An introduction to blood gas analysis

Blood gas analysis is a procedure that is associated with high dependency, intensive care and respiratory units, but equipment used to carry out blood gas analysis is now commonplace on hospital wards and in some community services. It is, therefore, important for nurses in primary and secondary care to understand the significance of blood gas analysis.

Pulse oximetry and blood gas analysis In many clinical situations blood gas analysis is preferable to pulse oximetry. Although pulse oximetry measures oxygen (O\textsubscript{2}) saturation it does not measure levels of carbon dioxide (CO\textsubscript{2}). This means patients breathing in high concentrations of O\textsubscript{2} might have a substantial rise in arterial CO\textsubscript{2} levels before an abnormal O\textsubscript{2} saturation reading would be registered by the pulse oximeter. Reliance on pulse oximetry to monitor patients who are retaining or excreting excessive amounts of CO\textsubscript{2} is of little value and may lead to deterioration or death (Scanlan et al, 1995).

Blood gases and associated physiology In order to analyse blood gases it is important to understand the associated physiology including the nature of acids and bases, and pH levels. It is also important to understand the role that the lungs and kidneys play in maintaining the acid-base balance of body fluids.

Acids An acid is a molecule that releases hydrogen ions (H\textsuperscript{+}) into a solution. Strong acids ionise completely by releasing all of their H\textsuperscript{+} ions into solution. Weak acids do not ionise completely.

Base A base is a molecule that releases hydroxyl ions (OH\textsuperscript{-}) into a solution, or accepts hydrogen ions. Bases may also be strong or weak.

pH The pH of a solution is a measure of its acidity or basicity. In other words it is a measure of the number of H\textsuperscript{+} ions in a solution. Most solutions have a pH between nought and 14. The smaller the pH value, the more H\textsuperscript{+} ions have been released into solution and the more acidic the solution is. A pH of 7 is exactly neutral. Pure water (H\textsubscript{2}O) is pH 7 because it has equal numbers of H\textsuperscript{+} ions and OH\textsuperscript{-} ions. Mixing equal quantities of H\textsuperscript{+} ions and OH\textsuperscript{-} ions results in a neutral solution.

pH and human physiology The normal pH of blood is between 7.35 and 7.45, but it is useful to use the figure 7.4 as normal. It is impossible to sustain life with a blood pH of below 6.8 or above 7.8.

There are a number of situations that can lead to a change in plasma pH. In order to minimise the potential for damage that an excessively acidic or alkaline (basic) environment could cause, the acid-base balance of blood plasma is buffered. Buffer systems exist to prevent large swings in pH. They act as a ‘sponge’ to ‘absorb’ acids or bases, before the acid or base can be removed from the body by the lungs or kidneys. Three major biological buffer systems exist: the bicarbonate, phosphate and protein systems.

Acid-base balance and the lungs CO\textsubscript{2} is carried in the blood in a number of ways. Some of the CO\textsubscript{2} combines with water to produce carbonic acid (H\textsubscript{2}CO\textsubscript{3}). As the level of CO\textsubscript{2} rises in the blood so does the level of carbonic acid. When carbonic acid, carried in the blood, reaches the lungs it dissociates into H\textsubscript{2}O and CO\textsubscript{2}. The CO\textsubscript{2} is then exhaled from the body by the lungs.

Respiratory acidosis In some circumstances, the level of CO\textsubscript{2} in the blood builds up forcing up the level of carbonic acid and causing blood pH to drop. This is called respiratory acidosis. Disorders that can result in respiratory acidosis include chronic obstructive pulmonary disease (COPD), trauma to the chest and central nervous system, and neurological disorders.

When carbonic acid levels rise in the blood there is a danger that hydrogen ions will be released resulting in a fall in pH. Bicarbonate (HCO\textsubscript{3}-) cannot directly buffer carbonic acid, but can stop it from releasing hydrogen ions into the blood as readily. An increase in serum bicarbonate can, therefore, reduce the impact that increased levels of carbonic acid has on blood pH. If the ratio of bicarbonate to dissolved CO\textsubscript{2} is 20:1 the pH of the blood is normal at 7.4. Any variation in the carbonic acid to bicarbonate ratio will alter blood pH.

The kidney can compensate for respiratory acidosis by producing more bicarbonate. For example, a patient may be hypercapnic (have a raised CO\textsubscript{2} level) and, therefore, have high levels of carbonic acid in the blood, but have a normal pH due to raised bicarbonate levels. The result is a pH in the normal range of 7.35 to 7.45, but on the acid side of 7.4, for example 7.38. This is described as compensated respiratory acidosis.

Even without renal compensation for acidosis, serum bicarbonate levels rise with carbonic acid levels due to a chemical process called hydration reaction. The rise is small compared with a rise due to renal compensation, and if bicarbonate levels are higher than the normal range (22-26 mEq/l) this is due to renal compensation.

Respiratory alkalosis If the lungs are eliminating CO\textsubscript{2} too efficiently then the level of carbonic acid in the blood may drop, with a resultant rise in its pH. This is called
respiratory alkalosis. Hyperventilation will result in respiratory alkalosis. Causes of hyperventilation include pain, anxiety, fever, stimulant drugs and sepsis. The kidneys can compensate for respiratory alkalosis by reducing the level of bicarbonate in the blood.

Metabolic (or non-respiratory) acidosis Acidosis can also be caused by metabolic problems such as diabetic ketoacidosis, lactic acidosis, and diarrhoea (the latter because of a loss of bicarbonate from the bowel). Metabolic acidosis results in a lower blood pH and levels of bicarbonate. The bicarbonate is lower either because it is used as a buffer or because it has been lost. Loss through diarrhoea is the primary cause of acidosis.

The lungs can compensate for metabolic acidosis by breathing off more CO₂, thus reducing serum levels of carbonic acid. This can be seen when a patient with diabetic ketoacidosis breathes deeply.

Metabolic (non-respiratory) alkalosis In some circumstances the body can increase its buffer base (bicarbonate), or lose acid, causing the blood pH to rise. This is called metabolic alkalosis. Vomiting (causing loss of acid), dehydration and electrolyte imbalance can all lead to metabolic alkalosis.

Arterial blood gas analysis results The normal values for arterial blood gases are:
- pH: 7.35–7.45;
- PaCO₂ (arterial partial pressure of carbon dioxide): 4.7–6.0kPa (kilopascals);
- PaO₂ (arterial partial pressure of oxygen): 11.3–14.0kPa;
- HCO₃⁻: 22–26mEq/l;
- Base excess: + or – 2.5mEq/l.

Base excess is a calculated figure that, when used in a mathematical equation reflects the amount of acid or base needed to change one litre of blood to pH7.4. A positive base excess indicates a gain of base or a loss of acid. This applies to non-respiratory (metabolic) imbalances only and is not used when assessing the impact of respiratory problems. A reliance on base excess to quantify metabolic acid-base disturbances can also be misleading (Scanlan et al, 1995).

The interpretation of readings follows six steps, which should be followed in the numerical sequence below.

1. Consider the results in the context of the patient’s history. Blood gas analysis can be misleading especially if there are mixed respiratory and non-respiratory factors.
2. Look at the PaO₂ reading. If the reading is below 8kPa the patient is classified as being in respiratory failure. If it is below 6.7kPa the patient is dangerously hypoxic.
3. Look at the pH. Is it acidic or basic (alkaline)?
4. Could the PaCO₂ reading explain a low or high pH? Remember that CO₂ combines with H₂O to form carbonic acid. If CO₂ levels explain the pH level then the problem is likely to be respiratory in origin. If the HCO₃⁻ level can explain changes in pH then it is likely that the primary disturbance is non-respiratory, or metabolic in origin.
5. Could the HCO₃⁻ levels explain changes in pH? A low HCO₃⁻ would explain a low pH, and a rise in HCO₃⁻ would explain a high pH. If the HCO₃⁻ level can explain changes in pH then it is likely that the primary disturbance is non-respiratory, or metabolic in origin.
6. Assess for compensation. Are the lungs or kidneys compensating for the primary problem? For example, is a low CO₂ compensating for metabolic acidosis? Is a rise in HCO₃⁻ compensating for respiratory acidosis? In these cases the pH could be within normal range but will not be 7.4. With COPD, a pH of less than 7.26 together with raised bicarbonate can indicate a poor prognosis.

### BOX 1. PRACTICAL EXERCISES FOR INTERPRETATING BLOOD GAS ANALYSIS

| PATIENT A | pH 7.36 |
| PaCO₂ | 8.64kPa |
| PaO₂ | 6.8kPa |
| HCO₃⁻ | 33mEq/l |

| PATIENT B | pH 7.37 |
| PaCO₂ | 7.33kPa |
| PaO₂ | 8.2kPa |
| HCO₃⁻ | 29mEq/l |

| PATIENT C | pH 7.36 |
| PaCO₂ | 3.42kPa |
| PaO₂ | 12.3kPa |
| HCO₃⁻ | 13mEq/l |

**ANSWERS**
A The patient is significantly hypoxic and has partially compensated respiratory acidosis
B Respiratory alkalosis
C Typical COPD: compensated respiratory acidosis
D Extremely hypoxic respiratory acidosis, poor prognosis
E Compensated metabolic acidosis.