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Learning Outcomes

Upon completion of this exercise, the participant will be able to:

- List the tests included in arterial blood gases and discuss their clinical use.
- Discuss the effects of exposure to air and elevated (room) temperature on pH, pO₂, and pCO₂.
- Interpret the acid/base status of patients (case studies) when given laboratory results and/or patient history.

Arterial blood gases (ABGs) are useful for determining the acid/base and oxygen/carbon dioxide status of a patient. ABGs include direct measurement of hydrogen ion concentration (pH) and the partial pressures for oxygen (pO₂) and carbon dioxide (pCO₂), and may include calculated parameters such as oxygen (O₂) saturation, bicarbonate (HCO₃⁻), and base excess/deficit. In order to obtain valid ABG results proper sample collection and handling prior to rapid testing is essential. In 2001 the American Association for Respiratory Care (AARC) published clinical practice guidelines for blood gas analysis and hemoximetry (CO-oximetry) (Respir Care 2001;46:498-505) that are available at the journal (Respiratory Care) website, http://www.rcjournal.com.

Unlike most other laboratory tests, the preferred sample for ABGs is arterial blood, typically taken from the radial artery on the inside of the wrist by a healthcare professional trained to perform such collections. The Allen test, compressing the radial and ulnar arteries of the wrist and then observing return of blood to the hand following release, should be performed before collection to verify that there is adequate circulation to the wrist. Alternate sites are the brachial artery in the elbow, the femoral artery in the groin, and the dorsalis pedis artery of the foot. For infants capillary blood from a heelstick may be used.

Samples should be collected anaerobically using a glass or plastic syringe of low diffusibility containing a sodium or lithium heparin anticoagulant. Special syringes prefilled with heparin or procedures for coating syringes with heparin are available. Air space or bubbles in the syringe should be removed immediately after collection. Immediately after the needle is removed, the syringe should be capped to maintain anaerobic conditions. Analysis should be performed as soon as possible (within 15 minutes; some references state within 5 minutes) and if this is not possible, the syringe should be placed in ice (some references recommend storage at room temperature if analysis performed within 30 minutes of collection). Analysis should be performed within 1 hour (some references state within 30 minutes) of collection. Improper collection and/or storage can cause erroneous results. Contact with air (bubbles in syringe, syringe not capped, etc) will cause increases in pO₂ and pH and decreases in pCO₂. Samples sitting at room temperature will be affected as follows: pO₂ and pH will be decreased and pCO₂ will be increased. Patients with elevated leukocyte or
platelet counts are susceptible to a decreased pO2, presumably due to increased metabolism, which may be slowed by storage on ice.

Interpretation of ABG results may be complicated by many factors and requires a fundamental understanding of several physiologic processes. The oxygenation status of the patient is determined using the pO2 value. Typically, pO2 values below 60 mm are considered hypoxemic, but there is a decrease in normal oxygenation with age. Normal oxygenation for age is approximately one-third of the age subtracted from 100, so a 60-year-old should have a pO2 of approximately 80. Hypoxemia can be due to decreased delivery of oxygen to the alveolar air sacs in the lungs (hypoventilation) or a decreased transfer of oxygen from the alveoli into the blood stream (possibly due to underlying lung disorders). Calculation of an alveolar to arterial oxygen gradient (A-a gradient) using pO2 and pCO2 values (Figure 1) helps to determine the cause of hypoxemia. A normal A-a gradient (10-20 mm Hg) in conjunction with hypoxemia would suggest hypoxemia due to hypoventilation and not due to underlying lung disorders.

**Figure 1.** \[A-a \text{ gradient} = [150 - 1.25(pCO2)] - pO2\]

Disturbances in the acid/base status of a patient may occur in many acute and chronic conditions and the ABG results help to determine whether the problem is respiratory or metabolic. Although the body utilizes several buffering systems to maintain a narrow pH range of 7.35 to 7.45, the primary system is the bicarbonate (HCO₃⁻)/carbonic acid (H₂CO₃) system. The relationship between pH, HCO₃⁻, and H₂CO₃ is expressed by the Henderson-Hasselbalch equation (Figure 2), which illustrates that the pH is proportional to the ratio of bicarbonate to carbonic acid. In order to maintain the pH of blood at 7.35-7.45, the ratio of HCO₃⁻ to H₂CO₃ should be maintained at 20:1. The ratio is maintained by a combination of respiratory and metabolic actions. In the respiratory aspect of acid/base regulation, H₂CO₃ concentrations are controlled by the lungs using the rate and depth of respiration. The H₂CO₃ concentration is directly related to the pCO₂ value (H₂CO₃ = 0.03 x pCO₂). For the metabolic aspect of acid/base regulation, HCO₃⁻ concentrations are controlled by renal regulation of bicarbonate excretion and resorption.

In the laboratory, pH and pCO₂ are measured as components of ABGs while HCO₃⁻ can be calculated using the Henderson-Hasselbalch equation and is frequently reported as part of ABGs. These values are used to determine the acid/base status of a patient. The pH determines whether the disturbance is acidosis (pH<7.35) or alkalosis (pH>7.45) and the pCO₂ and HCO₃⁻ values help determine whether the primary disturbance is respiratory (pCO₂ alteration is primary change) or metabolic (HCO₃⁻ alteration is primary change). The body’s compensatory mechanisms to restore pH to normal involve the opposite component of regulation, i.e., if the primary disturbance is respiratory, there is a metabolic compensation mechanism to change the HCO₃⁻ concentration in order to restore the ratio of HCO₃⁻ to H₂CO₃ to 20:1. The 4 primary acid/base disturbances are metabolic acidosis, respiratory acidosis, metabolic alkalosis, and respiratory alkalosis. The Table lists sample laboratory values and some
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conditions causing each of these primary disturbances. One way to remember these relationships is that in metabolic disorders, pH and HCO₃⁻ move in the same direction relative to normal values, and in respiratory disorders, pH and pCO₂ move in opposite directions. Interpretation of acid/base disturbances should be tempered with the realization that compensation occurs and sometimes this compensation leads to another acid/base disturbance.

In addition to the tests mentioned or discussed in this article, current blood gas instrumentation often includes CO-oximeter channels using spectrophotometry to measure hemoglobin species such as oxyhemoglobin, carboxyhemoglobin, methemoglobin, sulfhemoglobin and fetal hemoglobin. Additional analytes now measured in some ABG instruments include bilirubin, glucose, lactic acid, sodium, potassium, chloride, magnesium, and calcium.

Figure 2. Bicarbonate Buffering System in Blood: Henderson-Hasselbalch Equation and Observations

\[ \text{pH} = 6.1 + \log \frac{\text{HCO}_3^-}{\text{H}_2\text{CO}_3} \]

Observations:

\[ \text{pH is proportional to: } \log \frac{\text{HCO}_3^-}{\text{H}_2\text{CO}_3 (pCO}_2) \]

kidney metabolic lungs respiratory

THIS RATIO SHOULD BE 20:1

Table. Primary Acid/Base Disorders

<table>
<thead>
<tr>
<th>Condition</th>
<th>Laboratory Results</th>
<th>Possible Cause(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic acidosis</td>
<td>decreased</td>
<td>pH decreased HCO₃⁻ decreased Uncontrolled diabetes, severe diarrhea, liver disease, shock, renal failure, strenuous exercise</td>
</tr>
<tr>
<td>Respiratory acidosis</td>
<td>decreased</td>
<td>pH decreased H₂CO₃ (pCO₂) increased Chronic obstructive pulmonary disease (COPD), asthma, pneumonia, drug overdose, chest injury</td>
</tr>
<tr>
<td>Metabolic alkalosis</td>
<td>increased</td>
<td>pH increased HCO₃⁻ increased Diuretic therapy, hypokalemia, chronic vomiting, sodium bicarbonate overdose, high corticosteroid dose</td>
</tr>
<tr>
<td>Respiratory alkalosis</td>
<td>increased</td>
<td>pH increased H₂CO₃ (pCO₂) decreased Hyperventilation, pain, emotional distress, heart failure, anemia, CO poisoning, certain lung diseases</td>
</tr>
</tbody>
</table>

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