**Arterial Blood Gases: Interpreting Results**

**What is Involved in Interpreting Arterial Blood Gases?**

› Arterial blood gases (ABGs) refer to a laboratory test designed to assess respiratory status, metabolic status, and acid-base balance by measuring the acidity (pH) and levels of serum oxygen and carbon dioxide. (For information about how to perform an arterial puncture to obtain a blood sample for ABG analysis, see the series of related Nursing Practice & Skill topics)

• *What*: ABG interpretation refers to the analysis used by the clinician to evaluate the laboratory data obtained from arterial blood for acid-base disorders (ABDs) associated with imbalance in the respiratory and metabolic systems (e.g., respiratory failure, renal failure, ketoacidosis, hyperkalemic acidosis); total assessment requires evaluation of pH, anion gap, and electrolyte levels (Note: Electrolytes, the body’s chemical method of compensating for ABDs, is beyond the scope of this topic. For more information, see the series of related topics in Nursing Reference Center)

• *How*: After a sample of arterial blood is analyzed using a commercially available ABG analyzer—often at the point-of-care—to measure pH (i.e., acid-base status), partial pressure of oxygen in arterial blood (\(\text{PaO}_2\)), partial pressure of carbon dioxide in arterial blood (\(\text{PaCO}_2\)), bicarbonate ion (\(\text{HCO}_3^-\)) concentration, and oxygen saturation (\(\text{SaO}_2\); i.e., amount of oxygen bound to hemoglobin in arterial blood), the clinician uses a systematic step-wise approach to evaluate each of the ABG components to determine if the imbalance, if any, is due to a respiratory or metabolic issue

• *Where*: ABGs are routinely drawn and interpreted in emergency departments, operating rooms, and ICUs where critically ill or mechanically ventilated patients are receiving care. ABGs can be drawn and interpreted in any patient care setting where analysis of the patient’s respiratory, metabolic, and oxygenation status is indicated (e.g., asthma patient on a medical unit)

• *Who*: Nurses, respiratory therapists, physicians, and other advanced practice clinicians routinely interpret ABGs. ABG interpretation cannot be delegated to assistive healthcare personnel

**What is the Desired Outcome of Interpreting Arterial Blood Gases?**

› The desired outcome of interpreting ABGs is to obtain accurate information that can be used to more effectively manage ABDs and guide treatment

**Why is Interpretation of Arterial Blood Gases Important?**

› Interpretation of ABGs is important to determine if the patient is experiencing respiratory acidosis/alkalosis or metabolic acidosis/alkalosis, and if the body has initiated compensatory mechanisms to restore a neutral pH

• The normal functioning of all body systems depends upon maintaining a neutral pH (pH 7.35—7.45); a pH < 6.8 or > 7.8 is incompatible with life. Accurate ABG interpretation provides valuable information regarding the etiology of any deviation from a neutral pH and the ability of the body to maintain or restore a neutral pH
Facts and Figures

The arterial specimen used for ABG analysis is collected in a heparinized container to prevent coagulation—this involves using either a pre-packaged heparinized syringe which contains a dried heparin-based compound (e.g., lithium heparin, heparin sodium) or small volume of liquid heparin sodium, or manually heparinizing the syringe by coating (“heparin washing”) the inner barrel with 1:1,000 heparin solution. Pre-packaged heparinized syringes are widely preferred because manually prepared syringes do not contain a precise volume of heparin that can alter ABG values.

In a study conducted in Turkey, investigators reported that the sample dilution ratio and final heparin concentrations of blood samples collected in syringes prepared by clinicians varied widely and was significantly impacted by syringe volume, needle size, and sample volume. These variations did not significantly impact pH and PaO\(_2\) results, but produced unacceptable errors in pCO\(_2\) and electrolyte measurements (Küme et al., 2012).

Researchers in another study compared ABG measurement using conventional heparinized syringes with use of safety-engineered blood gas-specific syringes. Use of safety-engineered blood gas-specific syringes was associated with a significantly lower complication rate (e.g., rates of infection, local hematoma), reduced localized pain ratings, and higher patient-physiciansatisfaction (Baskin et al., 2014).

Researchers analyzed data from 736 cases of ABDs that presented to an emergency room in Turkey and observed the following (Kose et al., 2014):

- 76.5% had mixed ABD (i.e., two or more primary disorders occurring simultaneously [e.g., respiratory and metabolic issues]), with the most common mixed ABD being mixed metabolic acidosis and respiratory alkalosis.
  - Mortality was associated more frequently in cases with mixed metabolic acidosis and respiratory alkalosis and mixed metabolic and respiratory acidosis.
- 23.5% of patients had simple ABD (based either on respiratory or metabolic issues).
- Dyspnea was the most common complaint among the patient studied (44.4%).

Capillary blood gas (CBG) sampling is another method of approximating ABGs without the invasive, often painful, arterial puncture required to obtain an arterial specimen. CBG is not appropriate for patients who are in shock.

Researchers performing a meta-analysis on the reliability of CBG to predict ABG values found that CBGs predict ABG values within 0.43%, 3.00%, 2.80%, and 1.90% respectively for pH, pCO\(_2\), saO\(_2\), and pO\(_2\) values < 20 kPa/1.45 PSI (Richter et al., 2014).

What You Need to Know Before Interpreting Arterial Blood Gases

Normal ABG values for adults are as follows:

- pH (i.e., measure of free hydrogen [H\(_2\)] and hydroxyl [-OH] ions)
  - Normal: 7.35–7.45 (normal serum level is slightly basic/alkaline; neutral pH = 7)
- PaCO\(_2\): 35–45 mmHg; indicates the effectiveness of alveolar ventilation—measure of CO\(_2\) elimination—and reflects the level of serum acidity
  - PaCO\(_2\) < 35 mmHg indicates hyperventilation, coupled with a pH > 7.45 indicates respiratory alkalosis
  - PaCO\(_2\) > 45 mmHg indicates hypoventilation, coupled with a pH < 7.35 indicates respiratory acidosis
- HCO\(_3\) (i.e., chemical buffer used to balance serum acidity/alkalinity): 22–26 mEq/L (the units mEq/L and mmol/L for HCO\(_3\) are equivalent and are used interchangeably)
  - HCO\(_3\) > 26 mEq/L is associated with vomiting, dehydration/excessive use of diuretics, blood transfusion, excessive intake of acidic foods/drink, excessive use of antacids/medications with bicarbonate and conditions such as chronic obstructive pulmonary disease (COPD), pulmonary edema, Cushing’s disease
  - HCO\(_3\) < 22 mEq/L is associated with hyperventilation, liver or kidney disease, uncontrolled diabetes, myocardial infarction, diarrhea, dehydration/excessive use of diuretics, overdose of aspirin/alcohol
- PaO\(_2\): 80–100 mmHg; indicates the effectiveness of oxygen transport from lungs to blood
  - PaO\(_2\) < 80 mmHg indicates hypoxemia
- SaO\(_2\): 95–100% (i.e., measure of percentage of hemoglobin that is holding oxygen)
  - SaO\(_2\) < 95% indicates hypoxia
- Base excess (BE): -2 to +2 mmol/L
  - BE is a calculated value that represents the amount of strong acid needed to bring the pH to 7.4 if the PaCO\(_2\) is 40 mmHg; it reflects the metabolic component of any acid-base imbalance only
- Anion gap (AG): 8–16 mEq/L (varies depending upon laboratory facility)
The anion gap is a calculated value that is an approximate measure of the difference between the amount of positively charged ions (e.g., sodium, potassium, calcium, magnesium) and negatively charged ions (e.g., chloride, bicarbonate, albumin, phosphorus, citrate). The anion gap can be used in the differential diagnosis of metabolic acidosis and is particularly important when evaluating mixed ABDs.

- A high anion gap indicates elevated serum acidity due to metabolic processes and is indicative of metabolic acidosis.
- A low anion gap is relatively rare but is seen in conditions with an abnormal level of positively charged ions such as multiple myeloma or low albumin with increased immunoglobulins.

The pH is influenced by the respiratory and renal systems (Figure 1).

![Figure 1](image_url)

Figure 1: Acid-base imbalance can result from respiratory factors, metabolic factors, or a combination of the two. Copyright ©2018, EBSCO Information Services

- **Respiratory acidosis** occurs when acidosis arises as a result of respiratory factors, often due to respiratory depression; characterized by a pH < 7.35 and a PaCO$_2$ > 45 mmHg (the high CO$_2$ causes the pH to drop).
  - Symptoms of respiratory acidosis include slow or difficult breathing, headache, drowsiness/confusion, restlessness/tremor, tachycardia, changes in blood pressure, and cyanosis.

- **Respiratory alkalosis** occurs when alkalosis arises as a result of respiratory factors, often as a result of hyperventilation related to pulmonary disease, stroke, or anxiety. Respiratory alkalosis is characterized by a pH > 7.45 and a PaCO$_2$ < 35 mmHg (the low CO$_2$ causes the pH to rise).
  - Symptoms of respiratory alkalosis include light-headedness, dizziness, and numbness of hands and feet.

- **Metabolic acidosis** occurs when acidosis arises as a result of metabolic factors, e.g., ↑ lactic acid production by skeletal muscles, ↑ consumption of dietary fats or dietary acids, severe diarrhea, diabetic ketoacidosis, and shock. Metabolic acidosis is characterized by a pH < 7.35 and a HCO$_3^-$ < 22 mEq/L (the low HCO$_3^-$ causes the pH to drop). In addition, metabolic acidosis is associated with a BE < -2 mmol/L and a high anion gap.
  - Symptoms of metabolic acidosis include tachypnea; lethargy, confusion, decreased level of consciousness which can lead to coma; cardiac arrhythmias; shock; and death.

- **Metabolic alkalosis** occurs when alkalosis arises as a result of metabolic factors, e.g., severe/persistent vomiting (i.e., loss of gastric acid), excessive intake of antacids, and excessive use of steroids/diuretics. Metabolic alkalosis is characterized by a pH > 7.45 and a HCO$_3^-$ > 26 mEq/L (the high HCO$_3^-$ causes the pH to rise); in addition, the BE will be > 2 mmol/L.
  - Symptoms of metabolic alkalosis include slowed breathing/apneic episodes; cyanosis; nausea/vomiting/diarrhea; irritability/tremor/twitching, confusion; cardiac arrhythmias, particularly tachycardia; hypotension; and convulsions/coma.

Buffering is the body’s normal physiological compensatory mechanism that occurs when pH deviates from the normal range. The carbonic-acid bicarbonate buffer system—which involves balancing carbonic acid (H$_2$CO$_3$), bicarbonate
ion (HCO₃), and carbon dioxide (CO₂)—is one of the body’s chief methods of maintaining acid-base homeostasis, and involves compensation by both the respiratory and renal systems. (Figure 2)

Figure 2: The carbonic acid-bicarbonate buffer system is a compensatory mechanism used to maintain or restore a neutral pH. Copyright ©2018, EBSCO Information Services

- The respiratory system compensates by altering the amount of CO₂ produced by the lungs—when chemoreceptors in the body sense ↓ pH (acidotic), the respiratory system is stimulated to increase the rate and depth of respiration to “blow off” CO₂; when chemoreceptors sense that ↑ pH (alkalotic), the respiratory system is stimulated to decrease the rate and depth of respiration to retain CO₂
- The renal system compensates in two ways, by altering the amount of HCO₃ synthesized or retained by the kidneys and by the amount of hydrogen (H⁺) excreted in the urine. ↓ serum pH (acidotic) causes the kidneys to increase HCO₃ synthesis and retention and excrete more hydrogen ions (H⁺) in the urine (to buffer the excess acidity). ↑ serum pH (alkalotic) will cause the kidneys to respond by excreting more HCO₃ in the urine
- If by way of buffering the pH is returned to the normal reference range, the acid-base imbalance is considered fully compensated; if the pH remains outside the normal range, the acid-base imbalance is considered partially compensated
  - PaCO₂ will be normal in uncompensated metabolic acidosis and decreased in compensated metabolic acidosis (in an attempt to not contribute to the acidity of the blood and to restore a neutral pH)
  - PaCO₂ will be normal in uncompensated metabolic alkalosis and increased in compensated metabolic alkalosis (the lungs retain more CO₂ [hypoventilate] in an attempt to buffer alkalinity of the blood and restore a neutral pH)
  - HCO₃ will be normal in uncompensated respiratory acidosis and increased in compensated respiratory acidosis (the body retains HCO₃ in an attempt to buffer the acidity of the blood and restore a neutral pH)

<table>
<thead>
<tr>
<th>Acid-Base Disorder</th>
<th>pH</th>
<th>PaCO₂</th>
<th>HCO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory acidosis</td>
<td>&lt; 7.35</td>
<td>&gt; 45 mmHg</td>
<td>uncompensated: 22–26 mEq/L compensated: &gt; 26 mEq/L</td>
</tr>
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## Respiratory alkalosis

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## Metabolic acidosis

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## Metabolic alkalosis

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ABDs can be of mixed origin, in which there is no compensation but rather two primary mechanisms occurring simultaneously to cause acidosis and/or alkalosis; possible combinations include:

- mixed respiratory and metabolic alkalosis, characterized by a ↑ pH, ↑ HCO₃⁻, and a ↓ PaCO₂ (rather than the increased PaCO₂ that would be expected if the respiratory system were compensating for the metabolic alkalosis) can be caused by giving diuretics to a patient with liver disease
- mixed respiratory alkalosis and metabolic acidosis, characterized by a normal pH, a ↓ PaCO₂, and a normal to high anion gap; can be caused by sepsis or lactic acidosis
- mixed respiratory and metabolic acidosis, characterized by a ↓ pH, ↑ PaCO₂, and a normal to high anion gap; can be caused by pulmonary edema or severe pneumonia
- mixed respiratory acidosis and metabolic alkalosis, characterized by a normal pH and an ↑ PaCO₂; can occur in a patient with chronic obstructive pulmonary disease who is taking diuretics
- mixed metabolic acidosis and alkalosis, characterized by a normal pH, normal PaCO₂, normal HCO₃⁻ levels, and a high anion gap; can occur in patients with uremia and vomiting

Preliminary steps that should be performed before interpreting ABGs include the following:

- Review the facility protocol for interpreting ABGs, if one is available
- Review the treating clinician’s order for ABG testing and analysis (e.g., bedside or clinical laboratory, if specified)
- Review the manufacturer’s instructions for all equipment to be used, and verify that the equipment is in good working order
- Verify completion of facility informed consent documents, if necessary. Typically, the general consent for treatment executed by patients at admission to a medical facility includes standard provisions that encompass ABG testing
- Perform or prepare patient for arterial specimen collection; forward sample and send for analysis; for detailed information on drawing ABGs in different patient populations, see
  - Nursing Practice & Skill ... Arterial Blood Gases: Performing Arterial Puncture in the Adult Patient
  - Nursing Practice & Skill ... Arterial Blood Gases: Performing Arterial Puncture in the Pediatric Patient
  - Nursing Practice & Skill ... Arterial Blood Gases: Performing Arterial Puncture in the Neonate
- Obtain printed results of the ABG laboratory values

### How to Interpret Arterial Blood Gases

**Step 1: Evaluate the pH**

- Determine if the pH is
  - within the normal range (7.35–7.45)
    - If the pH is in the normal range, continue with interpretation as long-term compensation for a chronic disorder could yield a normal pH
    - ↓ (< 7.35), indicating acidosis
    - ↑ (> 7.45), indicating alkalosis

**Step 2: Evaluate the PaCO₂ level to determine if the respiratory system is contributing to or compensating for the acid-base imbalance**

- Determine if the PaCO₂ level is
  - within the normal range (35–45 mm Hg)
    - ↓ (< 35 mm Hg), indicates hyperventilation
    - ↑ (> 45 mm Hg), indicates hypoventilation
Step 3: Evaluate the HCO₃ level
• Determine if the HCO₃ level is
  – within the normal range (22–26 mEq/L)
  – ↓ (< 22 mEq/L)
  – ↑ (> 26 mEq/L)

Step 4: Determine the type of acid-base disorder present by comparing the direction of movement (of PaCO₂ or the HCO₃) in relation to the pH
• If the CO₂ level is increased or decreased in the opposite direction as the pH (i.e., a ↓ CO₂ and a ↑ pH or a ↑ CO₂ and a ↓ pH), the respiratory system is the cause of the acid-base imbalance; conversely, if the CO₂ level is not increased or decreased in the opposite direction as the pH, the respiratory system is not the cause of the acid-base imbalance
  – ↓ pH (< 7.35) and ↑ CO₂ (> 45 mmHg) indicates respiratory acidosis
  – ↑ pH (> 7.35) and ↓ CO₂ (< 35 mmHg) indicates respiratory alkalosis
An abnormal pH, together with a normal PaCO₂ level, suggests that the acid-base imbalance is of a non-respiratory (metabolic) origin
• If the HCO₃ level is increased or decreased in the same direction as the pH (i.e., a high HCO₃ and a high pH or a low HCO₃ and a low pH), the metabolic system is the cause of the acid-base imbalance; conversely, if the HCO₃ level is not increased or decreased in the same direction as the pH, the metabolic system is not the cause of the acid-base imbalance
  – ↓ pH (< 7.35) and ↓ HCO₃ (< 22 mEq/L) indicates metabolic acidosis
  – ↑ pH (> 7.45) and ↑ HCO₃ (> 26 mEq/L) indicates metabolic alkalosis
An abnormal pH, together with a normal level of HCO₃, suggests the acid-base imbalance is of a non-metabolic (respiratory) origin
– BE results can be evaluated to indicate the severity of the metabolic imbalance, as follows:
  - Mild (-4 mmol/L to -6 mmol/L) to severe metabolic acidosis (< -13 mmol/L)
  - Mild (4 mmol/L to 6 mmol/L) to severe metabolic alkalosis (> +13 mmol/L)
– AG is valuable in evaluating metabolic acidosis, especially when evaluating mixed ABDs
• Identify possible mixed acid-base imbalances, including
  – mixed respiratory and metabolic alkalosis, characterized by a high pH, ↑ HCO₃, and a ↓ PaCO₂
  – mixed respiratory alkalosis and metabolic acidosis, characterized by a normal pH, a ↓ PaCO₂, and a normal to high anion gap
  – mixed respiratory and metabolic acidosis, characterized by a ↓ pH, ↑ PaCO₂, and a normal to high anion gap
  – mixed respiratory acidosis and metabolic alkalosis, characterized by a normal pH and a ↓ PaCO₂
  – mixed metabolic acidosis and alkalosis, characterized by a normal pH, normal PaCO₂, normal HCO₃ levels, and a high anion gap

Step 5: Determine if the acid-base imbalance is compensated or uncompensated
• If the patient has respiratory acidosis or alkalosis, evaluate the HCO₃ level to determine if the body has engaged the appropriate compensatory mechanism to restore a neutral pH. If the pH has returned to a normal level, the imbalance is considered fully compensated; if the pH is still abnormal it is considered partially compensated
  – If the patient has either respiratory acidosis or alkalosis and the HCO₃ level is normal, it is considered uncompensated respiratory acidosis
  – If the patient has respiratory acidosis and the HCO₃ level is increased, it is considered fully compensated respiratory acidosis if the pH is normal and partially compensated respiratory acidosis if the pH is still low
  – If the patient has respiratory alkalosis and the HCO₂ level is decreased, it is considered fully compensated respiratory alkalosis if the pH is normal and partially compensated respiratory alkalosis if the pH is still high
• If the patient has metabolic acidosis or alkalosis, evaluate the PaCO₂ level to determine if the body has engaged the appropriate compensatory mechanism to restore a neutral pH
  – If the patient has either metabolic acidosis or alkalosis and the PaCO₂ level is normal, it is considered uncompensated metabolic acidosis
  – If the patient has metabolic acidosis and the PaCO₂ level is decreased, it is considered fully compensated metabolic acidosis if the pH is normal and partially compensated metabolic acidosis if the pH is still low
  – If the patient has metabolic alkalosis and the PaCO₂ level is increased, it is considered fully compensated metabolic alkalosis if the pH is normal and partially compensated metabolic alkalosis if the pH is still high
Step 6: Analyze the patient’s respiratory status
• If the PaO\textsubscript{2} is < 80 mm Hg, SaO\textsubscript{2} is < 95%, or PaCO\textsubscript{2} is < 35 mm Hg, oxygen supplementation or mechanical ventilation can be required

Update the patient’s plan of care, if appropriate, and document the following information in the patient’s medical record:
• The date and time of ABG sample collection
• The patient’s status at the time of sample collection
• Results of ABG interpretation
• Any interventions performed based on ABG interpretation
• Any unexpected patient events or outcomes, interventions performed, and whether or not the treating clinician was notified
• Patient/family member education, including topics presented, response to education provided/discussed, plan for follow-up education, and details regarding any barriers to communication and/or techniques that promoted successful communication

Other Tests, Treatments, or Procedures That Can Be Necessary Before or After Interpreting Arterial Blood Gases
• ABG results can be influenced by oxygen therapy, changes in mechanical ventilator setting, tracheal suctioning, or respiratory treatments; it is recommended that no changes in the patient’s respiratory care occur 20–30 minutes prior to drawing ABGs
• A pulmonary function test (measure of lung capacity and gas exchange) can be ordered to determine the precise cause of respiratory-based alterations in acid-base balance

What to Expect After Interpreting Arterial Blood Gases
• The analysis derived from ABG interpretation will permit effective management of ABDs and patient treatment; serial ABGs can be ordered to evaluate treatment effectiveness

Red Flags
• Extreme acidosis (pH < 7.1) or alkalosis (pH > 7.55) is a medical emergency regardless of the cause

What Do I Need to Tell the Patient/Patient’s Family?
• Reinforce physician explanation of ABG results to help the patient and family understand the related disease processes and treatment measures
• Reassure the patient that ABG measurement is a valuable method of determining respiratory and metabolic function; inform the patient that serial measurements can be necessary to evaluate treatment efficacy

Note
• Recent review of the literature has found no updated research evidence on this topic since previous publication on March 25, 2016

References


