

RESEARCH ARTICLE

A Graphical Tool for Arterial Blood Gas Interpretation using Standard Bicarbonate and Base Excess

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ABSTRACT

Introduction: Arterial blood gas (ABG) analysis plays an important role in the treatment of intensive care patients, especially for critically ill patients but are often difficult to understand, interpret, and sometimes confusing if both the metabolic and respiratory disturbances are found. There are only few graphical tools available depicting the respiratory and metabolic acid–base disturbances but are rarely used in clinical setting.

Aim: The aim of the current research study is to develop a newer graphical tool for ABG interpretation.

Materials and methods: A total of 120 arterial blood samples were collected and analyzed using ABG analyzer. The ABG parameters like pH, pCO₂, HCO₃, and standard HCO₃ values were noted. Standard base excess was calculated from the obtained data. Arterial blood gas interpretation was done and all the 120 samples were classified into various acid–base disorders. The difference in value between bicarbonate and standard bicarbonate (HCO₃ – standard HCO₃) was calculated. Carbonic acid was derived from pCO₂ values and the ratio (HCO₃ – standard HCO₃)/H₂CO₃ was found. The relationship between pCO₂, difference between bicarbonate and standard bicarbonate values, and the ratio (HCO₃ – standard HCO₃)/H₂CO₃ were graphically analyzed. A novel four-quadrant graph method was developed using standard base excess in the x-axis and the ratio (HCO₃ – standard HCO₃)/H₂CO₃ values in the y-axis.

Results: Each acid–base disorders will occupy any of the four quadrants and the normal cases with no acid–base disturbances will be seen around the center of the graph.

Conclusion: This newer graphical tool may help in easier and quicker interpretation of ABG reports compared with the other existing graphical tools.

Clinical significance: This simple four-quadrant graph method may provide a rough guide for ABG interpretation, which, when applied at the appropriate time, results in timely management.

Keywords: Graphical tool, Standard base excess, Standard bicarbonate.

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INTRODUCTION

Arterial blood gas analysis plays a vital role in the management of intensive care unit patients, especially for critically ill patients.¹ In ABG analysis, the pH and pCO₂ are measured parameters, but bicarbonate concentration is a calculated parameter derived from the modified Henderson equation.² Davenport or Bicarbonate-pH diagram is a graphical tool representing the relationship between pH, pCO₂, and bicarbonate to depict the respiratory and metabolic acid–base disturbances.³ This Davenport diagram is rarely used in clinical setting.

The bicarbonate concentration parameter is useful only in patients with normal respiration because it is a dependent variable, as it changes with alterations in the values of pCO₂.⁴⁻⁶ As pCO₂ increases, it reacts with water molecules to form carbonic acid which dissociates into hydrogen and bicarbonate ions. The hydrogen ions are buffered by non-bicarbonate buffers like albumin, hemoglobin, and phosphate buffer system. So, the concentration of bicarbonate increases as pCO₂ also increases.

This problem is solved by measuring standard bicarbonate. Standard bicarbonate is the concentration of bicarbonate in the plasma from blood which is equilibrated with a normal PaCO₂ (40 mm Hg) and a normal pO₂ (over 100 mm Hg) at a normal temperature (37°C).

The actual bicarbonate and the standard bicarbonate values are more or less similar, but in the presence of respiratory disturbances, the two values will deviate from each other. Hence, the difference between these two values denotes the respiratory influence on the metabolic component.⁴⁻⁶

Base excess is defined as the amount of strong acid that must be added to each liter of fully oxygenated blood to return the pH to 7.40 at a temperature of 37°C and a pCO₂ of 40 mm Hg. The normal level for base excess is –2 to +2 mEq/L.

A negative base excess indicates the presence of base deficit. Actual base excess is the base excess of the blood, while standard base excess is the base excess of

the extracellular fluid at hemoglobin concentration of 5 gm/dL.⁷⁻⁹

The understanding of acid–base disturbances, classifying and analyzing the ABG data is sometimes challenging and difficult, especially for mixed acid–base disorders. The ABG analysis report should be clinically correlated before interpretation. The diagnosis of acid–base disturbances is very important because earlier detection may help in the treatment of clinical derangements.¹⁰⁻¹²

In the present study, the difference in value between bicarbonate and standard bicarbonate was calculated and the ratio $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3$ was found. The aim of the current research study is to determine the correlation between standard base excess and the ratio of $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3$ and to apply them to analyze the various acid–base disorders in a four-quadrant graphical method for better ABG interpretation.

MATERIALS AND METHODS

Ethical committee clearance was obtained before the commencement of the study. Based on the previous ABG analysis research data available, sample size was calculated. A total of 120 ABG analysis samples were analyzed. Strict precautions were taken to avoid preanalytical errors and the consistency of the ABG report was checked by using the modified Henderson equation.² The samples were analyzed by a senior technician using ABG Analyzer GEM PREMIER 3000. Good quality control is maintained in the central clinical laboratory. Automated calibration is done in this instrument.

The main parameters like measured pH, pCO_2 , HCO_3 , and standard HCO_3 values were noted. Carbonic acid concentration was calculated from pCO_2 . The difference between bicarbonate and standard bicarbonate was calculated. The ratio between $(\text{HCO}_3 - \text{standard HCO}_3)$ and carbonic acid was calculated and represented by $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3$.

Calculation of Carbonic acid Concentration

The carbonic acid concentration (mmol/L) was calculated by the given formula:

$$\text{H}_2\text{CO}_3 = 0.03 \times \text{pCO}_2$$

Calculation of $(\text{HCO}_3 - \text{Standard HCO}_3)/\text{H}_2\text{CO}_3$

The difference between bicarbonate and standard bicarbonate value was calculated which is denoted by $(\text{HCO}_3 - \text{standard HCO}_3)$ (mmol/L or mEq/L). Carbonic acid was derived from pCO_2 values and the ratio $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3$ was found.

Calculation of Standard Base Excess

The standard base excess or the base excess of the extracellular fluid (mmol/L or mEq/L) is calculated by the following formula¹³:

$$\text{Standard base excess} = \text{HCO}_3 - 24.8 + 16.2 (\text{pH} - 7.4)$$

Calculations for some of the ABG samples are given below:

1. pH: 7.38 pCO_2 : 42 mm Hg, HCO_3 : 24.8 mmol/L, and standard HCO_3 : 24.6 mmol/L

Calculation

$$\text{H}_2\text{CO}_3 = 0.03 \times \text{pCO}_2$$

$$\text{Carbonic acid (H}_2\text{CO}_3) \text{ concentration} = 1.26 \text{ mmol/L}$$

$$(\text{HCO}_3 - \text{standard HCO}_3) = 24.8 - 24.6 = 0.2 \text{ mmol/L}$$

$$(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3 = 0.2/1.26 = 0.16$$

$$\text{Standard base excess} = \text{HCO}_3 - 24.8 + 16.2 (\text{pH} - 7.4)$$

$$= 24.8 - 24.8 + 16.2 (7.38 - 7.4)$$

$$= -0.32 \text{ mmol/L or mEq/L}$$

2. pH: 7.45 pCO_2 : 73 mm Hg, HCO_3 : 50.7 mmol/L, and standard HCO_3 : 42.3 mmol/L

Calculation

$$\text{Carbonic acid (H}_2\text{CO}_3) \text{ concentration} = 2.19 \text{ mmol/L}$$

$$(\text{HCO}_3 - \text{standard HCO}_3) = 50.7 - 42.3 = 8.4 \text{ mmol/L}$$

$$(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3 = 8.4/2.19 = 3.8$$

$$\text{Standard base excess} = \text{HCO}_3 - 24.8 + 16.2 (\text{pH} - 7.4)$$

$$= 50.7 - 24.8 + 16.2 (7.45 - 7.4)$$

$$= 26.71 \text{ mmol/L}$$

3. pH: 7.25 pCO_2 : 36 mm Hg, HCO_3 : 15.8 mmol/L, and standard HCO_3 : 16.4 mmol/L

Calculation

$$\text{Carbonic acid (H}_2\text{CO}_3) \text{ concentration} = 1.08 \text{ mmol/L}$$

$$(\text{HCO}_3 - \text{standard HCO}_3) = 15.8 - 16.4 = -0.6 \text{ mmol/L}$$

$$(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3 = -0.6/1.08 = -0.6$$

$$\text{Standard base excess} = \text{HCO}_3 - 24.8 + 16.2 (\text{pH} - 7.4)$$

$$= 15.8 - 24.8 + 16.2 (7.25 - 7.4)$$

$$= -11.43 \text{ mmol/L}$$

4. pH: 7.35 pCO_2 : 22 mm Hg, HCO_3 : 12.1 mmol/L, and standard HCO_3 : 15.7 mmol/L

Calculation

$$\text{Carbonic acid (H}_2\text{CO}_3) \text{ concentration} = 0.66 \text{ mmol/L}$$

$$(\text{HCO}_3 - \text{standard HCO}_3) = 12.1 - 15.7 = -3.6 \text{ mmol/L}$$

$$(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3 = -3.6/0.66 = -5.5$$

$$\text{Standard base excess} = \text{HCO}_3 - 24.8 + 16.2 (\text{pH} - 7.4)$$

$$= 12.1 - 24.8 + 16.2 (7.35 - 7.4)$$

$$= -13.51 \text{ mmol/L}$$

5. pH: 7.51 pCO_2 : 20 mm Hg, HCO_3 : 16 mmol/L, and standard HCO_3 : 20.6 mmol/L

Calculation

Carbonic acid (H_2CO_3) concentration = 0.6 mmol/L
 $(\text{HCO}_3 - \text{standard HCO}_3) = 16 - 20.6 = -4.6$ mmol/L
 $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3 = -4.6/0.6 = -7.7$
 Standard base excess = $\text{HCO}_3 - 24.8 + 16.2 (\text{pH} - 7.4)$
 $= 16 - 24.8 + 16.2 (7.51 - 7.4)$
 $= -7.02$ mmol/L

6. pH: 7.6 pCO_2 : 22 mm Hg, HCO_3 : 26.6 mmol/L, and standard HCO_3 : 29.8 mmol/L

Calculation

Carbonic acid (H_2CO_3) concentration = 0.66 mmol/L
 $(\text{HCO}_3 - \text{standard HCO}_3) = 26.6 - 29.8 = -3.2$ mmol/L
 $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3 = -3.2/0.66 = -4.8$

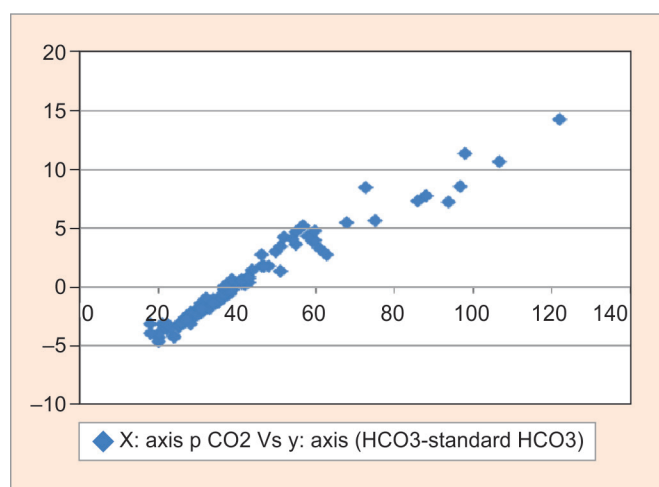
Standard base excess = $\text{HCO}_3 - 24.8 + 16.2 (\text{pH} - 7.4)$
 $= 26.6 - 24.8 + 16.2 (7.6 - 7.4)$
 $= 5.04$ mmol/L

RESULTS

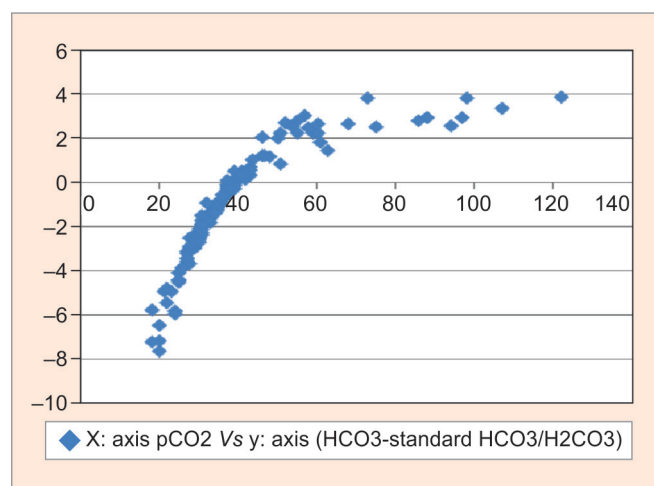
All 120 samples were classified into various acid-base disorders and are clearly depicted in Table 1. The relationship between pCO_2 , difference between bicarbonate and standard bicarbonate ($\text{HCO}_3 - \text{standard HCO}_3$) and the ratio $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3$ was analyzed and is shown in Graphs 1 and 2. The correlation between standard base excess and the ratio $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3$ was analyzed for various acid-base disorders and is clearly shown in the four-quadrant Graph 3.

Table 1: Classification and representation of various acid-base disorders in a four-quadrant graph

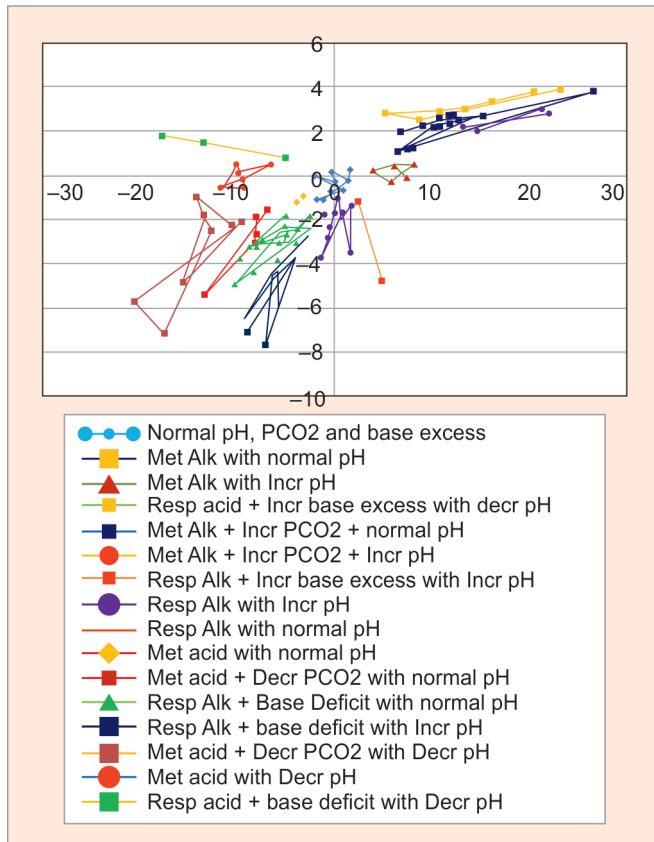
Acid-base disturbances with number of cases		$(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3$ range of values	Area in the quadrant graph	Number of samples
Normal: 10		-1.1 to 0.3	Around the center of the graph	10
Metabolic acidosis	Normal pH: 2	-0.9 and -1.2	3rd quadrant	9
	Decreased pH: 7	-0.6 to 0.5	3rd and 4th quadrants nearer to x-axis (negative)	
Metabolic acidosis with decreased PCO_2	Normal pH: 5	-5.5 to -1.5	3rd quadrant	13
	Decreases pH: 8	-7.2 to -0.9	3rd quadrant	
Respiratory acidosis with increased base excess	Decreased pH: 10	2.5 to 3.9	1st quadrant	10
Respiratory acidosis with base deficit	Decreased pH: 3	0.8 to 1.8	4th quadrant	3
Metabolic alkalosis	Normal pH: 4	-0.2 to 0.7	1st and 2nd quadrants nearer to x-axis (positive)	12
	Increased pH: 8	-0.3 to 0.5		
Metabolic alkalosis and increased PCO_2	Normal pH: 13	1.1 to 3.8	1st quadrant	17
	Increased pH: 4	2.0 to 3.0	1st quadrant	
Respiratory alkalosis	Normal pH: 2	-1.4 and -1.3	3rd quadrant just below the normal group	16
	Increased pH: 14	-3.7 to -1.0	2nd and 3rd quadrants nearer to y-axis (negative)	
Respiratory alkalosis with base deficit	Normal pH: 16	-4.9 to -1.8	3rd quadrant	28
	Increased pH: 12	-7.7 to -2.6	3rd quadrant	
Respiratory alkalosis and increased base excess	Increased pH: 2	-4.8 and -1.2	2nd quadrant	2



Graph 1: Relationship between pCO_2 and $(\text{HCO}_3 - \text{standard HCO}_3)$



Graph 2: Relationship between pCO_2 and $[(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3]$



Graph 3: Analysis of various acid–base disturbances using standard base excess (x-axis) and the ratio $(\text{HCO}_3^- - \text{standard HCO}_3^-) / \text{H}_2\text{CO}_3$ (y-axis) in the four-quadrant graph

DISCUSSION

The correlation between pCO_2 and $(\text{HCO}_3^- - \text{standard HCO}_3^-)$ and pCO_2 and ratio of $(\text{HCO}_3^- - \text{standard HCO}_3^-) / \text{H}_2\text{CO}_3$ is clearly shown in Graphs 1 and 2 respectively. From that, it is very clear that as the pCO_2 decreases, the ratio of $(\text{HCO}_3^- - \text{standard HCO}_3^-) / \text{H}_2\text{CO}_3$ also decreases and as the pCO_2 increases, the ratio of $(\text{HCO}_3^- - \text{standard HCO}_3^-) / \text{H}_2\text{CO}_3$ also increases and thereafter, the curve flattens. At pCO_2 of 40 mm Hg ratio of $(\text{HCO}_3^- - \text{standard HCO}_3^-) / \text{H}_2\text{CO}_3$ is zero because the difference between bicarbonate and standard bicarbonate value is zero ($\text{HCO}_3^- - \text{standard HCO}_3^-$ is zero).⁴⁻⁶

All 120 samples were classified into various acid–base disturbances and the results are tabulated in Table 1. The normal range for standard base excess is ± 2 mmol/L. If the value is > 2 mmol/L, then it denotes metabolic alkalosis and if the value is < -2 mmol/L, then it denotes metabolic acidosis (base deficit). In respiratory acidosis (due to hypoventilation), pCO_2 retention occurs and in respiratory alkalosis (due to hyperventilation), the pCO_2 value is decreased. The ratio of $(\text{HCO}_3^- - \text{standard HCO}_3^-) / \text{H}_2\text{CO}_3$ changes in respiratory disorders and also in metabolic acid–base disturbances associated with respiratory compensations.⁴⁻⁶

The ratio $(\text{HCO}_3^- - \text{standard HCO}_3^-) / \text{H}_2\text{CO}_3$ is greater positive for respiratory acidosis and greater negative for respiratory alkalosis.⁴⁻⁶

A new graphical tool is developed for ABG interpretation using standard base excess and the ratio of $(\text{HCO}_3^- - \text{standard HCO}_3^-) / \text{H}_2\text{CO}_3$ values. It contains four quadrants. In the x-axis, standard base excess values were taken and in the y-axis, ratio of $(\text{HCO}_3^- - \text{standard HCO}_3^-) / \text{H}_2\text{CO}_3$ values was taken to analyze the various acid–base disturbances which is clearly shown in the four-quadrant (Graph 3).

In the 1st quadrant (both x- and y-axes are positive), if the plotted area is toward the x-axis, then it represents metabolic alkalosis and if the area is toward the y-axis, then it represents respiratory acidosis. The plotted area in between and higher may represent combined acid–base disturbances (metabolic alkalosis and respiratory acidosis). The combined acid–base disturbances may be due to compensatory mechanism or mixed acid–base disorders.

In the 2nd quadrant (the x-axis is positive and the y-axis negative), if the plotted area is toward the y-axis, then it represents respiratory alkalosis and if the area is in between and lower, then it may represent combined acid–base disturbances (metabolic alkalosis and respiratory alkalosis).

In the 3rd quadrant (both x- and y-axes are negative), if the plotted area is toward the x-axis, then it represents metabolic acidosis and if the area is in between and lower, then it represents both metabolic acidosis and respiratory alkalosis.

In the 4th quadrant (the x-axis is negative and the y-axis is positive), if the area is toward the y-axis, then it represents respiratory acidosis and if the area is in between and higher, then it may represent both metabolic acidosis and respiratory acidosis.

The acid–base disorders can be classified and plotted in the four-quadrant graph by using the values of standard base excess and the ratio $(\text{HCO}_3^- - \text{standard HCO}_3^-) / \text{H}_2\text{CO}_3$. Each acid–base disorders will occupy any of the four quadrants and the normal ABG analysis reports will be seen around the center of the graph.

ABG interpretation is very essential for critically ill patients. Immediate analysis, interpretation, and prompt treatment may reduce the morbidity and mortality of the patients. Arterial blood gas reports should be interpreted with clinical correlation. This newer graphical tool clearly demonstrates that the different acid–base disorders in a four-quadrant graph method may provide a rough guide to interpret the results quickly and easily. The current research study tries to emphasize the clinical significance of this newer diagnostic tool, which, used along with other ABG parameters and proper clinical correlation, may help in better interpretation of ABG reports.

CONCLUSION

Arterial blood gas analysis and interpretation is sometimes challenging, especially for combined acid–base disturbances. A newer graphical tool developed using standard base excess and the ratio of $(\text{HCO}_3^- - \text{standard HCO}_3^-)/\text{H}_2\text{CO}_3$ may help in easier and quicker interpretation of ABG reports. This simple four-quadrant graph method may provide a rough guide for ABG interpretation, which, when applied at the appropriate time, results in timely management.

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