

A PRACTICAL APPROACH TO ACID-BASE BALANCE FOR SMALL ANIMAL PRACTITIONERS

IVMA CE Self-Study Offering

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AIM OF THIS ARTICLE

Acid-base balance (ABB) is a convoluted concept that requires detailed comprehension of the metabolic pathways used to eliminate the H⁺ ion from the body. Not surprisingly, many practitioners find it daunting to retain the key concepts and apply them in a meaningful way clinical practice. This article aims to review some of the major points about ABB, and to provide a stepwise approach to evaluating laboratory data in order to identify key aspects of acid-base disorders.

Although the chemical/biochemical basis of ABB is important, this article aims to share a practical and more factual, informal approach to the subject that will hopefully appeal to the majority of practitioners. Readers who crave extensive derivations of the Henderson-Hasselbalch equation are welcome to revisit their dusty textbooks for increased levels of excitement!

LEARNING OBJECTIVES

Following completion of this continuing education article, you will be able to:

- Indicate whether the pH level indicates acidosis or alkalosis
- List major sources of acids in the body
- Identify the major chemical buffer systems in the body
- Identify the cause of the pH imbalance as either respiratory or metabolic
- Distinguish between acidosis and alkalosis resulting from respiratory and metabolic factors
- Describe the importance of respiratory and renal compensations to ABB
- Determine if there is any compensation for the acid-base imbalance
- Identify the causes of high anion gap metabolic acidosis
- Use a systematic, step-by-step approach to diagnose acid-base disorders from laboratory data

SO WHAT IS ABB & WHY DO WE CARE ABOUT IT?

ABB is fundamental to physiologic homeostasis and refers to the way in which the body maintains a relatively constant pH despite continuous production of metabolic end products.

Because animal disease states lead to abnormalities of body fluid, electrolytes, and ABB, the ability to interpret acid-base data/clinical chemistry profiles enables the practitioner to identify the cause of the imbalance and provide appropriate treatment.

SOME BASICS OF ABB

In order to assess ABB, remember how the hydrogen ion (H^+) affects acids, bases, and pH:

An *acid* is a substance that can donate H^+ to a base. Examples include hydrochloric acid (HCl), nitric acid, the ammonium ion, lactic acid, acetic acid, and carbonic acid (H_2CO_3).

A *base* is a substance that can accept or bind H^+ . Examples include ammonia, lactate, acetate, and bicarbonate (HCO_3^-).

pH reflects the overall H^+ concentration in body fluids. Increasing the number of H^+ in the blood will lower pH (more acidic); while decreasing the number of H^+ will increase pH (more alkaline). Blood is slightly alkaline—for normal enzyme/cell function and metabolism, pH must remain within a narrow range. If blood becomes acidic, cardiac contraction force is decreased; if it becomes alkaline, neuromuscular function is impaired. A blood pH below 6.8 or above 7.8 is usually fatal.

To maintain ABB, any excess acids or bases that are either consumed or produced by the body must be excreted by the lungs or kidneys. This keeps systemic pH stable & preserves the body's buffers.

SOME COMMON ACIDS AND BASES IN THE BODY

Where are all these extra acids and bases coming from?

Endogenous sources: The body tends to produce more acids than bases.

- *Acids:* Daily metabolism is the main culprit for generating acidic compounds. Metabolism of:
 - Proteins (sulfur-containing amino acids) produces sulfuric acid
 - Phospholipids produces phosphoric acid
 - Carbohydrates and fats produces CO_2 (an acidic gas)
- *Bases:* Mostly derived from nutrients.

Exogenous sources: For example, excess acids may be introduced into the body in cases such as ethylene glycol toxicity. (See “metabolic acidosis” later on)

HOW DOES THE BODY REGULATE ABB TO PROTECT AGAINST THESE pH CHANGES?

Three buffer systems (chemical, respiratory, renal) in particular regulate the body's pH to guard against detrimental fluctuations that may result from increased levels of acid/base in the body:

Chemical buffers in blood, intracellular fluid (ICF), and extracellular fluid (ECF) represent the body's most efficient pH-balancing force. They act immediately—within seconds—to form the *first line of defense* against AB imbalance, combining with excess acids or bases in the body to maintain pH.

The key buffers are: *Bicarbonate* (in ECF)
 Phosphates (in ICF)
 Proteins (in ICF; especially hemoglobin in red blood cells) [*Note: plasma proteins play only a limited role in ECF buffering*]
 Carbonate (in bone – represents a large store of potential buffer; plays an important role in the body's long-term response to chronic acidosis)

Bicarbonate is one of the key chemical buffers, managing many of the imbalances that result from physiological processes, as well as pathological ones. Think of it like Tums for the bloodstream. It is alkaline and functions by binding excess acids in the blood. In this buffer system, CO₂ combines with water (H₂O) to produce carbonic acid (H₂CO₃)—this in turn rapidly breaks down into H⁺ and HCO₃⁻



The components of this key buffer system also happen to be easy to measure in the blood as part of the AB evaluation process: PCO₂ and HCO₃⁻

Two physiological buffers comprise the *second line of defense* against AB imbalance:

The respiratory system: The lungs regulate the concentration of CO₂ (acidic gas) in the blood: Chemoreceptors in the brain sense pH changes and vary the rate and depth of respirations to regulate CO₂ levels. Changes in ventilation serve to produce a change in PCO₂ within minutes. CO₂ combines with water to form H₂CO₃.

- *Increased ventilation:* Faster, deeper breathing eliminates CO₂ from the lungs, and less H₂CO₃ is formed, and pH increases.
- *Decreased ventilation:* Slower, shallower breathing reduces CO₂ excretion, & pH decreases.

The partial pressure of arterial CO₂ (PCO₂) reflects the level of CO₂ in the blood.

- An increased PCO₂ level indicates hypoventilation from shallow breathing
- A decreased PCO₂ level indicates hyperventilation

The respiratory system can handle twice as many acids and bases as the buffer systems, and responds within minutes, but provides only temporary compensation.

Basically, during metabolism, oxygen combines with glucose to generate energy. Acidic CO₂ is produced as a waste product of this process & is transported in the blood to the lungs for expiration: if ventilation is adequate, this respiratory acid is eliminated by expiration

The kidney: The kidney is important for long-term compensatory adjustments which may take hours to days before beginning to restore normal pH. It absorbs or excretes acids and bases, and can also produce HCO₃⁻ to replenish lost supplies.

- When blood is acidic, the kidneys reabsorb HCO₃⁻ and excrete H⁺
- When blood is alkaline, the kidneys excrete HCO₃⁻ and retain H⁺

SO WHAT ARE THE AB DISTURBANCES?

An AB disorder represents a change in the normal extracellular pH that may result when renal or respiratory function is abnormal, or when an excess of acid or base overwhelms excretory capacity.

The 2 disorders of ABB are acidosis (too much acid/not enough base in the blood) and alkalosis (too much base/too little acid in the blood). These disturbances are either metabolic or respiratory in origin.

- If the respiratory system is responsible, you'll detect it by reviewing the partial pressure of carbon dioxide (CO₂) in arterial blood (PCO₂), or serum CO₂ levels
- If the metabolic system is responsible, you'll detect it by reviewing serum HCO₃⁻ levels

AB disorders can be *simple* or *mixed*.

Simple AB Disorders

Simple AB disorders are common clinically, and 4 possibilities can arise:

- Metabolic acidosis
- Metabolic alkalosis
- Respiratory acidosis
- Respiratory alkalosis

Metabolic acidosis is the most common disorder encountered in veterinary clinical practice. The respiratory contribution to a change in pH can be determined by measuring PCO₂ and the metabolic component by measuring the base excess. Unless it is necessary to know the oxygenation status of a patient, venous blood samples will usually be sufficient.

Metabolic acidosis can result from an increase of acid in the body or by excess loss of bicarbonate. In veterinary medicine, the 5 most common causes of metabolic acidosis are:

Endogenous sources of acids: Uremia (uremic acids)
Ketosis (keto acids)
Lactacidemia (lactic acid)

Exogenous sources of acids: Ethylene glycol toxicity (glycolic acid)
Aspirin toxicity (acetylsalicylic acid)

***These 5 account for about 95% of cases of metabolic acidosis in small animal patients**

Metabolic alkalosis can result from either:

Acid (H⁺) loss: H⁺ is usually lost via the gastrointestinal tract through vomiting, or via the urinary tract through hyperaldosteronism.

Most common causes due to acid loss in small animals:

- **Vomiting*** (*also most common cause overall in small animals*)
- Renal losses as compensation for primary respiratory acidosis
- Loop/thiazide diuretics

Base gain: Less common than acid loss. Major examples:

- Administration of sodium bicarbonate to treat metabolic acidosis
- Administration of organic ions which are metabolized to HCO₃⁻ (eg, citrate in blood transfusions)

Respiratory acidosis is caused by hypoventilation or decreased gas exchange in the alveoli in the lungs, and develops when the lungs fail to adequately eliminate CO₂. May arise due to:

- Primary pulmonary diseases* that severely affect the lungs (such as respiratory obstruction)
- Neuromuscular disorders that impair the mechanics of breathing
- Drugs that decrease respiratory rate (general anesthetics)

Respiratory alkalosis is caused by hyperventilation and develops when the lungs eliminate too much CO₂.

- Compensation for primary metabolic acidosis*
- Any cause of hypoxemia (congestive heart failure, hypotension, anemia)

Mixed AB Disorders

Mixed AB disorders can also occur clinically. Although further discussion of this is beyond the scope of this article, just be aware that mixed disorders involve the simultaneous presence of 2 separate primary disturbances in the patient. (This is different from a primary disorder with expected compensation.) Basically, if the data seem to indicate that the body isn't compensating as expected, it means there is a mixed respiratory & metabolic issue. **Normal blood pH reflects a compensated AB imbalance, while an abnormal pH reflects an uncompensated one.**

INTERPRETING AB DISORDERS FROM LABORATORY DATA

Arterial blood gas (ABG) results and serum chemistry profiles provide the data used to evaluate ABB balance and diagnose AB disorders.

Note: Arterial versus venous blood samples?—only arterial samples are suitable for PO₂ measurements; but arterial or venous samples are suitable for pH, PCO₂, HCO₃⁻ evaluations.

A Systematic Way to Evaluate ABB

ABG analysis helps you evaluate the effectiveness of your patient's ventilation and ABB, and can also help you monitor your patient's response to treatment. The 3 key pieces of data to consider when assessing ABB are:

pH
PCO₂
HCO₃⁻

The main focus of interpreting ABG data is on understanding what the pH, CO₂, HCO₃⁻ values mean – and how their respective changes reflect what is happening in the body.

The following systematic approach is a simplified one, but can be applied to most ABG data sets to make some key interpretations about a patient's ABB.

- 1) **If you have PO₂ data, check the patient's oxygenation:** Look at the amount of oxygen dissolved in the blood (and therefore available for the tissues)—that's PO₂ on the ABG data set. Inevitably, we don't want PO₂ to be abnormally low for the patient.

- 2) **Look at pH to determine *acidosis versus alkalosis*:** This is a key point because it shows the overall trend. Check whether the pH is normal, decreased (acidosis), or increased (alkalosis). In most acute problems, pH will be acidic, because failure of ABB (whether respiratory or metabolic) leads to accumulation of acids in the body. Whatever the change, the next step is to try and find out why. (*Table 1 highlights the data patterns in simple AB disorders*)

- 3) **Look at the PCO₂ and HCO₃⁻:** What AB process (acidosis vs alkalosis) is causing the abnormal pH? In simple AB disorders, both values are abnormal, & the direction of change (increase/decrease) is the same for both. One of these values will represent the primary change, and the other will be the secondary—compensatory—change.
 - a. **Primary change:**
 - This is the one that correlates with the abnormal pH:
 - If high PCO₂ or low HCO₃⁻ Acidosis
 - If low PCO₂ or high HCO₃⁻ Alkalosis

 - b. **Compensatory change:** Now that you have identified the primary disturbance, the other abnormal parameter represents the secondary compensatory response *if the direction (increase/decrease) of the change is the same as for the primary*. If not, suspect a mixed AB disorder. (A normal pH with abnormal PCO₂ or HCO₃⁻ indicates 2 or more AB disorders.)

 - c. **Identify the specific disorder:**
 - *In acidosis:* If PCO₂ is high, the cause is respiratory (and bicarbonate levels can tell you about how the body is coping); if it's normal or low, look at the bicarbonate (it should be low) to confirm a metabolic cause.

 - *In alkalosis:* If PCO₂ is low, the cause is respiratory; if it's normal or high, look at the bicarbonate (it should be high) to confirm a metabolic cause.

(You likely have no problem remembering that *acidosis means the pH is decreased*, and *alkalosis means it is increased*. But if you have trouble recalling whether the acidosis/alkalosis is of metabolic or respiratory origin (the secondary response): Look at the CO₂ value—if its direction (increase or decrease) **M**atches that of the pH, it's **M**etabolic; If it's **R**eversed, it's **R**espiratory)

Table 1. Patterns Associated with AB Disorders

Disorder	Associated pH change	Associated H+ change	What was the primary disturbance?	What is the secondary response?
Metabolic acidosis	↓	↑	↓ HCO ₃ ⁻	↓ PCO ₂
Metabolic alkalosis	↑	↓	↑ HCO ₃ ⁻	↑ PCO ₂
Respiratory acidosis	↓	↑	↑ PCO ₂	↑ HCO ₃ ⁻
Respiratory alkalosis	↑	↓	↓ PCO ₂	↓ HCO ₃ ⁻

Some Additional Things to Consider:

Standard Base Excess (SBE): You may automatically receive this information as part of your ABG data set (may also just be called *Base Excess*). It's not essential for your interpretation, and its usefulness has been questioned. However, together with the HCO₃⁻ level, the SBE value gives you an indication of the metabolic component of the blood gas results:

- SBE>0 Indicates excess base = Metabolic alkalosis
- SBE<0 Indicates reduced base (ie, more acid) = Metabolic acidosis

Anion Gap (AG): In cases of metabolic acidosis, AG (along with chloride levels) data can help provide a more precise interpretation of the cause as either *secretional* (due to bicarbonate loss) or *titrational* (due to bicarbonate consumption) metabolic acidosis. Full discussion of this is beyond the scope of this particular article, but just note that it essentially represents the unmeasured anions that are inappropriately present in the body—***it indicates the presence of a foreign substance causing AB imbalance.*** It is calculated from electrolyte data in the chemistry profile—it's the difference between the measured cations (sodium & potassium) and anions (chloride & bicarbonate) in serum:

$$AG = (\text{Sodium ions} + \text{Potassium ions}) - (\text{Chloride ions} + \text{Bicarbonate ions})$$

Using the AG to identifying the process—as either bicarbonate loss or consumption—helps to formulate a short, specific list of differential diagnoses.

There are many potential unmeasured anions, but the major ones to consider in the AG are:

- Albumin
- Phosphate
- Lactate
- Urate
- Ketones

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Quiz – Please complete and submit to IVMA – fax – 317/974-0985, scan and email to info@invma.org or mail to 201 S. Capitol, #405, Indianapolis, IN, 46225.

Normal Blood pH and Blood Gas Data in Small Animals (Use for questions with tabulated data)

	PO ₂ (mmHg)	Blood pH	PCO ₂ (mmHg)	HCO ₃ ⁻ (mmol/L)
Canine	90-100	7.36-7.44	36-44	18-24
Feline	90-100	7.36-7.44	28-32	17-21

**pH & HCO₃⁻ ranges will vary slightly, depending on which textbook/reference laboratory you obtain data from*

1. Blood gas analysis data from a 7-year-old Weimaraner that presented with lethargy, dehydration, and ataxia:

	Blood pH	PCO ₂ (mmHg)	HCO ₃ ⁻ (mmol/L)
7-yr-old Weimaraner	7.35	26.8	13.2

These data suggest:

- a) Metabolic acidosis
 - b) Metabolic alkalosis
 - c) Respiratory acidosis
 - d) Respiratory alkalosis
2. Considering the Weimaraner in question 1, the most likely cause of the clinical signs and arterial blood gas data is:
- a) Long-term furosemide therapy
 - b) Congestive heart failure
 - c) Ethylene glycol toxicity
 - d) Upper respiratory obstruction
3. Which organ buffer system acts within minutes to help regulate acid-base balance?
- a) Lung
 - b) Liver
 - c) Kidney
 - d) Bone

4. Blood gas analysis data from a 3-year-old domestic shorthaired cat that presented with severe respiratory distress and oliguria.

	Blood pH	PO ₂ (mm Hg)	PCO ₂ (mmHg)	HCO ₃ ⁻ (mmol/L)
3-yr-old cat	7.15	68.8	38	13.9

These data suggest:

- a) Compensated mixed metabolic alkalosis and respiratory alkalosis
 - b) Uncompensated mixed metabolic alkalosis and respiratory alkalosis
 - c) Compensated mixed metabolic acidosis and respiratory acidosis
 - d) Uncompensated mixed metabolic acidosis and respiratory acidosis
5. Physical examination of the cat from question 4 ruled out upper airway obstruction; and radiography ruled out evidence of pneumothorax or hydrothorax. The most likely cause of the respiratory distress is therefore:

- a) Respiratory center depression
- b) Pulmonary obstruction
- c) Severe anemia
- d) Hypotension

6. General anesthesia can result in:

- a) Metabolic acidosis
- b) Metabolic alkalosis
- c) Respiratory acidosis
- d) Respiratory alkalosis

7. A 1-year-old mixed-breed dog presents with vomiting and rapid, deep respiration. Serum chemistry evaluation revealed a high anion gap. Blood gas analysis data were as follows:

	Blood pH	PO ₂ (mmHg)	PCO ₂ (mmHg)	HCO ₃ ⁻ (mmol/L)
1-yr-old mixed-breed dog	7.6	49.8	26.8	13.2

These data suggest:

- a) Compensated metabolic alkalosis
- b) Uncompensated mixed metabolic alkalosis and metabolic acidosis

- c) Compensated respiratory alkalosis
 - d) Uncompensated mixed respiratory alkalosis and respiratory alkalosis
8. What is the most likely cause of metabolic acidosis with a high anion gap in a dog?
- a) Hyperaldosteronism
 - b) Excess sodium bicarbonate administration
 - c) Renal tubular acidosis
 - d) Diabetic ketoacidosis
9. All are true of compensatory responses in acid-base disorders EXCEPT:
- a) Overcompensation occurs in mixed acid-base disturbances
 - b) An abnormal blood pH reflects an uncompensated acid-base disorder
 - c) The kidneys compensate slowly by adjusting HCO₃⁻ excretion within hours
 - d) A change in the respiratory or metabolic component of the acid–base status typically induces an opposite compensatory response
10. Excessive citrate in transfused blood can cause:
- a) Metabolic acidosis
 - b) Metabolic alkalosis
 - c) Respiratory acidosis
 - d) Respiratory alkalosis

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