A simple approach to blood gas analysis: the essentials

Lisa Angell VTS(Anaesthesia) RVN
Chris Seymour MA VetMB DVA DipECVAA FHEA MRCVS

Queen Mother Hospital for Animals, The Royal Veterinary College, Hawkshead Lane, North Mymms, Hatfield, Hertfordshire, AL9 7TA. UK

ABSTRACT: Blood gas analysis allows you to assess a patient's acid-base status as well as important aspects of respiratory function. Understanding the results might seem challenging initially, but the information can often be lifesaving if properly interpreted. One common cause of misunderstanding is the vague use of terminology, which this article aims to clarify. Portable and bench-top analysers are becoming more common in veterinary practice so it is even more important that RVNs know how to interpret the results.

Lisa Angell VTS(Anaesthesia) RVN

Lisa is the head anaesthesia nurse at the RVC's Queen Mother Hospital for Animals. She qualified as a veterinary nurse in 2007 and in 2012 became board certified as a veterinary technician specialist in anaesthesia.

Chris Seymour MA VetMB DVA DipECVAA FHEA MRCVS

Chris is part of the Veterinary Anaesthesia and Analgesia service at the Queen Mother Hospital for Animals and is particularly interested in safety in anaesthetic practice, intravenous fluid therapy during surgery and in providing the best possible pain management for all patients.

DOI: 10.1080/17415349.2015.1024431

First things first: definitions

Interpretation of results provided by blood gas analysis can often be confusing because of the inaccurate use of terminology. It is therefore important to define precisely what some terms actually mean, which we hope will help to avoid unnecessary misunderstanding:

- **Acidaemia**: a blood pH below the normal reference range
- **Acidosis**: a pathological process which would, if uncompensated, tend to reduce blood pH
- **Alkalaemia**: a blood pH above the normal reference range
- **Alkalosis**: a pathological process which would, if uncompensated, tend to increase blood pH
- **Hypoxaemia**: a low partial pressure of oxygen (PO_2) in arterial blood; normally it is defined as a PO_2 less than 60 mmHg (8 kPa)
- **Hypoxia**: a state of inadequate tissue oxygenation; hypoxia may be classified as either *generalized*, affecting the whole body, or *local*, affecting a region of the body
- **Partial pressure**: the pressure exerted by an individual gas in a gas mixture, indicated by the letter 'P'; for example PO_2 indicates the partial pressure of oxygen, which can be expressed either in mmHg or in kPa (kilopascals) (1 kPa = 7.5 mmHg)
- **Tension**: Another term for partial pressure

What information does a blood gas analyser provide?

Blood gas analysers (**Figure 1**) measure the pH and the partial pressures of oxygen and carbon dioxide (PO_2 and PCO_2 respectively) in a blood sample, which may be either arterial or venous (see below). From these measurements, the analyser can also calculate other useful values, including plasma bicarbonate concentration (HCO_3^-), base excess (BE) and the percentage saturation of haemoglobin with oxygen (SO_2). The added bonus of newer machines is that they also measure concentrations of electrolytes, lactate and glucose. Traditionally, blood gas tensions have been reported in mmHg, although there is an increasing trend to use the SI unit of kilopascals (kPa). Conversion from one to the other is straightforward, as 1 kPa = 7.5 mmHg.

Arterial samples

Arterial blood gas analysis is the 'gold standard' method for evaluating gas exchange; it provides invaluable information about a patient's oxygenation, ventilation and acid-base status. Accurate interpretation of the pH,

Figure 1. A portable blood gas analyser

PCO_2 and HCO_3^- alongside the clinical evaluation of a patient's history can help identify both respiratory and metabolic acidosis and alkalosis, as well as ongoing compensatory mechanisms.

Venous samples

Venous samples are suitable if we want to assess only acid-base status, although they can also give us some indication of oxygen extraction by the tissues if venous and arterial PO_2 values are compared. If the venous PO_2 is lower than expected, it suggests that perfusion of peripheral tissues is reduced. Venous blood must be sampled from the jugular vein because it is a close approximation to mixed venous blood (i.e. from the pulmonary artery). When taking jugular samples for venous blood gas analysis, it's very important that you do not compress the vein otherwise values for PO_2 and pH will be lower, whilst those for PCO_2 will be higher.

pH

The normal range for blood pH is 7.35–7.45. If the blood pH is less than 7.35, an *acidaemia* exists; if the blood pH is greater than 7.45, an *alkalaemia* exists. The terms *acidosis* and *alkalosis* are used to describe the *cause* of the acid-base disturbance; in other words, they refer to the processes occurring at a cellular level which, if uncorrected, would result in pH changes, i.e. either an acidaemia or an alkalaemia.

It is vital for normal body function that pH is kept within this narrow range, and three basic mechanisms are used to try to maintain homeostasis:

1. *Respiratory control of the partial pressure of carbon dioxide in arterial blood* ($PaCO_2$) by the respiratory centre in the central nervous system, which regulates ventilation: the lower the pH (and hence the higher the concentration of hydrogen ions, H^+), the more carbon dioxide (a volatile acid) is expired from the lungs. This is a rapid and powerful compensatory system.
2. *Renal bicarbonate control and excretion of metabolic (non-volatile) acids*: this is a relatively slow system (hours or days).
3. *Buffering by bicarbonate, sulphate and haemoglobin*; buffers are molecules that can either 'take up' or 'give up' hydrogen ions to maintain pH.

Arterial PO_2

The vast majority (98%) of oxygen in the blood is bound to haemoglobin, which is why pulse oximetry is such a valuable piece of equipment for monitoring oxygenation of our patients, especially during anaesthesia. The pulse oximeter provides two important measurements: the pulse rate and the percentage of haemoglobin saturated with oxygen (denoted as SpO_2 to distinguish it from the value of saturation calculated by a blood gas analyzer, SO_2). Only a tiny fraction (approximately 2%) of the total oxygen content in blood is dissolved, but it is this dissolved oxygen that generates the PO_2. You may be asking: why is the PO_2 important if it represents such a tiny fraction of the total amount of oxygen in the blood? The answer is that this pressure is needed to 'drive' oxygen into the cells. The partial pressure of oxygen in the tissues is lower than in arterial blood, so that oxygen molecules move down this pressure gradient, despite the affinity of haemoglobin for oxygen.

As a general rule of thumb, the arterial PO_2 (in mmHg) should be approximately five times the inspired percentage concentration of oxygen: for example, a patient breathing room air (21% oxygen) should have an arterial PO_2 of around 100 mmHg (13 kPa), whereas a patient breathing 100% oxygen should have an arterial PO_2 around 500 mmHg (66 kPa). Clinically significant hypoxaemia is diagnosed when a patient's arterial PO_2 is less than 80 mmHg (10.6 kPa) (**Table 1**). Values of 60 mmHg (8 kPa) or less require intervention, such as mechanical ventilation. Reduced inspired oxygen concentration and certain conditions including pneumonia and pulmonary oedema can affect oxygenation and cause hypoxaemia. In healthy small animals during anaesthesia, hypoxaemia is rare, providing an inspired oxygen concentration of at least 30% is administered.

Arterial PCO_2

Carbon dioxide is carried in the blood in three different ways (**Figure 2**). The majority (approximately 70%) is carried as bicarbonate (HCO_3^-) (due to a reaction with water, catalysed by carbonic anhydrase in red blood cells),

Table 1. Relationship between arterial oxygen tension (PO_2) and saturation of haemoglobin with oxygen (SO_2)

Status	Arterial PO_2	Arterial SO_2
Normal	> 80mmHg (> 10.6kPa)	> 95%
Serious hypoxaemia	< 60mmHg (< 8kPa)	< 90%
Critical hypoxaemia	< 40mmHg (< 5.3kPa)	< 75%

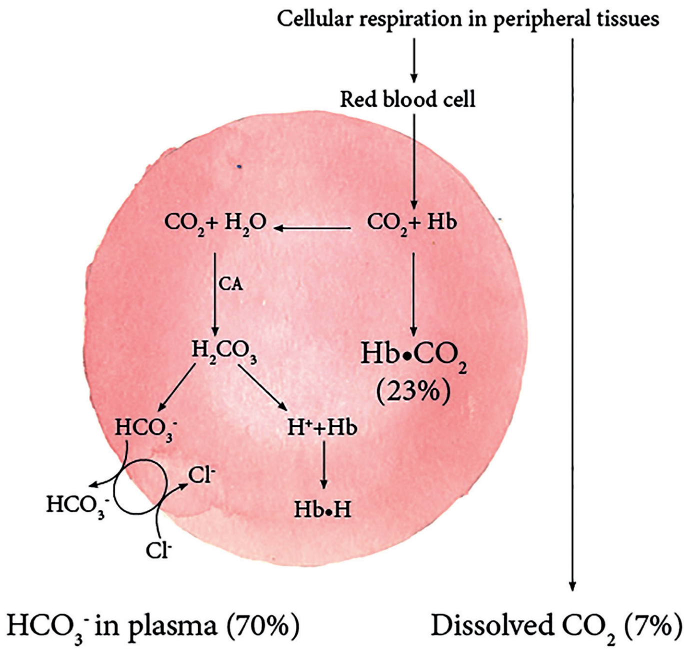

Figure 2. Diagram showing how carbon dioxide is carried in the blood (CA = carbonic anhydrase; Hb = haemoglobin; H_2CO_3 = carbonic acid; HCO_3^- = bicarbonate; Cl^- = chloride)

with 15% bound to haemoglobin and other proteins, and 7% is dissolved in the blood. The bicarbonate ions formed inside the red blood cell diffuse out in exchange for chloride ions (the so-called 'chloride shift'). As with oxygen, it is the dissolved fraction that generates the PCO_2. The anaesthetist can evaluate how well the patient is eliminating carbon dioxide by evaluating arterial PCO_2. The normal range in a conscious animal is 35–45 mmHg (4.6–6.0 kPa).

During general anaesthesia, arterial PCO_2 is usually slightly elevated due to the respiratory depression caused by most anaesthetics, and this can be treated as normal. An arterial PCO_2 of more than 60 mmHg (8 kPa) indicates that the patient is hypoventilating and mechanical ventilation may be required. The patient's depth of anaesthesia should be evaluated first and, if possible, concentrations of volatile anaesthetics reduced. Sometimes, even smaller increases in arterial PCO_2 can cause cardiac arrhythmias from catecholamine release, so any decision to intervene should be based on the patient's condition rather than on the actual value of arterial PCO_2.

For carbon dioxide, we can use end-tidal values provided by capnography as a good non-invasive estimate of arterial PCO_2. The two values are normally very similar, but there are occasions when they are not, for example in some types of lung disease, and in those situations arterial blood gas analysis is essential.

Bicarbonate

Bicarbonate concentration in the blood depends on both respiratory and metabolic components of acid-base balance. Blood gas analysers, therefore, usually provide a calculated value for *standard bicarbonate*. The standard bicarbonate is the concentration of HCO_3^- in a sample of blood kept at a temperature of 37°C and at an arterial PCO_2 of 40 mmHg (5.3 kPa). This measurement avoids any changes in HCO_3^- caused by respiration and is useful for assessing any metabolic disturbances in acid-base balance.

Base excess

Base excess gives us an idea of the metabolic contribution to an acidaemia or alkalaemia. It represents the amount of acid or base that would need to be added to a blood sample to produce a pH of 7.4, under the conditions specified for standard bicarbonate above.

Anion gap

The anion gap (AG) is the difference in the measured cations (positively charged ions: sodium $[Na^+]$ and potassium $[K^+]$) and the measured anions (negatively charged ions: chloride $[Cl^-]$ and bicarbonate $[HCO_3^-]$) in plasma:

$$AG = ([Na^+] + [K^+]) - ([Cl^-] + [HCO_3^-])$$

In order to maintain electroneutrality, the number of cations must equal the number of anions. An increased anion gap suggests an excess of unmeasured anions such as lactate, ketoacids (in uncontrolled diabetes mellitus), toxins (especially ethylene glycol – 'antifreeze') or accumulating metabolites in renal failure.

Interpreting blood gas values

Interpreting blood gas values need not be as daunting as you think, as long as some basic rules are followed. A guide to the normal reference ranges is shown in **Table 2**.

Table 2. Reference ranges for values provided by arterial blood gas analysis in dogs and cats

Parameter	Normal Values	Decreased	Increased
Arterial PO_2 (mmHg)	Approximately five times inspired percentage of O_2	Hypoxaemia Severe at <60mmHg	-
Arterial SO_2	95–100%	<90% indicates hypoxaemia	-
pH	7.35–7.45	Acidaemia	Alkalaemia
Arterial PCO_2 (mmHg)	35–45	Respiratory alkalosis	Respiratory acidosis
HCO_3^- (mmol/l)	22–36	Metabolic acidosis	Metabolic alkalosis
Anion gap canine (mmol/l)	12–25	-	Metabolic acidosis
Anion gap feline (mmol/l)	13–27	-	Metabolic acidosis
Base Excess	+4 to –4	Metabolic acidosis	Metabolic alkalosis

The five steps involved in interpreting blood gas values:

Step 1: What is the patient's oxygenation status?

- Evaluate the patient's arterial PO_2 and SO_2. If they are below normal there is evidence of hypoxaemia.

Step 2: Look at the pH

- As discussed earlier, normal pH is 7.35–7.45. A pH of less than 7.35 is considered acidaemia; a pH greater than 7.45 is considered alkalaemia. The actual pH value represents a summation of all processes tending to increase or decrease pH (acidosis and alkalosis).

Step 3: Look at the PCO_2

- Normal arterial PCO_2 is 35–45mmHg. If the value is below 35 mmHg (4.6 kPa), this suggests the patient has a respiratory alkalosis. If the value is greater than 45 mmHg (6.0 kPa), it suggests the patient has a respiratory acidosis. *Remember:* Acidosis and alkalosis are the processes occurring at a cellular level which, if uncorrected, would result in pH changes, i.e. either an acidaemia or an alkalaemia. It is therefore possible to have a respiratory acidosis with a normal pH if there is metabolic compensation.

Step 4: Look at the HCO_3^-

- Is the HCO_3^- out of the normal range? If it is below the normal range, it suggests the patient has a metabolic acidosis. If it is above the normal range, it suggests the patient has a metabolic alkalosis.

Step 5: Look at the base excess

- If the BE is less than –4, this suggests a metabolic acidosis.
- If the BE is greater than +4, this suggests a metabolic alkalosis.

Example

Table 3 shows the results of arterial blood gas analysis in a three-year-old male crossbreed dog presented after a road traffic accident. He was semi-conscious, with cold extremities and weak femoral pulses. Mucous membranes were pale and capillary refill time was greater than 2 seconds. The sample was obtained for baseline measurements as venous access was being obtained. Oxygen was supplied with a tight-fitting facemask. Look at the results and then work through Steps 1–5 thus:

Table 3. Results of arterial blood gas analysis from a three-year-old crossbreed dog (see text for case details)

Parameter	Value
pH	6.985
PCO_2 (mmHg)	46.1
PO_2 (mmHg)	444.8
Na^+ (mmol/l)	138.9
K^+ (mmol/l)	3.46
Cl^- (mmol/l)	100.2
Ca^{2+} (mmol/l)	0.96
Glucose (mmol/l)	26.07
Lactate (mmol/l)	10.4
Urea (mmol/l)	8.7
Creatinine (µmol/l)	73
Bicarbonate (mmol/l)	11.1
Base excess (mmol/l)	–20.7

Step 1: What is the patient's oxygenation status?

- The arterial PO_2 is just under 450 mmHg. Oxygen is being administered with a tight-fitting facemask, so inspired concentrations will approach 100%. The expected PO_2 is five times the inspired percentage, i.e. around 500%. The PO_2 is therefore roughly what we would expect and the dog is oxygenating well.

Step 2: Look at the pH.

- The results show a value of 6.98, indicating a severe acidaemia.

Step 3: Look at the PCO_2.

- The arterial PCO_2 is 46.1 mmHg, which is just outside the normal range of 35–45 mmHg. This shows the dog is ventilating adequately, and there is only a very slight respiratory acidosis.

Step 4: Look at the HCO_3^-.

- The value is 11.1 mmol/l, which is well below the normal range, suggesting a severe metabolic acidosis. Sometimes HCO_3^- concentrations can be low with hyperchloraemia (hyperchloraemic acidosis), but the chloride concentration is within the normal range.

Step 5: Look at the base excess.

- The BE is –20.7 mmol/l, indicating a severe metabolic acidosis. The most likely cause is a lactic acidosis, as lactate concentration is 10.4 mmol/l (it should normally be less than 2 mmol/l).

The anion gap is greater than normal, which is probably due to the increased concentration of lactate. In view of the clinical history, the most likely cause for the metabolic acidosis is blood loss, resulting in poor tissue perfusion and oxygen delivery and increased anaerobic metabolism, which is generating large quantities of lactic acid. The hyperglycaemia is probably the result of increased sympathetic drive caused by hypovolaemia.

Priority treatment is to restore circulating volume, with crystalloids, colloids or blood products as indicated by estimates of blood volume lost, clinical parameters and repeated laboratory tests. Repeat sampling is warranted to assess response to treatment.

Conclusion

The results of blood gas analysis can give important information on both gas exchange and acid-base balance. A structured approach to interpreting the results is vital when planning a treatment protocol. As with any laboratory tests, proper evaluation of results needs practice – but practice makes perfect!

Further reading

Coggon, J. M. (2008). Arterial blood gas analysis 1: Understanding ABG reports. *Nursing Times* 104(18), pp. 28–29.

Coggon, J. M. (2008). Arterial blood gas analysis 2: Compensatory mechanisms. *Nursing Times* 104(19). pp. 24–25.

Di Bartola, S. P. (2011). *Fluid, Electrolyte and Acid-Base Disorders in Small Animal Practice*. Philadelphia. Elsevier Saunders.

Hennessey, I. & Japp, A. (2007). *Arterial Blood Gases Made Easy*. London. Elsevier Churchill Livingstone.

McGrotty, Y. M. & Brown, A. (2013). Blood gases, electrolytes and interpretation. 1. Blood gases. *In Practice* 35(2). pp. 59–65.

Multiple Choice Questions

1. Which ONE of the following equations relating mmHg to kilopascals (kPa) is TRUE?

(a) 7.5mmHg = 1kPa

(b) 1mmHg = 75kPa

(c) 10mmHg = 1kPa

(d) 1mmHg = 7.5kPa

(e) 75mmHg = 1kPa

2. Which ONE of the following statements is TRUE?

(a) Acidaemia is defined as a blood pH above the normal range

(b) Alkalosis is a pathological process which tends to decrease blood pH

(c) Hypoxaemia is a state of inadequate tissue oxygenation

(d) Partial pressure is the pressure of an individual gas in a gas mixture

(e) The Anion Gap can be represented as $([Cl^-] + [HCO_3^-]) - ([Na^+] + [K^+])$

3. Serious hypoxaemia can be defined as an arterial oxygen tension less than:

(a) 50mmHg

(b) 80mmHg

(c) 60mmHg

(d) 40mmHg

(e) 20mmHg

4. You are monitoring anaesthesia in a 7 year-old entire female Labrador undergoing a fracture repair. She is breathing 2% isoflurane vaporized in oxygen through a parallel Lack system. Her expected arterial PO_2 is:

(a) 220mmHg

(b) 600mmHg

(c) 540mmHg

(d) 490mmHg

(e) 100mmHg

5. An arterial blood sample taken from an overweight German Shepherd dog undergoing splenectomy for a haemoabdomen indicates a PCO_2 of 8.5 kPa. His blood pressure measured with a Doppler placed on the metacarpus is 90mmHg. The most likely cause is:

(a) Increased cardiac output

(b) Anaesthesia-induced respiratory depression

(c) Hyperventilation in response to surgical stimuli

(d) Lactic acidosis as a result of hypovolaemia

(e) Cardiac arrhythmias associated with a splenic tumour

6. Which ONE of the following conditions is associated with a normal anion gap metabolic acidosis?

(a) Lactic acidosis (as a result of poor tissue perfusion)

(b) Ethylene glycol toxicity

(c) Severe diarrhoea

(d) Severe vomiting

(e) Diabetic ketoacidosis

For the answers to the MCQs, please go to: http://www.bvna.org.uk/publications/veterinary-nursing-journal

