Arterial Blood Gas Interpretation

Self-Learning Module
Introduction

Arterial blood gas (ABG) results enable nurses to assess and monitor a patient's oxygenation and ventilation status. Correct interpretation by the nurse is essential for quality and safe patient care. This self-learning module will provide an overview of the components to arterial blood gases, a step-by-step mechanism to interpret results and an opportunity to practice blood gas analysis.

Instructions

Review the article and supportive information provided in this self-learning module. After a thorough review, complete the practice blood gas results at the end of the module.

Acid-Base Balance

Acid-base balance is a reflection of the pH level. The pH is the measurement of the acidity or alkalinity of any fluid and is recorded on a scale from 1 (very acidic) to 14 (very alkalotic). A fluid with a pH of 7 (water) is considered neutral.

The pH of blood falls within a narrow range of 7.35 – 7.45. This range is essential for the body systems to function properly. Mechanisms are in place to ensure that a constant state of acid-base equilibrium exists within the blood at all times. Significant alterations from this range can interfere with cellular functioning and ultimately, if uncorrected, death. Therefore, it is essential that nurses recognize when a patient is not able to maintain this delicate balance, and intervene appropriately.

Oxygenation

Determination of oxygenation should be included in any physical assessment. When assessing ventilation status, it is important to look at the PaO₂ and SaO₂ levels.

- The PaO₂ represents the amount of oxygen dissolved in the blood. A normal value for arterial blood gas 80-100mmHg
- The SaO₂ represents the amount of oxygen bound to hemoglobin. A normal SaO₂ value for arterial blood gas is 95-100%

It is also important to note that assessment of ABGs includes determining the need for and treatment of pulmonary disease and determining acid-base balance in a patient with heart failure, renal failure, uncontrolled diabetes, a sleep disorder, severe infection, and drug overdose (Youngerman-Cole, 2006).
Buffers

The body has two buffer systems in place to maintain the pH level within its narrow range: The respiratory and renal systems.

**Respiratory buffer** – A normal by-product of cellular metabolism is carbon dioxide \((\text{CO}_2)\). \(\text{CO}_2\) is carried in the blood to the lungs, where the excess combines with water to form carbonic acid. The pH of the blood will change according to the amount of carbonic acid present. **The more carbonic acid present in the blood, the lower (more acidic) the pH level will become.** In response, the lungs will either increase or decrease the rate and depth of ventilation until balance is restored. This process occurs within 1 – 3 minutes in a healthy individual.

**Renal buffer** – The renal system acts as a buffer through its ability to excrete or retain bicarbonate \((\text{HCO}_3^-)\). Bicarbonate is considered alkaline although takes a little longer than the respiratory system to respond, is considered a powerful buffer. **As the blood pH decreases (more acidic), the kidneys will compensate by retaining HCO_3^- and likewise, as the blood pH increases, the kidneys excrete HCO_3^-**.

When the lungs and kidneys are working together, they are able to maintain the pH of the blood within its narrow range of 7.35 – 7.45. It’s when one or both of these buffer systems fail that the patient’s status is compromised reflecting in abnormal arterial blood gases. The earlier such compromise is detected, the more likely an appropriate intervention can successfully restore equilibrium.

**Acid-Base Imbalance**

Before reviewing acid-base disorders, it is important to know the normal lab values for each component:

<table>
<thead>
<tr>
<th>Lab value</th>
<th>Definition</th>
<th>Normal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Measurement of acidity or alkalinity</td>
<td>7.35 – 7.45</td>
</tr>
<tr>
<td>(\text{PaO}_2)</td>
<td>Amount of oxygen dissolved in arterial blood</td>
<td>80 – 100 mm Hg</td>
</tr>
<tr>
<td>(\text{SaO}_2)</td>
<td>Arterial oxygen saturation</td>
<td>95 – 100%</td>
</tr>
<tr>
<td>(\text{PaCO}_2)</td>
<td>Amount of carbon dioxide dissolved in arterial blood</td>
<td>35 – 45 mm Hg</td>
</tr>
<tr>
<td>(\text{HCO}_3^-)</td>
<td>Amount of bicarbonate in the bloodstream</td>
<td>22 – 26 mEq/liter</td>
</tr>
</tbody>
</table>

**Respiratory Acidosis** – Respiratory acidosis is defined as a **pH less than 7.35 with a \(\text{PaCO}_2\) greater than 45 mm HG**. Acidosis is primarily caused by an accumulation of \(\text{CO}_2\) through the production of carbonic acid. Any condition that results in hypoventilation can cause respiratory acidosis by preventing the exhalation of \(\text{CO}_2\). These conditions include:
- Central nervous system depression related to trauma, narcotics, sedatives or anesthesia
- Impaired respiratory muscle function related to spinal cord injury, neuromuscular disease or blocking agents
- Pulmonary disorders such as atelectasis, pneumonia, pneumothorax, embolus, pulmonary edema or obstruction
- Hypoventilation related to pain, chest wall injury or abdominal distention

If CO₂ levels become extremely high, drowsiness and unresponsiveness may be noted. Increasing ventilation and treatment of the underlying cause will correct respiratory acidosis. Although patients with hypoventilation often require supplemental oxygen, it is important to remember that oxygen alone will not completely correct the problem.

**Respiratory Alkalosis** – Respiratory alkalosis is defined as a pH greater than 7.45 with a PaCO₂ less than 35 mm Hg. Any condition that causes hyperventilation can result in respiratory alkalosis. These conditions include:
- Psychological responses such as anxiety, severe stress or fear
- Unresolved pain
- Increased metabolic demands such as fever, sepsis, or pregnancy
- Central nervous system lesions

Signs and symptoms include light-headedness, numbness and tingling, confusion, inability to concentrate, blurred vision, dysrhythmias, palpitations, and titanic spasms of the arms and legs. Treatment centers on resolving the underlying problem.

**Metabolic Acidosis** – Metabolic acidosis is defined as a pH of less than 7.35 and a bicarbonate level of less than 22mEq/L. It is caused by either a deficit of base in the bloodstream or an excess of acids, other than CO₂. Causes of metabolic acidosis include:
- Renal failure
- Diabetic Ketoacidosis
- Anaerobic metabolism
- Starvation
- Salicylate intoxication

Symptoms of metabolic acidosis include headache, confusion, restlessness, lethargy, Kussmaul respirations, warm-flushed skin, and nausea and vomiting. Treatment is dependant upon the cause. Hypoxemia is typically present and can compromise tissue perfusion.

**Metabolic Alkalosis** – Metabolic alkalosis is defined as a pH of greater than 7.45 and a bicarbonate level greater than 26mEq/L. An excess of base or a loss of acid within the body can lead to metabolic alkalosis. Causes include:
- Protracted vomiting
- Aggressive gastric suctioning
- Excess administration of diuretics
Symptoms include dizziness, lethargy, disorientation, weakness, muscle twitching, nausea, vomiting, respiratory depression, seizures and coma. Metabolic alkalosis is difficult to treat but can respond to medications that excrete bicarbonate. In severe cases, IV administration of acids may be used.

**Interpreting ABG results**

Interpretation of ABG results can initially appear daunting. However, by following a step-by-step process, you can successfully interpret blood gas results.

**Initial consideration: Determine state of oxygenation**
The state of oxygenation should always be included in the assessment of respiratory function. It is important to include oxygenation status when discussing acid-base balance results.

An oxygen level less than normal is considered hypoxia.

| pO₂ > 80 | Normal |
| pO₂ <80 | Hypoxia |

**Step 1: Examine the pH level**
A pH greater than 7.45 is considered alkalotic. If it is less than 7.35 it is considered acidotic.

| pH <7.35 | Acidotic |
| pH >7.45 | Alkalotic |

**Step 2: Examine the PaCO₂ level**
To determine this, examine the CO₂ level.
1. The CO₂ level and pH have an inverse relationship in respiratory imbalance.
2. If the CO₂ is elevated and the pH is less than 7.35, it is respiratory acidosis.
3. If the CO₂ is low and the pH is greater than 7.45, it is respiratory alkalosis.
4. If the CO₂ is within normal range, the imbalance is not caused from a respiratory issue.

**Step 3: Examine the HCO₃ level**
In metabolic balance disorders, the pH of the blood and the level of HCO₃ will be moving in the same direction.
1. If the pH is elevated above 7.45, the HCO₃ will also be elevated above 26mm/Hg.
2. If the pH is less than 7.35, the HCO₃ will also be less than normal or less than 22mm/Hg.
Putting it all together:

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>PaCO₂</th>
<th>HCO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory Acidosis</td>
<td>↓</td>
<td>↑</td>
<td>Normal</td>
</tr>
<tr>
<td>Respiratory Alkalosis</td>
<td>↑</td>
<td>↓</td>
<td>Normal</td>
</tr>
<tr>
<td>Metabolic Acidosis</td>
<td>↓</td>
<td>Normal</td>
<td>↓</td>
</tr>
<tr>
<td>Metabolic Alkalosis</td>
<td>↑</td>
<td>Normal</td>
<td>↑</td>
</tr>
</tbody>
</table>

Examples

A 64-year old patient is admitted with an exacerbation of COPD. Her arterial blood gas results are as follows:

pH       7.23
PaCO₂    56
HCO₃     24

Follow the steps:
Step 1: *Examine the pH level.* The pH is below normal therefore, we know it is acidosis.
Step 2: *Examine the PaCO₂ level.* The PaCO₂ is high which is in the opposite direction of the pH. Therefore, we know it is a respiratory issue.
Step 3: *Examine the HCO₃ level:* The HCO₃ level is normal. This confirms that it is a respiratory imbalance.

*Interpretation = Respiratory Acidosis*

A 24-year patient is admitted with Diabetic Ketoacidosis. His initial arterial blood gas results are as follows:

pH       7.19
PaCO₂    44
HCO₃     18

Follow the steps:
Step 1: *Examine the pH level.* The pH is below normal therefore, we know it is acidosis.
Step 2: *Examine the PaCO₂ level.* The PaCO₂ is within normal range. Therefore, this is not a respiratory disorder.
Step 3: *Examine the HCO₃ level.* The HCO₃ level is below normal and follows the same direction as the pH. This confirms that it is a metabolic disorder.

*Interpretation = Metabolic Acidosis*

A 72-year old patient is admitted to your unit with a bowel obstruction. He has complained of vomiting for the last several days. His arterial blood gas results are as follows:
Follow the steps:
Step 1: *Examine the pH level.* The pH is above normal therefore, we know this is an alkalotic state.
Step 2: *Examine the PaCO₂ level.* The PaCO₂ is within normal range. Therefore, this is not a respiratory issue.
Step 3: *Examine the HCO₃ level.* The HCO₃ is above normal. This confirms that this is a metabolic disorder.

*Interpretation = Metabolic Alkalosis*

A 32-year old patient with a history of chronic anxiety is breathing rapidly and complaining of numbness and tingling in his hands and around his mouth. His arterial blood gases are as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.51</td>
</tr>
<tr>
<td>PaCO₂</td>
<td>28</td>
</tr>
<tr>
<td>HCO₃</td>
<td>22</td>
</tr>
</tbody>
</table>

Follow the steps:
Step 1: *Examine the pH level.* The pH is above normal. Therefore, we know this is an alkalotic state.
Step 2: *Examine the PaCO₂ level.* The PaCO₂ is below normal and moving in the opposite direction of the pH. Therefore, we know this is a respiratory disorder.
Step 3: *Examine the HCO₃ level.* The HCO₃ is within normal range. This confirms that this is a respiratory disorder.

*Interpretation = Respiratory Alkalosis*

**Compensation**

Earlier in this module, we mentioned that the body has buffer systems (respiratory and renal) that are always trying to maintain a constant state of balance or equilibrium. Whenever there is an imbalance, these buffer systems step in to “rebalance” the blood and return it to its normal state. This is called compensation.

A patient can be uncompensated (as in the examples above), partially compensated, or fully compensated. The key to determining whether a patient is partially or fully compensated is by looking at the pH level. If the pH is still within normal range, it is fully compensated. If not, then it is either partially compensated or uncompensated.
In order to identify patients that are partially compensated, let’s go back to the 3-step process.

**Step 1:** *Examine the pH level.* Normal is within 7.35 – 7.45 in a fully compensated patient.

**Step 2:** *Examine the PaCO₂ level.* In an uncompensated state, the pH is abnormal. The pH and the CO₂ move in the opposite direction when the imbalance is caused by a respiratory disorder. As the pH moves away from the normal range, the renal system will attempt to compensate by retaining or excreting HCO₃⁻ thereby shifting the pH towards equilibrium.

**Step 3:** *Examine the HCO₃ level.* In cases involving metabolic acidosis or alkalosis, we find the respiratory buffer system kicking in by adjusting the rate of ventilation – either hyperventilation to “blow off” CO₂ when in an acidotic state or by hypoventilation when in an alkalotic state.

Note: The buffer system will never overcompensate!

For example, a patient is in metabolic acidosis with a pH of 7.28, PaCO₂ of 40 and an HCO₃ of 18. This is an uncompensated state (note the abnormal pH).

The respiratory buffer system will then cause hyperventilation resulting in the following results: pH 7.33, PaCO₂ of 36 and an HCO₃ of 18. This is a partially compensated state. Note how the pH is still outside of normal range but you can see how the PaCO₂ level is dropping to create a more alkalotic environment which will compensate for the metabolic acidosis.

As the respiratory buffer system continues to move towards equilibrium, you see the following results: pH 7.36, PaCO₂ of 35 and an HCO₃ level of 20. This patient has fully compensated metabolic acidosis. In this case, the pH will only go as high as 7.40 by staying within range for normal acidic.

The pH level is what determines whether it is partially or fully compensated.

<table>
<thead>
<tr>
<th>Fully Compensated</th>
<th>pH</th>
<th>PaCO₂</th>
<th>HCO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory Acidosis</td>
<td>Normal, &lt; 7.40</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Respiratory Alkalosis</td>
<td>Normal, &gt; 7.40</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Metabolic Acidosis</td>
<td>Normal, &lt; 7.40</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Metabolic Alkalosis</td>
<td>Normal, &gt; 7.40</td>
<td>↑</td>
<td>↑</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Partially Compensated</th>
<th>pH</th>
<th>PaCO₂</th>
<th>HCO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory Acidosis</td>
<td>↓</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Respiratory Alkalosis</td>
<td>↑</td>
<td>↓</td>
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</tr>
<tr>
<td>Metabolic Acidosis</td>
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<tr>
<td>Metabolic Alkalosis</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
</tbody>
</table>

**Example**
A 47-year old kidney dialysis patient is admitted to the hospital. He has missed his last 2 dialysis treatments. His blood gas results are as follows:

\[
\begin{align*}
\text{pH} & : 7.32 \\
\text{PaCO}_2 & : 34 \\
\text{HCO}_3 & : 18
\end{align*}
\]

Step 1: *Examine the pH level.* It is low, therefore it is acidosis.

Step 2: *Examine the PaCO\(_2\) level.* It is low. The pH and PaCO\(_2\) are moving in the same direction; therefore this is a metabolic disorder. In this case, the lungs are now attempting to compensate by “blowing off” excessive CO\(_2\), and therefore increasing the pH.

Step 3: *Examine the HCO\(_3\) level.* It is low. This confirms that it is a metabolic issue.

**Interpretation = metabolic acidosis partially compensated.**

You know it is *partially compensated* because there is a shift in the PaCO\(_2\) (a decrease) to adjust for the acidotic state created by the metabolic state.

**Important concept:**
The only 2 ways an *acidotic* state can exist is from either too much pCO\(_2\) or too little HCO\(_3\).
The only 2 ways an *alkalotic* state can exist is from either too little pCO\(_2\) or too much HCO\(_3\).
ABG Interpretation

Interpret the following blood gas results. Circle the correct answer. There is only one correct answer for each.

1. $\text{pH } 7.26$ \hspace{0.5cm} $\text{PaCO}_2 \ 52$ \hspace{0.5cm} $\text{HCO}_3 \ 26$
   a. Metabolic acidosis
   b. Metabolic alkalosis
   c. Respiratory alkalosis
   d. Respiratory acidosis

2. $\text{pH } 7.46$ \hspace{0.5cm} $\text{PaCO}_2 \ 33$ \hspace{0.5cm} $\text{HCO}_3 \ 26$
   a. Respiratory alkalosis
   b. Respiratory acidosis
   c. Metabolic alkalosis
   d. Metabolic acidosis

3. $\text{pH } 7.31$ \hspace{0.5cm} $\text{PaCO}_2 \ 60$ \hspace{0.5cm} $\text{HCO}_3 \ 22$
   a. Respiratory acidosis
   b. Respiratory alkalosis
   c. Metabolic acidosis
   d. Metabolic alkalosis

4. $\text{pH } 7.48$ \hspace{0.5cm} $\text{PaCO}_2 \ 41$ \hspace{0.5cm} $\text{HCO}_3 \ 31$
   a. Metabolic acidosis – uncompensated
   b. Normal
   c. Respiratory alkalosis – full compensation
   d. Metabolic alkalosis – uncompensated

5. $\text{pH } 7.39$ \hspace{0.5cm} $\text{PaCO}_2 \ 55$ \hspace{0.5cm} $\text{HCO}_3 \ 28$
   a. Normal
   b. Respiratory acidosis – fully compensated
   c. Respiratory acidosis – partially compensated
   d. Respiratory acidosis – uncompensated

6. $\text{pH } 7.19$ \hspace{0.5cm} $\text{PaCO}_2 \ 68$ \hspace{0.5cm} $\text{HCO}_3 \ 26$
   a. Metabolic acidosis – uncompensated
b. Metabolic acidosis – fully compensated  
c. Respiratory acidosis – uncompensated  
d. Respiratory acidosis – fully compensated

7. pH 7.32  
   \( \text{PaCO}_2 \ 48 \)  
   \( \text{HCO}_3 \ 36 \)
   a. Respiratory acidosis – uncompensated  
   b. Metabolic acidosis – partially compensated  
   c. Respiratory acidosis – partially compensated  
   d. Metabolic acidosis – fully compensated

8. pH 7.36  
   \( \text{PaCO}_2 \ 30 \)  
   \( \text{HCO}_3 \ 14 \)
   a. Respiratory acidosis – partially compensated  
   b. Respiratory alkalosis – uncompensated  
   c. Metabolic acidosis – fully compensated  
   d. Metabolic alkalosis – uncompensated

9. pH 7.48  
   \( \text{PaCO}_2 \ 50 \)  
   \( \text{HCO}_3 \ 18 \)
   a. Metabolic alkalosis – uncompensated  
   b. Metabolic alkalosis – partially compensated  
   c. Metabolic alkalosis – fully compensated  
   d. Metabolic acidosis – fully compensated

10. pH 7.31  
    \( \text{PaCO}_2 \ 60 \)  
    \( \text{HCO}_3 \ 26 \)
    a. Normal  
    b. Respiratory acidosis – uncompensated  
    c. Respiratory acidosis – full compensation  
    d. Respiratory alkalosis – uncompensated
References


ABG Interpretation
Answer Key

Interpret the following blood gas results. Circle the correct answer. There is only one correct answer for each.

1. $pH \ 7.26 \quad PaCO_2 \ 52 \quad HCO_3 \ 26$
   a. Metabolic acidosis
   b. Metabolic alkalosis
   c. Respiratory alkalosis
   d. Respiratory acidosis – correct answer

2. $pH \ 7.46 \quad PaCO_2 \ 33 \quad HCO_3 \ 26$
   a. Respiratory alkalosis - correct answer
   b. Respiratory acidosis
   c. Metabolic alkalosis
   d. Metabolic acidosis

3. $pH \ 7.31 \quad PaCO_2 \ 60 \quad HCO_3 \ 22$
   a. Respiratory acidosis – correct answer
   b. Respiratory alkalosis
   c. Metabolic acidosis - correct answer
   d. Metabolic alkalosis

4. $pH \ 7.48 \quad PaCO_2 \ 41 \quad HCO_3 \ 31$
   a. Metabolic acidosis – uncompensated
   b. Normal
   c. Respiratory alkalosis – full compensation
   d. Metabolic alkalosis – uncompensated – correct answer

5. $pH \ 7.39 \quad PaCO_2 \ 55 \quad HCO_3 \ 28$
   a. Normal
   b. Respiratory acidosis – fully compensated – correct answer
   c. Respiratory acidosis – partially compensated
   d. Respiratory acidosis – uncompensated
6. pH 7.19  \( \text{PaCO}_2 \) 68  \( \text{HCO}_3 \) 26
   a. Metabolic acidosis – uncompensated
   b. Metabolic acidosis – fully compensated
   c. Respiratory acidosis – uncompensated – correct answer
   d. Respiratory acidosis – fully compensated

7. pH 7.32  \( \text{PaCO}_2 \) 48  \( \text{HCO}_3 \) 36
   a. Respiratory acidosis – uncompensated
   b. Metabolic acidosis – partially compensated
   c. Respiratory acidosis – partially compensated – correct answer
   d. Metabolic acidosis – fully compensated

8. pH 7.36  \( \text{PaCO}_2 \) 30  \( \text{HCO}_3 \) 14
   a. Respiratory acidosis – partially compensated
   b. Respiratory alkalosis – compensated
   c. Metabolic acidosis – fully compensated – correct answer
   d. Metabolic alkalosis – uncompensated

9. pH 7.48  \( \text{PaCO}_2 \) 50  \( \text{HCO}_3 \) 18
   a. Metabolic alkalosis – uncompensated
   b. Metabolic alkalosis – partially compensated – correct answer
   c. Metabolic alkalosis – fully compensated
   d. Metabolic acidosis – fully compensated

10. pH 7.31  \( \text{PaCO}_2 \) 60  \( \text{HCO}_3 \) 26
    a. Normal
    b. Respiratory acidosis – uncompensated – correct answer
    c. Respiratory acidosis – full compensation
    d. Respiratory alkalosis – uncompensated