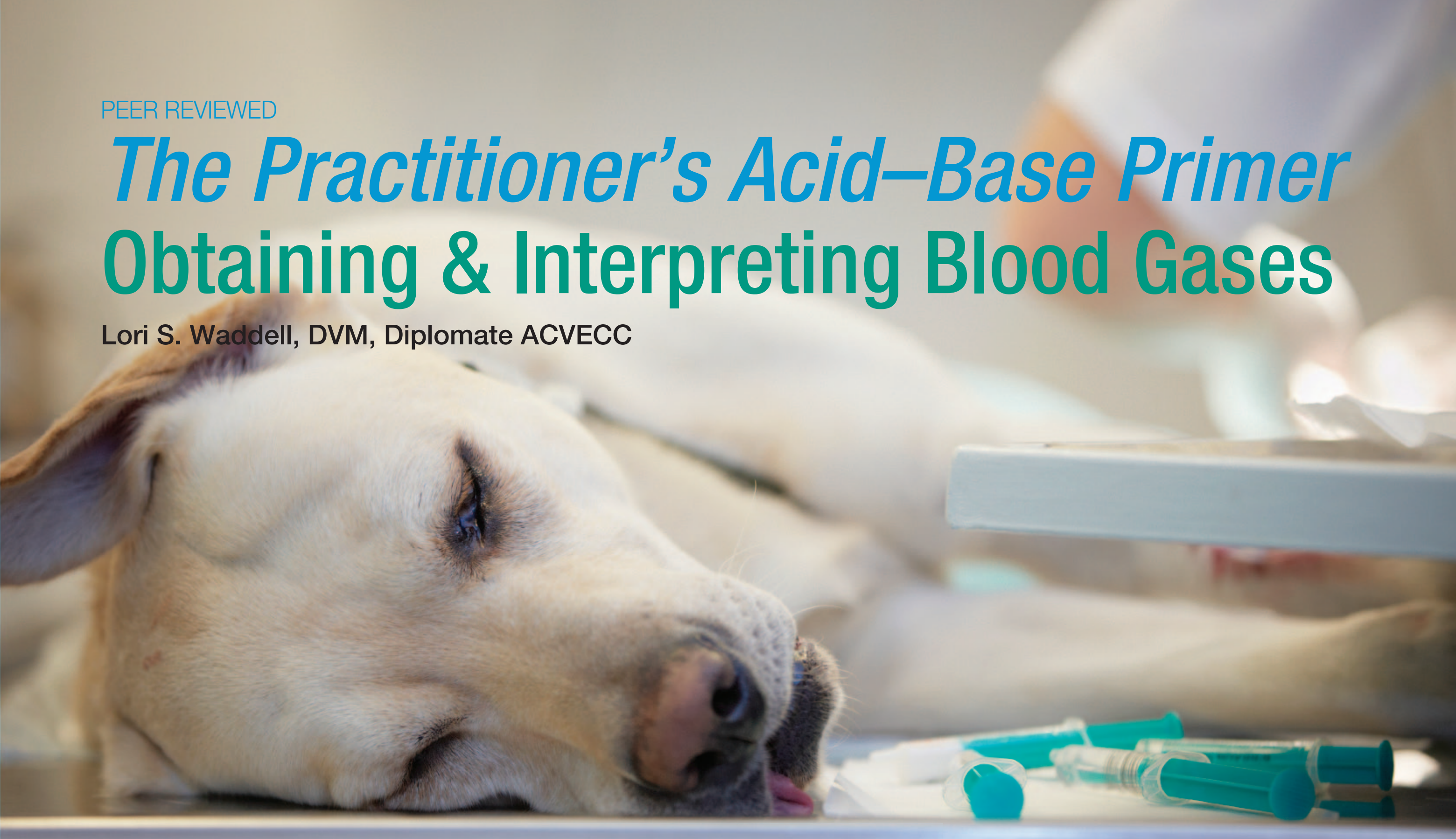

PEER REVIEWED

The Practitioner's Acid–Base Primer

Obtaining & Interpreting Blood Gases

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This article is the first in a 2-part series that addresses alterations in acid–base and respiratory function, which are common in both emergency patients as well as hospitalized, critically ill patients. Familiarity with obtaining and interpreting blood gases can be essential in the management of these patients.

Part 1 will cover obtaining and interpreting blood gases, while **Part 2** will discuss differential diagnoses and therapeutic options associated with acid–base abnormalities.

ACID–BASE OVERVIEW

Metabolic acid–base alterations can lead to:

- Altered cardiovascular, neurologic, and respiratory function
- Altered response to various drug therapies.

Signs of acid–base disturbances are usually vague and cannot be differentiated from clinical signs associated with the underlying disease, making blood gas analysis essential. Both arterial and venous blood gas samples can be used to interpret metabolic derangements.

Metabolic acid–base alterations can often be corrected via appropriate IV fluid therapy, other pharmacologic interventions and, ultimately, by addressing the underlying disease.

RESPIRATORY FUNCTION OVERVIEW

Respiratory function, more specifically the patient's ability to oxygenate and ventilate, can be evaluated with **arterial blood gases**. However, in most cases, **venous blood gases** can also be used to assess ventilation, as venous CO_2 is typically about 5 mm Hg higher than arterial CO_2.

Other options for respiratory function evaluation include physical examination findings and pulse oximetry to detect hypoxemia, although arterial blood gases remain the gold standard.

Figure 1. *Arterial blood gas sample being entered into a blood gas analyzer (heska.com)*

BLOOD GAS ANALYZERS

There are a variety of different blood gas analyzers on the market, ranging from small point-of-care analyzers to larger laboratory equipment (**Figure 1**). Smaller machines are less expensive, relatively good quality, and easy to run and maintain. Some of the larger machines require high maintenance but also provide the best quality control and are more economical when large numbers of samples are anticipated. The type of practice and volume of blood gases the practice evaluates help determine which type of analyzer is best.

REVIEW OF DEFINITIONS

- An **ACID** is a molecule that donates a hydrogen ion (H^+) when a base molecule accepts one.
- A **BUFFER** is a weak acid or base, which helps protect against large changes in pH.
  - The **primary extracellular buffer** is bicarbonate.
  - The **intracellular buffers** are phosphate, proteins, and hemoglobin.
  - Bone also acts as a buffer.
- **pH** is the measure of acidity/alkalinity, and equal to the negative logarithm of H^+ concentration.
- **ACIDEMIA** is a blood pH < 7.35; **ALKALEMIA** is a blood pH > 7.45.

Table 1. Normal Blood Gas Values

	Arterial Values	Venous Values
DOGS[1]		
pH	7.395 ± 0.03	7.352 ± 0.02
PO_2 (mm Hg)	102.1 ± 6.8	55 ± 9.6
PCO_2 (mm Hg)	36.8 ± 2.7	42.1 ± 4.4
HCO_3^- (mmol/L)	21.4 ± 1.6	22.1 ± 2
BE (mmol/L)	-1.8 ± 1.6	-2.1 ± 1.7
CATS[2]		
pH	7.34 ± 0.1	7.30 ± 0.08
PO_2 (mm Hg)	102.9 ± 15	38.6 ± 11
PCO_2 (mm Hg)	33.6 ± 7	41.8 ± 9
HCO_3^- (mmol/L)	17.5 ± 3	19.4 ± 4
BE (mmol/L)	-6.4 ± 5	-5.7 ± 5

- **ACIDOSIS** and **ALKALOSIS** refer to the process causing a pH disturbance. Four basic types of acid–base disturbances have been classified by the traditional Henderson–Hasselbach approach:
  1. **Metabolic acidosis:** A primary gain in acid or loss of base
  2. **Metabolic alkalosis:** A primary gain in base or loss of acid
  3. **Respiratory acidosis:** Retention of CO_2 due to CO_2 production outpacing alveolar ventilation
  4. **Respiratory alkalosis:** Removal of CO_2 (by ventilation) outpacing CO_2 production
- **PaO_2** is the partial pressure of oxygen dissolved in arterial blood. It is a measure of oxygenation, not ventilation.
- **$PaCO_2$** is the partial pressure of carbon dioxide dissolved in arterial blood. It provides the best measure of a patient's ability to ventilate and determines whether respiratory acidosis or alkalosis is present. Remember that CO_2 is approximately 20× more diffusible than O_2, making it easier for a patient to maintain normal CO_2 concentrations in the presence of lung disease.
- **$PvCO_2$** is the partial pressure of carbon dioxide dissolved in venous blood. When the sample has been obtained properly, it measures a patient's ability to ventilate, similar to $PaCO_2$.
- **BASE EXCESS/DEFICIT (BE):**
  - Reflects the metabolic portion of the acid–base balance, which takes into account all of the body's buffer systems
  - Estimates how much base needs to be added or subtracted to achieve a normal pH at normal temperature
  - Evaluates for metabolic acidosis or alkalosis.

- Patients with hypoxemia may become cyanotic, but this sign will not present until hypoxia is severe, and may only become evident just prior to death, making it an unreliable indicator of adequate oxygenation.
- Respiratory rate and effort can be difficult to interpret as they are affected by many other factors, such as pain, excitement, fear, and metabolic derangements, and can be masked by sedation or anesthesia.

If a patient is in respiratory distress, supplemental oxygen should be provided prior to obtaining samples for blood gas analysis.

OBTAINING & HANDLING BLOOD GAS SAMPLES

It is essential that blood gas samples be properly obtained and handled, particularly venous samples. Sample error can be introduced in a number of ways (see **Potential Sample Errors**, page 46).

Venous Samples

1. Ideally, a venous sample should be taken from a central catheter (in the cranial or caudal vena cava) or by direct jugular venipuncture in order to obtain the best representation of the global acid–base and respiratory status.
2. Samples should be capped off to prevent exposure to air; then processed immediately. If the sample cannot be processed immediately, it should be placed on ice until evaluation can take place.
3. Samples can either be:
   - Processed immediately without anticoagulant
   - Drawn into a syringe that has been coated in heparin until they can be processed.
4. To prepare a sample with heparin, coat a 3-mL syringe with a small amount of liquid heparin; then draw air up to the syringe's 3-mL mark and forcibly expel the heparin several times. While most of the heparin will be removed from the syringe, enough heparin will remain to affect the measured ionized calcium, which will be unreliable.[3]

STEP BY STEP: OBTAINING ARTERIAL BLOOD GAS SAMPLES

What You Will Need

- Lithium heparin arterial blood gas syringe with needle (usually 25 gauge) ***or***
- 25-gauge needle and 3-mL syringe coated with liquid heparin (as described for venous sample collection)[3]

Step by Step: Obtaining an Arterial Sample

1. **Clip and aseptically prepare the site** chosen for arterial puncture; a metatarsal branch of the dorsal pedal artery is the most common site used.
2. **Place the patient in lateral recumbency**, using the recumbent limb.
3. With the nondominant hand, **palpate the pulse** between the second and third metatarsals.
4. With the dominant hand, **slowly insert the needle** at a 30° to 40° angle. Continue very slowly advancing the needle, watching for a flash of blood in the needle's hub.
   - If no flash is seen, slowly back the needle out, watching for a flash (it is possible that the needle was inserted through the vessel and a sample can be obtained as the needle is backed out).
   - Otherwise, once the needle is very superficial, redirect it if a sample has not yet been obtained.
5. Once a flash is seen:
   - If an arterial blood gas syringe is being used, **allow the syringe to automatically fill**.
   - If a 3-mL syringe is being used, **gently aspirate the plunger** to withdraw blood.
6. After the quantity of blood needed has been obtained, **remove the needle from the artery and apply pressure to the site**, followed by application of a pressure bandage for 30 to 60 minutes.[3]

Step by Step: Placing an Arterial Catheter

Arterial catheters are extremely useful in patients that require repeat arterial blood gas sampling, such as those on mechanical ventilation.

1. **Use of sedation or a local anesthetic**, such as lidocaine, is recommended. Placement during general anesthesia is ideal.
2. **Clip and aseptically prepare the site** chosen for arterial puncture; a metatarsal branch of the dorsal pedal artery is the most common site used. The radial, coccygeal, femoral, and auricular arteries may also be catheterized; however, catheters at these sites are less well tolerated in awake patients and, therefore, more commonly used during anesthesia.[3,4]
3. **Place the patient in lateral recumbency**, using the recumbent limb.
4. Using an over-the-needle short catheter (usually 22-gauge), **penetrate the skin** between the second and third metatarsals and approximately 1/3 distally from the hock to the metatarsophalangeal joint. *If the skin is very thick, make a small nick in the skin with the bevel of a 20-gauge needle prior to inserting the catheter, which prevents burring.*
5. The artery travels dorsolaterally (see **Figure 3**, page 46), at an approximately 30° angle to a perpendicular line drawn between these 2 joints; **angle the catheter appropriately.**
6. Once arterial blood has flashed into the catheter, **advance it into the artery and remove the needle stylet**.
7. **Attach a t-piece to the catheter, inject a small quantity (1–1.5 mL) of heparinized saline**, and **tape the catheter in place** as would be done for a standard IV catheter.
8. **Label the catheter as *arterial*** to avoid inadvertent administration of injections through the catheter.

Arterial Catheters in Cats

Arterial catheters are difficult to place in cats due to their small size. Additionally, cats have less collateral circulation in their distal limbs and, therefore, are more predisposed to ischemic injury of the foot or tail after arterial catheterization. Arterial catheters should not be left in cats for longer than 6 to 8 hours.[4]

Skill Set Required

Obtaining arterial blood samples requires more skill than that required for obtaining venous samples; the vessel cannot be seen and only palpated by pulse (with the exception of the auricular artery, which can often be seen and felt running down the middle of the dorsal aspect of the pinna). Practice, especially on anesthetized patients, and knowledge of the anatomic location of the artery are helpful when developing this skill.

Figure 2. *Obtaining an arterial blood gas sample from the dorsal pedal artery of a 2-year-old neutered male pitbull that was anesthetized for exploratory laparotomy and foreign body removal (from the pylorus of stomach) after presenting for vomiting*

POTENTIAL SAMPLE ERRORS

- **If a sample is obtained from a peripheral vein** in patients with poor perfusion, the sample may reflect the acid–base status of that limb alone rather than that of the whole body.
- **If a limb's vein is occluded for several minutes** to obtain a sample, the sample may reflect lactic acidosis specific only to that limb.
- **If the sample is not immediately evaluated *or* placed on ice until evaluation**, ongoing cellular metabolism by red blood cells will continue to use O_2, produce CO_2, decrease pH, and eventually, once O_2 has been depleted, increase lactate concentration, which further reduces pH as well as HCO_3^- and BE.
- **If the sample is exposed to air** (ie, a blood tube with air in it or an uncapped syringe), the oxygen from the atmosphere will diffuse into the sample while CO_2 diffuses out, which directly affects PaO_2, $PaCO_2$, and pH, rendering the calculated values for HCO_3^- and BE inaccurate and making the sample worthless for acid–base interpretation.

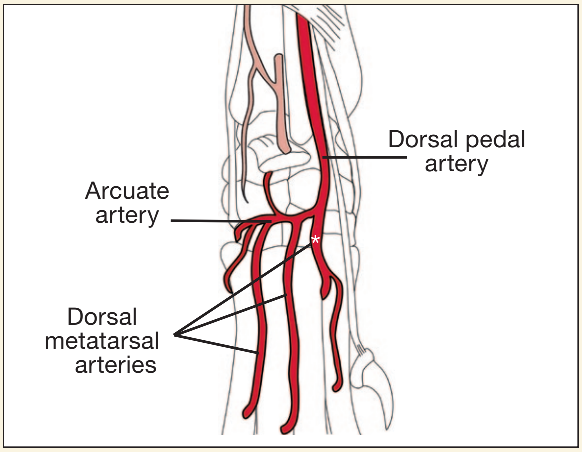

Figure 3. *Diagram showing the dorsal pedal artery and its branches, the dorsal metatarsal arteries. The branch between the second and third metatarsals(*) is most commonly used for arterial puncture and arterial catheter placement.*

Arterial Samples

For additional information, see **Step by Step: Obtaining Arterial Blood Gas Samples**, page 45.

1. Use of a local anesthetic will make the procedure more comfortable for awake patients.
2. Based on the patient, there are numerous sites from which an arterial sample can be taken:

- **Awake dogs:** A metatarsal branch of the dorsal pedal artery is preferred.
- **Anesthetized patients:** Coccygeal, auricular, and radial arteries may also be used; sample collection from these arteries is not well tolerated in awake patients.[3]
- **Small patients:** The femoral artery is typically used; however, if there is excessive bleeding after sampling, this bleeding is much harder to manage with a pressure bandage compared to other sites. Only use this site if sampling from other sites is not possible.
- **Cats:** Arterial puncture in cats is particularly difficult due to their smaller arteries and the fact that they are hard to restrain. Therefore, cats should be sedated or under general anesthesia. The dorsal pedal, femoral, and coccygeal arteries are the most common sites used in anesthetized cats.

Patients in respiratory distress may not tolerate the positioning and restraint needed to obtain arterial samples. A venous blood gas and pulse oximetry reading may be preferable in these patients.

INTERPRETING BLOOD GAS RESULTS

There are 6 steps required to interpret blood gas results:

1. Determine If Sample Is Venous or Arterial

Either sample type can be used to evaluate overall acid–base status, with the exception of severe shock and post arrest situations, which may result in large discrepancies between arterial and venous samples. Poor tissue perfusion can result in sizeable increases in CO_2 and secondary decreases in pH on the venous side despite low to normal CO_2 on the arterial side.

- Although information can be gained about ventilation from a venous sample, only an arterial sample can truly assess oxygenation.
- If unable to obtain an arterial sample, use:
  - » Pulse oximetry to measure oxygen saturation

TABLE 2. EXPECTED COMPENSATORY CHANGES[1]

Disorder	Changes	Compensatory Response
Metabolic acidosis	↓ HCO_3^-	0.7 mm Hg *decrease* in $PaCO_2$ for each 1 mEq/L *decrease* in HCO_3^-
Metabolic alkalosis	↑ HCO_3^-	0.7 mm Hg *increase* in $PaCO_2$ for each 1 mEq/L *increase* in HCO_3^-
Acute respiratory acidosis	↑ $PaCO_2$	1.5 mEq/L *increase* in HCO_3^- for each 10 mm Hg *increase* in $PaCO_2$
Chronic respiratory acidosis	↑ $PaCO_2$	3.5 mEq/L *increase* in HCO_3^- for each 10 mm Hg *increase* in $PaCO_2$
Acute respiratory alkalosis	↓ $PaCO_2$	2.5 mEq/L *decrease* in HCO_3^- for each 10 mm Hg *decrease* in $PaCO_2$
Chronic respiratory alkalosis	↓ $PaCO_2$	5.5 mEq/L *decrease* in HCO_3^- for each 10 mm Hg *decrease* in $PaCO_2$

» Venous sample to evaluate acid–base status and estimate ventilation.
- If the patient is intubated, end tidal CO_2 can also be used to estimate ventilation, but with severe pulmonary disease, end tidal CO_2 can be much lower than $PaCO_2$.

2. Assess Patient for Acidemia (pH < 7.35) or Alkalemia (pH > 7.45)

If pH is within normal limits, the patient's body may have compensated for underlying disturbances or a mixed disturbance may be present. See Steps 3 and 4 to evaluate if metabolic or respiratory disturbances are present despite normal pH.

3. Perform Additional Assessments for Acidosis

- **Respiratory acidosis** is present if $PaCO_2 > 45$ mm Hg.
- **Metabolic acidosis** is present if BE < -4 mmol/L (or $HCO_3^- < 19$ mmol/L).

4. Perform Additional Assessments for Alkalosis

- **Respiratory alkalosis** is present if $PaCO_2 < 35$ mm Hg
- **Metabolic alkalosis** is present if BE > 2 mmol/L (or $HCO_3^- > 25$ mmol/L)

For cats, substitute the reported normal values for $PaCO_2$ and BE from **Table 1** into steps 3 and 4.

5. Assess Oxygenation

Normal PaO_2 is 90 to 100 mm Hg. If the patient is on supplemental oxygen, PaO_2 should equal approximately 5× the FiO_2; the FiO_2 of room air is 21%.

These rules apply to the normal values listed in **Table 1** for dogs.

6. Determine Whether Compensatory Changes Have Occurred

For example, if a primary metabolic acidosis is present, a compensatory respiratory alkalosis may also exist. Remember the rules of compensation:

- A change in the respiratory or metabolic component of the acid–base status normally induces an opposite compensatory response in an effort to normalize the pH.
- The lungs can compensate quickly by adjusting minute ventilation in a matter of minutes.
- The kidneys compensate more slowly, with compensation beginning within a few hours and maximum compensation taking 4 to 5 days.
- The absence or presence and degree of compensation provides some information about the chronicity of the disturbance (**Table 2**).
- Overcompensation does not occur.

Other Useful Equations

Another tool for interpreting lung function is the PaO_2:FiO_2 ratio, which allows arterial blood gases and concentrations of inspired oxygen to be evaluated and compared. A normal PaO_2:FiO_2 ratio is approximately 500 (PaO_2 = 100 mm Hg, FiO_2 = 0.21). If a patient is on 100% oxygen, the expected PaO_2 would be 500 mm Hg. This is helpful in interpreting samples from patients under general anesthesia and those on supplemental oxygen that are too unstable to obtain samples when breathing room air.

IN SUMMARY

Interpretation of venous and arterial blood gases can be essential to treatment of many patients. Blood gas analyzers are becoming more common in veterinary practices and this analysis can aid in diagnosis and therapy for patients, indicating:

- When fluid therapy is indicated
- What fluid types are the best choices
- If sodium bicarbonate should be administered
- When oxygen and mechanical ventilation are needed, including when the patient can be weaned off this support. ■

BE = base excess/deficit; CO_2 = carbon dioxide; FiO_2 = fractional inspired oxygen concentration; GI = gastrointestinal; HCO_3^- = bicarbonate; PaO_2 = partial pressure of oxygen in arterial blood; $PaCO_2$ = partial pressure of carbon dioxide in arterial blood

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Suggested Reading

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