AMPATHCHAT no. 94

ARTERIAL BLOOD GAS INTERPRETATION

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Arterial blood gas (ABG) analysis plays an essential role in the following:[1,2]

- Objective evaluation of a patient's oxygenation and ventilation status.
- Monitoring of response to therapeutic interventions (e.g. after administration of supplemental oxygen or mechanical ventilation or insulin in diabetic ketoacidosis).
- Evaluation and monitoring of acid-base disturbances.
- Detection of abnormal haemoglobins (e.g., carboxyhaemoglobin and methaemoglobin).

Modern analysers not only measure blood gases but also incorporate electrolytes, haemoglobin, co-oximetry, and other analytes including glucose, lactate, bilirubin, ionized calcium and magnesium.[2]

ABG parameters reflecting blood oxygenation are partial pressure of oxygen (pO_2) and oxygen saturation (SaO_2), whereas pH, partial pressure of carbon dioxide (pCO_2) and bicarbonate (HCO_3-) reflect the acid-base balance.

We will focus primarily on acid-base balance in this article. Interpretation of acid-base balance and ABG analysis can be challenging, however, by understanding basic concepts (Table 1) and following a simplified and systematic approach using pH, HCO_3- and pCO_2 as the primary parameters, and understanding the concept of compensation, it can be possible to interpret ABG results with relative ease.

Table 1: Basic concepts and definitions[3,4]

pH	An index of acidity or alkalinity of the blood. It is an expression of the hydrogen ion concentration [H+]
pCO_2	Partial pressure of carbon dioxide dissolved in blood. Assesses the respiratory component
HCO_3-	A base and indicates the buffering capacity of the blood. Assesses the metabolic component
Total CO_3-	The sum of bicarbonate, dissolved CO_2 and carbonic acid (H_2CO_3). Often used interchangeably with bicarbonate, which represents 95% of total CO_2
Standard HCO_3-	The concentration of bicarbonate from blood equilibrated to 37°C and a $PaCO_2$ of 40 mmHg (5.3 kPa). At these standard conditions, respiratory influence is eliminated, and thus standard bicarbonate reflects purely the metabolic component
Actual HCO_3-	The concentration of bicarbonate in plasma without correction and is affected by the respiratory component
Base excess	The amount of strong acid that must be added theoretically to each litre of fully oxygenated blood to return the pH to 7.40 at a temperature of 37°C and a pCO_2 of 40 mmHg (5.3 kPa). Assesses the metabolic component.
pO_2	Partial pressure of oxygen and represents to the ability of the lungs to oxygenate the blood
SaO_2	Percentage of haemoglobin saturated with oxygen in arterial blood, excludes certain dyshaemoglobinaemias
Acidaemia	An arterial pH less than 7.35
Alkalaemia	An arterial pH more than 7.45
Hypoxaemia	A decrease in the pO_2 in arterial blood, typically less than 60 mmHg (8 kPa)
Acidosis	A process characterised by a decrease in the pH (increase in [H+]), caused either by a fall in HCO_3- or an increase in pCO_2
Alkalosis	A process characterised by an increase in the pH (decrease in [H+]) due to a decrease in pCO_2 or an elevation of HCO_3-
Acid	A donor of H+ ions
Base	An acceptor of H+ ions
Buffer	A solution that minimises changes in pH, when acids or bases are added
Single acid-base disorder	A single primary process of acidosis or alkalosis that can explain the observed pH
Mixed acid-base disorder	The coexistence of two or more primary processes to explain the observed pH

PHYSIOLOGY

Normal metabolic processes (from metabolism of carbohydrates, lipids and proteins) result in the production of acids that generate extensive amounts of hydrogen ions. Metabolic acids are classified as volatile acids, namely carbon dioxide (CO_2) and non-volatile acids including the organic lactate, ketones, free fatty acids and non-organic sulphates and phosphates.[3]

Acid-base balance refers to the balance between input (intake and production) and output (elimination) of hydrogen (H+) ions.[5] This balance is maintained by respiratory elimination of carbon dioxide, metabolic utilisation of organic acids, and renal excretion of non-volatile acids with buffering of excess acid in the extracellular fluid by HCO_3-.[3,4] Physiological buffers include proteins, phosphate and haemoglobin in erythrocytes, with the bicarbonate/carbonic acid (HCO_3-/H_2CO_3) system being the most abundant and important. At a ph of 7.4, the ratio HCO_3-: H_2CO_3 is maintained at 20:1.[6] Arterial pH is reflected by the ratio of [HCO_3-] to pCO_2.

The respiratory system adjusts the concentration of H+ or pCO_2, through changes in alveolar ventilation. The renal system eliminates the H+ through the formation of urea or ammonium ion and the reabsorption of HCO_3-.[7] The kidneys can excrete variable quantities of acid or base in response to pH; in acidosis, there is increased excretion of acid and conserved excretion of base. The opposite is true for alkalosis. Therefore, the respiratory and renal systems coordinate to regulate H+ homeostasis by regulating pCO_2 and HCO_3- levels.

SPECIMENS FOR ABG ANALYSIS

According to the guidelines of the American Association for Respiratory Care, the "gold standard" sample for blood gas analysis is arterial blood, collected either by needle puncture of an artery or via an indwelling arterial catheter.[8] While a venous blood sample may be easier to collect than an arterial sample, they are not interchangeable due to the much lower pO_2 level in venous blood.[1,7] Thus, if assessment of oxygenation status is not required, venous samples may be used.

ABG testing is affected by pre-analytical variables and therefore correct specimen collection, and handling is essential to ensure reliable results.[2,5]

- Collection should be performed by experienced staff as it is technically challenging and potentially painful, and may cause the patient to hyperventilate, thus lowering the pCO_2 and increasing pH.
- Blood is collected commonly from the radial or branchial arteries into a syringe containing a defined amount of heparin to maintain appropriate anticoagulant to blood ratio.
- Collections should be performed anaerobically, to prevent exposure to atmospheric air as this may falsely increase the pH and pO_2 while decreasing the pCO_2. There must be no air before and after blood is collected. If there are air bubbles in the sample, they should be expelled before capping the syringe.
- Blood should be adequately mixed to prevent clot formation.
- Prompt transport and analysis of ABG samples is essential, preferably within 30 minutes of collection. If delay is anticipated, the capped syringe should be transported on ice (which slows down in vitro cell metabolism).

INTERPRETATION OF BLOOD GASES

pH is maintained between 7.35 and 7.45 and [H+] ranges from 35 – 45 nmol/L.
pCO_2 represents the carbon dioxideconcentration i.e. the balance between cellular production of CO_2 and the ventilatory removal of CO_2. It reflects the RESPIRATORY component of the acid-base balance.
A rise in pCO_2 usually indicates inadequate ventilation (hypoventilation) and a respiratory acidosis, whereas a decreased pCO_2 indicates hyperventilation and a respiratory alkalosis.
HCO_3- represents the METABOLIC or renal component. Metabolic acidosis develops when [H+] accumulates or HCO_3- is lost.
Metabolic alkalosis may develop from loss of [H+] or gain of HCO_3-. It is calculated from the measured pH and pCO_2.

COMPENSATION

For normal physiological function, the pH is maintained within a narrow range due to compensatory mechanisms. Compensation is a homeostatic response to an acid-base disorder in which the body attempts to restore pH to normal by altering the HCO_3-/H_2CO_3 ratio back towards normal.[6]

In healthy individuals, a primary acid-base disturbance in one component will invoke counter compensatory response by the other component. When interpreting an ABG it is important to note that compensation in one component is always in the same direction as the primary derangement in the other component.[9] In metabolic acidosis the primary disorder results from low HCO_3- and the compensatory response is a respiratory alkalosis (low pCO_2). This is often the case with simple acid base disorders.

The respiratory response is rapid (within 24 hours) whereas the metabolic response is slower, occurring over 2 – 5 days.[6]

Therefore, depending on when the blood gas specimen was collected compensation may or may not have happened.Complete compensation returns the pH to normal, although the pCO_2 and HCO_3- may remain grossly deranged. However, compensation is often incomplete with an abnormal pH.

STEP BY STEP APPROACH TO ABG ANALYSIS

If the reference ranges are available, and then a systematic approach is followed, and ABG's can be interpreted without difficulty in most cases.

1. LOOK AT THE pH

To determine the presence of acidosis or alkalosis. It is important to remember that a pH within the normal range does not exclude an acid-base disorder and may signify the presence of a mixed acid base disorder. In this case, observe whether the pH is sitting towards the 'acidotic' or 'alkalotic' end of that range.[9] It should be noted that, compensation rarely returns pH to complete normal; only towards normal, except in chronic respiratory alkalosis.

2. LOOK AT THE pCO_2 AND THE HCO_3-

To determine the primary disorder. The pCO_2 assesses the contribution of the respiratory system to the pH whereas the HCO_3- assesses the contribution of the metabolic component. The question is whether the pCO_2 or HCO_3- is contributing to or attempting to compensate for the problem.[9]

- If pH is low (acidosis): low HCO_3- or high pCO_2
- If pH is high (alkalosis): high HCO_3- or low pCO_2

In primary respiratory disorders the pH and pCO_2 change in opposite directions, while metabolic disorders are characterised by changes in the same direction (Table 2).

Table 2: Characteristics of Primary Acid-Base disorders

	pH	pCO_2	HCO_3-	Compensation
Metabolic Acidosis	↓	N	↓	↓ in pCO_2
Metabolic Alkalosis	↑	N	↑	↑ in pCO_2
Respiratory Acidosis	↓	↑	N	↑ in HCO_3
Respiratory Alkalosis	↑	↓	N	↓ in HCO_3

N – Normal: within the reference interval, if compensation has not occurred.

3. ASSESS THE ADEQUACY OF COMPENSATION

Is there compensation for the primary disturbance? Is it complete or partial and appropriate? When pCO_2 and HCO_3- are abnormal in the same direction (high or low) then compensation is present. Appropriateness may be assessed using various compensation formulae (Table 3).[7,10]

If the observed compensation is inconsistent with the expected result, mixed acid base disorders should be suspected. In these disorders, changes in pCO_2 and HCO_3 are in opposite directions.

Table 3: Compensation formulae for the four primary acid-base disorders

Primary Disorder	Expected Result
Respiratory Acidosis (acute)	Expected HCO_3- = 24 + 0.1 x (pCO_2 – 40)
Respiratory Acidosis (chronic)	Expected HCO_3- = 24 + 0.4 x (pCO_2 – 40)
Respiratory Alkalosis (acute)	Expected HCO_3-= 24 – 0.2 x (40 – pCO_2)
Respiratory Alkalosis (chronic	Expected HCO_3- = 24 – 0.5 x (40 – pCO_2)
Metabolic Acidosis	Expected pCO_2 = (1.5 x HCO_3- + 8) ±2
Metabolic Alkalosis	Expected pCO_2 = (0.7 x HCO_3- – 24) ± 2

HCO_3- in mmol/L, where 24 mmol/L represents the baseline 'ideal' value. pCO_2 in mmHg where 40 mmHg represents the baseline 'ideal' value. Italics – the observed pCO_2 and HCO_3- in the patient's sample.

4. ASSESS ADEQUACY OF OXYGENATION

A pO_2 and SaO_2 that is less than expected indicates hypoxaemia, when taking age, altitude and FiO_2, into consideration. A grossly low SaO_2 (e.g. 70%) may indicate that the blood gas was incorrectly collected from a vein (contains deoxygenated blood) and a repeat ABG may be required.

5. OTHER USEFUL PARAMETERS: ANION GAP, DELTA RATIO AND DELTA GAP

Electrolyte measurement found in modern analysers may also be useful in further clarification of metabolic acidosis and in the detection of mixed acid-base disorders.

The anion gap (AG) is the difference between the measured cations (sodium and potassium) and measured anions (bicarbonate and chloride).[7] It represents unmeasured anions that are present in serum but not accounted for by the AG equation. It is utilised to classify metabolic acidosis into high AG metabolic acidosis (HAGMA) and normal AG metabolic acidosis (NAGMA).

The ideal values correspond to the laboratory mean values of 12mmol/L and 24 mmol/L for AG and HCO_3- respectively.

The delta ratio and delta gap are used to identify coexisting acid-base disorders in patients with HAGMA and are calculated only if the anion gap is elevated. The delta ratio is the ratio of the change in anion gap and the change in bicarbonate ($\Delta AG/\Delta HCO_3$-). The delta gap describes the difference between the ΔAG and ΔHCO_3-.

$$Delta\ Ratio = \frac{Measured\ AG - ideal\ AG}{ideal\ HCO_3\text{-} - measured\ HCO_3\text{-}} = \frac{\Delta AG}{\Delta HCO_3\text{-}}$$

The fall in HCO_3- is usually accompanied by an equivalent increase in the ΔAG and thus a 1:1 ratio is presumed.[7] Interpretation of the delta ratio and gap is displayed in table 4.

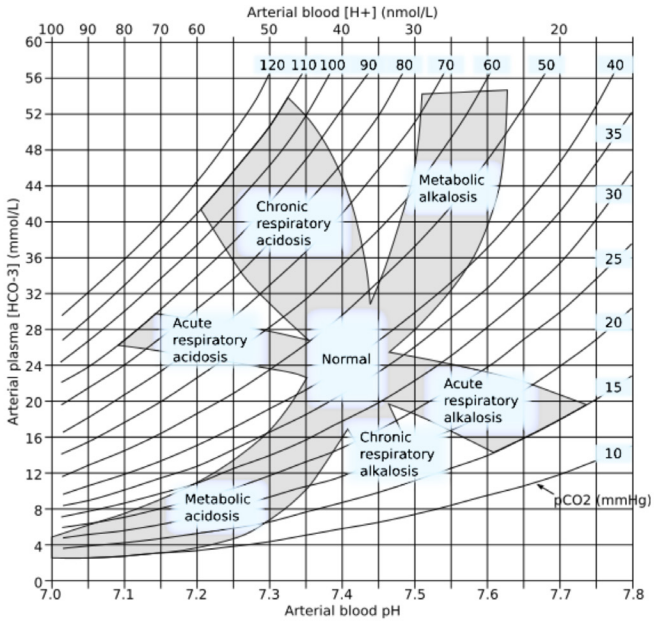
Table 4: Interpretation of delta gap and delta ratio

Delta Ratio	Delta Gap	Interpretation
< 0.4		Pure NAGMA
0.4 – 0.8	≤ -6	HAGMA and NAGMA
0.8 – 2.0	0	Pure HAGMA
> 2.0	≥ 6	HAGMA with metabolic alkalosis

ACID-BASE NOMOGRAM

Alternatively, a nomogram may be used to classify acid base status (Figure 1).[12] The acid-base nomogram is a graphical representation of the relationship between the pH, HCO_3- and pCO_2. The pH and HCO_3- are plotted on the x and y axis respectively. The curved lines (isobars) indicate the pCO_2.
Normal acid-base status is represented by a pH of 7.4, a pCO_2 of 40 mmHg and a HCO_3- of 24 mmol/L. The shaded areas represent the 95 per cent confidence limits for the normal compensations to simple primary acid-base disorders. The patient's status is indicated by the intersection of the measured pH, HCO_3- and pCO_2. If it falls within the shaded area, it is suggestive of a simple acid-base disturbance. However, if outside the shaded area, this suggests the presence of a mixed acid-base disorder.

FIGURE 1: ACID-BASE NOMOGRAM



In summary, an ABG is critical in the appropriate diagnosis and management of acid-base disorders and assessment of ventilation and oxygenation. Correct specimen handling is crucial for accurate interpretation of obtained results. By understanding acid-base physiology and following a basic approach, ABGs can be interpreted with relative ease.

REFERENCES AVAILABLE ON REQUEST
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