Blood Gas Analysis & Acid-Base Disorders

Dr. Badri Paudel

“How can someone have both a metabolic acidosis and a metabolic alkalosis, Robot?" “It does not compute!”

Acid-base balance maintained by

- Buffer systems
- Respiration
- Renal function
  - Maintain tight control within range 7.35 – 7.45

The Carbonic Acid-Bicarbonate Buffer System

Kidney tubules and pH Regulation

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The Central Role of the Carbonic Acid-Bicarbonate Buffer System in the Regulation of Plasma pH

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Acid-Base Disorders

- Respiratory acid base disorders
  - Result when abnormal respiratory function causes rise or fall in CO₂ in ECF
- Metabolic acid-base disorders
  - Generation of organic or fixed acids
  - Anything affecting concentration of bicarbonate ions in ECF

Respiratory Acid-Base Regulation

Do comprehensive history taking and physical examination

- Clinical state = Acid-base disorder
- ...
- ...
- ...
- ...
- ...
- ...
- ...

- Pregnancy = Respiratory alkalosis
- Diuretic use = Metabolic alkalosis
- COPD = Respiratory acidosis

The response to acidosis

The response to alkalosis

Respiratory Acid-Base Regulation

Respiratory Acid-Base Regulation

Respiratory Acid-Base Regulation

Respiratory Acid-Base Regulation
8 Sequential Rules:

- Rule #1
  - primary disorder is an acidosis or an alkalosis
- Rule #2
  - Must know the PaCO₂ and serum HCO₃⁻
- Rule #3
  - Must be able to establish that the available data (pH, PaCO₂, and HCO₃⁻) are consistent

Are the data consistent?

- The Henderson Equation:
  
  \[ [H^+] = 24 \times \frac{PaCO_2}{HCO_3^-} \]

Convert [H⁺] to pH:

- Subtract calculated [H⁺] from 80; this gives the last two digits of a pH beginning with 7
  - example: calculated [H⁺] of 24 converts to pH of (80-24)~7.56
  - example: calculated [H⁺] of 53 converts to pH of (80-53)~7.27
- Refer to table 1 in handout for more precise conversion, or if calculated [H⁺] exceeds 80

Relationship between [H⁺] & pH

<table>
<thead>
<tr>
<th>pH</th>
<th>[H⁺]</th>
<th>pH</th>
<th>[H⁺]</th>
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<tr>
<td>7.80</td>
<td>16</td>
<td>7.30</td>
<td>50</td>
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<td>7.75</td>
<td>18</td>
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<td>7.70</td>
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<td>22</td>
<td>7.15</td>
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<td>7.60</td>
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<td>7.55</td>
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<td>7.45</td>
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<td>7.35</td>
<td>45</td>
<td>6.80</td>
<td>159</td>
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Simple Acid-Base Disorders:

<table>
<thead>
<tr>
<th>Type of Disorder</th>
<th>pH</th>
<th>PaCO₂</th>
<th>HCO₃⁻</th>
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<tbody>
<tr>
<td>Metabolic Acidosis</td>
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<tr>
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8 Sequential Rules:

- Rule #4:
  - must know if compensation is appropriate
  - compensation never overshoots

Must have known "rules of thumb" to interpret appropriateness of compensation

Rules of Compensation:

- Metabolic Acidosis
  - PaCO$_2$ should fall by 1 to 1.5 mm Hg x the fall in plasma [HCO$_3$]

- Metabolic Alkalosis
  - PaCO$_2$ should rise by .25 to 1 mm Hg x the rise in plasma [HCO$_3$]
**Rules of Compensation:**

- **Acute Respiratory Alkalosis**
  - Plasma [HCO$_3^-$] should fall by ~1-3 mmole/l for each 10 mm Hg decrement in PaCO$_2$, usually not to less than 18 mmoles/l
- **Chronic Respiratory Alkalosis**
  - Plasma [HCO$_3^-$] should fall by ~2-5 mmole/l for each 10 mm Hg decrement in PaCO$_2$, usually not to less than 14 mmoles/l

**Compensation formulas for simple acid-base disorders**

<table>
<thead>
<tr>
<th>Acid-base disorder</th>
<th>Compensation formula*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic acidosis</td>
<td>Change in PaCO$_2$ = 1.2 x change in HCO$_3^-$</td>
</tr>
<tr>
<td>Metabolic alkalosis</td>
<td>Change in PaCO$_2$ = 0.6 x change in HCO$_3^-$</td>
</tr>
<tr>
<td>Acute respiratory acidosis</td>
<td>Change in HCO$_3^-$ = 0.1 x change in PaCO$_2$</td>
</tr>
<tr>
<td>Chronic respiratory acidosis</td>
<td>Change in HCO$_3^-$ = 0.35 x change in PaCO$_2$</td>
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**Compensation formulas for simple acid-base disorders contd.**

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* A positive or negative change represents an increase or decrease, respectively, from the normal value of 40 mmHg for PaCO$_2$ or 24 mEq/L for HCO$_3^-$

**Compensation limits**

- **Met. alkalosis** PaCO$_2$ <55
- **Resp. alkalosis** HCO$_3^-$ >12
- **Resp. acidosis** HCO$_3^-$ <30
- **Met. acidosis** PaCO$_2$ >10 mmHg

Acute/Chronic phase only with respiratory disorders.

**Case #1:**

- A 4 year old with chronic renal failure presents to the pedes ER with history of increasing azotemia, weakness, and lethargy. Exam reveals the patient to be modestly hypertensive, and tachypneic. Labs reveal BUN=100, and Creatinine=8.
- How can we tell if an acid-base disorder is present?

**Case #1:**

- Steps 1&2: must know pH, PaCO$_2$, HCO$_3^-$
- pH=7.37, PaCO$_2$=22, and HCO$_3^-$=12
- Step 3: are the available data consistent?

$$[H^+] = 24 \times \frac{PaCO_2}{HCO_3^-}$$
**Case #1:**

- $[\text{H}^+]$=44, equates to pH~7.36; data are thus consistent
- What is the primary disorder?
- _______ Acidosis
- Which variable (PaCO$_2$, HCO$_3^-$) is deranged in a direction consistent with acidosis?
- Primary disorder is Metabolic Acidosis

**Is compensation appropriate?**

- HCO$_3^-$ is decreased by 12 mmoles/l
- PaCO$_2$ should decrease by 1 to 1.5 times the fall in HCO$_3^-$; expect PaCO$_2$ to decrease by 12-18 mm Hg or be between 22-28 mm Hg
- Since PaCO$_2$ is 22 mm Hg, compensation is appropriate, and the data are consistent with a simple metabolic acidosis with respiratory compensation

**8 Sequential Rules:**

- Rule #5:
  - If the data are consistent with a simple disorder, it does not guarantee that a simple disorder exists; need to examine the patient’s history
- Rule #6:
  - When compensatory responses do not lie within the accepted range, by definition a combined disorder exists.

**Case #2:**

- A 15 year old female is brought to the pedes ER in an obtunded state. Per her family, patient history is notable for progressive weakness/ malingering over two months. A recent complete physical demonstrated decreased DTRs symmetrically, without other abnormal findings. Exam shows shallow, tachypneic respiratory effort.

**Case #2: Steps 1, 2, and 3**

- What baseline information is required?
- PaCO$_2$=40 mm Hg, HCO$_3^-$=7, pH=6.88
- Are the data internally consistent?

$$[H^+] = 24 \times \frac{PaCO_2}{HCO_3^-}$$

- [H$^+$]~140, which equates to a pH~6.85, so data are internally consistent
- What is the primary disturbance?
- _______ Acidosis
- Which variable is deranged in a direction which is consistent with acidosis?
- PaCO$_2$ WNL, ergo, Metabolic Acidosis

**Case #2:**

- [H$^+$]~140, which equates to a pH~6.85, so data are internally consistent
- What is the primary disturbance?
- _______ Acidosis
- Which variable is deranged in a direction which is consistent with acidosis?
- PaCO$_2$ WNL, ergo, Metabolic Acidosis
**Is compensation appropriate?**

- Metabolic Acidosis
  - PaCO$_2$ should fall by 1 to 1.5 mm Hg x the fall in plasma [HCO$_3^-$]
- HCO$_3^-$ decreased by 17, so we expect PaCO$_2$ to be decreased by 17-26
- PaCO$_2$ WNL; since PaCO$_2$ inappropriately high, there is a *combined* metabolic acidosis and respiratory acidosis

**Case #3:**

- A 16 year old male with sickle cell anemia, hemochromatosis, & subsequent cirrhosis, presents with a several day history of emesis. At presentation to the pedes ER, he is hypotensive, orthostatic, and confused.

- What acid-base disorders might be anticipated based on the above information?

**Case #3:**

- What baseline information is available?
  - pH=7.55, PaCO$_2$=66
  - Hytes: Na$^+ =166$, K$^+ =3.0$, Cl$^-$=90, HCO$_3^-$=56
- Are the data internally consistent?

$$[H^+] = 24 \times \frac{PaCO_2}{HCO_3^-}$$

**Case #3:**

- What is the primary abnormality?
- "________ Alkalosis"
- PaCO$_2$↑ed, HCO$_3^-$↑ed, therefore........
- Metabolic Alkalosis presumed due to emesis
- Is compensation appropriate?

**Case #3:**

- Metabolic Alkalosis
  - PaCO$_2$ should rise by .25 to 1 mm Hg x the rise in plasma [HCO$_3^-$]
- HCO$_3^-$↑ed by 32; PaCO$_2$ should ↑ by 8-32
- PaCO$_2$↑ed by 26, so compensation appears appropriate
- What about multiple risk factors for lactic acidosis?

**Case #3:**

- 16 yo male with *sickle cell anemia*, hemochromatosis, & subsequent *cirrhosis*, and several days of *emesis*. In the pedes ER, he is *hypotensive, orthostatic*, and *confused*.
- Emesis-loss of H$^+$ (HCl)-metabolic alkalosis
- Orthostatic hypotension-?lactic acidosis
- SCD-decreased O$_2$ delivery-?lactic acidosis
- Cirrhosis-decreased lactate metabolism
Case #3:

- Could there be a concealed lactic acidosis?
- What is the anion gap?
- \(Na^+ - (Cl^- + HCO_3^-)\), normally 12-14
- Anion gap here is 166 - (90 + 56) = 20
- ↑ed anion gap implies metabolic acidosis
- Combined metabolic alkalosis & metabolic acidosis therefore present

8 Sequential Rules:

- Rule #7: Always calculate the anion gap
- Often it is the only sign of an occult metabolic acidosis
  - Acidotic patients partially treated with HCO_3^-
  - Acidotic patients with emesis
- May be the only sign of metabolic acidosis “concealed” by concomitant acid-base disorders

Causes of Anion Gap Acidosis:

- Endogenous acidosis
  - Uremia (uncleared organic acids)
  - Ketoacidosis, Lactic acidosis (increased organic acid production), Rhabdomyolysis
- Exogenous acidosis
  - Ingestions: salicylate, iron; paraldehyde use
- Other Ingestions:
  - Methanol toxicity, Ethylene Glycol toxicity

Anion Gap:

- Based on the concept of electroneutrality; the assumption that the sum of all available cations = the sum of all available anions. Restated as:
  \[Na^+ + \text{Unmeasured Cations (UC)} = Cl^- + HCO_3^- + \text{Unmeasured Anions (UA)}\]; conventionally restated:
  \[Na^+ - (Cl^- + HCO_3^-) = UA - UC = \text{Anion Gap} = 12 \text{ to } 14\]

Occult metabolic acidosis post-Rx:

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Ketoacidosis</th>
<th>Post-RX</th>
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</thead>
<tbody>
<tr>
<td>(Na^+)</td>
<td>140</td>
<td>140</td>
<td>148</td>
</tr>
<tr>
<td>Cl^-</td>
<td>105</td>
<td>105</td>
<td>98</td>
</tr>
<tr>
<td>HCO_3^-</td>
<td>25</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>ketones</td>
<td>0</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>AG</td>
<td>10</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>pH</td>
<td>7.40</td>
<td>7.30</td>
<td>7.40</td>
</tr>
<tr>
<td>PaCO_2</td>
<td>40</td>
<td>31</td>
<td>40</td>
</tr>
</tbody>
</table>
Case #4:

- A 3 year old is brought to the pedes ER at ~3am, stuporous and tachypneic. History is remarkable for his parents having cleaned out their medicine cabinet earlier that day. An ABG and electrolytes have been accidentally drawn by the nurse.

Case #4:

- Available data: pH=7.53, PaCO$_2$=12; Na$^+=140$, K$^+=3.0$, Cl$^-=106$, HCO$_3^-=10$
- Are the data internally consistent?

$$[H^+] = 24 \times \frac{PaCO_2}{HCO_3^-}$$

Case #4:

- Is compensation appropriate?
- Acute respiratory alkalosis
  - Plasma [HCO$_3^-$] should fall by ~1-3 mmole/l for each 10 mm Hg decrement in PaCO$_2$, usually not to less than 18 mmole/l
  - PaCO$_2$ ↓ed by ~30 mm Hg; HCO$_3^-$ should fall by 3-9 mmole/l; HCO$_3^-$ ↓ is too great, so superimposed metabolic acidosis

Case #4:

- [H$^+$]~29, so pH~7.51; data consistent
- What is the primary disturbance?
  - "_________ Alkalosis"
- Which variable (PaCO$_2$, HCO$_3^-$) is deranged in a direction consistent with alkalosis?
  - ↓ed PaCO$_2$, ↓ed HCO$_3^-$; so “Respiratory Alkalosis”

Case #4:

- What is the anion gap?
  - 140 - (106 + 10) = 24; elevated anion gap consistent with metabolic acidosis
- What is the differential diagnosis?
  - Combined (true) respiratory alkalosis and metabolic acidosis seen in sepsis, or salicylate intoxication

Case #5:

- A 5 year old with Bartter’s Syndrome is brought to clinic, where she collapses. She has recently been febrile, but history is otherwise unremarkable. An ABG and serum electrolytes are obtained: pH=6.9, PaCO$_2$=81; Na$^+=142$, K$^+=2.8$, Cl$^-=87$, HCO$_3^-=16$
Case #5:

- Are the data consistent?
  \[
  [H^+] = 24 \times \frac{PaCO_2}{HCO_3^-}
  \]
  - \[H^+\]=122, pH~6.9; data are consistent

Case #5:

- What is the primary disturbance?
  - "________ Acidosis"
- Which variable (PaCO\textsubscript{2}, HCO\textsubscript{3}) is deranged in a direction consistent with acidosis?
  - Both; pick most abnormal value--
    - "Respiratory Acidosis"
- Is compensation appropriate?

Case #5:

- Acute Respiratory Acidosis
  - Plasma [HCO\textsubscript{3}] should rise by ~1mmole/l for each 10 mm Hg increment in PaCO\textsubscript{2}
  - Since HCO\textsubscript{3} is inappropriately depressed, compensation is not appropriate, and there is a concomitant metabolic acidosis as well
  - What is the anion gap?
  - AG=39, confirms metabolic acidosis

Case #5:

- Combined Respiratory Acidosis and Metabolic Acidosis; are there other disorders present?
  - What about the dx of Bartter’s Syndrome?
  - Bartter’s Syndrome characterized by hypokalemic metabolic alkalosis
  - Does this patient have a concealed metabolic alkalosis?

Case #5:

- Anion gap is 39, or 25-27 greater than normal
  - Typically, increases in anion gap correlate with decreases in HCO\textsubscript{3}
  - Assuming a 1:1 relationship, as anion gap increases by 25, HCO\textsubscript{3} should fall by 25
  - Starting HCO\textsubscript{3} must have been 16 + 25 = 41

Case #5:

- Therefore, starting HCO\textsubscript{3} was ~41 mmol/l, consistent with expected chronic metabolic alkalosis. This metabolic alkalosis was “concealed” by the supervening profound metabolic and respiratory acidoses associated with her arrest event.
  - Final diagnosis: Metabolic alkalosis, metabolic acidosis, & respiratory acidosis
8 Sequential Rules: Rule #8

- Rule #8: Mixed Acid-Base Disorders
- Coexistant metabolic acidosis and metabolic alkalosis may occur. Always check the change in the anion gap vs. decrement in bicarbonate to rule out a concealed metabolic disorder.

Case #6:

- A 3 year old toddler is brought to the ER at 3 am after being found unarousable on his bedroom floor, with urinary incontinence. EMS monitoring at the scene revealed sinus bradycardia. One amp of D$_{50}$W and 5 mg of naloxone were given IV without response. Vital signs are stable; respiratory effort is regular, but tachypneic. He is acyanotic.

Case #6:

- Initial lab studies (lytes, ABG & urine tox screen) are sent. Initial dextrostick is $>$800.
- Initial available data are:
  - Na$^+$=154, K=5.6, Cl=106, HCO$_3$=5, BUN=6, creatinine=1.7, glucose=804, PO$_4$=12.3, Ca$^+$=9.8, NH$_4$=160, serum osms=517
  - pH=6.80, PaCO$_2$=33, PaO$_2$=298

Case #6:

- What is the primary disturbance?
  - ______ Acidosis
- Metabolic Acidosis
- Is compensation appropriate?
  - No; PaCO$_2$ level is inappropriately high
- Are other disorders present?
  - Respiratory acidosis (due to evolving coma)

Case #6:

- What is the calculated serum osmolality, and does an osmolal gap exist?
  - $2$(Na) + BUN/2.8 + Glucose/18
  - Calculated=355, Measured=517
- What is the most likely diagnosis?
  - How can this be confirmed definitively?
  - Review of urinalysis
  - Serum ethylene glycol level
Case #6:

Anion gap metabolic acidosis

Methanol, ethylene glycol,
ethyl alcohol, isopropyl alcohol

Osmolar gap

Bicarbonate Rx Controversy

Disadvantages of treating ACUTE metabolic acidosis
- Intracellular lactate production
- Paradoxical intracellular acidosis
- Left shift of O₂ dissociation curve
- Na load
  Treat when pH<7.1

Advantages of treating CHRONIC metabolic acidosis
- Negative nitrogen balance
- Growth retardation
- Progression of renal disease

Osmolar Gap

INCREASED OSMOLAR GAP with ACIDOSIS
- Methanol
- Ethylene glycol
- Renal failure
- Ketoacidosis
- Without Acidosis
- Ethanol, isopropyl alcohol
- TURP (glycerine)
- Mannitol