As technology has improved, become more reliable, and more cost effective, point-of-care blood gas testing has become an increasingly common clinical tool found in primary care and emergency veterinary hospitals. These tests are not only more reliable and cost effective, but they allow the veterinarian to receive results within minutes, improving patient evaluation and patient care.

**BLOOD GAS ANALYSIS**

Blood gas evaluation is important to consider in patients that present with diseases that include, but are not limited to, metabolic disease, hypovolemia, toxicity, or gastrointestinal upset including vomiting and diarrhea.

When we evaluate a blood gas, common parameters evaluated include pH, partial pressure of arterial oxygen (PaO₂), and the partial pressure of carbon dioxide (PCO₂) of blood. These values assist in interpretation of the overall acid-base status, respiratory and metabolic contributions, and pulmonary function. More specifically, the partial pressure of arterial oxygen (PaO₂) allows us to assess oxygenation of the patient and the partial pressure of carbon dioxide (PCO₂) assesses ventilation.

When a blood gas is performed, most clinicians will first evaluate the pH. On average, the normal pH is considered to be between 7.35 and 7.45. Acidemia is defined as a pH below 7.35, while a pH above the normal range (7.45) would be considered alkalemia. The lower the pH, the more severe the acidemia. Severe acidemia may result in systemic illness including decreased cardiac output, decreased cardiac contractility, impaired renal and hepatic blood flow, decreased arterial blood pressure, and neurological alterations. Acidemia may also shift the oxygen-hemoglobin dissociation curve to the right, worsening oxygen delivery to tissues.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dog</th>
<th>Cat</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.35-7.46</td>
<td>7.31-7.46</td>
</tr>
<tr>
<td>PCO₂ (mm Hg)</td>
<td>32-43</td>
<td>26-36</td>
</tr>
<tr>
<td>HCO₃⁻ (mEq/l)</td>
<td>18-26</td>
<td>14-22</td>
</tr>
<tr>
<td>BE</td>
<td>+1 to -5</td>
<td>-2 to -8</td>
</tr>
<tr>
<td>PaO₂ (mm Hg)</td>
<td>80-105</td>
<td>95-115</td>
</tr>
</tbody>
</table>

Table: Normal arterial blood gas values (Dibartola's Fluid Therapy Small Animal Practice).

Once the pH is evaluated the clinician should determine if the pH abnormality (acidosis or alkalosis) is metabolic or respiratory in origin.

Metabolic acid-base abnormalities include either a metabolic acidosis or a metabolic alkalosis. The author enjoys (medically…) seeing a **metabolic acidosis** on blood gas evaluation as there are a limited number of processes that cause this abnormality. A metabolic acidosis is characterized by a decreased pH, negative base excess (BE), and decreased plasma bicarbonate (HCO₃⁻) concentration commonly seen with clinical diseases including diabetic ketoacidosis (DKA), toxicities (e.g., ethylene glycol, aspirin/salicylates), renal failure, and lactic acidosis. **Metabolic alkalosis** is much less common in clinical practice, resulting from increased HCO₃⁻ concentrations and an increased pH (pH > 7.45). Clinically, we see a metabolic alkalosis in cases of upper gastrointestinal (GI) obstruction or following the use of furosemide (or other loop diuretics). Less common causes for metabolic alkalosis include hypochloremia, penicillin derivatives, and an iatrogenic complication of sodium bicarbonate therapy.
While metabolic disturbances result from alterations in base excess (BE) and plasma bicarbonate (HCO₃⁻), respiratory changes are typically due to alterations in PCO₂. Increased PCO₂ levels, due to hypoventilation, results in a respiratory acidosis. Hypoventilation results from causes including, but not limited to, toxins (e.g., muscle relaxants, sedatives, etc.) Conversely, hyperventilation results in a respiratory alkalosis, with a lower PCO₂. We commonly see this hyperventilation (i.e. panting) from pain, hyperthermia, or primary respiratory disorders including pneumonia or pulmonary thromboembolism.

While each of the conditions discussed can be found in isolation, we can also see mixed acid-base abnormalities. A mixed disorder results from two or more separate, primary acid-base abnormalities.

**The author uses the following steps in blood gas analysis:**

1. Is the pH normal? If not, is the pH acidemic or alkalemic?
2. Is the base excess (BE) normal? If not, is the BE more negative (acidemic) or more positive (alkalemic)
3. PaCO₂/PCO₂ = evaluation of respiratory component
4. If there is an abnormality, does the patient show a compensatory response?
5. Treat the patient, not a number. Do the abnormalities present make sense in the clinical picture?

**1) pH**

The pH is the concentration of free hydrogen ions (H⁺) expressed as a negative logarithm - meaning that the more hydrogen ions (acids) there are, the lower the number will be. It reflects the balance between acids and bases, buffers and compensatory mechanisms rather than being a measure of the total amount of acids and bases. If the pH is lower than the normal range, an acidemia exists. If the pH is higher than the normal range, an alkalemia exists. If the pH is normal but there are other blood gas disturbances (abnormal PCO₂, HCO₃⁻, BE, etc.) this would prompt the clinician to evaluate a potential mixed acid-base or compensated disorder.

**2) Base excess (BE)**

The base excess, otherwise knows as base deficit, is a calculated value reflecting the metabolic portion of the acid/base balance. It takes into account all of the body's buffer systems and is an estimate of how much base needs to be added or taken away from the system to achieve a normal pH at a normal temperature. When the base excess is negative (e.g., BE -10 mm Hg) a primary metabolic acidosis exists. When the base excess is positive (e.g., BE +10 mm Hg) a primary metabolic alkalosis exists

**3) Bicarbonate (HCO₃⁻)**

Next, the metabolic (HCO₃⁻) and respiratory (PCO₂) components of the blood gas are evaluated. Bicarbonate (HCO₃⁻) is a calculated value based on pH and CO₂. The kidneys balance hydrogen ions and bicarbonate ions, normally excreting H⁺ (acid) and retaining HCO₃⁻ (base) to help maintain pH balance. This represents the metabolic component of acid-base regulation.

**4) Partial pressure of dissolved oxygen in arterial blood. (PaO₂)**

If an arterial sample is obtained, the clinician can also determine if the patient is hypoxemic. PaO₂ is the partial pressure of dissolved oxygen in arterial blood. A decrease in PaO₂ is defined as hypoxemia, notably less than 80 mm Hg.

**5) Partial pressure of dissolved carbon dioxide (PCO₂)**

PCO₂ is the partial pressure of dissolved carbon dioxide in blood and is a direct measure of alveolar ventilation. While metabolic changes within the kidney may takes days, changes in the level of CO₂ by altering ventilation results in a rapid alteration in CO₂ and therefore pH.
Further evaluation of oxygenation and ventilation can be evaluated through calculations using an arterial blood gas sample.

1) The alveolar-arterial oxygen gradient ($P_{A\text{O}_2}$-$P_{a\text{O}_2}$ gradient), which is the difference between the amount of oxygen within the alveoli of the lungs (calculated) and the amount of oxygen dissolved in the arterial blood (measured) can be used to evaluate the severity of pulmonary dysfunction.

$$P_{A\text{O}_2} = [(P_B - P_{H_2O}) \times FiO_2] - P_{a\text{CO}_2} \times (1/RQ)$$

- $P_B$ is barometric pressure
- $P_{H_2O}$ is partial pressure of water vapor at 100% humidity.

$P_{A\text{O}_2}$ of an animal with normal lungs at sea level ($P_B = 760$, $P_{H_2O} = 47$) breathing room air ($FiO_2 = 0.21$) with normal ventilation ($P_{a\text{CO}_2} = 40$) is thus approximately:

$$P_{A\text{O}_2} = 713 \times 0.21 - 40/0.9 = 149 \text{ mm Hg}$$

Normally $P_{A\text{O}_2}$-$P_{a\text{O}_2}$ gradient < 20 mm Hg in normally functioning lung

2) The $P_{a\text{O}_2}$/FiO$_2$ ratio can also be used.

For example, a patient with normal lung function breathing room air: $P_{a\text{O}_2}$/FiO$_2 = 105/0.21 = 500$

$P_{a\text{O}_2}$/FiO$_2$ < 300 consistent with acute lung injury
$P_{a\text{O}_2}$/FiO$_2$ < 200 consistent with ARDS

**Compensation**

While the body will attempt to compensate for a primary acid-base abnormality, the general rule is that the body will not over-compensate.

- Metabolic acidosis: ↓ $P_{a\text{CO}_2}$ of 0.7 mm Hg per 1 mEq/L ↓ $HCO_3$
- Metabolic alkalosis: ↑ $P_{a\text{CO}_2}$ of 0.7 mm Hg per 1 mEq/L ↑ $HCO_3$
- Respiratory acidosis: ↑ 0.15 to 0.35 mEq/L $HCO_3$ per 1 mm Hg ↑ $P_{a\text{CO}_2}$
- Respiratory alkalosis: ↓ 0.25 to 0.55 mEq/L $HCO_3$ per 1 mm Hg ↓ $P_{a\text{CO}_2}$

**CONCLUSION**

Blood gas analysis is a rapid, cost effective, cage-side test that will empower the clinician to assess whether an abnormality in oxygenation or ventilation exists, to monitor its severity, and to assess response to therapy. Both arterial and venous blood gas analysis can provide valuable information, improving the quality of care for your patients.

References: