Acid-Base and Electrolytes

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Objectives

• Identify the 4 major acid-base disturbances, giving typical values for PCO$_2$, pH, and HCO$_3$

• List the most common causes for each of the major acid-base disturbances

• Describe the significance of the “anion gap”

• Differentiate pseudohyponatremia from genuine hyponatremia
Important Fact #1

• Venous Blood Gas (VBG) samples can be used for Acid-Base analysis

  – Arterial Blood Gas (ABG) samples are required only for PO$_2$ and for PaO$_2$

  – VBG samples are acceptable because
    • pH and PCO$_2$ are comparable to ABG samples
    • **exception:** patients in severe circulatory failure (shock)
    • VBG samples can also be used to measure carboxyhemoglobin and methemoglobin
Important Fact #2
(from high school chemistry)

H₂O + CO₂ ⇌ H₂CO₃ ⇌ H⁺ + HCO₃⁻

K = \frac{[H⁺][HCO₃⁻]}{[H₂O][CO₂]} = \frac{[H⁺][HCO₃⁻]}{PCO₂}

[H⁺] = K \frac{PCO₂}{[HCO₃⁻]}
Implications

- $[H^+]$ is inversely proportional to $\text{HCO}_3^-$
  - decreases as $\text{HCO}_3^-$ increases (obvious)

- $[H^+]$ is directly proportional to $\text{PCO}_2$
  - increases (more acid) as $\text{PCO}_2$ increases

- If $\frac{\text{PCO}_2}{\text{HCO}_3^-}$ does not change
  
  $\Rightarrow$ \[H^+\] does not change!

- $\text{pH} = -\log_{10}[H^+]$
  
  if $H^+$ does not change, $\text{pH}$ does not change
Important Fact #3

- Know 3 “normal” values
  - $\text{PCO}_2 = 40$
  - $\text{HCO}_3^- = 24$
  - $\text{H}^+ = 40$ (pH=7.40)

- You can derive $K = 24$

Also:

- 40 nmol/L $[\text{H}^+] = 7.40$
- 30 nmol/L $[\text{H}^+] = 7.50 \Rightarrow +10 \text{ nmol} \sim -0.10 \text{ pH}$
- 50 nmol/L $[\text{H}^+] = 7.30 \Rightarrow -10 \text{ nmol} \sim +0.10 \text{ pH}$
A Normal H+ (pH) Does Not Exclude an Acid-Base Disturbance

• In each of the following cases, the H+ (and pH) are the same:

\[
\frac{PCO_2}{HCO_3^-} = \frac{40}{24} = \frac{10}{6} = \frac{80}{48}
\]

• But only the first case (40/24) is normal; the others (10/6 and 80/48) represent severe disturbances!
pH & Henderson-Hasselbalch

this is an example of a buffer, a topic covered elsewhere in the course

\[
[H^+] = K \frac{PCO_2}{[HCO_3^-]}
\]

\[
\text{pH} = pK + \log_{10} \frac{PCO_2}{[HCO_3^-]} - \frac{[HCO_3^-]}{PCO_2}
\]
Important Fact #4

• The body does not try to maintain H⁺, but it helps to think it does

• In most acid-base disturbances, there is
  – a 1° disturbance, followed by
  – a 2° compensation
    which may take time to develop
    which partially, but never fully,
    corrects the 1° disturbance
This Method for Acid-Base Analysis

• Exploits these four important facts
• Enables you to correctly
  – diagnose ~95% of acid-based disturbances
  – recognize the other ~5% as exceptions
Respiratory Alkalosis

<table>
<thead>
<tr>
<th>Disturbance</th>
<th>PCO₂ (mm Hg)</th>
<th>HCO₃⁻ (mEq/L)</th>
<th>H⁺ (mEq/L)</th>
<th>pH</th>
<th>Common Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory Alkalosis</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↑</td>
<td></td>
</tr>
</tbody>
</table>

Common Causes:
- Sepsis
- Anxiety

Compensation:

<table>
<thead>
<tr>
<th>PCO₂ (40)</th>
<th>HCO₃⁻ (24)</th>
<th>H⁺ (40)</th>
<th>ΔH⁺ (from 40)</th>
<th>Predicted pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>18</td>
<td>24 (20/18)=27</td>
<td>-13</td>
<td>7.53</td>
</tr>
</tbody>
</table>

“normal values” in parentheses
### Acute Respiratory Alkalosis (no renal compensation)

<table>
<thead>
<tr>
<th>Disturbance</th>
<th>PCO₂ (40)</th>
<th>HCO₃⁻ (24)</th>
<th>H⁺ (40)</th>
<th>ΔH⁺ (from 40)</th>
<th>Predicted pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory Alkalosis</td>
<td>20</td>
<td>24</td>
<td>24(20/24)=20</td>
<td>-20</td>
<td>7.60</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>18</td>
<td>24(20/18)=27</td>
<td>-13</td>
<td>7.53</td>
</tr>
</tbody>
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Common Causes:
- Sepsis
- Anxiety

**Notes:**
- no compensation
- compensation
Respiratory Acidosis

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<th>PCO₂</th>
<th>HCO₃⁻</th>
<th>H⁺</th>
<th>pH</th>
<th>Common Causes</th>
</tr>
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<tbody>
<tr>
<td>Respiratory Acidosis</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↓</td>
<td>Chronic Lung Disease, Poor Ventilator Settings</td>
</tr>
</tbody>
</table>

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<tr>
<th>PCO₂</th>
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<th>ΔH⁺ (from 40)</th>
<th>Predicted pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>30</td>
<td>48</td>
<td>+8</td>
<td>7.32</td>
</tr>
</tbody>
</table>
Metabolic Alkalosis

<table>
<thead>
<tr>
<th>Disturbance</th>
<th>PCO₂</th>
<th>HCO₃⁻</th>
<th>H⁺</th>
<th>pH</th>
<th>Common Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic Alkalosis</td>
<td>↑</td>
<td>↑</td>
<td>↓</td>
<td>↑</td>
<td>Vomiting, Diuretic Therapy</td>
</tr>
</tbody>
</table>

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<tr>
<th></th>
<th>PCO₂</th>
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<th>H⁺</th>
<th>ΔH⁺</th>
<th>Predicted pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic Alkalosis</td>
<td>45</td>
<td>32</td>
<td>24(45/32)=34</td>
<td>-6</td>
<td>7.46</td>
</tr>
</tbody>
</table>
Metabolic Acidosis

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<th>Disturbance</th>
<th>PCO₂ (40)</th>
<th>HCO₃⁻ (24)</th>
<th>H⁺ (40)</th>
<th>ΔH⁺ (from 40)</th>
<th>Predicted pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic Acidosis</td>
<td>30</td>
<td>15</td>
<td>24(30/15)=48</td>
<td>+8</td>
<td>7.32</td>
</tr>
</tbody>
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Common Causes:
Diarrhea
Diabetic Ketoacidosis
Summary: Acid-Base Disturbances (with compensation)

PCO$_2$ and HCO$_3^-$ always move in same direction!
- if only one changes $\Rightarrow$ acute disturbance
- if different direction $\Rightarrow$ >1 disturbance!
Anion Gap

measured (but ignored) cations

Mg++ = 1
Ca++ = 3
K+ = 5

Na+ = 140

“anion gap”

unmeasured anions

Acids = 9
Proteins = 16
HCO3- = 24
Cl- = 100
Metabolic Acidosis

$\text{HCO}_3^-$ Decreases from 24 to 12

- Normal anion gap
  - Chloride has increased, replacing lost $\text{HCO}_3$

- Increased anion gap
  - Chloride has not changed
  - A new anion has replaced lost $\text{HCO}_3$

- $\text{HCO}_3 = 12$
- $\text{Cl} = 112$
- $? = 12$
- $\text{HCO}_3 = 12$
- $\text{Cl} = 100$
On to Electrolytes

- $\text{HCO}_3^-$: covered already with acid-base
- $\text{Cl}^-$: covered already with anion gap

that leaves Na and K

specifically --
- pseudohyponatremia
- pre-analytic issues affecting hyperkalemia
Some General Comments

• measurement of Na, K, Cl:
  – ISE (ion selective electrodes)

• measurement of HCO3:
  – usually, spectrophotometry
  – ABG analyzers: calculated from PCO₂ and pH

• focus in this talk will be measurement issues

• medical disorders will not be covered here
  – Hypo- and hyper-natremia are usually disorders of water (SIADH, lack of free access to water)
Pseudohyponatremia

- hyponatremia is a fairly common abnormality.
- pseudohyponatremia is relatively rare, but one needs to rule it out often, so that only the patients with real hyponatremia receive treatment.
ISE Measurement

• Distinguish between
  – Activity (in aqueous phase)
  – Concentration (in total volume)

• Serum is normally 93% water and 7% solids
  – the latter is comprised of proteins and triglycerides

• ISE:
  – electrode is permeable to all but ion of interest
  – difference in concentration of ion across electrode yields voltage difference (Nernst equation)

• Samples typically undergo large dilution for ISE:
  – separate phases disappear
  – one needs to correct result back to original sample
1.0 mL sample, [Na] = 135 mmol/L actually 93% aqueous, contains 126 umol Na measured Na = 126 mmol/L corrected for 93% aqueous $\rightarrow$ 135 mmol/L

1 mL sample, [Na] = 135 mmol/L actually 85% aqueous, contains 115 umol Na measured Na = 115 mmol/L corrected for 93% aqueous $\rightarrow$ 124 mmol/L
1.0 mL sample, [Na] = 135 mmol/L
Direct ISE measures 135 mmol/L

1.0 mL sample, [Na] = 135 mmol/L
Direct ISE measures 135 mmol/L
Final Notes on Pseudohyponatremia

• If you suspect it, you can determine the true [Na] by
  – using a non-dilutional ISE (e.g., ABG analyzer)
  – measuring osmolality (more on this later)

• You can also suspect it when you come across samples with
  – very high total protein (e.g., multiple myeloma)
  – very high triglycerides (e.g., lipemic samples)

• You might consider confirming all very low [Na]

• Whenever a clinician inquires about falsely low [Na],
  you should confirm your results
Hyperkalemia: Is It Real?
Things to Watch Out For (1)

“Hemolysis”: in vitro vs in vivo

– in vitro (real but not present in patient)
  • poor phlebotomy, prolonged storage without centrifugation
  • rejecting such samples may not be the best solution
    – A normal or low K on a hemolyzed sample may be helpful
    – Hgb indices can be used to calculate degree of hemolysis

– in vivo (real and present in the patient)
  • in vivo hemolysis can be life-threatening
    – e.g., acute transfusion reaction, babesiosis
  • importance of hemoglobinuria to distinguish from in vitro
High platelet counts
- serum K is ~0.5 mmol/L higher than plasma K
- difference is proportional to platelet count
- during clotting, platelets release K
- with platelet counts >500K, effect may become clinically significant
- to prove this is the case, analyze a plasma sample (e.g., heparin)

Also reported with high WBC counts (and/or fragile WBCs)
Self-Assessment Question 1

Which of the following represents the typical findings in a respiratory alkalosis?

A) increased PCO$_2$, decreased HCO$_3$
B) increased PCO$_2$, increased HCO$_3$
C) decreased PCO$_2$, decreased HCO$_3$
D) decreases PCO$_2$, increased HCO$_3$
Self-Assessment Question 2

Which of the following is a cause for a normal anion gap metabolic acidosis?

A) diarrhea
B) diabetic ketoacidosis
C) vomiting
D) lactic acidosis
Self-Assessment Question 3

Pseudohyponatremia can be caused by which of the following:

A) high glucose concentrations
B) low platelet counts
C) high concentrations of serum proteins (e.g., multiple myeloma)
D) high concentrations of ADH