# Clarifying the Confusion of Arterial Blood Gas Analysis: Is it Compensation or Combination?

A three-step method for interpreting complex acid–base imbalances.

**ABSTRACT:** Arterial blood gas (ABG) analysis assesses the adequacy of ventilation, oxygenation, and the acid–base status of the body by measuring the levels of pH, oxygen, carbon dioxide, and bicarbonate in arterial blood. Interpretation of ABG results, which can play a major role in diagnosis and treatment of patients with pulmonary and other critical conditions, can sometimes be difficult. This article focuses on basic ABG analysis and interpretation, discusses the combinations of imbalances that may occur, and reviews the compensatory mechanisms that arise as a result.

**Keywords:** acid–base imbalances, arterial blood gas, arterial blood gas analysis, respiratory and metabolic compensation

Arterial blood gas (ABG) analysis assesses the adequacy of ventilation, oxygenation, and the acid–base status of the body by measuring the levels of pH, oxygen, carbon dioxide, and bicarbonate in arterial blood. The values of carbon dioxide and oxygen—expressed as the partial pressure of carbon dioxide ($PaCO_2$) and the partial pressure of oxygen ($PaO_2$)—are important in the diagnosis and treatment of patients with pulmonary and other critical conditions. The levels of pH and bicarbonate assist in the diagnosis of renal and other metabolic conditions.

A venous blood sample may be easier to obtain than an arterial sample, but they are not interchangeable. Several review articles have examined the use of venous blood gas rather than ABG analysis in evaluating a patient's respiratory status.[1-3] They showed that venous blood has a lower pH level, less oxygen, and a higher $PaCO_2$ level than arterial blood because it has not yet entered the right side of the heart and the lungs, where gas exchange occurs. Therefore, venous blood gas and ABG values should not be used interchangeably; arterial blood sampling remains the preferred method

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**Table 1.** Basic ABG Analysis

| pH (normal: 7.35–7.45) | $PaCO_2$ (normal: 35–45 mmHg) | $HCO_3$ (normal: 22–26 mEq/L) | Analysis and Interpretation |
|---|---|---|---|
| < 7.35 (acidosis) | > 45 | Normal | Respiratory acidosis |
| < 7.35 (acidosis) | Normal | < 22 | Metabolic acidosis |
| > 7.45 (alkalosis) | < 35 | Normal | Respiratory alkalosis |
| > 7.45 (alkalosis) | Normal | > 26 | Metabolic alkalosis |

for assessing a patient's acid–base and respiratory status.

Interpretation of acid–base imbalances and compensation begins with an understanding of the principles of the regulatory mechanisms that control the body's acidity and alkalinity—the pH balance—which is necessary for homeostasis. Two body systems, the respiratory system and the renal system, are primarily responsible for controlling blood pH levels. With a basic knowledge of these mechanisms, clinicians can determine the presence of respiratory and renal acid–base imbalances in a variety of critical conditions including head injury, drug overdose, stroke, diabetic ketoacidosis, and pulmonary edema. Yet it can be more difficult to interpret combinations of respiratory and metabolic imbalances and understand how the body compensates for such complex imbalances.

In this article, we focus on basic ABG analysis and interpretation, discuss the combinations of imbalances that may occur, and review the compensatory mechanisms that arise as a result. We also present a three-step method of ABG analysis, with examples of various values.

## A REVIEW OF ACID–BASE BALANCE

**The respiratory system** maintains normal blood pH levels through the regulation of carbon dioxide, an acid that exits the body through exhalation. When carbon dioxide levels increase in the body, the respiratory center is stimulated to initiate breathing. Hyperventilation causes a decrease in carbon dioxide and leads to alkalosis—an increased pH level. Hypoventilation causes an increase in carbon dioxide and leads to acidosis—a decreased pH level. The respiratory system can regulate changes in blood pH levels within minutes, simply by increasing or decreasing the respiratory rate.

**The renal system,** also called the metabolic system in this context, assists in regulating blood acidity and alkalinity through the excretion of hydrogen ions (H+) and bicarbonate—the latter expressed as $HCO_3$. Bicarbonate is a base that acts as a buffer in the blood. Increased bicarbonate levels and decreased hydrogen ions in the blood lead to alkalosis and a rise in pH level. Decreased bicarbonate levels and increased hydrogen ions in the blood cause acidosis and a decrease in pH level. The renal system takes several hours or even days to adjust these changes in blood pH levels.

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## INTERPRETATION OF BASIC ABG VALUES

Four values are used in ABG analysis: pH, $PaCO_2$, $HCO_3$, and $PaO_2$. The $PaO_2$ level reveals the patient's oxygenation status; carbon dioxide is considered an acid and bicarbonate a base.

Normal ABG values are as follows[4]:

- pH: 7.35 to 7.45

- $PaCO_2$: 35 to 45 mmHg
- $HCO_3$: 22 to 26 mEq/L
- $PaO_2$: 80 to 100 mmHg

Some institutions may use slightly different reference ranges, but variations are not clinically significant.

Abnormalities in the $PaCO_2$ level indicate a respiratory problem, and abnormalities in the $HCO_3$ level indicate a metabolic problem. Analysis and interpretation of basic ABG values can be determined by the following steps.

**Step 1. Examine the pH level.** If pH falls below normal (less than 7.35) the patient is acidotic; if it rises above normal (more than 7.45) the patient is alkalotic.

**Step 2. Examine the $PaCO_2$ level.** A $PaCO_2$ elevation (over 45 mmHg), along with a decrease in pH, indicates respiratory acidosis. A $PaCO_2$ decrease (under 35 mmHg), along with elevated pH, indicates respiratory alkalosis. The $HCO_3$ level is normal with both respiratory imbalances.

**Step 3. Examine the $HCO_3$ and $PaO_2$ levels.** An elevation of $HCO_3$ (over 26 mEq/L), along with elevated pH, indicates metabolic alkalosis. A decrease of $HCO_3$ (under 22 mEq/L), along with decreased pH, indicates metabolic acidosis (see Table 1). If the $PaO_2$ level is decreased (less than 80 mmHg), hypoxemia is present.

Pulmonary embolism, asthma, opioid overdose, and hypoxia are some conditions that may cause respiratory acidosis or alkalosis; diabetic ketoacidosis and renal failure may lead to metabolic acidosis or alkalosis.

## COMBINATION RESPIRATORY AND METABOLIC ACIDOSIS OR ALKALOSIS

The presence of a combination of respiratory and metabolic acidosis or alkalosis can similarly be determined in three steps. With these types of disorders, the pH, $PaCO_2$, and the $HCO_3$ levels are all abnormal. The precise conditions they may be associated with depend on many patient-related factors, including comorbidities.

**Step 1. Examine the pH level.** Below-normal pH levels (less than 7.35) indicate acidosis, and higher-than-normal pH levels (more than 7.45) indicate alkalosis.

**Step 2. Examine the $PaCO_2$ and $HCO_3$ levels.** Both values are abnormal, but in opposition to each other—one value is elevated, while the other is decreased.

**Step 3. Interpret the results.** For combined respiratory and metabolic *acidosis*, the $PaCO_2$ level is elevated and the $HCO_3$ level is decreased. Too much acid and too little base in the blood causes an acidotic pH level, and the result is combined respiratory and metabolic acidosis. For combined respiratory and metabolic *alkalosis*, the $PaCO_2$ level is decreased and the $HCO_3$ level is elevated. Too little acid and too much base cause alkalosis (see Table 2).

Consider the following examples:

pH 7.30↓ $HCO_3$ 19↓ $PaCO_2$ 50↑

*Interpretation: combination respiratory and metabolic acidosis*

(1) The pH level is below 7.35 (acidosis).
(2) The $HCO_3$ level is low, insufficient to neutralize acid within the body.
(3) The $PaCO_2$ level is high from an increase of carbon dioxide in the body.

pH 7.50↑ $HCO_3$ 30↑ $PaCO_2$ 30↓

*Interpretation: combination respiratory and metabolic alkalosis*

(1) The pH level is greater than 7.45 (alkalosis).
(2) The $HCO_3$ or bicarbonate level is high; bicarbonate is a base.
(3) The $PaCO_2$ level is low; since carbon dioxide is an acid, there is not enough acid in the body to neutralize the base.

## COMPENSATION OF RESPIRATORY AND METABOLIC ACIDOSIS OR ALKALOSIS

For compensation to occur, the renal and respiratory systems work together to regain and maintain a normal blood pH level. Other processes assist with compensation (for example, the central and sympathetic nervous systems and the chemical buffer system), but the kidneys and lungs are the major organs involved. Initially, partial compensation may occur.

**Table 2.** Combination Respiratory and Metabolic Acid–Base Imbalances

| pH (normal: 7.35–7.45) | $PaCO_2$ (normal: 35–45 mmHg) | $HCO_3$ (normal: 22–26 mEq/L) | Analysis and Interpretation |
|---|---|---|---|
| < 7.35 (acidosis) | > 45 | < 22 | Combination respiratory and metabolic acidosis |
| > 7.45 (alkalosis) | < 35 | > 26 | Combination respiratory and metabolic alkalosis |

**Table 3.** Compensation of ABGs

| pH (normal: 7.35–7.45) | $PaCO_2$ (normal: 35–45 mmHg) | $HCO_3$ (normal: 22–26 mEq/L) | Analysis and Interpretation |
|---|---|---|---|
| Normal but close to acidotic (7.35–7.39) | > 45 | > 26 | Compensated respiratory acidosis (the renal system has compensated for a respiratory problem) |
| Normal but close to acidotic (7.35–7.39) | < 35 | < 22 | Compensated metabolic acidosis (the respiratory system has compensated for a metabolic problem) |
| Normal but close to alkalotic (7.41–7.45) | < 35 | < 22 | Compensated respiratory alkalosis (the renal system has compensated for a respiratory problem) |
| Normal but close to alkalotic (7.41–7.45) | > 45 | > 26 | Compensated metabolic alkalosis (the respiratory system has compensated for a metabolic problem) |

This indicates that the body is attempting to correct the imbalance, but the pH level remains abnormal. Serial ABG measurements are needed to determine if the pH is progressing toward a normal level. When it reaches normal, complete compensation has occurred.

The respiratory system compensates for metabolic acid–base imbalances within minutes, and the renal system compensates for a respiratory acid–base problem, but it may take days. The steps for determining compensation are the same as for identifying combination types of respiratory and metabolic disorders.

**Step 1. Examine the pH level.** If the pH is normal, but both $PaCO_2$ and $HCO_3$ are abnormal, compensation has occurred.

**Step 2. Examine the $PaCO_2$ level along with the $HCO_3$ level.** Both values will be abnormal, but in the same direction—both elevated or both decreased.

**Step 3. Interpret the results.** Examine all three values together. With 7.40 as the midpoint of the normal pH range, determine if the pH level is closer to the alkalotic or acidotic end of the range. If pH is normal but closer to the acidotic end, and both $PaCO_2$ and $HCO_3$ are elevated, the *kidneys* have compensated for a *respiratory* problem. If the pH is normal, but closer to the alkalotic end of the normal range, and both $PaCO_2$ and $HCO_3$ are elevated, the *lungs* have compensated for a *metabolic* problem (see Table 3).

Consider the following examples:

pH 7.35 $HCO_3$ 30↑ $PaCO_2$ 50↑
*Analysis: compensated respiratory acidosis*
The pH level is at the lowest end of normal before being considered acidotic. An elevated $PaCO_2$ level will give you an acidotic pH, but an elevated $HCO_3$ level will not give you an acidotic pH. Therefore, the renal system has compensated for a respiratory problem.

pH 7.45 $HCO_3$ 30↑ $PaCO_2$ 50↑
*Analysis: compensated metabolic alkalosis*
The pH level is at the highest end of normal before being considered alkalotic. Both the $PaCO_2$ and $HCO_3$ levels are elevated. An elevated $PaCO_2$ level will not give you an alkalotic pH, but an elevated $HCO_3$ level will cause an alkalotic pH level. Therefore, the respiratory system has compensated for a metabolic problem.

pH 7.43 $HCO_3$ 18↓ $PaCO_2$ 30↓
*Analysis: compensated respiratory alkalosis*
The pH level is closer to the higher end of normal. Both the $HCO_3$ and $PaCO_2$ levels are decreased. A low $HCO_3$ level will not cause an alkalotic pH, but a low $PaCO_2$ level will cause the pH to be alkalotic. Therefore, the renal system has compensated for a respiratory problem.

pH 7.38 $HCO_3$ 18↓ $PaCO_2$ 30↓

*Analysis: compensated metabolic acidosis*

The pH level is closer to the lower end of normal. Both the $HCO_3$ and $PaCO_2$ levels are decreased. A low $HCO_3$ level will cause an acidotic pH, but a low $PaCO_2$ level will not cause the pH to be acidotic. Therefore, the respiratory system has compensated for a metabolic problem.

An abnormal pH level with $PaCO_2$ and $HCO_3$ levels that are also abnormal in the same direction indicates partial compensation. Recognizing gradual changes in serial values of ABG results will assist in determining if the respiratory system is compensating for a metabolic problem or if the kidneys are compensating for a respiratory problem. ABG analysis is a useful diagnostic tool in evaluating a patient's respiratory status.

Because interpretation of ABG results can sometimes be difficult, especially when attempting to determine compensation or combination types of imbalances, the ROME mnemonic (**r**espiratory, **o**pposite; **m**etabolic, **e**qual) can be helpful. To recap: When all ABG values are abnormal, either a combination type of imbalance exists or the body is attempting to compensate for an imbalance. In general, when the $PaCO_2$ and $HCO_3$ levels are in opposition, a combination imbalance exists. When the $PaCO_2$ and $HCO_3$ levels are abnormal in the same direction (both elevated or both decreased), compensation is occurring. Patient assessment continues to be the highest priority for evaluating a patient's overall condition, but analysis of ABGs plays a major role in patient management. ▼

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