Dysnatremias:

Hypernatremia and Polyuria

A story of water and volume

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No disclosures
OBJECTIVES

• Physiology/pathophysiology of total body water and volume
• Evaluation and treatment of hypernatremia
• Sodium concentrations of body fluid losses and parenteral and enteral “fluid” inputs to estimate water and volume components
• Challenges in assessing intravascular volume
• Apply this information to the clinical setting
Regulation of Total Body Water and Sodium

WATER:
Antidiuretic hormone (ADH)
- Stimulates thirst and renal water reabsorption
- Increased by hyperosmolality, hypothalamic hypoperfusion, nausea, vomiting, stress and narcotics
- Decreased by hyponatremia

INTRAVASCULAR VOLUME:
Renin-Angiotensin-Aldosterone (RAAS)
- Stimulates sodium reabsorption by the kidney
  - Increased by renal hypoperfusion
  - Decreased by hypervolemia, ACEI, ARBs, Spironolactone
Distribution of TBW

Proportions given for 70kg male\(^1\), may vary in illness\(^2\).

Normal conditions

Extracellular Fluid

Intracellular Fluid

Plasma

ECF

SODIUM

POTASSIUM
Serum Sodium Concentration

Serum $[\text{Na}^+] = \frac{\text{exchangeable body (sodium+potassium)}}{\text{total body water}}$

= amount of sodium/volume of ECF water

Normal serum $[\text{Na}+]$ is 140 mEq/L of serum

Normal saline is 154 mEq/L of water

WHY?

Only 91% of serum is water
HYPERNATREMIA
S[Na+] > 145 mEq/L

S[Na+] can be measured by
1) Autoanalyzer for BMP
2) Flame photometer for ABG or VBG

QUESTIONS:
1) Are they always the same? No. WHY?
2) Can pseudohyponatremia occur?
Pseudohyponatremia

Normal plasma

9% protein/lipid

91% plasma water

Na 154

Hypoproteinemic plasma

5% protein/lipid

95% plasma water

Na 154

Apparent concentration of Na in serum by indirect method (BMP)

154 x 0.91 = 140 mEq/L of serum

154 x 0.95 = 146 mEq/L of serum

S[Na+] is “normal” if measured directly with ion-sensitive electrodes in undiluted plasma in the ABG lab in the presence of low protein and lipids.
PseudohypERNatremia

- Low serum protein concentrations increase the water phase of serum to >91% and can result in an artifactual increase of serum [Na+] by indirect potentiometry (BMP) compared to direct potentiometry (ABG/VBG).
- > 4 mEq/L difference in 25% of ICU, 8% of hospitalized specimens
- 97% with > 4 mEq/L difference were due to low protein concentrations.
Pseudohypernatremia in our ICU
(Paul Loener, MD Regional ACP 2014)

• 30 ICU patients with total protein concentrations ≤6 g/dL
• Serum [Na+] by BMP greater than on ABG in 29 of 30 patients.
• 30% had differences of ≥ 4 mEq/L

SIGNIFICANCE: Free water replacement should be calculated using **direct ISE methods** to avoid overcorrection and hyponatremia.
Diagnostic Approach to Hypernatremia

- Assess for **PseudoHYPERnatreima** (overestimating $[Na^+]$)
  
  Compare $[Na^+]$ by BMP with VBG/ABG
  
  $[Na^+]$ may be **HIGHER** on BMP than VBG/ABG due to hypoproteinemia/hypolipidemia increasing % serum water
  
  **CORRECT** $[Na^+]$ VALUE is via VBG/ABG

- Assess for **Hyperosmolar states** - water shifts from ICF to ECF with increased glucose, mannitol or contrast

  **Decrease in $[Na^+] = 2x(Serum \text{ glucose} - 100)/100**

  e.g. If serum glucose is 900, $2x (900-100)/100 = 8x2=16$, so $[Na^+]$ is actually 16 mEq/L higher than on VBG or ABG when corrected for water shift due to hyperglycemia
Causes of Hypernatremia

Free water intake < free water losses
or
Administration of hypertonic sodium solutions

Resulting in a total body free water deficit relative to total body exchangeable sodium
HYPERNATREMIA TREATMENT

1. Recognize and correct underlying problem
2. Calculate the free water deficit
5. Replace 1/2 of free water deficit in 24 hours. Not to decrease serum $[\text{Na}^+] > 0.5 \text{ mEq/L/hr}$ or $8-10 \text{ mEq/L/d}$ to avoid cerebral edema
7. Replace ongoing water losses
   - insensible losses
   - GI losses
   - renal losses
5. Maintain euvoolemia.
1. **Recognize and correct underlying problem**
2. Calculate the free water deficit
5. Replace 1/2 of free water deficit in 24 hours. Not to decrease serum $[\text{Na}^+] > 0.5$ mEq/L/hr or 8-10 mEq/L/d to avoid cerebral edema
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5. Maintain euvolemia.
HYPERNATREMIA

CLINICAL CIRCUMSTANCES

- Decreased Thirst
  - Unable to drink
  - Reset osmostat
  - Elderly/Infants
    - AMS

- Hypotonic losses
  - Pure water losses
    - Diabetes Insipidus
      - Central
      - Nephrogenic
  - Water loss > Na loss
    - Renal, GI
      - Lung, skin

- Hypertonic
  - Na Bicarbonate
  - 3% Saline
  - TPN
Hypotonic “fluid” losses
Water losses > sodium losses

Renal
• Pure water losses - DI
• Osmotic diuresis - glucose, contrast, mannitol, urea, diuretics
  – Losses ~ 1/2 normal saline (Ur [Na⁺] ~80 mEq/L)
  – Always check urine [Na⁺]

Non-renal
• GI:
  – Gastric
  – Osmotic diarrhea: sorbital or lactulose
• SWEAT
• RESPIRATION
POLYURIA

Definition:
Urine output > 3 liters/day
CAUSES OF POLYURIA

• OSMOTIC - uncontrolled diabetes mellitus
  - ionic contrast, mannitol, electrolytes
• WATER    - psychogenic polydipsisia
  - central diabetes insipidus
  - nephrogenic diabetes insipidus
PRIMARY POLYDIPSIA

A primary increase in water intake
- In psychiatric illnesses +/- phenothiazines
- Hypothalamic lesions of the thirst center
  - infiltrative disease such as sarcoidosis

May cause hyponatremia
If water intake = water losses, \( S[Na+] \) unchanged
If water intake > water loses, \( S[Na+] \) decreases
Deficient secretion of antidiuretic hormone

- Familial
- Idiopathic - most often (? autoimmune injury to the ADH-producing cells)
- Acquired - trauma, pituitary surgery, or hypoxic or ischemic encephalopathy
  
  If water losses = water intake, $S[Na+]$ unchanged
  
  If water losses > water intake, $S[Na+]$ increases
NEPHROGENIC DIABETES INSIPIDUS

• Familial
• Acquired
  – Renal Medullary Diseases
    Obstructive uropathy  Analgesic nephropathy
    Medullary cystic disease  Sickle cell disease
  – Metabolic Disorders - Chronic hypokalemia,
    - Hypercalcemia
  – Drugs: Lithium, demeclocycline, foscarnat, cidofovir

If water losses = water intake, $S[Na+]$ unchanged
If water losses > water intake, $S[Na+]$ increases
POLYURIA
Water diuresis

Serum Osmolality

- Decreased
  - Psychogenic polydipsia

- Increased
  - Central DI
    - No ADH
  - Nephrogenic DI
    - High ADH
POLYURIA

Definition: >3 liters of urine/day

Pure water
- Urine Osm Hypotonic to serum
  - U/P osm <0.7
    - Do Water deprivation test if Sosm <300

Osmotic
- Urine Osm Isotonic (300 mOsm/kg)
  - U/P osm >0.8
    - Electrolyte fraction = \( \frac{2(UNa+UK)}{Uosm} \)
      - >0.6 = electrolyte
        - Saline
        - Bicarbonate
      - <0.4 = nonelectrolyte
        - Glucose, Urea
        - Mannitol, Contrast
Complete:
Increase >50%

Partial:
Increase >10%

Water restriction or 5% saline

Aqueous vasopressin or DDAVP

Complete CDI
Complete NDI

Primary polydipsia

$U_{osm}$ (mosm/kg)

$P_{osm}$ (mosm/kg)
### Differentiation of Polyuria

<table>
<thead>
<tr>
<th></th>
<th>Osmotic diuresis</th>
<th>Primary Polydipsa</th>
<th>Central DI</th>
<th>Nephro DI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Posm</strong></td>
<td>Increased</td>
<td><strong>Decreased</strong></td>
<td>Increased</td>
<td>Increased</td>
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<tr>
<td><strong>Uosm</strong></td>
<td>Isotonic</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Decreased</td>
</tr>
<tr>
<td><strong>Plasma</strong></td>
<td>Increased</td>
<td><strong>Decreased</strong></td>
<td>Decreased</td>
<td>Increased</td>
</tr>
<tr>
<td><strong>AVP</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Uosm with Dehydration</strong></td>
<td>No effect</td>
<td><strong>Increased</strong></td>
<td>No effect</td>
<td>No effect</td>
</tr>
<tr>
<td><strong>Uosm after AVP</strong></td>
<td>No effect</td>
<td>No effect</td>
<td></td>
<td><strong>Increased</strong></td>
</tr>
</tbody>
</table>
Therapy of Diabetes Insipidus

• CENTRAL DI: DDAVP 10 - 20 U IN q 12-24 hrs
  Chlorpropamide, clofibrate, carbamazepine
  plus APPROPRIATE FREE WATER INTAKE

• NEPHROGENIC DI: HCTZ/Amiloride, sodium and protein restriction (decreased osmolar load), ? NSAIDs plus APPROPRIATE FREE WATER INTAKE.

• PSYCHOGENIC POLYDIPSIA:
  Decrease free water intake
HYPERNATREMIA

• CALCULATE FREE WATER DEFICIT
  – $S[Na^+] \times 0.5 \ (TBwt) = 140 \ {\text{mEq/l}} \times \text{new TBW}$

• Replace ongoing losses
  – Insensible
  – Sensible
HYPERNATREMIA TREATMENT

1. Recognize and correct underlying problem
2. Calculate the free water deficit
5. Replace 1/2 of free water deficit every 24 hours.
   Do not decrease serum [Na⁺] >0.5 mEq/L/hr or 8-10 mEq/L/d to avoid cerebral edema
4. Replace ongoing water losses
   - insensible losses
   - GI losses
   - renal losses
5. Maintain euvolemia.
HYPERNATREMIA

• CALCULATE FREE WATER DEFICIT
  – \( S[Na^+] \times 0.5 \times (TBwt) = 140 \text{ mEq/l } \times \text{new TBW} \)

The patient is a 65 year old female, found down. Weight 60 kg
\( S[Na^+] \) 165 mEq/L
Serum glucose 75 mg/dL
Serum total protein 7.5 g/dL
No contrast or mannitol given

\( TBW = 0.5 \times TBwt = 0.5 \times 60 \text{ kg} = 30 \text{ liters} \)
\( S[Na^+] \times 0.5 \times (TBwt) = 140 \text{ mEq/l } \times \text{new TBW} \)
\( 165 \times 30/140 = 35.4 \text{ liters} = \text{the TBW if } S[Na^+] \text{ were } 140 \text{ mEq/L} \)
Free water deficit = 35.4-30 liters = 5.4 liters

• Replace \( \frac{1}{2} \) the free water deficit in 24 hours (2.7 L) not to decrease
\( S[Na^+] \) more than 8 -10 mEq/L in 24 hours with
FREE WATER PO or IV
HYPERNATREMIA TREATMENT

1. Recognize and correct underlying problem
2. Calculate the free water deficit
3. Replace 1/2 of free water deficit in 24 hours. Do not decrease serum $[\text{Na}^+] > 0.5 \text{ mEq/L/hr}$ or 8-10 mEq/L/d to avoid cerebral edema
4. Replace ongoing water losses
   - insensible losses
   - GI losses
   - renal losses
5. Maintain euvoolemia.
PROBLEM

Net “fluid” balance and changes in total body weight reflect changes in volume and water and are NOT useful.

Determining ongoing water and sodium requirements in hospitalized patients remains difficult since sodium concentrations of most body fluid losses are neither known or routinely measured.
Sodium concentrations of body fluids: A systematic literature review

Kaptein EM, Sreeramoju D, Kaptein JS, Kaptein MJ
Clinical Nephrology 2016
Sodium concentrations of body fluids: A systematic literature review

Kaptein EM, Sreeramoju D, Kaptein JS, Kaptein MJ
Clinical Nephrology
October, 2016
Goals

Know specific sodium and water content of
- Body fluid losses, and
- Parenteral and enteral fluids administered

Use this information to

1) replace sodium and water losses of specific body fluids to minimize development of water and volume disorders, and

2) prescribe appropriate therapy for hypo- and hypernatremia, and for hypo- and hypervolemia.
Methods

- Systematic search and literature review of $[\text{Na}^+]$ of body fluids lost in adult humans
  - PubMed database
  - Searching related references
- Reviewed >7,000 titles, abstracts, full-text articles
- Inclusion criteria:
  - Peer-reviewed, extractable sodium concentrations measured in body fluids whose losses are routinely quantified in hospitalized patients.
Results

• 107 full-text articles had extractable sodium concentrations. Overall means and standard deviations (SDs) are shown from 84 studies with raw data or means and SDs.

• Sodium concentrations are fluid-specific and consistent.

• Gastric [Na⁺] with high acid (44+12 mEq/L) vs. low acid (55+13 mEq/L) was statistically but not clinically different.

• Sodium concentrations of diarrhea are mechanism specific.

• Pleural, peritoneal, and edema fluid, are isonatremic to plasma, as are ultrafiltrates of plasma with hemodialysis and peritoneal dialysis, since all are derived from plasma.

• No data were found for wounds or lymph (isonatremic).
Mean sodium concentrations of body fluid losses
# Sodium concentrations of body fluid losses

<table>
<thead>
<tr>
<th>Body Fluid</th>
<th>[Na(^+)] mEq/L</th>
<th>Normal saline (%)</th>
<th>Water (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastric</td>
<td>50</td>
<td>33</td>
<td>67</td>
</tr>
<tr>
<td>Bile</td>
<td>185</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Pancreatic</td>
<td>156</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Small bowel</td>
<td>120</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td><strong>DIARRHEA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cholera</td>
<td>128</td>
<td>85</td>
<td>15</td>
</tr>
<tr>
<td>non-osmotic laxatives</td>
<td>88</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>secretory diarrhea</td>
<td>53</td>
<td>33</td>
<td>67</td>
</tr>
<tr>
<td>sorbitol</td>
<td>63</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>lactulose</td>
<td>26</td>
<td>15</td>
<td>85</td>
</tr>
<tr>
<td>polyethylene glycol</td>
<td>15</td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td>Pleural, peritoneal, dialysate, (wounds)</td>
<td>137</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>
Sodium concentrations of parenteral and enteral solutions

These are pharmaceuticals
CHECK [Na\(^+\)] for each solution
Divide by 154 mEq/L to assess proportion of NS and H\(_2\)O
Proportions for a 70kg male, may vary in illness


- RBCs stay intravascular.
- Isonatremic solutions equilibrate across the ECF (IV plus EV).
- Hypervolemia or hypovolemia reflect total body sodium excess or deficit.
- Free water (FW) equilibrates across both ECF and ICF.
- Free water gain/loss primarily affects serum [Na⁺].
- Hypernatremia / hyponatremia reflects free water deficit or excess.

MJ Kaptein, MD
Background

Proportions for a 70kg male, may vary in illness


- EVEREST trial using a vaptan to block renal ADH effect showed 4.5 liter aquaresis did not change CHF morbidity or mortality, suggesting free water has minimal volume effect.
- Hyponatremia was improved.
- Conclusion: water is not volume
- [Na\(^+\)] of all fluids lost and gained can be divided by [Na\(^+\)] of plasma water (normally 154 mEq/L) to determine what proportion will distribute as isonatremic solution.

MJ Kaptein, MD
<table>
<thead>
<tr>
<th>Body Fluid Lost</th>
<th>[Na⁺] (mEq/L)</th>
<th>NET (mL)</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastric</td>
<td>49.0</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Small bowel</td>
<td>117</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diarrhea - non-osmotic</td>
<td>69.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osmotic diarrhea - sorbitol</td>
<td>63.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osmotic diarrhea - lactulose</td>
<td>26.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osmotic diarrhea - PEG</td>
<td>13.0</td>
<td></td>
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<td></td>
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<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dialysis net ultrafiltrate removed</td>
<td>134</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urine ---- enter [Na⁺] or estimate 77 mEq/L</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Insensible losses</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Parenteral Solutions**

- Net volume given during dialysis: 154
- Packed PRBCs*: 155
- albumin$/$plasma/cryo/IVIG/platelets: 130
- Normal saline: 154
- Plasma-lyte A: 140
- Ringer's lactate: 130
- D5W: 0.0
- NaHCO₃ concentrate (50 mEq per 50 mL): 1000
- 100 mEq NaHCO₃ in 1L D5W: 100

**Enteral Solutions**

- Pulmocare/Nutren 2.0: 57.0
- Fibersource HN: 52.2
- Impact Peptide 1.5/Nutren Pulmonary: 50.9
- Isosource HN: 48.7
- Diabetisource AC: 46.1
- Novasource Renal/Osmolyte/Jevity: 41.1
- Replete Fiber: 38.1
- Ensure/Nepro: 36.8
- Peptamen: 35.8
- Suplena: 34.3
- Vivonex RTF: 30.4
- TwoCal HN: 15.0
- Renalcalc/Benaprotein: 3.4

**Other solutions**

- Enter [Na⁺]
Case 1

• A surgical patient is euvolemic and normonatremic. Serum Creatinine 4.5 mg/dL.

• Outputs:
  – Chest tube and wound drains: 2500 mL/24 hours
  – Stool: 500 mL/24 hours
  – Urine output: 1500 mL/24 hours, Urine [Na+] 60 mEq/L
  – Insensible losses: ~1000 mL/24 hours

• How should these losses be replaced?
<table>
<thead>
<tr>
<th>ENTRIES IN YELLOW AREAS</th>
<th>gain/loss NS (mL)</th>
<th>gain/loss H2O (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ONLY (as positive values) (use &quot;Space, Backspace, Delete&quot; to clear cells)</td>
<td>[Na$^+$] (mEq/L)</td>
<td>T (mL)</td>
</tr>
<tr>
<td>BODY FLUID LOST</td>
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<td></td>
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<td>134</td>
</tr>
<tr>
<td>Urine ---- enter [Na$^+$] or estimated</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>Insensible losses</td>
<td></td>
<td>0.0</td>
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<td>PARENTERAL SOLUTIONS</td>
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<tr>
<td>Plasma-lyte A</td>
<td></td>
<td>140</td>
</tr>
<tr>
<td>Ringer's lactate</td>
<td></td>
<td>130</td>
</tr>
<tr>
<td>D5W</td>
<td></td>
<td>0.0</td>
</tr>
<tr>
<td>NaHCO3 concentrate (50 mEq per 50 mL)</td>
<td></td>
<td>1000</td>
</tr>
<tr>
<td>100 mEq NaHCO3 in 1L D5W</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>TPN ------------------------------ enter [Na$^+$]</td>
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<tr>
<td>ENTERAL SOLUTIONS</td>
<td></td>
<td></td>
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<tr>
<td>Pulmocare/Nutren 2.0</td>
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<td>57.0</td>
</tr>
<tr>
<td>Fibersource HN</td>
<td></td>
<td>52.2</td>
</tr>
<tr>
<td>Impact Peptide1.5/Nutren Pulmonary</td>
<td></td>
<td>50.9</td>
</tr>
</tbody>
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Case 1

• A surgical patient is euvoletic and normonatremic. Serum Creatinine 4.5 mg/dL.

• Outputs:
  – Chest tube and wound drains: 2500 mL/24 hours
  – Stool: 500 mL/24 hours
  – Urine output: 1500 mL/24 hours, Urine [Na+] 60 mEq/L
  – Insensible losses: ~1000 mL/24 hours

• Replacement estimates:
  – NS for all of chest tube and wound drains, ½ of stool output, ½ of urine output
  – D5W for ½ of stool output, ½ of urine output, PLUS insensible losses of 1000 mL
  – Enteral and parenteral sodium and water contributions have to be accounted for

NET: 3000 mL of NS and 2500 mL of water are required to prevent hypovolemia and hypernatremia
Case 2

• An elderly patient with ESRD and peripheral edema develops pulmonary edema after HD/UF. She has Hg of 4.5 g/dL and a STEMI.

• During HD she received 1000 mL of pRBCs and tolerated 2000 mL removal with UF.

What happened?
<table>
<thead>
<tr>
<th>Body Fluid Lost</th>
<th>Gain/loss NS (mL)</th>
<th>Gain/loss H2O (mL)</th>
</tr>
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<tr>
<td>Small bowel</td>
<td>117</td>
<td></td>
</tr>
<tr>
<td>Diarrhea - non-osmotic</td>
<td>69.0</td>
<td></td>
</tr>
<tr>
<td>Osmotic diarrhea - sorbitol</td>
<td>63.0</td>
<td></td>
</tr>
<tr>
<td>Osmotic diarrhea - lactulose</td>
<td>26.0</td>
<td></td>
</tr>
<tr>
<td>Osmotic diarrhea - PEG</td>
<td>13.0</td>
<td></td>
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<tr>
<td>Pleural/peritoneal fluid/wound</td>
<td>137</td>
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</tr>
<tr>
<td>Dialysis net ultrafiltrate removed</td>
<td>134</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000</td>
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</tr>
<tr>
<td></td>
<td>-1740</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-260</td>
<td></td>
</tr>
<tr>
<td>Urine</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insensible losses</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parenteral Solutions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net volume given during dialysis</td>
<td>154</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packed PRBCs*</td>
<td>155</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2803</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Albumin$/plasma/cryo/IVIG/platelets</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Normal saline</td>
<td>154</td>
<td></td>
</tr>
<tr>
<td>Plasma-lyte A</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>Ringer's lactate</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>D5W</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>NaHCO3 concentrate (50 mEq per 50 mL)</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>NaHCO3 in 1L D5W</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPN</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enteral Solutions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmocare/Nutren 2.0</td>
<td>57.0</td>
<td></td>
</tr>
<tr>
<td>Fibersource HN</td>
<td>52.2</td>
<td></td>
</tr>
</tbody>
</table>
Case 2

- An elderly patient with ESRD and peripheral edema develops pulmonary edema after HD/UF. She has Hg of 4.5 g/dL and a STEMI.
- During HD she received 1000 mL of pRBCs and tolerated 2000 mL removal with UF.

What happened?

RESULT: Gained approximately net 1000 mL NS equivalent resulting in pulmonary edema
Case 3

A 58 year old woman with CHF has been on “fluid” restriction and a loop diuretic for 1 week. She still has 3+ edema of both legs. Her serum sodium is 155 mEq/L and she is complaining of thirst.

How should she be treated?

1) Continue fluid restriction
2) Give free water
3) Give NS and free water
4) Give free water, restrict sodium intake and continue the loop diuretic
A 58 year old woman with CHF has been on “fluid” restriction and a loop diuretic for 1 week. She still has 3+ edema of both legs. Her serum sodium is 155 mEq/L and she is complaining of thirst.

How should she be treated?

1) Continue fluid restriction
2) Give free water
3) Give NS and free water
4) Give free water, restrict sodium intake and continue the loop diuretic
Summary

- Knowledge of sodium concentrations of body fluid losses and of parenteral and enteral fluids can be used to optimize volume status and sodium concentration.

- Specific replacement of sodium and water losses should be more effective in preventing and treating imbalance of free water (hyponatremia/hypernatremia) or sodium (hypovolemic/hypervolemic) than replacement protocols based on cumulative “fluid” balance or total body weight changes.
Assessment

• Total body water status
  - use serum [Na⁺]
  - calculate free water deficit and ongoing losses

• Intravascular volume status
  - more difficult
Approach to Hypernatremia

- Assess $S[Na^+]$ for effects of changes in serum protein/lipid concentrations and osmoles

- Calculate free water deficit and ongoing losses and replace appropriately

- Assess ECF and intravascular volume status
  - Increased
  - Decreased
  - Euvolemic
Hospitalized and critically ill patients are frequently not in steady state.

They frequently have mismatch
- between blood pressure and intravascular volume
- between extravascular and intravascular volume

Physical exam, CVP, and PCWP have limited sensitivity and specificity to determine intravascular volume.

We need a practical way to assess intravascular volume status to guide volume therapy.
### Mismatch between intravascular volume and blood pressure
(States in which blood pressure is not primarily determined by intravascular volume)

<table>
<thead>
<tr>
<th>Intravascular volume low</th>
<th>Vasoconstriction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood pressure high</td>
<td>• Stimulants (cocaine, amphetamines), catecholamines (pheochromocytoma, severe stress, delirium tremens)</td>
</tr>
<tr>
<td></td>
<td>• Severe hypothyroidism</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intravascular volume high</th>
<th>Cardiac dysfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood pressure low</td>
<td>• Cardiogenic shock</td>
</tr>
<tr>
<td></td>
<td>• Severe cardiomyopathy, heart failure, valvular heart disease</td>
</tr>
<tr>
<td></td>
<td>Vasodilation</td>
</tr>
<tr>
<td></td>
<td>• Distributive shock + excess volume resuscitation</td>
</tr>
<tr>
<td></td>
<td>• Autonomic neuropathy</td>
</tr>
</tbody>
</table>
### Mismatch between intravascular and extravascular volume

<table>
<thead>
<tr>
<th>Intravascular volume low</th>
<th>Extravascular volume high</th>
<th>Vasodilation and/or “third spacing”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• Distributive shock (sepsis, anaphylaxis)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Hemorrhagic pancreatitis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Crush injury</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delayed re-equilibration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Severe renal failure + diuresis or ultrafiltration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Nephrotic syndrome + diuresis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• End-stage liver disease + diuresis or large-volume paracentesis or ultrafiltration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Heart failure + diuresis or ultrafiltration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intravascular volume high</th>
<th>Extravascular volume not high</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ultrasound of the inferior vena cava collapsibility index for estimation of relative intravascular volume.

\[ \text{IVC CI} = \left( \frac{\text{IVC}_{\text{max}} - \text{IVC}_{\text{min}}}{\text{IVC}_{\text{max}}} \right) \times 100\% \]
Position of US probe for visualization of IVC

Corresponding Ultrasound Image of IVC

K. Killu et al, The ICU Ultrasound Pocketbook 2010
• IVC measured 2 cm from right atrium or at hepatic vein
• Collapsibility Index = (IVCmax – IVCmin) / IVCmax
Intravascular overload
Intravascular depletion
IVC small, collapsing
IVC total collapse
Advantages of bedside IVC US

• Assessment of intravascular volume at the time of clinical evaluation to guide volume administration, diuresis or ultrafiltration
• Multiple assessments of intravascular volume as needed after therapeutic interventions or change in patient status
• No delay between need for assessment and results of IVC US
Principles for treatment of concurrent sodium and water disorders

<table>
<thead>
<tr>
<th>Clinical status</th>
<th>Hyponatremia</th>
<th>Normal Plasma [Na⁺]</th>
<th>Hypernatremia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euvolemia</td>
<td>Replace ongoing sodium losses with isonatremic solution. Loop diuretic to impair urine concentrating ability. Restrict free water. Do not replace water losses.</td>
<td>Replace ongoing sodium and free water losses.</td>
<td>Replace ongoing sodium losses with isonatremic solution. Replace ½ free water deficit, and all ongoing free water losses.</td>
</tr>
</tbody>
</table>
Assessment and Management of Hypernatremia

1) Correct free water deficit and replace ongoing water losses
2) Assess intravascular volume
3) Make the patient euvolemic and replace ongoing volume losses

REQUIRES

1) Knowledge of inputs and outputs that contribute to intravascular volume and total body water
2) Accurate intravascular volume assessment
QUESTIONS?