YOU’RE WORKING IN THE emergency department when Doug Phillips arrives complaining of shortness of breath. Mr. Phillips, 67, has a history of chronic obstructive pulmonary disease (COPD). A physical exam reveals a barrel-shaped chest, slightly cyanotic nail beds with slow capillary refill time, and digital clubbing. His breath sounds are distant with inspiratory crackles. He sits on the edge of his chair, leaning forward, with both hands on his knees. You draw a blood sample for arterial blood gas (ABG) analysis. What will it show?

In this article, we’ll describe a step-by-step approach to interpreting ABG results, which tell you about oxygenation and acid-base balance in the patient’s blood and guide treatment decisions. First, though, let’s take a closer look at each of the values measured by ABG analysis.

Five components
Arterial blood gas values have five basic components that you use to assess patients: percentage of oxygenation and
hemoglobin saturated with oxygen in arterial blood (SaO₂), partial pressure of oxygen dissolved in arterial blood (PaO₂), arterial blood acidity or alkalinity (pH), partial pressure of carbon dioxide in arterial blood (PaCO₂), and concentration of bicarbonate ions in arterial blood (HCO₃⁻). Let’s look at what each one tells you about your patient’s condition. (For normal test parameters, see ABGs in Adults: What’s Normal?)

- **SaO₂ and PaO₂: An oxygenation review.** Oxygen is transported in the blood in two forms. Oxyhemoglobin (oxygen bound to hemoglobin molecules in red blood cells [RBCs]) accounts for about 97% of the oxygen in the blood and is measured as SaO₂. A normal oxyhemoglobin saturation should be greater than 95%; if the value drops to 90% or less, immediately assess the patient and administer oxygen.

  The remaining 3% of oxygen in the blood travels as oxygen molecules dissolved in the blood and is measured as PaO₂. The measured PaO₂ is related to the patient’s SaO₂ level: As oxygen is dissolving into the blood, it’s also combining with hemoglobin in the RBCs. With a higher PaO₂, hemoglobin quickly takes up oxygen molecules until the hemoglobin is saturated. At that point, the SaO₂ is 100%. (Note that more oxygen can still dissolve into the blood, so the PaO₂ can climb higher than normal. For example, in a young person with no lung disease breathing 100% oxygen for a short period, the PaO₂ could reach 600 mm Hg.)

  The relationship between PaO₂ and SaO₂ is shown by the S-shaped oxyhemoglobin dissociation curve. Changes in certain parameters that occur in the body will cause a shift of the S-shaped curve to the left or right. A shift to the left, which indicates hemoglobin’s increased affinity for oxygen (inhibiting oxygen release to the cells), can be caused by increased pH, decreased temperature, or decreased PaCO₂. A shift to the right, which indicates hemoglobin’s decreased affinity for oxygen and easier movement of oxygen into cells, can be caused by decreased pH, increased temperature, and increased PaCO₂.

  If the patient is hypoxemic, the low oxygen content in his blood will be reflected in low PaO₂ and SaO₂ values. Mild hypoxemia is defined as a PaO₂ of 60 to 79 mm Hg; moderate hypoxemia, 40 to 59 mm Hg; and severe hypoxemia, less than 40 mm Hg.

  Prolonged or severe hypoxemia leads to tissue hypoxia and anaerobic metabolism, altering the patient’s acid–base status. Administering supplemental oxygen to a patient who’s hypoxic or hypoxic may prevent large changes in acid–base status.

- **pH: Acid or base?** The acidity or alkalinity of a solution is measured by its pH: The more hydrogen ions in a solution, the more acidic it is. The normal range for pH is narrow (7.35 to 7.45); below 6.8 or above 7.8, the body’s metabolic processes fail and the patient dies.

- **PaCO₂: A respiratory parameter.** The PaCO₂ is a measure of the partial pressure that dissolved carbon dioxide exerts in the plasma and is directly related to the amount of carbon dioxide being produced by the cells. The PaCO₂ is regulated by the lungs and can be used to determine if an acid–base disturbance is respiratory in origin. This value is inversely related to the rate of alveolar ventilation, so a patient with bradypnea retains carbon dioxide. Increased ventilation reduces PaCO₂, and decreased ventilation raises PaCO₂. A PaCO₂ level below 35 mm Hg causes alkalosis, and a level above 45 mm Hg causes acidosis. The body can adjust the level of PaCO₂ in the body in a matter of minutes by increasing or decreasing respiratory rate or the volume of air breathed.

- **HCO₃⁻: Metabolic parameter.** The bicarbonate ion (HCO₃⁻) is the acid-base component regulated by the kidneys. Acting as the body’s buffer system, the kidneys retain or excrete the alkalotic bicarbonate ion as needed. You can use the HCO₃⁻ value to determine if the source of an acid–base disturbance is respiratory or metabolic. An HCO₃⁻ level below 22 mEq/liter indicates acidosis; above 26 mEq/liter indicates alkalosis. Unlike the respiratory system, which can make a quick adjustment to change PaCO₂ levels, the renal system needs much more time to alter HCO₃⁻ levels. In a person with normal renal function, HCO₃⁻ adjustments may take several hours. In someone who’s elderly or who has decreased renal function, HCO₃⁻ adjustments may take several days.

  Acute causes of changes in acid-base balance include oversedation and head traumo-

<table>
<thead>
<tr>
<th>ABGs in adults: What’s normal?</th>
<th>Normal range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ABG component</strong></td>
<td><strong>Normal range</strong></td>
</tr>
<tr>
<td>pH</td>
<td>7.35-7.45</td>
</tr>
<tr>
<td>PaCO₂</td>
<td>35-45 mm Hg</td>
</tr>
<tr>
<td>PaO₂</td>
<td>80-100 mm Hg</td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>22-26 mEq/liter</td>
</tr>
<tr>
<td>SaO₂</td>
<td>95%-100%</td>
</tr>
</tbody>
</table>

ma (resulting in respiratory acido-
ma), anxiety and anemia (resulting in respiratory alkalosis), starva-
tion and diabetic ketoacidosis
(resulting in metabolic acidosis), and vomiting and prolonged naso-
gastric tube suctioning (resulting in metabolic alkalosis).

**Complicating things
with compensation**

Compensation is the body’s attempt to maintain a normal pH level. The respiratory system controls the carbon dioxide level, and the renal system controls the bicarbonate level. The body uses these two systems to oppose each other in order to maintain a normal pH. For example, if one system changes in the acidic direction, the other will compensate in the alkalotic direction.

A patient who's breathing

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### Test your ABG interpretation skills

#### Case 1

<table>
<thead>
<tr>
<th>The patient’s values are:</th>
<th>pH, 7.32</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaCO2, 31 mm Hg</td>
<td></td>
</tr>
<tr>
<td>HCO\textsubscript{3}\textsuperscript{–}, 19 mEq/liter</td>
<td></td>
</tr>
<tr>
<td>PaO2, 78 mm Hg</td>
<td></td>
</tr>
<tr>
<td>SaO\textsubscript{2}, 89%</td>
<td></td>
</tr>
</tbody>
</table>

**Step 1**: The PaO\textsubscript{2} and SaO\textsubscript{2} indicate mild hypoxemia. Administer supplemental oxygen and continue to monitor the patient’s oxygenation status.

**Step 2**: The pH indicates acidosis.

**Step 3**: The PaCO\textsubscript{2} level indicates alkalosis in the respiratory component of the ABG.

**Step 4**: The HCO\textsubscript{3}\textsuperscript{–} indicates acidosis in the metabolic component of the ABG.

**Step 5**: This patient is in acidosis because the pH is below normal. The origin of the acidosis is metabolic because the HCO\textsubscript{3}\textsuperscript{–} value matches the acid-base status of the pH.

**Step 6**: The PaCO\textsubscript{2} isn’t within normal limits, so the patient is partially compensated.

**Step 7**: The patient is in partially compensated metabolic acidosis with mild hypoxemia.

#### Case 2

<table>
<thead>
<tr>
<th>The patient’s values are:</th>
<th>pH, 7.36</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaCO2, 29 mm Hg</td>
<td></td>
</tr>
<tr>
<td>HCO\textsubscript{3}\textsuperscript{–}, 20 mEq/liter</td>
<td></td>
</tr>
<tr>
<td>PaO2, 108 mm Hg</td>
<td></td>
</tr>
<tr>
<td>SaO\textsubscript{2}, 99%</td>
<td></td>
</tr>
</tbody>
</table>

**Step 1**: The PaO\textsubscript{2} and SaO\textsubscript{2} indicate no hypoxemia.

**Step 2**: The pH indicates acidosis.

**Step 3**: The PaCO\textsubscript{2} level indicates alkalosis in the respiratory component of the ABG.

**Step 4**: The HCO\textsubscript{3}\textsuperscript{–} level indicates acidosis in the metabolic component of the ABG.

**Step 5**: The patient is in acidosis because the pH is on the low side of the normal range. The origin of the acidosis is metabolic because the HCO\textsubscript{3}\textsuperscript{–} matches the acid-base status of the pH.

**Step 6**: The PaCO\textsubscript{2} isn’t within normal limits, but the pH is, so the patient is fully compensated.

**Step 7**: The patient is in fully compensated metabolic acidosis with normal oxygenation.

#### Case 3

<table>
<thead>
<tr>
<th>The patient’s values are:</th>
<th>pH, 7.37</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaCO2, 58 mm Hg</td>
<td></td>
</tr>
<tr>
<td>HCO\textsubscript{3}\textsuperscript{–}, 29 mEq/liter</td>
<td></td>
</tr>
<tr>
<td>PaO2, 65 mm Hg</td>
<td></td>
</tr>
<tr>
<td>SaO\textsubscript{2}, 87%</td>
<td></td>
</tr>
</tbody>
</table>

**Step 1**: The PaO\textsubscript{2} and SaO\textsubscript{2} indicate mild hypoxemia. Administer oxygen and continue to monitor the patient’s oxygenation status.

**Step 2**: The pH indicates acidosis.

**Step 3**: The PaCO\textsubscript{2} level indicates acidosis in the respiratory component of the ABG.

**Step 4**: The HCO\textsubscript{3}\textsuperscript{–} level indicates alkalosis in the metabolic component of the ABG.

**Step 5**: The patient is in acidosis because the pH is on the low side of the normal range. The origin of the acidosis is respiratory because the PaCO\textsubscript{2} matches the acid-base status of the pH.

**Step 6**: The HCO\textsubscript{3}\textsuperscript{–} isn’t within normal limits, but the pH is, so the patient is fully compensated.

**Step 7**: The patient is in fully compensated respiratory acidosis with mild hypoxemia. This is a typical ABG for a stable patient with chronic obstructive pulmonary disease (COPD) and is a commonly seen acid-base disturbance, given the many Americans with COPD.
rapidly blows off too much carbon dioxide, reducing his PaCO₂ and increasing the pH of arterial blood. The body tries to compensate for this alkalosis by using the kidneys to excrete more bicarbonate, which makes arterial blood more acidic.

An uncompensated status indicates that one of the body systems (respiratory or kidneys) has made no attempt to compensate for the changing pH. A partially compensated status indicates that the opposing body system is attempting to compensate but hasn’t changed enough to bring the pH back to normal limits. In this case, the opposing body system value will be outside its normal range in the direction opposite to the cause of the problem.

A fully compensated status consists of pH within normal limits and values for the respiratory and metabolic components that are outside their normal ranges but in opposite directions. Remember that patients with COPD often have ABG results that show fully compensated respiratory acidosis.

As carbon dioxide levels in the blood increase, more hydrogen ions are generated and the pH will drop, resulting in acidosis. As carbon dioxide decreases, fewer hydrogen ions are generated and the pH increases, resulting in alkalosis. Increases in HCO₃⁻ in the blood take hydrogen ions out of circulation, resulting in alkalosis; decreases in HCO₃⁻ leave more hydrogen ions in circulation, resulting in acidosis.

Now let’s apply these principles to interpreting a patient’s ABG results.

**Taking a systematic approach**

Suppose your patient’s ABG results are as follows: pH, 7.52; PaCO₂, 30 mm Hg; HCO₃⁻, 24 mEq/liter; PaO₂, 89 mm Hg; and SaO₂, 96%.

You can see immediately that the pH is elevated, the PaCO₂ is low, and the remaining values are within normal limits. How do you assess what these values tell you about the patient’s condition? Follow these steps:

**Step 1:** Examine the PaO₂ and the SaO₂ levels to determine if hypoxemia exists and intervene if necessary. In our example, both values are within normal limits, so the patient isn’t hypoxemic. Continue to monitor his oxygenation status.

**Step 2:** Examine the pH and determine if it indicates acidosis or alkalosis and circle the correct term. Note that a pH between 7.35 and 7.40 is considered normal acidic; a pH between 7.41 and 7.45 is considered normal alkalotic. In the example, the pH of 7.52 indicates a clear alkalosis.

**Step 3:** Examine the PaCO₂ and determine if it indicates acidosis or alkalosis. In this example, the PaCO₂ is low, so the respiratory component indicates alkalosis.

**Step 4:** Examine the HCO₃⁻ and determine if it indicates acidosis or alkalosis. In the example, this metabolic component is normal.

**Step 5:** Identify the origin of the acid-base disturbance as respiratory or metabolic. Circle the acidosis or alkalosis that matches the pH. In this case, the PaCO₂ matches the pH, indicating respiratory alkalosis.

**Step 6:** Now determine whether the patient is in compensation. Is the pH within normal limits? If so, the patient is fully compensated. If not, look at the value you didn’t circle (the one that didn’t match the pH)—the HCO₃⁻ in our example. Its within normal limits, so the patient is uncompensated. If this value had been outside the normal limits on the acidic side (because the pH was outside normal), the patient would be partially compensated.

**Step 7:** Put it all together: The patient is in uncompensated respiratory alkalosis with normal oxygenation.

For more practice, see *Test Your ABG Interpretation Skills.*

**Easy does it**

With practice and careful thought, you can improve your skill and accuracy at ABG interpretation. By adding your knowledge of your patient’s clinical condition to what’s happening with his oxygenation, ventilation, and acid-base balance, you can intervene correctly and deliver better patient care.

**SELECTED REFERENCES**


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**SELECTED WEB SITE**

Virtual Hospital

An Approach to the Analysis of Arterial Blood Gases and Acid-Base Disorders

http://www.vh.org/adult/provider/ internalmedicine/bloodgases

Last accessed on July 1, 2004.