/L

Cell swells as water is pulled in from ECF

Hypernatremia: Na⁺ greater than 150 mEq/L

Cell shrinks as water is pulled out into ECF
Critical Thinking Exercise:

• Situation: A 47 year old woman was taken to the ER after she developed a rapid heart rate and agitation. Physical assessment revealed dry oral mucous membranes, poor skin turgor, and fever of 101.3 orally. The client’s daughter stated her mother had been very hungry recently and drinking more fluids than usual. Suspecting DM, the practitioner obtained serum electrolytes and glucose levels, which revealed serum sodium of 163 mEq/L and serum glucose of 360 mg/dL.
Electrolyte Replacement

Potassium
Normal 3.5-5.1

• Muscle weakness, cardiac toxicity <3.0
• Vast majority is intracellular
• Insulin pushes K into cells
• Acidosis pulls K from the cells

• KCl or KPO₄ po (bitter)
  – Tabs, liquid, powder
  – Slow release
• KCl IV 10 mEq/h via peripheral and 15-20 mEq/hr via central

Magnesium levels should be monitored and replacement given if necessary since potassium repletion is ineffective in the presence of hypomagnesemia.
Hypokalemia

Risk Factors for developing hypokalemia
1. diarrhea, vomiting
2. amphotericin B
3. diuretics
4. metabolic alkalosis
5. insulin
6. beta2 agonists (e.g., terbutaline B)
Standard K\(^+\) Concentration in I.V. Solutions

1 Cnc: <60 mEq/L
2 Rate of adm: <10-20 mEq/hr
3 daily dosage: <100 mEq/day
4 Monitor ECG and serum K\(^+\)
5 Urine output: >0.5 ml/kg/hr
Oral Potassium Administration Guidelines

Asymptomatic patients with serum potassium levels < 3.8 mEq/L.

• Adult doses from 40-100 mEq/day may be required for potassium repletion given in 2 - 4 divided doses per day.

• In adults, start with 20-40 mEq/day and titrate to desired level.

• A 40 mEq dose may be given every 2 hours for a maximum dose of 120 mEq within a 6 hour period.

• When oral potassium therapy is combined with parenteral supplementation for adults, a maximum total dose (IV + PO) is 120 mEq within a 6 hour period.
Oral Potassium Administration Guidelines

• Potassium levels must be checked after each replacement dose or with AM lab.

• If using immediate release preparations (KCl powder), a level should be checked no sooner than 120 minutes.

• If using a sustained release product, a level should be checked no sooner than 4-6 hours.

• Patients receiving maintenance doses of oral potassium do not require levels after each dose.
Hyperkalemia

Peaked T wave
Hyperkalemia

Wide QRS
Hyperkalemia

• Serum Potassium greater than 5.5 mEq/L
- More dangerous than hypokalemia because cardiac arrest is frequently associated with high serum K+ levels
Hyperkalemia

• Causes:
  - Decreased renal potassium excretion as seen with renal failure and oliguria
  - High potassium intake
  - Renal insufficiency
  - Shift of potassium out of the cell as seen in acidosis
Hyperkalemia

- Medical/Nursing Management:
  - Monitor EKG changes – telemetry
  - Administer Calcium IV (1 gm) to neutralize the potassium
  - Give Insulin (10 units) and D50W (25 ml)
  - Give Kayexelate (30 gms orally or 50 gms PR.)
Calcium:

• For every 1 g/dL decrease of serum albumin less than 4.0 g/dL, add 0.8 mg/dL to total serum calcium

• Use caution in cases of concomitant digoxin therapy

• Normal serum calcium range is considered to be 8.5-10.5mg/dL at OHSU.
Calcium

• Intravenous replacement should be used if severe symptomatic hypocalcemia exists (corrected calcium is <8 mg/dl) or if there is a high risk for complications secondary to hypocalcemia.
Calcium:

• **IV replacement:**
  
  – If a central access is present use: Calcium Chloride (13.2 mEq or 272 mg elemental calcium/1 gm CaCl2)
  
  – If no central access is present use: Calcium Gluconate (4.7 mEq or 94 mg elemental calcium/1 gm calcium gluconate)

• 1 AMPULE Calcium Chloride = 3 AMPULES of Calcium Gluconate.

• **Avoid ordering as AMPULES**
Calcium:

As a guideline, the total calcium will increase by 0.5 mg/dl for every gram of calcium gluconate given intravenously.

• Avoid ordering as AMPULES
Calcium:

Give one gram calcium gluconate in 100 mL IV solution and infuse over one hour.

<table>
<thead>
<tr>
<th>Calcium Level</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-8.5 mg/dL</td>
<td>1 gram calcium gluconate IV over 60 minutes</td>
</tr>
<tr>
<td>7-8 mg/dL</td>
<td>2 grams calcium gluconate IV over 60 minutes</td>
</tr>
<tr>
<td>6-7 mg/dL</td>
<td>3 grams calcium gluconate IV over 120 minutes and recheck your lab 4 hours after replacement</td>
</tr>
<tr>
<td>Below 6 mg/dl</td>
<td>Call consult service</td>
</tr>
</tbody>
</table>
Calcium

• INFUSION RATE:
  – Infuse over 30-60 minutes.
  – Rapid administration may cause bradycardia, hypotension and vasodilation.
  – *Infiltration of IV calcium may cause severe tissue necrosis and sloughing.*
## Oral Calcium Preparations

<table>
<thead>
<tr>
<th>Calcium Preparation</th>
<th>Calcium Content Per Pill</th>
<th>Pill Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium carbonate</td>
<td>200 or 250 mg</td>
<td>500 or 650 mg</td>
</tr>
<tr>
<td>Calcium gluconate</td>
<td>90 mg</td>
<td>1000 mg</td>
</tr>
<tr>
<td>Calcium citrate</td>
<td>200 mg</td>
<td>950 mg</td>
</tr>
<tr>
<td>Calcium lactate</td>
<td>60 mg</td>
<td>300 mg</td>
</tr>
</tbody>
</table>

- Absorption is variable and depends on PTH, Vitamin D, and gastric pH.

- Calcium acetate (Phos Lo®) is available for phosphate binding and not calcium replacement in patients with renal insufficiency since its calcium absorption is poor.
Magnesium:

• Normal magnesium levels at OHSU: 1.8-2.5mg/dL

• Expect magnesium depletion in patients with extensive GI losses (e.g. diarrhea, high NG output), alcoholism, and those taking aminoglycosides, loop diuretics, cyclosporine, tacrolimus, cisplatin, and/or amphotericin
PO replacement is preferred in asymptomatic patients able to tolerate PO or PT meds (diarrhea)
Magnesium oxide: 400 mg to 800 mg TID
Slow Mg: less diarrhea, however, less Mg too.
*Oral absorption is variable with 15-50 % of a dose being absorbed.

**IV:**
- IV replacement is with 1 gm Magnesium Sulfate (MgSO4) in 100 mL IV solution given over 60 minutes
  
  - If level is:
    - 1.5-1.9 mg/dL  1 gram MgSO4 IV over 60 minutes
    - 1.2-1.4 mg/dL  2 grams MgSO4 IV over 120 minutes
    - 0.8-1.1 mg/dL  3 grams MgSO4 IV IV over 120 minutes and 4 hours after replacement, check serum Mg level
Phosphorus

Normal levels at OHSU: 2.4-4.7 mg/dL
Mix Na or K phosphate in 250 mL IV solution and infuse over 4-6 hours.

If serum phosphate < 1.5-2 mg/dl AND K⁺ ≤ 3.5 mEq/L

Give 15 mmol potassium phosphate (0.25 mmol/kg) in 250 mL IV solution over 4-6 hours.

*Do not give additional K⁺ replacement as this will provide 22 mEq/L of K⁺*

• If serum phosphate < 1.5-2 mg/dl AND K⁺ > 4.5 mEq/L

Give 15 mmol sodium phosphate (0.25 mmol/kg) in 250mL IV solution over 4-6 hours.
**Phosphorus**

If serum Phosphate between 1.0-1.5 mg/dL AND K$^+$ ≤ 3.5 mEq/L

- Give 30 mmol *potassium phosphate* (Max. of 0.50 mmoL/kg) in 500 mL I.V solution over 6 hours.

*Do not give additional K$^+$ replacement as this will provide 44 mEq/L of K$^+$*

- If serum Phosphate between 1.0-1.5 mg/dL AND K$^+$ > 4.5 mEq/L
  
  - Give 30 mmol *sodium phosphate* (Max. of 0.50 mmoL/kg) in 250mL I.V solution over 6 hours.
# Phosphorus

## Oral Phosphate Preparations

<table>
<thead>
<tr>
<th>Phosphate Preparation</th>
<th>Phosphate Content Per Pill/PK (mg)</th>
<th>K Content Per Pill/PK (mEq)</th>
<th>Na Content Per Pill/PK (mEq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-Phos Neutral</td>
<td>250 mg</td>
<td>1.1 mEq</td>
<td>13.1 mEq</td>
</tr>
<tr>
<td>Neutra-Phos*</td>
<td>250 mg</td>
<td>7.1 mEq</td>
<td>7.1 mEq</td>
</tr>
<tr>
<td>Neutra-Phos K*</td>
<td>250 mg</td>
<td>14.2 mEq</td>
<td>0</td>
</tr>
</tbody>
</table>
Phosphorus

- Oral Dosage:
- K-Phos Neutral 250 mg Tablet: 1 Tablet TID
- Neutra Phos: Mix one Package in 75 ml TID
- Neutra Phos K: Mix one Package in 75 ml TID
Hyperphosphatemia

• Serum Phosphorus level greater than 4.5 mEq/L
• Causes
  - Renal failure
  - Chemotherapy
  - Hypoparathyroidism
  - High phosphate intake
Hyperphosphatemia

• Clinical manifestations
  - Tetany
  - Muscle weakness
  - Similar to Hypocalcemia because of reciprocal relationship
Hyperphosphatemia

- Treat underlying cause
- Avoid phosphorus rich foods
  • Aluminum-containing phosphate binders
  • Calcium-containing phosphate binders
  • Phosphate binders that contain no aluminum or calcium
    – Sevelamer (Renagel)
    – Lanthanum carbonate (Fosrenol)
Renal Dialysis

• Hemodialysis
• Peritoneal dialysis
Hemodialysis
AV Fistula and AV Graft
Types of Arteriovenous Fistulas

- Radiocephalic
- Brachiocephalic
- Brachiobasilic

Key structures:
- Cephalic vein
- Radial artery
- Median cubital branch of cephalic vein
- AVF anastomosis
- Brachial artery
- Basilic vein
- Brachial artery
- AVF anastomosis
Hemodialysis
Hemodialysis (HD)

Dialyzer

Access $Q_B$ (400-500 mL/min)

Return
Hemodialysis (HD)

Diffusion

Dialysate $Q_{di}$
500 – 800 mL/min

Ultrafiltrate + Spent Dialysate $Q_{Do}$

Access $Q_B$ (400-500 mL/min)

Return

Dialyzer

Countercurrent flow
### Example of Dialysate Composition

<table>
<thead>
<tr>
<th>Dialysate</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>135-145 mEq/L</td>
</tr>
<tr>
<td>Potassium</td>
<td>0-4 mEq/L</td>
</tr>
<tr>
<td>Chloride</td>
<td>100-124 mEq/L</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>30-38 mEq/L</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.5-1.0 mEq/L</td>
</tr>
<tr>
<td>Calcium</td>
<td>2.5-3.5 mEq/L</td>
</tr>
<tr>
<td>Dextrose</td>
<td>200 mg/dL</td>
</tr>
</tbody>
</table>
Blood in

Dialysate Out
+ Ultrafiltrate Out

Dialysate In

Filtered blood out
Anatomy of a Dialyzer

Blood in

Dialysate out

Dialysate in

Cross Section

Hollow fiber membrane

Inside the Fiber
(blood)

Outside the Fiber
(ultrafiltrate)

Filtered blood out
Diffusion

Blood

Dialysate

Dialyzer

Waste

Dialysate
Diffusion
<table>
<thead>
<tr>
<th>Solutes</th>
<th>Molecular Weight (daltons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albumin</td>
<td>55,000 – 60,000</td>
</tr>
<tr>
<td>Beta 2 Microglobulin</td>
<td>11,800</td>
</tr>
<tr>
<td>Inulin</td>
<td>5,200</td>
</tr>
<tr>
<td>Vitamin B&lt;sub&gt;12&lt;/sub&gt;</td>
<td>1,355</td>
</tr>
<tr>
<td>Aluminum/Desferoxamine Complex</td>
<td>700</td>
</tr>
<tr>
<td>Glucose</td>
<td>180</td>
</tr>
<tr>
<td>Uric Acid</td>
<td>168</td>
</tr>
<tr>
<td>Creatinine</td>
<td>113</td>
</tr>
<tr>
<td>Phosphate</td>
<td>80</td>
</tr>
<tr>
<td>Urea</td>
<td>60</td>
</tr>
<tr>
<td>Potassium</td>
<td>35</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>31</td>
</tr>
<tr>
<td>Sodium</td>
<td>23</td>
</tr>
<tr>
<td>Medications</td>
<td>Various</td>
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# Types of Dialyzers

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<thead>
<tr>
<th>Dialyzer Type</th>
<th>$K_{uf}$ (mL/hr/mmHg)</th>
<th>Surface Area (M$^2$)</th>
<th>$K_oA$ (mL/min)</th>
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<tbody>
<tr>
<td>Low-flux low-efficiency CA 90</td>
<td>7.3</td>
<td>0.9</td>
<td>515</td>
</tr>
<tr>
<td>Low-flux high-efficiency CA 170</td>
<td>7.6</td>
<td>1.7</td>
<td>1005</td>
</tr>
<tr>
<td>High-flux low efficiency F50S</td>
<td>30</td>
<td>1.0</td>
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</tr>
<tr>
<td>High-flux high efficiency Optiflux F 200NR</td>
<td>56</td>
<td>2.0</td>
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Low-flux: $K_{uf} < 10$ mL/hr/mmHg  
High-flux: $K_{uf} > 20$ mL/hr/mmHg  
Low-efficiency: $K_oA < 600$ mL/min  
High-efficiency: $K_oA > 600$ mL/min
Definitions

• Efficiency
  – Function of surface area
  – Described by a constant call KoA
  – Refers to the capacity to remove urea
  – Has small pores (low flux) or large pores (high flux)
# Types of Dialyzers

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Low-efficiency: $K_{oA} < 600$ mL/min  
High-efficiency: $K_{oA} > 600$ mL/min
Question

• The best type of dialyzer to remove middle molecules and urea is
A. Low flux; low efficiency
B. Low flux; high efficiency
C. High flux; low efficiency
D. High flux; high efficiency
Hemodialysis (HD)

Diffusion and Ultrafiltration

Low permeable dialyzer

Access

$Q_B$ (400-500 mL/min)

Ultrafiltrate + Spent Dialysate

$Q_{Di}$

500 – 800 mL/min

$Q_{UF} = Q_{Di} - Q_{Do}$

(100-300 mL/hr)

Countercurrent flow

Return
Factors Affecting Drug Removal during Hemodialysis

• Concentration gradient
• Molecular weight
  – Related to speed and size
• Membrane thickness
• Pore size
• Degree of protein binding
Example - Amlodipine

- MW 567.1 daltons
- $V_D = 21$ L/kg
- Protein binding $> 95\%$
Yes or No

• Is amlodipine removed by hemodialysis?
Metronidazole (Flagyl)

- MW = 171.2 daltons
- $V_D = 0.25 – 0.85$ L/kg
- Plasma protein binding = 20%
Yes or No

• Is metronidazole removed by hemodialysis?
Continuous Venovenous Hemofiltration (CVVHDF)

Replacement fluid $Q_R$

Ultrafiltration and Convection

Access $Q_B$ (50–200 mL/min)

Predilution

Postdilution

Highly permeable filter

Return

Ultrafiltrate $Q_{UF}$ (500–2000 mL/hr)
Conclusion

- Maintenance fluid therapy: normal loss
- (IWL + Urine)
- Suitable in hypertonic dehydration
- Minimized risk of potassium depletion in cases of prolonged inadequate oral intake
- ‘Ready for use” product associated with less risk of contamination
- Many factors might effect drugs dosing in AKI and CKD