ABG analysis is an indispensable test for critically ill patients or patients treated in an ICU. Interpretation of ABG analysis seems complicated; however, an understanding of the basic physiology can ease the interpretation. In this article, the basic physiology behind ABG analysis and a stepwise approach to interpreting ABG analysis will be discussed in detail.

Overview of ABG Analysis

Analysis of arterial blood gases (ABG) is an essential investigation in the management of critically ill patients as it provides important information about alveolar ventilation, oxygenation, and acid-base balance.

Measurement of ABG includes measurement of three parameters, i.e., pH, \( \text{PaCO}_2 \), and \( \text{PaO}_2 \); however, measurement of bicarbonate (\( \text{HCO}_3^- \)) and electrolytes is almost always done simultaneously to complete the whole picture of acid-base & electrolyte balance/imbalance.

Important values

**pH**

- Normal blood pH: 7.36–7.44
- Acidemia: pH < 7.35
- Alkalemia: pH > 7.45

**\( \text{PaCO}_2 \) & \( \text{PaO}_2 \)**
- Normal PaO\(_2\): 80–100 mm Hg
- Normal PaCO\(_2\): 36–44 mm Hg
- Respiratory acidosis: Acidemia with PaCO\(_2\) > 44 mm Hg
- Respiratory alkalosis: Alkalemia with PaCO\(_2\) < 36 mm Hg

HCO\(_3\)
- Normal HCO\(_3\)-: 20–28 mEq/L
- Metabolic acidosis: Acidemia with HCO\(_3\)- < 20 mEq/L
- Metabolic alkalosis: Alkalemia with HCO\(_3\)- > 28 mEq/L
- Normal base excess/deficit: 0 ± 2 mEq/L

Anion Gap
- Normal Anion Gap (AG): 12 mEq/L
- Anion Gap Metabolic Acidosis (AGMA): Metabolic acidosis with AG > 12
- Non-Anion Gap Metabolic Acidosis (NAGMA): Metabolic acidosis with normal AG

Basic Physiological Concepts

PaCO\(_2\) is the best parameter that reflects alveolar ventilation; high (> 44 mm Hg) and low (< 36 mm Hg) PaCO\(_2\) levels suggest alveolar hypoventilation and alveolar hyperventilation respectively.

The status of oxygenation is affected mainly by PaO\(_2\), FiO\(_2\), and hemoglobin content along with its affinity and saturation with oxygen. The presence of hypoxemia (PaO\(_2\) < 80 mm Hg at sea level while breathing room air) does not necessarily mean the...
Blood pH is maintained in the narrow range (7.36–7.44) by lungs, kidneys and blood buffers. In general, the blood buffer system (H₂CO₃/HCO₃⁻) acts within a fraction of seconds, the respiratory system takes about 1–15 minutes, and kidneys may take many minutes to many days to adjust H⁺ ions concentration.

**PaCO₂** is mainly controlled by lungs and is a marker of respiratory acid-base disturbance. HCO₃⁻ is mainly controlled by kidneys and blood buffers, but it does not always purely indicate metabolic acid-base disturbance as it is affected by hydrolysis effect.

Plasma bicarbonate can be calculated using the **Henderson-Hasselbalch equation**; while standard bicarbonate is plasma bicarbonate obtained after blood has been equilibrated at 37°C with a PaCO₂ of 40 mm Hg.

**Henderson-Hasselbalch equation:**  
\[ pH = 6.1 + \log_{10} \left( \frac{[HCO_3^-]}{0.03 \times PaCO_2} \right) \]

The difference between the measured bicarbonate and the calculated bicarbonate is known as **base excess** (if positive value) or **base deficit** (if negative value).

In acidemia, an excess of H⁺ ions enter intracellular space, hence, K⁺ ions move out from intracellular space into the plasma to maintain electroneutrality. Thus, acidemia is associated with hyperkalemia.

In distal renal tubular cells, K⁺ or H⁺ ions are exchanged for Na⁺ ions. In alkalemia, as H⁺ ions are retained, K⁺ ions are exchanged for Na⁺ ions, leading to hypokalemia.

**Compensation:** In response to primary acid-base disturbance, the respiratory system or kidneys attempt to maintain normal pH by the compensatory response. Compensation “moves the pH towards normal”, but compensation can never “overshoot” the normal pH.

Respiratory compensation for a primary metabolic derangement is immediate and usually improves over the course of hours, while renal compensation for a primary respiratory derangement is gradual and improves over days as it takes time for the kidneys to generate/eliminate HCO₃⁻.
Anion Gap (AG)

Calculation of anion gap is very important for metabolic acidosis. In electroneutrality:

\[
\text{Unmeasured anions} + \text{Cl}^- + \text{HCO}_3^- = \text{Unmeasured cations} + \text{Na}^+ 
\]

Unmeasured anions are usually proteins, SO₄, PO₄, organic anions, etc. and unmeasured cations are K⁺, Ca²⁺, Mg²⁺, etc. Therefore:

\[
\text{Anion Gap (AG)} = \text{Na}^+ - (\text{Cl}^- + \text{HCO}_3^-) = \text{Unmeasured anions} - \text{Unmeasured cations}
\]

An elevated anion gap refers to an increase in unmeasured anions. Normal AG: 12 mEq/L

Respiratory Acidosis

Key features: pH < 7.35 with PaCO₂ > 44 mm Hg

Causes: Basically, causes of respiratory acidosis are those that cause CO₂ retention or hypoventilation.

- Upper airway disorders such as obstruction, laryngospasm, obstructive sleep apnea
- Lower airway disorders such as COPD, asthma
- Thoracic cage abnormalities restricting respiratory movements such as flail chest, kyphoscoliosis
- Neuromuscular disorders affecting ventilation such as AIDP
- CNS depression due to CNS disorders, opioids, sedatives, etc.
- Respiratory muscle fatigue following any prolonged/severe respiratory disease

Respiratory Alkalosis

Key features: pH > 7.45 with PaCO₂ < 36 mm Hg

Causes: Basically, causes of respiratory alkalosis are those that cause CO₂ washout or hyperventilation.

- Hyperventilation due to pain, anxiety, hysteria, CNS tumor/disorder, pulmonary embolism, etc.
- Hypoxemia due to high altitude or any other cause
- Early salicylate poisoning

Metabolic Acidosis

Key features: pH < 7.35 with HCO₃⁻ < 20 mEq/L

Metabolic acidosis is further sub-classified on the basis of anion gap.

\[
\text{Anion Gap (AG)} = \text{Na}^+ - (\text{Cl}^- + \text{HCO}_3^-)/p > 12 \text{ mEq/L}
\]

Causes of high Anion Gap Metabolic Acidosis (AGMA) (AG > 12 mEq/L):

- Methanol (formic acid) poisoning
- Uremia
- Diabetic ketoacidosis, Drugs
- Propylene glycol poisoning
- Iron poisoning, Isoniazid
- Lactic acidosis
- Ethylene glycol (→ oxalic acid) poisoning, Ethanol poisoning (Alcoholic ketoacidosis)
- Salicylate poisoning

⇒ Mnemonic: MUDPILES

OR

- Lactic acidosis
- Uremia
- Salicylate poisoning