Mixed Acid Base Disorders: It’s Complicated

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ABG Interpretation: A Teaching Tool to Detect Mixed Acid Base Disorders: It’s Complicated...not?

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Objectives

- To present an ABG worksheet that can be used to teach ABG interpretation
- To emphasize that the first step in interpretation is to anticipate the findings based on the clinical scenario
- To emphasize the importance of a step-wise approach to ABG interpretation
  - Identifying the primary disorder
  - Differentiating simple from mixed disorders
- To emphasize that the utility of ABG interpretation is ultimately to understand what is going on in a patient to guide further management
References

• Rose BD, Post TW, Clinical Physiology of Acid Based and Electrolyte Disorders, 5th Ed 2001

• Brenner & Rector’s The Kidney, 9th Ed 2012
Steps in ABG Analysis

1. From the clinical scenario, what acid base disorder do you anticipate?
2. Does the patient have acidemia or alkalemia?
3. What is the primary acid base disorder?
4. Is it a simple or mixed acid base disorder?
   1. Based on the limits of compensation
   2. Based on the Anion Gap and Delta Ratio
5. If hypercapnic, what is the A-a gradient (alveolar-arterial gradient)?
6. State your complete interpretation of the ABG results, including possible etiologies of all disorders.
7. State your plan of care.
**WORKSHEET FOR ABG INTERPRETATION**

**CASE DESCRIPTION**  *Describe the circumstances at the time the ABG sample was taken.*

---

**Expected Acid Base Disorder:**

<table>
<thead>
<tr>
<th>RR (bpm)</th>
<th>FiO₂ (%)</th>
<th>PaO₂ (mmHg)</th>
<th>pH</th>
<th>PaCO₂ (mmHg)</th>
<th>HCO₃⁻ (mEq/L)</th>
<th>Na⁺ (mmol/L)</th>
<th>Cl⁻ (mmol/L)</th>
<th>Alb (g/dL)</th>
<th>Phos (mmol/L)</th>
</tr>
</thead>
</table>

[HCO₃⁻]albumin = \[24 \times \text{PaCO₂} \times 10^{0.867}\]

Normal Gap (NG) = [Alb]² + [Phos] * 1.6 + /- 2
OR = [Na⁺] - [Cl⁻] = [HCO₃⁻]albumin * 2.57(4.0 - [Alb])
OR = [Na⁺] - [Cl⁻] = [HCO₃⁻]albumin * If w/o [Alb] & [Phos]

Anion Gap (AG) = [Na⁺] - [Cl⁻] - [HCO₃⁻]

SBE = 0.9287 * (HCO₃⁻) - 24.4 + 14.83 * (pH - 7.4)

Delta Ratio = (AG - NG) / (24 - [HCO₃⁻])

Est. baseline HCO₃⁻ = [HCO₃⁻]albumin + ΔAG

Expected [Cl⁻] based on [Na⁺] - [Na⁺] / 1.4

**Primary Acid Base Disorder**

- **Metabolic Acidosis**: If [HCO₃⁻] is 10-40 mEq/L, then ePaCO₂ = [HCO₃⁻] + 15 +/- 2, Else, ePaCO₂ = [HCO₃⁻] * 1.5 + 8 +/- 2

- **Metabolic Alkalosis**: If [HCO₃⁻] is 10-40 mEq/L, then ePaCO₂ = [HCO₃⁻] + 15 +/- 2, Else, ePaCO₂ = 0.7([HCO₃⁻] - 24) + 40 +/- 2

**Respiratory Disorder**

If pH if acute = 7.4 + 0.008 * (40 - PaCO₂)

**Respiratory Acidosis**

If [HCO₃⁻] = 24 + 0.4*(PaCO₂ - 40) + /- 1 if acute

If [HCO₃⁻] = 24 + 0.3*(PaCO₂ - 40) + /- 1 if chronic

**Respiratory Alkalosis**

If [HCO₃⁻] = 24 + 0.4*(PaCO₂ - 40) + /- 1 if acute

If [HCO₃⁻] = 24 + 0.3*(PaCO₂ - 40) + /- 1 if chronic

**Simple Acid Base Disorder**

**Mixed Disorder, with**

---

**If hypercapnic:**

- [P₂O₃] = (pH) * 7.13 - [P₂CO₂] / [Q]²
- A-a Gradient = [P₂O₃] - [P₂O₂]
- A-a gradient for age = (Age / 4) + 4

The patient’s A-a gradient is

- **Normal**: -正常
- **Elevated**: -升高

- **Normal** if adequately fed
- **Elevated** if underfed, > 1.0 if overfed

Complete interpretation of the ABG, and its etiology:

---

**PLAN:**

---

References:

- Rose BD, Post TW, Clinical Physiology of Acid Base and Electrolyte Disorders, 5th Ed 2001; Siemens & Rector’s The Kidney, 5th Ed 2012.
From the clinical scenario, what acid base disorder do you anticipate?

CASE DESCRIPTION *Describe the circumstances at the time the ABG sample was taken.

62 year old M/F  Known case of HTN & type 2 DM. At the time the ABG was taken, the patient had just had one seizure episode, noted to have upward gaze & clenched teeth. The patient also passed out from blood in his stools before he lost consciousness and was rushed to the ER. At the ER, he was diaphoretic & he presented with tachycardia. He had elevated BP, was tachypneic, although afebrile. No vomiting. No diarrhea.

Expected Acid Base Disorder: Metabolic acidosis

62 year old male, known diabetic and hypertensive, with CKD
Brought to the E.R. unconscious after a generalized tonic-clonic seizure episode
Hypertensive, tachypneic
No vomiting, no diarrhea
## Respiratory Alkalosis

### Table 2. Possible etiologies of Respiratory Alkalosis

| Hypoxemia                        | • Pneumonia, interstitial fibrosis, emboli, edema  
|                                 | • CHF, hypotension, severe anemia               
|                                 | • High altitude residence                      |
| Pulmonary disease                | • Psychogenic/voluntary hyperventilation       
| Direct stimulation of medullary | • Hepatic failure, gram negative septicemia,   
| respiratory center              |    salicylate intoxication, post-correction of 
|                                 |    metabolic acidosis                          
|                                 | • Pregnancy, luteal phase of menstrual cycle  
|                                 |    (progesterone)                              
|                                 | • Neurologic disorders: Pontine tumor, Cerebrovascular Accident |
Metabolic Acidosis

- **High [H+]**
  - Normal Gap
  - High Gap
  - Can’t excrete [H+]
  - Losing too much [HCO3]
  - High [H+] Load

<table>
<thead>
<tr>
<th>Normal Anion Gap</th>
<th>Cannot excrete H⁺</th>
<th>Cannot make NH₄⁺</th>
<th>Cannot secrete H⁺</th>
<th>Too much HCO₃ Loss</th>
<th>Gastrointestinal</th>
<th>Renal</th>
<th>Uremia, RTA Type IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Anion Gap</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Too much H⁺ load</td>
<td></td>
<td>Diarrhea, fistulas, ureterosigmoidostomy, cholestyramine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RTA Type II</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lactic acidosis, ketoacidosis, uremia, ingestion, inhalation (toluene), hyperalimentation, rhabdomyolysis</td>
</tr>
</tbody>
</table>
# Respiratory Acidosis

## Table 1. Possible etiologies of Respiratory Acidosis

<table>
<thead>
<tr>
<th>Category</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhibition of medullary respiratory center</td>
<td>Opiates, anaesthetics, sedatives, oxygen in chronic hypercapnia, cardiac arrest, central sleep apnea</td>
</tr>
<tr>
<td></td>
<td>Extreme obesity, CNS lesions, metabolic alkalosis</td>
</tr>
<tr>
<td>Muscle weakness</td>
<td>Myasthenia gravis crisis, periodic paralysis, aminoglycosides, Guillain Barre syndrome, severe hypokalemia, severe hypophosphatemia</td>
</tr>
<tr>
<td></td>
<td>Spinal cord injury, polio-myelitis, ALS, multiple sclerosis, myxedema, kyphoscoliosis, extreme obesity</td>
</tr>
<tr>
<td>Upper airway obstruction</td>
<td>Aspiration, obstructive sleep apnea, laryngospasm</td>
</tr>
<tr>
<td>Pulmonary Capillary Gas Exchange Disorder</td>
<td>ARDS, acute cardiogenic pulmonary edema, severe asthma or pneumonia, pneumothorax or hemothorax</td>
</tr>
<tr>
<td></td>
<td>COPD, extreme obesity</td>
</tr>
</tbody>
</table>
# Metabolic Alkalosis

## Table 4. Possible etiologies of Metabolic Alkalosis

<table>
<thead>
<tr>
<th>Etiology</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrointestinal hydrogen loss</td>
<td>Vomiting</td>
</tr>
<tr>
<td></td>
<td>Nasogastric suction, Chloride losing diarrhea, Antacid therapy</td>
</tr>
<tr>
<td>Renal hydrogen loss</td>
<td>Diuretics, mineralocorticoid excess</td>
</tr>
<tr>
<td></td>
<td>Hypokalemia</td>
</tr>
<tr>
<td></td>
<td>Post-chronic hypercapnia, low chloride intake, carbenicillin intake,</td>
</tr>
<tr>
<td></td>
<td>hypercalcemia / milk-alkali, refeeding</td>
</tr>
<tr>
<td>Bicarbonate administration</td>
<td></td>
</tr>
<tr>
<td>Contraction alkalosis</td>
<td>Diuretics, gastric losses, sweat losses in cystic fibrosis</td>
</tr>
</tbody>
</table>
62 year old male, known diabetic and hypertensive, with CKD
Brought to the E.R. unconscious after a generalized tonic-clonic seizure episode
Hypertensive, tachypneic

EXPECTED ACID BASE DISORDERS:
• Respiratory alkalosis
• Metabolic acidosis, high gap
• Metabolic acidosis, normal gap
Does the patient have acidemia or alkalemia? What is the primary acid base disorder?

CASE DESCRIPTION
*Describe the circumstances at the time the ABG sample was taken.

62 year old M/F known case of HTN & type 2 DM. At the time the ABG was taken, the patient had just had one seizure episode, noted to have upward gaze & clenched teeth. The patient also passed out fresh blood in his stools before he lost consciousness and was rushed to the ER. At the ER, he was diaphoretic and presented with tachypnea. He had elevated BP, was tachycardic, although afibrile. No vomiting. No diarrhea.

Expected Acid Base Disorder: diabetic acidosis

<table>
<thead>
<tr>
<th>RR bpm</th>
<th>FiO₂ %</th>
<th>PaO₂ mmHg</th>
<th>pH</th>
<th>PaCO₂ mmHg</th>
<th>HCO₃ mEq/L</th>
<th>Na mmol/L</th>
<th>Cl mmol/L</th>
<th>Alb g/dL</th>
<th>Phos mmol/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>21</td>
<td>130</td>
<td>7.23</td>
<td>34.5</td>
<td>14.7</td>
<td>137</td>
<td>106</td>
<td>4.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>P_aCO_2</td>
<td>[HCO_3]</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Normal Range for</td>
<td>7.4</td>
<td>40</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial Blood Gas</td>
<td>7.37-7.43</td>
<td>36-44</td>
<td>22-26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal Range for</td>
<td>7.35</td>
<td>45</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Venous Blood Gas</td>
<td>7.32-7.36</td>
<td>43-49</td>
<td>23-27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Metabolic Acidosis</strong></td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Metabolic Alkalosis</strong></td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Respiratory Acidosis</strong></td>
<td>↓</td>
<td>↑</td>
<td>↑</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Respiratory Alkalosis</strong></td>
<td>↑</td>
<td>↓</td>
<td>↓</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Is it a simple or mixed acid base disorder? Based on the limits of compensation

\[
e_{\text{PaCO}_2} = 14.7 + 15 = 29.7 \pm 2 \text{ mmHg}
\]
Based on the Limits of Compensation:

- $e\text{PaCO}_2 = 29.7 \pm 2$ mmHg
- Actual $\text{PaCO}_2 = 34.5$ mmHg
- Hence, the patient has a **Mixed Acid Base Disorder**:
  - Metabolic Acidosis
  - Respiratory Acidosis
\[
[H^+] \text{ nmol/L} = 24 \times \frac{\text{PaCO}_2 \text{ mmHg}}{[\text{HCO}_3^-] \text{ mmol/L}}
\]
pH $\rightarrow$ [H$^+$]

- pH = $-\log [H^+]$ in mol/L
- $10^{-pH} = [H^+]$ in mol/L
- Normal pH = 7.4
- $10^{-7.4} = 3.98 \times 10^{-8}$ mol/L
- $10^{-7.4} = 40 \times 10^{-9}$ mol/L
- $10^{-7.4} = 40$ nmol/L
pH \rightarrow [H^+] 

- pH = -\log [H^+] \text{ in mol/L}
- 10^{-pH} = [H^+] \text{ in mol/L}
- Normal pH = 7.4
- 10^{-7.4} = 3.98 \times 10^{-8} \text{ mol/L}
- 10^{-7.4} = 40 \times 10^{-9} \text{ mol/L}
- 10^{-7.4} = 40 \text{ nmol/L}
pH → [H⁺]

- pH = -log [H⁺] in mol/L
- 10⁻ᵖᴴ = [H⁺] in mol/L
- 10⁽⁹⁻ᵖᴴ⁾ = [H⁺] in nmol/L
- Normal pH = 7.4
- 10⁻⁷.⁴ mol/L = 3.98 x 10⁻⁸ mol/L
- 10⁽⁹⁻⁷.⁴⁾ nmol/L = 10¹.⁶ nmol/L
- 10¹.⁶ = 39.8 nmol/L = 40 nmol/L
pH \rightarrow [H^+] 

- pH = -\log [H^+] \text{ in mol/L} 
- 10^{-pH} = [H^+] \text{ in mol/L} 
- 10^{(9 - pH)} = [H^+] \text{ in nmol/L} 
- Normal pH = 7.4 
- 10^{-7.4} \text{ mol/L} = 3.98 \times 10^{-8} \text{ mol/L} 
- 10^{(9 - 7.4)} \text{ nmol/L} = 10^{1.6} \text{ nmol/L} 
- 10^{1.6} = 39.8 \text{ nmol/L} = 40 \text{ nmol/L}
Convert pH to $[H^+]$ nmol/L

$10^{(9 - \text{pH})} = [H^+] \text{ nmol/L}$
Convert pH to \([H^+]\) nmol/L

\[
10^{(9 - 7.23)} = [H^+] \text{ nmol/L} \\
10^{1.77} = [H^+] \text{ nmol/L} \\
10^{1.77} = 58.9 \text{ nmol/L}
\]
\[
[H^+] \text{ nmol/L} = 24 \times \frac{\text{PaCO}_2 \text{ mmHg}}{[\text{HCO}_3^-] \text{ mmol/L}}
\]

\[
[\text{HCO}_3^-] \text{ mmol/L} = 24 \times \frac{\text{PaCO}_2 \text{ mmHg}}{10^{(9 - \text{pH})}} \text{ nmol/L}
\]

*The ABG machine directly measures pH and PaCO\textsubscript{2} but only derives HCO\textsubscript{3}^-.*
\[ [H^+] \text{ nmol/L} = 24 \times \frac{\text{PaCO}_2 \text{ mmHg}}{[\text{HCO}_3^-] \text{ mmol/L}} \]

**Table:**

<table>
<thead>
<tr>
<th>pH</th>
<th>PaCO(_2) mmHg</th>
<th>HCO(_3^-) mEq/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.23</td>
<td>34.5</td>
<td>14.7</td>
</tr>
</tbody>
</table>

\[ [\text{HCO}_3^-] \text{ mmol/L} = 24 \times \frac{34.5 \text{ mmHg}}{58.9 \text{ nmol/L}} \]

\[ = 14.1 \text{ mmol/L} \]
Is it a simple or mixed acid base disorder? Based on the Anion Gap and Delta Ratio

- Anion Gap = Na – (Cl + HCO₃⁻)
- Anion Gap = 137 – 106 – 14.7
- Anion Gap = 16.3 mmol/L
The Anion Gap

Cations

Na

Anion Gap

HCO3

Cl

Anions
The Normal Anion Gap

\[ = 10 - (2 \times (4 - [\text{Alb g/dl}])) - (1.6 \times (1.2 - [\text{Phos mmol/L}])) \]

- Normal Anion Gap
  - Mostly Albumin and Phosphorus
  - Normal Gap = \((2 \times [\text{Alb}] \text{ g/dL}) + (1.6 \times [\text{Phos}] \text{ mmol/L})\)
    - Normal Albumin = 4 g/dL
    - Normal Phosphorus = 1.2 mmol/L
    - Normal Gap = \((2 \times 4) + (1.6 \times 1.2) = 9.92, \text{ or } \sim 10 \text{ mmol/L}\)
  - Normal Gap
    \[ = 10 - (2 \times (4 - [\text{Alb g/dl}])) - (1.6 \times (1.2 - [\text{Phos mmol/L}])) \]
High Gap Metabolic Acidosis

Patient’s Anion Gap = 16.3 mmol/L
Normal Anion Gap = 10 mmol/L

High Anion Gap Metabolic Acidosis
Normal Gap Metabolic Acidosis

Normal Anion Gap (Hyperchloremic) Metabolic Acidosis

Anion Gap
Normal Gap Metabolic Acidosis

Normal [Na] = 140 mmol/L
Normal [Cl] = 100 mmol/L
Normal [Na]:[Cl] = 1.4

[Na]:[Cl] < 1.4 → Hyperchloremia

Hyperchloremic Acidosis
High and Normal Gap Acidosis

Diagram showing the balance of cations and anions in normal and high gap acidosis conditions.

- High and Normal Gap Acidosis
- HAG with NAG (Hyperchloremic) Metabolic Acidosis
High Gap Acidosis with Metabolic Alkalosis
High Gap Acidosis with Normal Gap Acidosis

High Gap Acidosis with Metabolic Alkalosis
Delta Ratio

\[ \text{Delta Ratio} = \text{Patient's Anion Gap} - \text{Patient's Normal Anion Gap} \]
\[ = \Delta AG \]
\[ = \frac{\Delta AG}{\Delta [\text{HCO}_3^-]} \]

- \( \Delta AG > 2 \) = HAG metabolic acidosis with metabolic alkalosis
Delta Ratio = Patient’s Anion Gap – Patient’s Normal Anion Gap
( 24 – [HCO₃⁻])

Delta Ratio = \(\Delta \text{AG} \div \Delta [\text{HCO}_3^-]\)

• <1 = HAG with NAG metabolic acidosis
Delta Ratio = ΔAG / Δ[HCO_3^-]

<table>
<thead>
<tr>
<th>Delta Ratio</th>
<th>Concomitant Metabolic Disorder</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;2</td>
<td>HAG Metabolic Acidosis with Metabolic Alkalosis</td>
</tr>
<tr>
<td>1-2</td>
<td>HAG Metabolic Acidosis only</td>
</tr>
<tr>
<td>&lt;1</td>
<td>HAG with NAG Metabolic Acidosis</td>
</tr>
</tbody>
</table>

**Delta Ratio > 2**

- HAG Metabolic Acidosis with Metabolic Alkalosis

**Delta Ratio < 1**

- HAG Metabolic Acidosis with Metabolic Alkalosis
- HAG with NAG (Hyperchloremic) Metabolic Acidosis
Delta Ratio

\[ \Delta \text{AG} = \Delta [\text{HCO}_3] \]

- \(<1 = \text{HAG with NAG metabolic acidosis}\)

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<thead>
<tr>
<th>RR bpm</th>
<th>FiO(_2) %</th>
<th>PaO(_2) mmHg</th>
<th>pH</th>
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<td></td>
</tr>
</tbody>
</table>

\[
\text{Delta Ratio} = \frac{16.3 - 10}{24 - 14.7} = 0.68
\]

- \(<1 = \text{HAG with NAG metabolic acidosis}\)
Is it a simple or mixed acid base disorder?

Based on the Anion Gap and Delta Ratio

- **Anion Gap** = 16.3 mmol/L  (Normal Anion Gap = 10 mmol/L)
- **[Na]:[Cl]** = 1.29, or <1.4
- **Delta Ratio** = 0.68, or <1
- **PaCO\(_2\)** = 34.5 mmHg  (ePaCO\(_2\) = 29.7+/-2 mmHg)
- **Mixed HAG and NAG Metabolic Acidosis and Respiratory Acidosis**
# Respiratory Acidosis

## Table 1. Possible etiologies of Respiratory Acidosis

<table>
<thead>
<tr>
<th>Condition</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhibition of medullary respiratory center</td>
<td>- Opiates, anaesthetics, sedatives, oxygen in chronic hypercapnia, cardiac arrest, central sleep apnea</td>
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<td>- Extreme obesity, CNS lesions, metabolic alkalosis</td>
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<td>Muscle weakness</td>
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<td>- Spinal cord injury, poliomyelitis, ALS, multiple sclerosis, myxedema, kyphoscoliosis, extreme obesity</td>
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</tr>
<tr>
<td></td>
<td>- COPD, extreme obesity</td>
</tr>
</tbody>
</table>
The A-a gradient

<table>
<thead>
<tr>
<th>If hypercapnic:</th>
<th>The patient’s A-a gradient is</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P(_A)O(_2) = (FiO(_2)) \times 713 - P(_a)CO(_2)/RQ</td>
<td>☐ Normal</td>
<td>☐ Elevated</td>
</tr>
<tr>
<td>A-a Gradient = P(_A)O(_2) - P(_a)O(_2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-a gradient for age = (Age/4) + 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P(_A)O(_2) = 100 mgHg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P(_a)O(_2) = 80-100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^RQ = 0.8-1.0\) if adequately fed
\(<0.8\) if underfed, \(>1.0\) if overfed
If hypercapnic, what is the A-a gradient (alveolar-arterial gradient)?

<table>
<thead>
<tr>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{PAO}_2 \text{ in mmHg} )</td>
</tr>
</tbody>
</table>
| \( \text{FiO}_2 \times 713 - (\text{P}_{\text{aCO}_2}/0.8) \)  
  \( \text{P}_{\text{aO}_2} = \text{FiO}_2 \times (\text{Atm P} - \text{H}_2\text{O P}) - (\text{P}_{\text{aCO}_2}/\text{RQ}) \)  
  \( 713 = 760 \text{ (Atm P at sea level)} - 47 \text{ (H}_2\text{O P at 100% humidity, 37°C)} \)  
  \( 0.8 = \text{Respiratory Quotient on a regular diet with 60% carbohydrate} \) |

| A-a gradient in mmHg |
| \( \text{PAO}_2 - \text{PaO}_2 \) |

| Expected A-a gradient for age |
| \( (\text{Age}/4) + 4 \) |

a. High A-a gradient, consider: V/Q Mismatch, Shunt, Alveolar hypoventilation  
b. Normal A-a gradient, consider: Hypoventilation, Low FiO\text{2} state, Chest wall disorder, Metabolic Alkalosis

\[
\text{PAO}_2 = .40 \times 713 - (34.5/0.8) = 285 - 43 = 242
\]

A-a gradient = 242 - 138 = 104

Expected A-a gradient for age = 62/4 + 4 = 19.5 mmHg

Therefore, the patient’s A-a gradient is elevated.
So far, we know the patient has:

- **Metabolic Acidosis**
  - High Anion Gap (16.3 mmol/L), AND
  - Normal Anion Gap (Na:Cl <1.4, Delta Ratio <1), AND

- **Respiratory Acidosis**
  - Pulmonary Cause
State your complete interpretation of the ABG results, including possible etiologies of all disorders.

<table>
<thead>
<tr>
<th>Acid Base Disorder</th>
<th>Possible Etiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic Acidosis, High Gap</td>
<td>Rhabdomyolysis?</td>
</tr>
<tr>
<td></td>
<td>Lactic Acidosis?</td>
</tr>
<tr>
<td></td>
<td>Uremia?</td>
</tr>
<tr>
<td></td>
<td>Ingestion?</td>
</tr>
<tr>
<td>Metabolic Acidosis, Normal Gap</td>
<td>Uremia?</td>
</tr>
<tr>
<td></td>
<td>RTA Type IV?</td>
</tr>
<tr>
<td>Respiratory Acidosis, Pulmonary</td>
<td>Pneumonia?</td>
</tr>
<tr>
<td></td>
<td>Aspiration?</td>
</tr>
<tr>
<td></td>
<td>Ingestion?</td>
</tr>
<tr>
<td></td>
<td>CNS Lesion?</td>
</tr>
</tbody>
</table>
## State your plan of care.

<table>
<thead>
<tr>
<th>Acid Base Disorder</th>
<th>Possible Etiology</th>
<th>Diagnostic Plan</th>
<th>Therapeutic Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic Acidosis, Normal Gap</td>
<td>Uremia? RTA Type IV?</td>
<td>Creatinine K, Urine pH</td>
<td>Renal Support... Review meds, diet. Address HyperK?</td>
</tr>
<tr>
<td>Respiratory Acidosis, Pulmonary</td>
<td>Pneumonia? Aspiration? Ingestion? CNS Lesion?</td>
<td>Chest Xray Review History Review Neuro Exam, CT scan head</td>
<td>Antibiotic coverage Pulmonary support Neurology support and management</td>
</tr>
</tbody>
</table>
Steps in ABG Analysis

1. From the clinical scenario, what acid base disorder do you anticipate?
2. Does the patient have acidemia or alkalemia?
3. What is the primary acid base disorder?
4. Is it a simple or mixed acid base disorder?
   1. Based on the limits of compensation
   2. Based on the Anion Gap and Delta Ratio
5. If hypercapnic, what is the A-a gradient?
6. State your complete interpretation of the ABG results, including possible etiologies of all disorders.
7. State your plan of care.
• To present an ABG worksheet that can be used to teach ABG interpretation
• To emphasize that the first step in interpretation is to anticipate the findings based on the clinical scenario
• To emphasize the importance of a step-wise approach to ABG interpretation
  – Identifying the primary disorder
  – Differentiating simple from mixed disorders
• To emphasize that the utility of ABG interpretation is ultimately to understand what is going on in a patient to guide further management
**CASE DESCRIPTION**
*Describe the circumstances at the time the ABG sample was taken.*

______ year old M / F

---

**Expected Acid Base Disorder:**

<table>
<thead>
<tr>
<th>RR</th>
<th>FiO2</th>
<th>PaO2 mmHg</th>
<th>pH</th>
<th>PaCO2 mmHg</th>
<th>HCO3 mEq/L</th>
<th>Na mmol/L</th>
<th>Cl mmol/L</th>
<th>Alb g/dl</th>
<th>Phos mmol/L</th>
</tr>
</thead>
</table>

\[
\text{[HCO}_3\text{]}_{\text{calculated}} = 24 \times \text{PaCO}_2 / 10^{4/2} \\
\text{Normal Gap (NG)} = |\text{[Al]}| - 2 + |\text{[Phos]}| \\
\text{OR} = |\text{[Na]}| - |\text{[Cl]}| - |\text{[HCO}_3\text{]}| - 2.5\times|\text{[HCO}_3\text{]}| - |\text{[Al]}| \\
\text{Anion Gap (AG)} = |\text{[Na]}| - |\text{[Cl]}| - |\text{[HCO}_3\text{]}| \\
\text{SBE} = 0.9287 \times ([\text{HCO}_3] - 24.4 + 14.83 \times (\text{pH} - 7.4)) \\
\text{Delta Ratio} = (\text{AG} - \text{NG})/(24 - [\text{HCO}_3]) \\
\text{Est. baseline } \text{HCO}_3 = \text{[HCO}_3\text{]}_{\text{calculated}} + \Delta \text{AG} \\
\text{Expected [Cl] based on } [\text{Na}] = [\text{Na}]/1.4
\]

**Primary Acid Base Disorder**

<table>
<thead>
<tr>
<th>Metabolic Acidosis</th>
<th>Expected Compensatory Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>If [HCO3] is 10-40 mEq/L, then ePaCO2 = [HCO3] + 15 +/- 2, Else ePaCO2 = [HCO3] + 15 +/- 2, Else</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metabolic Alkalosis</th>
<th>Expected Compensatory Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>If [HCO3] is 10-40 mEq/L, then ePaCO2 = [HCO3] + 15 +/- 2, Else ePaCO2 = 0.7*[HCO3]-24 + 40 +/- 2</td>
<td></td>
</tr>
</tbody>
</table>

**Respiratory Disorder**

<table>
<thead>
<tr>
<th>Respiratory Acidosis</th>
<th>Expected Compensatory Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>e[HCO3] = 24 + 0.1*(Pco2 - 40) +/- 1 if acute e[HCO3] = 24 + 0.3*(Pco2 - 40) +/- 1 if chronic</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Respiratory Alkalosis</th>
<th>Expected Compensatory Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>e[HCO3] = 24 + 0.2*(Pco2 - 40) +/- 1 if chronic e[HCO3] = 24 + 0.4*(Pco2 - 40) +/- 1 if chronic</td>
<td></td>
</tr>
</tbody>
</table>

**Simple Acid Base Disorder**

**Mixed Disorder, with**

**If hypercapnic:**

\[
P_aO_2 = (P_FIO2) * 713 - P_CO2/RQ^{*} = \]  
\[
A-a Gradient = PaO2 - FIO2 = \]  
\[
A-a gradient for age = (Age/4) * 4 = \]

The patient’s A-a gradient is

<table>
<thead>
<tr>
<th>Normal</th>
<th>Elevated</th>
</tr>
</thead>
<tbody>
<tr>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

*RQ = 0.8-1.0 if adequately fed <0.8 if underfed, >1.0 if overfed

Complete interpretation of the ABG, and its etiology:

---

**PLAN:**

---
THANK YOU!

Expected Acid Base Disorder:

<table>
<thead>
<tr>
<th>RR (bpm)</th>
<th>FiO₂ (%)</th>
<th>PaO₂ (mmHg)</th>
<th>pH</th>
<th>PaCO₂ (mmHg)</th>
<th>HCO₃ (mEq/L)</th>
<th>Na (mmol/L)</th>
<th>Cl (mmol/L)</th>
<th>Alb (g/dL)</th>
<th>Phos (mmol/L)</th>
</tr>
</thead>
</table>

\[
[HCO₃]_{calculated} = 24 \times \text{PaCO₂} / 10^{0.525}
\]

Normal Gap (NG) = \([\text{Alb}]^2 + [\text{Phos}]^1.6 + /- 2\)

OR = \([\text{Na}]-[\text{Cl}] - [\text{HCO₃}]_{calculated} - 2.5 \times (4.6 - \text{Alb})\)

OR = \([\text{Na}]-[\text{Cl}] - [\text{HCO₃}]_{calculated} - \text{if w/o [Alb] & [Phos]}\)

Anion Gap (AG) = \([\text{Na}]-[\text{Cl}] - [\text{HCO₃}]_{calculated}\)

SBE = 0.9287 \times ([HCO₃] - 24 + 14.83 \times [pH - 7.4])

Delta Ratio = \((\text{AG} - \text{NG}) / (24 - [\text{HCO₃}])\)

Est. baseline [HCO₃] = \([\text{HCO₃}]_{calculated} + \Delta \text{AG}\)

Expected [Cl] based on \([\text{Na}] - [\text{Cl}] / 1.4\)

Primary Acid Base Disorder

<table>
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<tr>
<th>Metabolic Acidosis</th>
<th>Expected Compensatory Response</th>
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<tbody>
<tr>
<td>If [HCO₃] is 10-40 mEq/L, then ePaCO₂ = [HCO₃] + 15 +/− 2, Else.</td>
<td>ePaCO₂</td>
</tr>
<tr>
<td>If [HCO₃] is 10-40 mEq/L, then ePaCO₂ = [HCO₃] + 15 +/− 2, Else.</td>
<td>ePaCO₂</td>
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</tbody>
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Respiratory Disorder

pH if acute = 7.4 + 0.008 \times (40 - PaCO₂)

pH if acute = 7.4 + 0.008 \times (40 - PaCO₂)

If hypercapnic:

\[
\text{PaO₂} = (\text{FiO₂} \times 713 - \text{PaCO₂} / RQ^-1)
\]

\[
\text{A-a Gradient} = \text{PaO₂} - \text{FiO₂} \\
\text{A-a gradient for age} = (\text{Age} / 4) + 4
\]

The patient's A-a gradient is \(\text{RQ} = 0.8-1.0\) if adequately fed

\(<0.8\) if underfed, \(>1.0\) if overfed

Complete interpretation of the ABG, and its etiology:

<table>
<thead>
<tr>
<th>PLAN:</th>
</tr>
</thead>
<tbody>
<tr>
<td>-------</td>
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<tr>
<td>-------</td>
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<td>-------</td>
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<tr>
<td>-------</td>
</tr>
</tbody>
</table>

References:
For Primary Respiratory Disorders:

• The pH changes by 0.008 units for every 1 mmHg change in PaCO₂

• Given PaCO₂:
  \[ \text{expected } pH = 7.4 + 0.008 \times (40 - \text{PaCO}_2) \]

• If \( pH = \text{exp } pH \), then the respiratory disorder is a simple acute respiratory disorder.

• If \( pH <> \text{e } pH \), then the respiratory disorder is not acute and possibly not simple.