Interpretation of Arterial Blood Gas Analysis

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Introduction

Blood gas analysis (arterial and/or venous) is a routine test and commonly used monitoring modality. Blood gas has vast information; when this information is interpreted with background clinical condition it helps in diagnosis

Indications for Arterial Blood Gas (ABG)

- Severe respiratory or metabolic disorders

- Clinical features of hypoxia or hypercarbia

- Shock

- Sepsis

- Decreased cardiac output

- Renal failure

- Multiorgan dysfunction

- Diabetic ketoacidosis

Samples Collection and Transport

Ideal artery for sampling is radial. One must perform "Allen Test" to ensure collateral blood supply by ulnar artery before puncturing radial artery (Table 1).

Indwelling arterial line of radial or femoral artery can be used for sample collection.

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Table 1.

Comparison of blood gas analysis at different sites

Variables	Arterial	Venous
pH	Same	Lower
$PaCO_2$	Lower	Higher
PaO_2	Higher	Lower
HCO_3	Same	Same

Precautions for collection of blood sample

1. Heparin is acidic and lowers pH. Use heparin of lower strength (1000 instead of 5000 units per ml) or heplock solution.

2. Use small volume of heparinised saline just for lubricating syringe and plunger. If volume is more, dissolved oxygen in heparinised saline may increase PaO_2.

3. Avoid air bubble and let syringe fill spontaneously.

4. It is desirable to use a glass syringe as plastic syringes are permeable to air.

5. The sample should be processed immediately, preferably within 30 minutes. Blood is a living medium. The cells consume oxygen and produce CO_2. Drop in PaO_2 depends on initial PaO_2. If the latter is very high, significant drop may be noticed. The changes are as depicted in Table 2. Slush of ice (not cubes) should be used for storing samples till processing. The sample should be shaken before putting in machine (Fig. 1).

Figure 1. Arterial blood gas analysis machine.

Table 2.

Changes in ABG every 10 minutes *in vitro*

	37°C	4°C
pH	0.01	0.001
$PaCO_2$	0.1 mmHg	0.01 mmHg
PaO_2	0.1 mmHg	0.01 mmHg

For minimal error, blood sample should be stored at 4°C, if it cannot be processed immediately for minimal error.

Terminology and Normal ABGs

Terminology

Acidosis pH <7.35

Alkalosis pH >7.45

Acidemia and alkalemia refer to blood while acidosis, alkalosis to tissue pH.

THb

THb is total hemoglobin of patient. Few machines measure hemoglobin, others need this information to be fed. Hemoglobin is required to calculate oxygen content (O_2CT) of blood.

Temp

Patient temperature has to be fed into machine because the machine measures all values at 37°C. Temperature affects pH, $PaCO_2$ and PaO_2. Hence, it is desirable to have values corrected for patient temperature.

BE, St BE(SBE), BB

Base excess (BE) refers to actual base excess in variance from (above or below) total buffer base (BB). Normal BB is 48–49 mmol/l. If BB is 40, it means buffer base is reduced by nearly 8 mmol/l, or BE is −8 (also called base deficit). If BB is 60, it means buffer base is increased by nearly 12 mmol/l, or BE is +12.

Standard base excess (SBE) is the BE adjusted for temprature of 30°C and $PaCO_2$ of 40 mmHg.

BB is dependent on hemoglobin, as 25% of BB is constituted by hemoglobin buffer. Fifty percent of BB is contributed by bicarbonate and 25% by other buffers (proteins, phosphate, sulfate).

HCO_3; St HCO_3 (SBC); TCO_2

TCO_2 is sum of HCO_3^- and amount of CO_2 dissolved in plasma. For each mmHg $PaCO_2$, 0.03 ml CO_2 is dissolved per 100 ml of plasma. As HCO_3^- values change with CO_2 levels, standard bicarbonate (st HCO_3^-) is used to denote value of HCO_3^-, independent of CO_2 changes (i.e., at $PaCO_2$ of 40 and temperature of 37°C).

St. pH

Standard pH (st. pH) is the pH adjusted for temperature of 37°C and $PaCO_2$ of 40 mmHg. This would represent pH value purely due to metabolic status.

[H^+]

It is the concentration of hydrogen ions in nmol/l at 37°C patient's temperature.

$$[H^+]nEq/l = 24 \times (PaCO_2/ HCO_3)$$

O_2CT

It is the sum of oxygen bound to hemoglobin and oxygen dissolved in plasma. For each gram saturated Hb, 1.34 ml O_2 is bound to hemoglobin and for each mmHg PaO_2 0.003 ml oxygen is dissolved per 100 ml of plasma.

$$O_2CT = 1.34 \times Hb \times SaO_2 + 0.003\ PaO_2$$

SaO_2 sat

It is the proportion/percentage of arterial hemoglobin which is saturated with oxygen.

AaDO$_2$

This refers to the alveolar-to-arterial oxygen gradient. Normal value is 5–15 mmHg.

RQ

Respiratory quotient (RQ) is the amount of CO_2 liberated per minute divided by amount of O_2 utilized per minute. Normal values are 200 ml/250 ml = 0.8.

FiO$_2$

It is inspired oxygen fraction (FiO$_2$) concentration. This value has to be fed to machine; it is required for calculation of alveolar oxygen concentration.

Details about pH

$$pH = pK + \log_{10}(HCO_3^-/H_2CO_3)$$ (Henderson–Hasselbach euqation)

Normal pH = 7.35 – 7.45

Types of Acid–base Disorder

- Metabolic acidosis

- Metabolic alkalosis

- Acute respiratory acidosis

- Chronic Respiratory acidosis

- Acute respiratory alkalosis

- Chronic Respiratory alkalosis

Metabolic acidosis

Metabolic acidosisis is a process that causes primary decrease in plasma bicarbonate concentration. This can be due to gain in acid or loss of bicarbonate (Table 3).

Types of metabolic acidosis are as follows:

A. High anion gap (AG)

B. Non-AG acidosis or normal AG acidosis

High-AG acidosis

High-AG acidosis results from production of endogenous acid. It results from addition of hydrogen ion and an unmeasured anion in the blood. The hydrogen ions are buffered by bicarbonate causing decrease in its concentration.

Anion gap = Unmeasured anions – Unmeasured cations

$AG = Na - (Cl + HCO_3^-)$

Normal AG = 12 ± 2 mEq/l

Reference AG is influenced by albumin concentration in blood.

Adjusted AG = Observed AG + 2.5 [4.0 – measured albumin (g/dl)]

If an elevated AG metabolic acidosis is present, the "delta–delta ratio" should be calculated to determine if a second metabolic disorder is present.

The delta–delta calculation compares the deviation from normal of the AG with that of HCO_3^- (normal $[HCO_3^-]$ ≈ 22–26 mEq/l). In a simple AG acidosis, these values would be expected to roughly equal one another (HCO_3^- decreasing by one unit for every unit the AG increases); however because not all H^+ is buffered by HCO_3^-, the Δ in the AG usually exceeds the Δ in HCO_3^-.

If $\Delta AG/\Delta HCO_3^-$ <1, an elevated gap metabolic acidosis and a normal gap acidosis are both present.

If $\Delta AG/\Delta HCO_3^-$ = 1–2, a simple elevated gap metabolic acidosis is present.

If $\Delta AG/\Delta HCO_3^-$ >2, an elevated gap metabolic acidosis and a metabolic alkalosis are both present.

Non-AG acidosis or normal AG acidosis

It is also known as hyperchloremic acidosis and drop in bicarbonate is the primary pathology. Sometime increased chloride can cause non-AG acidosis.
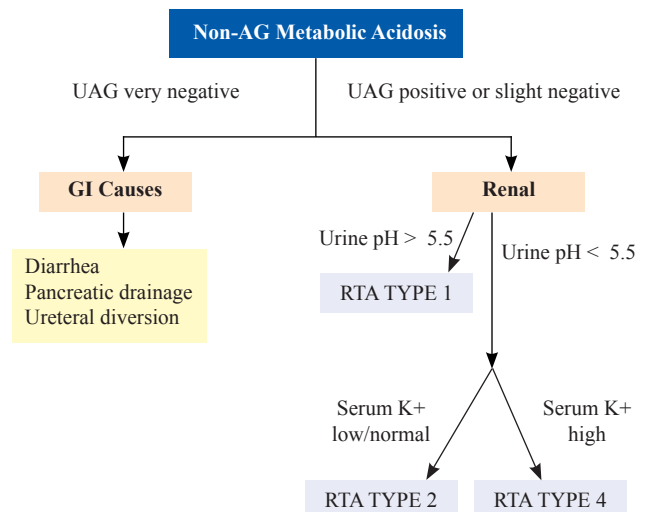
Urinary AG = (Urine Na^+ + Urine K^+) – Urine Cl^-

Table 3.

Causes of metabolic acidosis

High-AG acidosis	Normal AG acidosis
M - Methanol	F - Fistula
U - Uremia	U - Uretero-enterostomy
D - Diabetic ketoacidosis	S - Saline administration (large volume)
P - Paraldehyde/propylene	E - Endocrine (hyperparathyroidism)
glycol	D - Diarrhea
I - Isoniazide	C - Carbonic anhydrase inhibitors
L - Lactic acidosis	(acetazolamide)
E - Ethylene glycol	A - Ammonium chloride
S - Salicylate intoxication	R - Renal tubular acidosis (type 1,2,4)
R - Renal failure	S - Spironolactone
(MUDPILES)	(FUSEDCARS)

In compensated metabolic acidosis, there are $PaCO_2$ less than 30, low HCO_3, with a pH of 7.3–7.4.

Expected $PaCO_2 = (1.5 \times HCO_3^-) + (8\pm2)$

In uncompensated metabolic acidosis, the following conditions prevail:

■ Normal $PaCO_2$, low HCO_3^- and a pH less than 7.30

■ Occurs as a result of increased production of acids and/or failure to eliminate these acids

Respiratory system is not compensating by increasing alveolar ventilation (hyperventilation).

Metabolic alkalosis

Metabolic alkalosis is a process that causes primarily increase in HCO_3^- concentration. It can be either generated by loss of hydrogen ion or gain of HCO_3^- and compensated by respiratory system.

Expected $PaCO_2 = (0.7 \times HCO_3^-) + (21\pm2)$

Causes of metabolic alkalosis are as follows:

- Extracellular fluid volume depletion

- Severe potassium depletion

- Mineralocorticoid excess syndrome
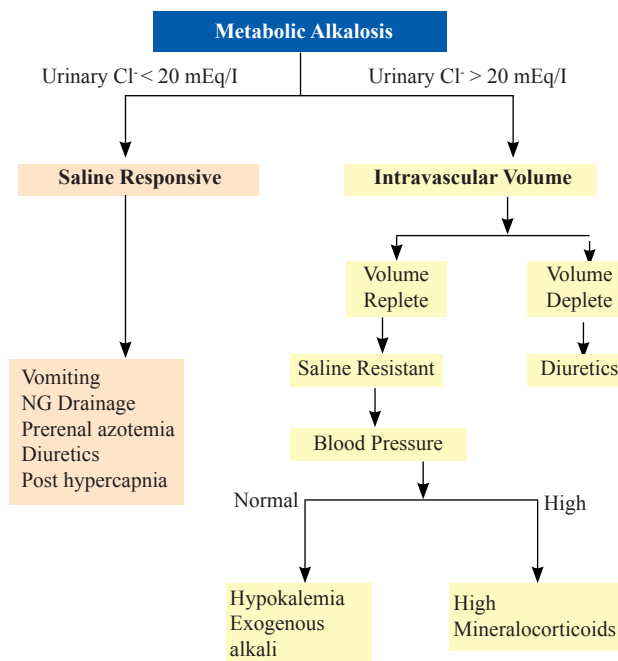
Acute respiratory acidosis

■ $PaCO_2$ is elevated and pH is acidotic

■ The decrease in pH is accounted for entirely by the increase in $PaCO_2$

■ Bicarbonate and base excess will be in the normal range because the kidneys have not had adequate time to establish effective compensatory mechanisms

Causes are as follows:

- Respiratory pathophysiology (airway obstruction, severe pneumonia, chest trauma/pneumothorax)

- Acute drug intoxication (narcotics, sedatives)

- Residual neuromuscular blockade

- Central nervous system disease (head trauma)

Chronic respiratory acidosis

■ $PaCO_2$ is elevated with a pH in the acceptable range

■ Renal mechanisms increase the excretion of H^+ within 24 hours and may correct the resulting acidosis caused by chronic retention of CO_2 to a certain extent

Causes are as follows:

- Chronic lung disease (e.g., chronic obstructive pulmonary disease)

- Neuromuscular disease

- Extreme obesity

- Chest wall deformity

Acute respiratory alkalosis

■ $PaCO_2$ is low and the pH is alkalotic

■ The increase in pH is accounted for entirely by the decrease in $PaCO_2$

■ Bicarbonate and base excess will be in the normal range because the kidneys have not had sufficient time to establish effective compensatory mechanisms

Causes are as follows:

- Pain

- Anxiety

- Hypoxemia

- Restrictive lung disease

- Severe congestive heart failure

- Pulmonary emboli

- Drugs

- Sepsis

- Fever

- Thyrotoxicosis

- Pregnancy

- Overaggressive mechanical ventilation

- Hepatic failure

Chronic respiratory alkalosis

In chronic respiratory alkalosis, metabolic component compensates almost completely. Therefore there will be little change in pH.

Oxygenation Assessment

A–a gradient. The alveolar–arterial oxygenation gradient

is the difference between P_AO_2 and P_aO_2 [a normal A–a gradient $\approx$ (age in years + 10)/4]. The source of this normal gradient is a physiological shunt due to bronchial blood flow (which bypasses the alveoli and is therefore not oxygenated) and a small portion of coronary venous blood that drains directly into the left ventricle via the thebesian veins.

A–a oxygen ratio $= P_aO_2 / P_AO_2$

Normal range > 0.77

$$P_AO_2 = FIO_2 \times 713 - (P_aCO_2/RQ)$$

It is used to approximate the change expected in P_aO_2 for a given increase in F_IO_2.

P_aO_2/ F_IO_2 ratio: Normal range = 300–500;

Gas exchange derangement = 200–300;

Severe hypoxia < 200.

ABG Interpretation – Steps

First, does the patient have an acidosis or an alkalosis?

Second, what is the primary problem – metabolic or respiratory?

Third, is there any compensation by the patient?

Respiratory compensation is immediate while renal compensation takes time.

Normal values

pH= 7.35–7.45	(Reference value 7.4)
$PaCO_2$= 35–45 mmHg	(Reference value 40)
HCO_3^-= 22–26 mEq/l	(Reference value24)

Abnormal values

pH < 7.35	Acidosis (metabolic and/or respiratory)
pH > 7.45	Alkalosis (metabolic and/or respiratory)
$PaCO_2$> 45 mmHg	Respiratory acidosis (alveolar hypoventilation)
$PaCO_2$< 35 mmHg	Respiratory alkalosis (alveolar hyperventilation)
HCO_3< 22 mEq/l	Metabolic acidosis
HCO_3> 26 mEq/l	Metabolic alkalosis

Putting it together:

Respiratory

■ $PaCO_2$> 45 with a pH < 7.35 represents a respiratory acidosis

- $PaCO_2 < 35$ with a pH > 7.45 represents a respiratory alkalosis

- For a primary respiratory problem, pH and $PaCO_2$ move in the opposite direction

  - For each deviation in PaCO2 of 10 mmHg in either direction, 0.08 pH units change in the opposite direction

Metabolic

- $HCO_3 < 22$ with a pH < 7.35 represents a metabolic acidosis

- $HCO_3 > 26$ with a pH > 7.45 represents a metabolic alkalosis

- For a primary metabolic problem, pH and HCO_3- are in the same direction, and $PaCO_2$ is also in the same direction

- Fourth, look for compensation

  - The body's attempt to return the acid/base status to normal (i.e., pH closer to 7.4)

Primary Problem	Compensation
Respiratory acidosis	Metabolic alkalosis
Respiratory alkalosis	Metabolic acidosis
Metabolic acidosis	Respiratory alkalosis
Metabolic alkalosis	Respiratory acidosis

Expected Compensation

Respiratory acidosis (1/4)

- Acute – the pH decreases 0.008 units for every 1 mm Hg increase in $PaCO_2$; HCO_3-1 mEq/l per 10 mm Hg $PaCO_2$

- Chronic – the pH decreases 0.003 units for every 1 mm Hg increase in $PaCO_2$; HCO_3-4 mEq/l per 10 mm Hg $PaCO_2$

Expected compensation

Respiratory alkalosis (2/5)

- Acute – the pH increases 0.008 units for every 1 mmHg decrease in $PaCO_2$; HCO_3- 2mEq/l per 10 mmHg $PaCO_2$

- Chronic – the pH increases 0.0017 units for every 1 mmHg decrease in $PaCO_2$; HCO_3- 5 mEq/l per 10 mmHg $PaCO_2$

Expected Compensation

Metabolic acidosis

- Expected $PaCO_2 = 1.5(HCO_3) + 8\ (\pm 2)$

- $PaCO_2$ 1-1.5 per 1 mEq/l HCO_3

Metabolic alkalosis

- Expected $PaCO_2 = 0.7(HCO_3) + 21\ (\pm 2)$

- $PaCO_2$ 0.5–1.0 per 1 mEq/l HCO_3

RADIOMETER ABL800 BASIC

ABL800 Basic			07:59 AM	11/25/2013
Patient Report	Syringe - S 195 uL		Sample #	77208

Identifications
  Patient ID
  Patient Last Name
  Sex   Male
  Sample type   Arterial
  $FO_2(I)$ 21.0%
  T   37.0%C

pH	7.407		[7.350	- 7.450]
$pCO2$	41.1	mmHg	[35.0	- 45.0]
pO_2	104	mmHg	[83.0	- 108]
$cHCO_3^-(P.st)c$	25.5	g/dL		
↓ ctHb	9.2	g/dL	[12.0	- 16.0]
sO_2	98.1	%	[95.0	- 99.0]
cK^+	4.1	mmol/L	[3.5	- 4.5]
↑ ctHb	139	mg/dL	[70.0	- 105.0]
↓ cLac	0.5	mmol/L	[0.5	- 1.6]
↓ cNa^+	124	mmol/L	[135	- 145]
↓ cCl^-	95	mmol/L	[98	- 106]
↓ cCa^{2+}	1.06	mmol/L	[1.15	- 1.29]
ABEc	1.2	mmol/L		
Calculated Values				
$cCa^{2+}(7.4)c$	1.07	mmol/L		
$ctCo_2(P)c$	59.7	vol%		
Anion Gapc	3.1	mmol/L		
Anion Gap, K^+c	7.1	mmol/L		
Hctc	28.6	%		
pH(st)c	7.416			
p50e	26.44	mmHg		
pO_2(A-a)e	---.-	mmHg		
pO_2(a/A)e	104.6	%		
RIe	-4	%		
mOsmc	255.2	mmol/kg		
Temperature Corrected Values				
pH(T)	7.407			
$pCO_2(T)$	41.1	mmHg		
$pO_2(T)$	104	mmHg		

Notes

↑   Value(s) above reference range
↓   Value(s) below reference range
c   Calculated value(s)
e   Estimated value(s)

Figure 2. A typical arterial blood gas analysis report.

References

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Picture courtesy: Rachna Kasliwal