Perfecting your acid-base balancing act

How to detect and correct acid-base disorders

By Michelle Fournier, MN, RN, CCRN

WHEN IT COMES TO ACIDS AND BASES, the difference between life and death is balance. The body's acid-base balance depends on some delicately balanced chemical reactions. The hydrogen ion (H^+) affects pH, and pH regulation influences the speed of cellular reactions, cell function, cell permeability, and the very integrity of cell structure.

When an imbalance develops, you can detect it quickly by knowing how to assess your patient and interpret arterial blood gas (ABG) values. And you can restore the balance by targeting your interventions to the specific acid-base disorder you find.

Basics of acid-base balance

Before assessing a patient's acid-base balance, you need to understand how the H^+ affects acids, bases, and pH.

- An *acid* is a substance that can donate H^+ to a base. Examples include hydrochloric acid, nitric acid, 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. The higher the number of H^+ in the blood, the lower the pH; and the lower the number of H^+, the higher the pH.

A solution containing more base than acid has fewer H^+ and a higher pH. A solution containing more acid than base has more H^+ and a lower pH. The pH of water (H_2O), 7.4, is considered neutral.

The pH of blood is slightly alkaline and has a normal range of 7.35 to 7.45. For normal enzyme and cell function and normal metabolism, the blood's pH must remain in this narrow range. If the blood is acidic, the force of cardiac contractions diminishes. If the blood is alkaline, neuromuscular function becomes impaired. A blood pH below 6.8 or above 7.8 is usually fatal.

CE 1.8 contact hours

LEARNING OBJECTIVES

1. Identify four disturbances of acid-base balance.
2. Discuss nursing interventions for patients with acid-base imbalances.
3. Describe how to interpret arterial blood gas values.

pH also reflects the balance between the percentage of H^+ and the percentage of HCO_3^-. Generally, pH is maintained at a ratio of 20 parts HCO_3^- to 1 part H_2CO_3. (See *Fast facts on acid-base balance.*)

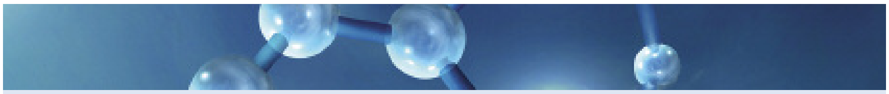
Regulating acid-base balance

Three regulating systems maintain the body's pH: chemical buffers, the respiratory system, and the renal system.

Chemical buffers, substances that combine with excess acids or bases, act immediately to maintain pH and are the body's most efficient pH-balancing force. These buffers appear in blood, intracellular fluid, and extracellular fluid. The main chemical buffers are bicarbonate, phosphate, and protein.

The second line of defense against acid-base imbalances is the respiratory system. The lungs regulate carbon dioxide (CO_2) in the blood, which combines with H_2O to form H_2CO_3. Chemoreceptors in the brain sense pH changes and vary the rate and depth of respirations to regulate CO_2 levels. Faster, deeper breathing eliminates CO_2 from the lungs, and less H_2CO_3 is formed, so pH rises. Alternatively, slower, shallower breathing reduces CO_2 excretion, so pH falls.

The partial pressure of arterial



Fast facts on acid-base balance

- The more hydrogen ion (H^+) in the blood, the lower the pH.
- The less H^+ in the blood, the higher the pH.
- When partial pressure of arterial carbon dioxide (Paco_2) rises, pH falls.
- When Paco_2 falls, pH rises.
- In respiratory acid-base disorders, pH and Paco_2 move in opposite directions. Bicarbonate (HCO_3^-) remains normal until compensation occurs.
- In metabolic acid-base disorders, pH and HCO_3^- move in the same direction. Paco_2 remains normal until compensation occurs.

CO_2 (Paco_2) level reflects the level of CO_2 in the blood. Normal Paco_2 is 35 to 45 mm Hg. A higher CO_2 level indicates hypoventilation from shallow breathing. A lower Paco_2 level indicates hyperventilation. The respiratory system, which can handle twice as many acids and bases as the buffer systems, responds in minutes, but compensation is temporary. Long-term adjustments require the renal system.

The renal system maintains acid-base balance by absorbing or excreting acids and bases. Also, the kidneys can produce HCO_3^- to replenish lost supplies. The normal HCO_3^- level is 22 to 26 mEq/L. When blood is acidic, the kidneys reabsorb HCO_3^- and excrete H^+. When blood is alkaline, the kidneys excrete HCO_3^- and retain H^+. Unlike the lungs, the kidneys may take 24 hours before starting to restore normal pH.

Compensating for imbalances

The two disorders of acid-base balance are acidosis and alkalosis. In acidosis, the blood has too much acid (or too little base). In alkalosis, the blood has too much base (or too little acid). The cause of these acid-base disorders is either respiratory or metabolic. If the respiratory system is responsible, you'll detect it by reviewing Paco_2 or serum CO_2 levels. If the metabolic system is responsible, you'll detect it by reviewing serum HCO_3^- levels.

To regain acid-base balance, the lungs may respond to a metabolic disorder, and the kidneys may respond to a respiratory disorder. If pH remains abnormal, the respiratory or metabolic response is called *partial compensation*. If the pH returns to normal, the response is called *complete compensation*. Keep in mind that the respiratory or renal system will never overcompensate. A compensatory mechanism won't make an acidotic patient alkalotic or an alkalotic patient acidotic.

Understanding acidosis and alkalosis

Caused by hypoventilation, respiratory acidosis develops when the lungs don't adequately eliminate CO_2. The hypoventilation may result from diseases that severely affect the lungs, diseases of the nerves and muscles of the chest that impair the mechanics of breathing, or drugs that slow a patient's respirations. Respiratory acidosis causes a pH below 7.35 and a Paco_2 above 45 mm Hg. HCO_3^- is normal. (See *Causes of acid-base imbalances at a glance*.)

Caused by hyperventilation, respiratory alkalosis develops when the lungs eliminate too much CO_2. The most common cause of hyperventilation is anxiety. Respiratory alkalosis causes a pH above 7.45 and a Paco_2 below 35 mm Hg. HCO_3^- is normal.

Metabolic acidosis may result from:
- ingestion of an acidic substance or a substance that can be metabolized to an acid
- production of excess acid
- an inability of the kidneys to excrete normal amounts of acid
- a loss of base.

Metabolic acidosis causes a HCO_3^- below 22 mEq/L and a pH below 7.35. Paco_2 is normal.

Metabolic alkalosis may result from:
- loss of stomach acid
- an excess loss of sodium or potassium
- a renal loss of H^+
- a gain of base.

Metabolic alkalosis causes a HCO_3^- above 26 mEq/L and a pH above 7.45. Paco_2 is normal.

ABG analysis in four steps

ABG analysis is a diagnostic test that helps you assess the effectiveness of your patient's ventilation and acid-base balance. The results also help you monitor your patient's response to treatment. ABG analysis provides several test results, but only three are essential for evaluating acid-base balance: pH, Paco_2, and HCO_3^-. Memorize these normal values for adults:
- pH: 7.35 to 7.45
- Paco_2: 35 to 45 mm Hg
- HCO_3^-: 22 to 26 mEq/L.

Remember, the key to interpreting ABG values at the bedside is consistency. Follow these four simple steps every time:
- *Step 1*. List the results for the three essential values: pH, Paco_2, and HCO_3^-.
- *Step 2*. Compare them with normal values. If a result indicates excessive acid, write an A next to it. If a result indicates excessive base, write a B next to it. And if a result indicates a normal balance, write an N next to it. The pH will tell you whether the patient has acidosis or alkalosis.
- *Step 3*. If you've written the same letter for two or three results, circle them. If you circle pH and Paco_2, your patient has a respiratory disorder. If you circle pH and HCO_3^-, your patient has a

metabolic disorder. If you circle all three results, your patient has a combined respiratory and metabolic acid-base disturbance. (See *Interpreting arterial blood gas values*.)

- *Step 4*. To check for compensation, look at the result you didn't circle. If it has moved from the normal value in the opposite direction of those circled, compensation is occurring. If the value remains in the normal range, no compensation has occurred. Once compensation is complete, the pH will return to normal.

Keep in mind that several factors can make ABG results inaccurate:

- using improper technique to draw the arterial blood sample
- drawing venous blood instead of arterial blood
- drawing an ABG sample within 20 minutes of a procedure, such as suctioning or administering respiratory treatment
- allowing air bubbles in the sample
- delaying transport of the sample to the lab.

Nursing implications

ABG values provide important information about your patient's condition. But never underestimate the importance of your clinical assessment and judgment. As a nurse, you are the most important advocate for your patients because you are constantly at the bedside, monitoring, assessing, intervening, and reevaluating.

Your role begins with identifying patients at risk for acid-base disturbances, including those who have or are at risk for:

- significant electrolyte imbalances
- net gain or loss of acids
- net gain or loss of bases
- ventilation abnormalities
- abnormal kidney function.

Assess patients carefully to identify early clues of acid-base disturbances. Consider what your

Causes of acid-base imbalances at a glance

Listed below are specific causes of the four acid-base disorders.

Respiratory acidosis

The primary problem is alveolar hypoventilation (increased partial pressure of arterial carbon dioxide [$PaCO_2$]), which may result from:

- acute pulmonary edema
- central nervous system depression
- chronic respiratory disease
- disorders of respiratory muscles and chest wall
- inadequate mechanical ventilation
- oversedation
- severe pulmonary infections.

Respiratory alkalosis

The primary problem is alveolar hyperventilation (decreased $PaCO_2$), which may result from:

- anxiety
- early sepsis
- excessive mechanical ventilation
- exercise
- fear
- heart failure
- hypermetabolic states such as fever
- hypoxemia
- liver failure
- pain.

Metabolic acidosis

The primary problems are increased acid and decreased bicarbonate (HCO_3^-). Increased acid results from:

- anaerobic metabolism
- hyperalimentation
- ketoacidosis
- renal failure
- salicylate intoxication
- severe sepsis
- starvation.

Decreased HCO_3^- results from:

- anhydrase inhibitors such as acetazolamide
- diarrhea
- hyperkalemia
- intestinal fistulas.

Metabolic alkalosis

The primary problems are increased HCO_3^- and decreased acid. Increased HCO_3^- results from:

- excessive ingestion of antacids
- excessive use of bicarbonate
- lactate administration in dialysis.

Decreased acid results from:

- hyperaldosteronism
- hypokalemia
- hypochloremia
- loop or thiazide diuretics
- nasogastric suction
- steroids
- vomiting.

Interpreting arterial blood gas values

The table shows the values for acid-base disorders.

Disorder	pH	$Paco_2$	HCO_3^-	Compensation
Respiratory acidosis	↓	↑	N	$HCO_3^- > 26$ mEq/L
Respiratory alkalosis	↑	↓	N	$HCO_3^- < 21$ mEq/L
Metabolic acidosis	↓	N	↓	$Paco_2 < 35$ mm Hg
Metabolic alkalosis	↑	N	↑	$Paco_2 > 45$ mm Hg

$Paco_2$ = partial pressure of arterial carbon dioxide
HCO_3^- = bicarbonate
↑ = increased level; ↓ = decreased level; N = normal level.

patient's vital signs are telling you. Count your patient's respirations for a full minute. What are the rate and the depth? Are they clues to an impending or underlying respiratory or metabolic problem? What is your patient's level of consciousness? Confusion can be an early sign of an acid-base disturbance. Correlate your patient's fluid balance and creatinine levels with kidney function. Always correlate your assessment findings with your patient's diagnosis. Do they match? Or is some clue pointing in a different direction? Be sure to double-check the implications and adverse effects of all drugs you administer.

Treating acid-base imbalances

Treatment for *metabolic acidosis* focuses on correcting the underlying cause. For a diabetic patient, treatment consists of controlling blood glucose and insulin levels. In a case of poisoning, treatment focuses on eliminating the toxin from the blood. Correcting the underlying cause of sepsis may include antibiotic therapy, fluid administration, and surgery. You may also treat the acidosis directly. If it's mild, administering I.V. fluid may correct the problem. If acidosis is severe, you may give bicarbonate I.V., as prescribed.

Treatment for *metabolic alkalosis* also focuses on the underlying cause. Frequently, an electrolyte imbalance causes this disorder, so treatment consists of replacing fluid, sodium, and potassium.

The treatment goal for *respiratory acidosis* is to improve ventilation. Expect to administer drugs such as bronchodilators to improve breathing and, in severe cases, to use mechanical ventilation. Maintain good pulmonary hygiene.

Usually, the only treatment goal for *respiratory alkalosis* is to slow the breathing rate. If anxiety is the cause, encourage the patient to slow his or her breathing. Some patients may need an anxiolytic. If pain is causing rapid, shallow breathing, provide pain relief. Breathing into a paper bag allows a patient to rebreathe CO_2, raising the level of CO_2 in the blood.

Practice makes perfect

Use the case histories below to test your acid-base knowledge with some examples. Read each history and try to determine the cause of the signs and symptoms. Then, read the interpretation section to see how well you did. (See *Beyond pH, $Paco_2$, and HCO_3^-.*)

Case history 1

Mary Barker, 34, comes to the emergency department (ED) with acute shortness of breath and pain on her right side. She smokes one pack of cigarettes a day and recently started taking birth control pills. Her blood pressure is 140/80 mm Hg; her pulse is 110 beats/minute; and her respiratory rate is 44 breaths/minute. Her ABG values are as follows:

- pH: 7.50
- $Paco_2$: 29 mm Hg
- Partial pressure of arterial oxygen (Pao_2): 64 mm Hg
- HCO_3^-: 24 mm Hg
- Oxygen saturation (SaO_2): 86%.

Interpretation: These ABG values reveal respiratory alkalosis without compensation. The patient's pH and $Paco_2$ are alkalotic, and her HCO_3^- is normal, indicating no compensation. You would administer oxygen (O_2) therapy, as ordered, to increase SaO_2 to more than 95%; encourage the patient to breathe slowly and regularly to decrease CO_2 loss; administer an analgesic, as ordered, to ease pain; and support her emotionally to decrease anxiety. Based on the clues, the probable underlying cause is pulmonary embolism.

Case history 2

John Stewart, 22, is brought to the ED for an overdose of a tricyclic antidepressant. He's unconscious and has a respiratory rate of 5 to 8 breaths/minute. His ABG values are as follows:

- pH: 7.25
- $Paco_2$: 61 mm Hg
- Pao_2: 76 mm Hg
- HCO_3^-: 26 mm Hg
- SaO_2: 89%.

Interpretation: These ABG values reveal respiratory acidosis without compensation. The patient's pH and $Paco_2$ are acidotic, and his HCO_3^- is normal, indicating no compensation. You would administer O_2, as ordered. The patient may be intubated to protect his airway and placed on a mechanical ventilator. You would also treat the underlying cause by performing gastric lavage and administering activated charcoal. This patient's condition may progress to metabolic acidosis. If so, you would give sodium bicarbonate to reverse the acidosis.

Beyond pH, $Paco_2$, and HCO_3^-

To identify acid-base disorders, you need only three arterial blood gas (ABG) values—pH, partial pressure of arterial carbon dioxide ($Paco_2$), and bicarbonate (HCO_3^-). But depending on the circumstances, you may find value in other ABG values.

One is a measurement of the partial pressure of arterial oxygen (Pao_2). The normal range for Pao_2 is 80 to 100 mm Hg. But Pao_2 varies with age and decreases after age 60 without signs of hypoxia. Pao_2 levels may also be lower in people who live at higher altitudes.

Another valuable ABG value is oxygen saturation (SaO_2), which is a measure of the percentage of hemoglobin actually carrying oxygen. The normal range for SaO_2 is 95% to 100%.

Case history 3

Steve Burr, 38, has type 1 diabetes. He hasn't been feeling well for the last 3 days and hasn't eaten or injected his insulin. He's confused and lethargic. His respiratory rate is 32 breaths/minute, and his breath has a fruity odor. His serum glucose level is 620 mg/dL. While receiving 40% O_2, his ABG values are:

- pH: 7.15
- $Paco_2$: 30 mm Hg
- Pao_2: 130 mm Hg
- HCO_3^-: 10 mm Hg
- SaO_2: 94%.

Interpretation: These ABG values reveal metabolic acidosis with partial respiratory compensation. The patient's pH and HCO_3^- indicate acidosis. His $Paco_2$ is lower than normal, reflecting the lungs' attempt to compensate. Because pH is abnormal, you know compensation isn't complete.

ABG values only

Try interpreting this set of ABG values without a clinical scenario:

- pH: 7.49
- $Paco_2$: 40 mm Hg
- Pao_2: 85 mm Hg
- HCO_3^-: 29 mm Hg
- SaO_2: 90%

Interpretation: These values reveal uncompensated metabolic alkalosis. The pH and HCO_3^- indicate alkalosis. $Paco_2$ is normal, indicating no compensation.

Now, interpret these values:

- pH: 7.25
- $Paco_2$: 56 mm Hg
- Pao_2: 80 mm Hg
- HCO_3^-: 15 mm Hg
- SaO_2 : 93%

Interpretation: These values reveal mixed acidosis. The pH, HCO_3^-, and $Paco_2$ all indicate acidosis.

Back in balance

How did you do? Whether you aced this practice quiz or not, remember that integrating your ABG interpretation skills into your patient assessments takes practice. By becoming more adept at identifying specific acid-base disorders, you can ensure that patients receive the appropriate nursing interventions and get back in balance as quickly as possible. ✩

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Purpose/goal: To provide nurses with information so they can better care for patients with an acid-base imbalance.