Acid-Base Disorders

Jai Radhakrishnan, MD, MS
Diagnostic Considerations

- **Data points required:**
  - ABG: pH, pCO$_2$, HCO$_3^-$
  - Chem-7 panel: anion gap

- **Step 1:** Acidemia/alkalemia (Primary disorder)
- **Step 2:** Compensation
- **Step 3:** Anion gap / “delta AG-delta HCO$_3^-$"
Step 1: Primary Disorder

- **Alkalemia**
  - Metabolic alkalosis (high HCO₃)
  - Respiratory alkalosis (low pCO₂)

- **Acidemia**
  - Metabolic acidosis (low HCO₃)
  - Respiratory acidosis (high PCO₂)

<table>
<thead>
<tr>
<th>pH</th>
<th>pCO₂</th>
<th>HCO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.45</td>
<td>46</td>
<td>31</td>
</tr>
<tr>
<td>7.46</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>7.34</td>
<td>28</td>
<td>15</td>
</tr>
<tr>
<td>7.34</td>
<td>56</td>
<td>30</td>
</tr>
</tbody>
</table>
Step 2: Compensation

**LIMITS**

- **Met. alkalosis**
  - $\text{PCO}_2 < 55$

- **Resp. alkalosis**
  - $\text{HCO}_3 > 12$

- **Resp. acidosis**
  - $\text{HCO}_3 < 45$

- **Met. acidosis**
  - $\text{PCO}_2 > 10$ mmHg

Acute/Chronic phase only with respiratory disorders.
Formulae, or, more pain and suffering

- **Metabolic acidosis**
  - Change in PaCO2 = 1.2 x change in HCO3-

- **Metabolic alkalosis**
  - Change in PaCO2 = 0.6 x change in HCO3

- **Acute respiratory acidosis**
  - Change in HCO3- = 0.1 x change in PaCO2

- **Chronic respiratory acidosis**
  - Change in HCO3- = 0.35 x change in PaCO2

- **Acute respiratory alkalosis**
  - Change in HCO3- = 0.2 x change in PaCO2

- **Chronic respiratory alkalosis**
  - Change in HCO3- = 0.5 x change in PaCO2

*A positive or negative change represents an increase or decrease, respectively, from the normal value of 40 mm Hg for PaCO2 or 24 mEq/L for HCO3-.
MedCalc: Acid-Base Calculator

Arterial Blood Gas (ABG) values: | Anion Gap values:
---|---
pH: 7.50 | Sodium (Na⁺): 140 mEq/L
\(P_{CO_2}\): 25 mm Hg | Bicarbonate (HCO₃⁻): 40 mEq/L
HCO₃⁻: 22 mEq/L | Chloride (Cl⁻): 108 mEq/L

Acid-Base Interpretation:

Acute (uncompensated) primary respiratory alkalosis

pH > 7.52 and HCO₃ > 20, for acute (uncompensated)
pH < 7.43 and HCO₃ < 17, for chronic (compensated)

expected pH = 7.57
expected CO₂ = 29

DISCLAIMER: All calculations must be confirmed before use. The authors make no claims of the accuracy of the information contained herein; and these suggested doses are not a substitute for clinical judgement. Neither MedCalc.com nor any other party involved in the preparation or publication of this site shall be liable for any special, consequential, or exemplary damages resulting in whole or part from any users use of or reliance upon this material.

Copyright © 1996-2005 MedCalc.com
Created by: Charles Hu
Created: Monday, October 4, 1999
Last Modified: Saturday, December 9, 2001
Step 3: Anion Gap

- $\text{Na}^+ - (\text{HCO}_3^- + \text{Cl}^-)$
- Normal: $\sim 12$
- *Albumin* contributes 2-4 to the A.G.
- A narrow or positive AG implies excessive unmeasured cations (light chains)
- A.G. $>20$ implies the presence of a wide anion-gap metabolic acidosis
“Delta-Delta” Relationships in Metabolic Acidosis

![Bar chart showing AG and HCO3 levels in different metabolic states.]

- AG Met Acid + Met Alk
- AG Met Acid + NAG Met Acid
Make your ABG diagnoses

- pH 7.28, PaCO₂ 50 mm Hg, HCO₃⁻ 23 mEq/L
  - Acute Respiratory Acidosis

- pH 7.50, PaCO₂ 33 mm Hg, HCO₃⁻ 25 mEq/L
  - Acute primary respiratory alkalosis, with metabolic alkalosis

- pH 7.10, PaCO₂ 38 mm Hg, HCO₃⁻ 14 mEq/L (AG=25)
  - Primary Metabolic Acidosis (+gap), with respiratory acidosis
An 80 year male patient with osteoarthritis was found comatose:

- Physical exam: ecchymoses +
- Labs: 140|105|20 Glucose=80 Ketones=1+
  4.8 |15 |1.5  ABG (RA)=7.45/15/85

- Step 1: Acidemia/alkalemia (Primary disorder)
- Step 2: Compensation
- Step 3: Anion gap

Differential Diagnoses
- Sepsis
- Salicylate
- Cirrhosis
Watch that Delta, Delta!

A 25 year old type 1 diabetic is admitted in shock. After fluid resuscitation, the following labs are drawn:

**ABG**: 7.32/32/100 (RA)

**Chem 7**: 125|80|20  Glucose=875 Ketones=3+

4.9 | 20|1.5

- **Step 1**: Acidemia/alkalemia (Primary disorder)
- **Step 2**: Compensation
- **Step 3**: Anion gap
Watch that Delta, Delta, Delta.
METABOLIC ACIDOSIS

WIDE ANION GAP
(OTHER ACIDS)

- Lactic acid
- Ketoacids
- Sulfuric acid (Renal failure)
- Ingestions
  - Methanol
  - Ethylene glycol

NORMAL ANION GAP
(HCL)

- Renal HCO₃ loss
- GI HCO₃ loss
- HCl consumption
  - TPN
Case: Would you use HCO₃⁻?

A 50 year old male s/p AMI is in code status and CPR is being performed. ABG: 7.10/40/300/10/-14

Would you administer NaHCO₃?
The Bicarbonate Controversy

Disadvantages of treating **ACUTE** metabolic acidosis
- Intracellular lactate production
- Paradoxical intracellular acidosis
- Left shift of $O_2$ dissociation curve
- Na load
  **Treat when pH < 7.1**

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

- Deficit/ liter
- Volume of distribution (1/2 body weight)
- Amount of NaHCO\textsubscript{3} 
  \[=\text{deficit} \times V_d\]

E.g. to increase serum bicarbonate from 2 to 12 meq/liter in a 70 kg male:
- Deficit=10
- \(V_d=35\)
- Amount=350 meq \approx 7 amps
Is this RTA?

NORMAL ANION GAP (HCL)

- Renal HCO$_3$ loss
  - Proximal
  - Distal
  - Hyporenin/Hypo aldo
- GI HCO$_3$ loss
- HCl consumption
  - TPN
A 38-year-old woman was admitted with severe weakness (3rd episode)

PMH: artificial tears for dry eyes

Laboratory
- sodium 141 mEq/L
- potassium 3.0 mEq/L
- carbon dioxide 14 mEq/L
- chloride 114 mEq/L
- BUN/creatinine 14 mg/dL (5.0 mmol/L)/ 0.8 mg/dL (70.7 µmol/L)
- Albumin 4.3
ABG

- pH 7.18
- $P_{CO_2}$ 23 mm Hg
- $P_{O_2}$ 100 mmHg
- sodium 141 mEq/L
- potassium 3.0 mEq/L
- carbon dioxide 14 mEq/L
- chloride 114 mEq/L **AG 13**
- BUN/creatinine 14 mg/dL (5.0 mmol/L)/ 0.8 mg/dL (70.7 µmol/L)
- Albumin 4.3
Reclamation of Bicarbonate

Lumen

PROXIMAL TUBULE

Blood

HCO₃⁻ → Na⁺ → H⁺ → H₂CO₃ → CO₂ → CO₂ → H₂O → H₂O

CA IV

NHE-3

NBC-1

Na⁺ → 3 HCO₃⁻ → 3 Na⁺ → K⁺ → ATP

Acidification of Urine

CORTICAL COLLECTING TUBULE

Lumen

HPO_4^- = NH_3

H^+ - ATPase

H^+, K^+ - ATPase

H_2CO_3

CA II

H_2O

Blood

HCO_3^-

Cl^-

3 Na^+

K^+

The Role of Aldosterone

Reabsorption of Na, Cl, HCO₃

Loss of Proton and K
Total Body K⁺ Excess Decreases Proximal Tubule Acidification and Ammoniagenesis via Intracellular Alkalosis

1. Failed CCD
   K⁺ secretion
2. Total body
   K⁺ excess
3. K⁺ entry
   into proximal
tubule cells

4. Alkalinization of
   prox tubule cell
   by K⁺/H⁺ exchange
Urine pH vs. Plasma bicarbonate in RTA

(Oxford Textbook of Nephrology - Soriano et al, 1967)
Urinary Anion Gap

- Urine (Na+K) – Cl
- Proton is partially excreted as NH$_4$ (unmeasured cation)
- The gap is usually Zero or Negative
- In dRTA the anion gap will remain zero or positive
- In other acidoses, the gap will become more negative.
Urine

- Urine pH 6.5
- Urinary anion gap +4
Positive urine anion gap
\((Cl^- < Na^+ + K^+)\)

Distal renal defect

Plasma \(K^+\)

\(\uparrow\)

Acid load

\(\downarrow\) N

\(\uparrow\)

UpH > 5.5

\(\downarrow\)

Sodium bicarbonate load

\(\downarrow\) U-B \(P_{CO_2}\) < 20 mmHg

Distal RTA

Secretory defect

Look for nephrocalcinosis

\(\uparrow\)

\(\downarrow\)

\(\uparrow\) Hyperkalemic distal RTA

Voltage-dependent defect

Look for \(Na^+\) transport defect

\(\downarrow\)

\(\downarrow\) Type 4 RTA

\(\uparrow\) Look for aldosterone deficiency and renal disease

Nephrocalcinosis
- Schirmer’s test positive
- + antibodies to the Ro/SSA and La/SSB
- Cryocrit +

**DIAGNOSIS:**
- **Sjogren’s syndrome with distal RTA**
## Comparison of Normal Anion-Gap Acidoses

<table>
<thead>
<tr>
<th>Finding</th>
<th>Type 1 RTA</th>
<th>Type 2 RTA</th>
<th>Type 4 RTA</th>
<th>GI Bicarbonate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal anion-gap acidosis</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Minimum urine pH</td>
<td>&gt;5.5</td>
<td>&lt;5.5</td>
<td>&lt;5.5</td>
<td>5 to 6</td>
</tr>
<tr>
<td>% Filtered bicarbonate excreted</td>
<td>&lt;10</td>
<td>&gt;15</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Serum potassium</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Fanconi syndrome</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Stones/nephrocalcinosis</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Urine anion gap</td>
<td>Positive</td>
<td>Negative</td>
<td>Positive</td>
<td>Negative</td>
</tr>
<tr>
<td>Daily bicarbonate replacement needs</td>
<td>&lt;4 mmol/kg</td>
<td>&gt;4 mmol/kg</td>
<td>&lt;4 mmol/kg</td>
<td>Variable</td>
</tr>
</tbody>
</table>
Case

27 year old alcoholic admitted with altered mental status.

Physical exam: Mild hypovolumia

Labs: ABG=7.30/30/100 (RA)

Chem 7: \[ \frac{116}{66} \frac{56}{\triangle = 35} \]

5.0 \[ \frac{15}{2.9} \]

Ketones weak +, glucose=100

Lactate= 4.0

Calculated Osm=156

Measured Osm= 350
Osmolar Gap
(Hyperosmolar Hyponatremia)

- Calculated osmolality = \(2\text{Na} + \frac{\text{BUN}}{2.8} + \frac{\text{Gluc}}{18}\)
- Measured osmolality = (lab)
- OSMOLAR GAP:
  - (measured - calculated)
  - \(< 10\)

**INCREASED OSMOLAR GAP**

**with ACIDOSIS**
- Methanol
- Ethylene glycol
- Renal failure
- Ketoacidosis

**Without Acidosis**
- Ethanol, isopropyl alcohol
- TURP (glycine)
- Mannitol
METABOLIC ALKALOSIS
Metabolic Alkalosis-Pathogenesis

Step 1: GENERATION
- Vomiting
- Renal loss
  - Diuretics
  - Aldosterone
- Addition of HCO₃
  - Post-CPR
  - Multi transfusion
Metabolic Alkalosis-Pathogenesis

Step 2: **MAINTENANCE**
(prevention of kidneys getting rid of HCO$_3^-$)

- Decrease GFR
- Aldosterone
- Hypokalemia
Distal Tubule

- Reabsorption of Na, Cl, HCO3
- Loss of Proton and K
Classification of Metabolic Alkalosis by Treatment

- **SALINE RESPONSIVE**
  - Volume depletion

- **SALINE RESISTANT**
  - Primary hyperaldosteronism
  - Effective volume depletion
    - Cirrhosis/ascites
    - COPD/RHF
Treatment of Saline-Resistant Metabolic Alkalosis

- Spironolactone
- Acetazolamide
- HCl IV
A 60 year old woman with Hep-C cirrhosis is admitted with variceal bleed. After being rapidly transfused 8 U PRBC, she is taken to the OR. Post op labs:

7.53/50/99/40  AG=14

Ascites begins to reaccumulate.
How would you treat her alkalosis?
A 30 year old woman with peptic ulcer disease is admitted with severe protracted vomiting.

Exam: BP 90/50, poor skin turgor

Labs:  
- Na: 123
- K: 80
- Ca: 10
- bicarb: 3.0
- BUN: 35
- creatinine: 1.2

What is the mechanism of her metabolic alkalosis?

What do you expect the urine pH to be?

How would you treat her?