

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

4,800

Open access books available

122,000

International authors and editors

135M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Who Is Balancing: Is It RBC or Acid-Base Status?

T. Rajini Samuel

Abstract

Hemoglobin is an important intracellular protein buffer present inside the red blood cells (RBC). When the partial pressure of carbon dioxide ($p\text{CO}_2$) is increased, it freely diffuses into the RBC where it reacts with water molecules to form carbonic acid which dissociates to form bicarbonate and hydrogen ions by the enzyme carbonic anhydrase. Hydrogen ions liberated in this reaction are buffered by hemoglobin. Oxyhemoglobin is a stronger acid than deoxyhemoglobin. Oxygenation of hemoglobin causes an increase in net titratable hydrogen ion due to the Haldane effect. As the oxygen saturation of hemoglobin ($s\text{O}_2$) increases, the base excess is changed in the acidic direction, or as the $s\text{O}_2$ decreases, the base excess is changed in alkaline direction. The changes in the level of the enzyme carbonic anhydrase in RBC are related to the changes in pH, $p\text{CO}_2$, and bicarbonate levels in the blood. The understanding of the acid-base balance is a challenging task, but at the same time, it has immense clinical value. The relationship of carbonic anhydrase enzyme present inside the RBC in maintaining the acid-base balance to the commonly employed arterial blood gas (ABG) parameters like pH, $p\text{CO}_2$ bicarbonate, and base excess may help us for better understanding.

Keywords: acid-base balance, carbonic anhydrase enzyme, oxygen saturation, hemoglobin

1. Introduction

Arterial blood gas (ABG) analysis plays a vital role in the management of intensive care unit patients, especially for critically ill patients, but the interpretation is sometimes a challenging task especially if the acid-base disturbances are complex [1–5]. In ABG analysis, the pH and $p\text{CO}_2$ 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, $p\text{CO}_2$, and bicarbonate to depict the respiratory and metabolic acid-base disturbances. This Davenport diagram is rarely used in clinical setting [1].

Simple acid-base disorders are very easy to diagnose, but combined acid-base disorders due to either *compensatory* mechanisms or *mixed disorders* are often difficult and sometimes confusing. The *four acid-base disorders* are metabolic acidosis, metabolic alkalosis, respiratory acidosis, and respiratory alkalosis. Simple acid-base disorder is the presence of any of the four disorders with appropriate compensations. *Mixed acid-base disorder* denotes the presence of more than one primary disturbances which can be suspected from a lesser or greater than expected

compensations. *Respiratory disorders* are associated with appropriate renal compensatory mechanisms, and similarly metabolic disorders are compensated by respiratory mechanisms [6, 7].

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 mmHg. 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 (ECF)* at hemoglobin concentration of 5 gm/dL [8–10].

Under *normal ventilation*, bicarbonate parameter is useful, but in patients with abnormal ventilation (respiration), it may not reflect the true status because bicarbonate is a dependent variable and it changes with the concentration of pCO₂. 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 [11, 12].

Standard bicarbonate is the concentration of bicarbonate in the plasma from blood which is equilibrated with a normal pCO₂ (40 mmHg) and a normal pO₂ (over 100 mmHg) at a normal temperature (37°C). The *actual bicarbonate* and the *standard bicarbonate* concentrations are approximately equal under normal ventilation, but in abnormal respiration (either hypoventilation or hyperventilation), the two values alter and deviate from each other depending on the changes in the concentration of pCO₂ [1].

The bicarbonate value is increased in respiratory acidosis and decreased in respiratory alkalosis. So, the difference between bicarbonate and standard bicarbonate value is positive for respiratory acidosis and negative for respiratory alkalosis. If the acid-base disorder is purely metabolic without respiratory compensation, then the bicarbonate and standard bicarbonate values are more or less closer. If the metabolic disorder is compensated by respiratory mechanisms, then the two values alter and deviate from each other.

The most commonly used approach for arterial blood gas (ABG) analysis interpretation is a physiological approach based on the bicarbonate-carbon dioxide buffer system. The major buffer system in the ECF is the carbon dioxide-bicarbonate buffer system, and other buffer systems that play a role in buffering are protein and phosphate buffer systems. The buffers are substances that resist changes in pH. All buffers in a common solution are in equilibrium with the same hydrogen ion concentration. Therefore, whenever there is a change in hydrogen ion concentration in the extracellular fluid, the balance of all the buffer systems changes at the same time. This phenomenon is called the isohydric principle. Henderson-Hasselbalch equation concentrating on the bicarbonate-pCO₂ buffer is based on this principle. This approach is very simple and easier, but a major drawback of this is it is unable to quantify the metabolic (non-respiratory) component and does not explain the causative mechanism of metabolic acid-base disturbances [8].

2. Base excess

Base excess approach was developed to quantify the metabolic component, but it was *criticized* because it represents the whole blood and *did not* accurately represent the *whole body behavior*. Blood volume diluted with interstitial fluid represents the effective extracellular fluid hemoglobin concentration of 5 g/dl. *Standard base excess*

or extracellular base excess is the base excess at hemoglobin concentration of 5 g/dl [8–12].

Oxyhemoglobin is a stronger acid than deoxyhemoglobin. Oxygenation of hemoglobin causes an increase in net titratable hydrogen ion because hydrogen ions are liberated from the oxygen-linked buffer groups due to the Haldane effect. So, the variation of oxygen saturation of hemoglobin (sO_2) influences the base excess result. The formula for calculating this is

$$cBase(B, \text{oxygenated}) = cBase(B, \text{actual}) - 0.2 \times ctHb \times (1 - sO_2)$$

or

$$cBase(B, \text{actual}) = cBase(B, \text{oxygenated}) + 0.2 \times ctHb \times (1 - sO_2)$$

As the sO_2 increases, the term $0.2 \times ctHb \times (1 - sO_2)$ decreases, so the base excess is changed in the acidotic direction because it is slightly decreased, or as the sO_2 decreases, the term $0.2 \times ctHb \times (1 - sO_2)$ increases, so the base excess is changed in alkaline direction because it is slightly increased [8–10].

The correlation between pCO_2 and $(HCO_3 - \text{standard } HCO_3)/H_2CO_3$ and pCO_2 and ratio of $(HCO_3/\text{standard } HCO_3)$ is clearly shown in **Figures 1** and **2**, respectively. From that, it is very clear that as the pCO_2 decreases, the ratio of $(HCO_3 - \text{standard } HCO_3)/H_2CO_3$ also decreases and, as the pCO_2 increases, the ratio of $(HCO_3 - \text{standard } HCO_3)/H_2CO_3$ also increases and, thereafter, the curve flattens. At pCO_2 of 40 mmHg, the ratio of $(HCO_3 - \text{standard } HCO_3)/H_2CO_3$ is zero because the difference between bicarbonate and standard bicarbonate value is zero ($HCO_3 - \text{standard } HCO_3$ is zero). 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 $(HCO_3 - \text{standard } HCO_3)/H_2CO_3$ changes in respiratory disorders and also in metabolic acid-base disturbances associated with respiratory compensations. The ratio of $(HCO_3 - \text{standard } HCO_3)/H_2CO_3$ is greater positive for respiratory acidosis and greater negative for respiratory alkalosis [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). Using this concept a four-quadrant graphical tool can be constructed for ABG interpretation using standard base excess

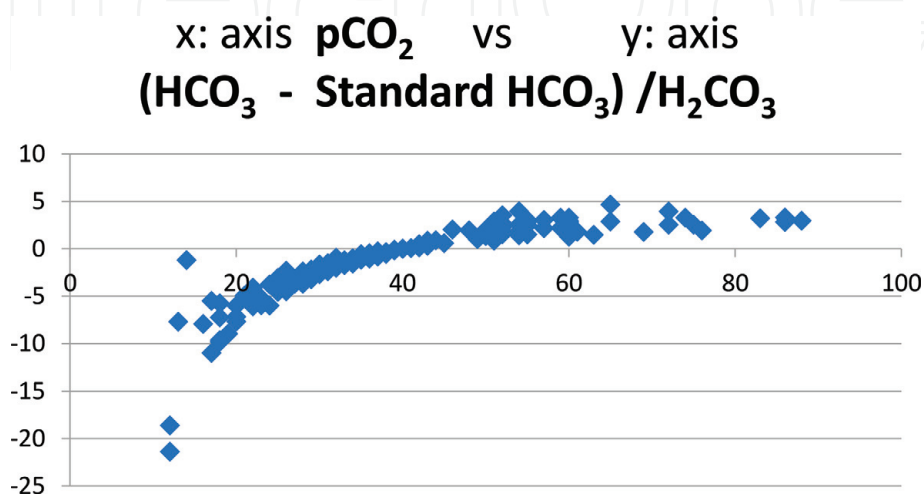


Figure 1.
 Relation between pCO_2 and $(HCO_3 - \text{standard } HCO_3)/H_2CO_3$.

x: axis pCO_2 vs y: axis $HCO_3 / Std HCO_3$

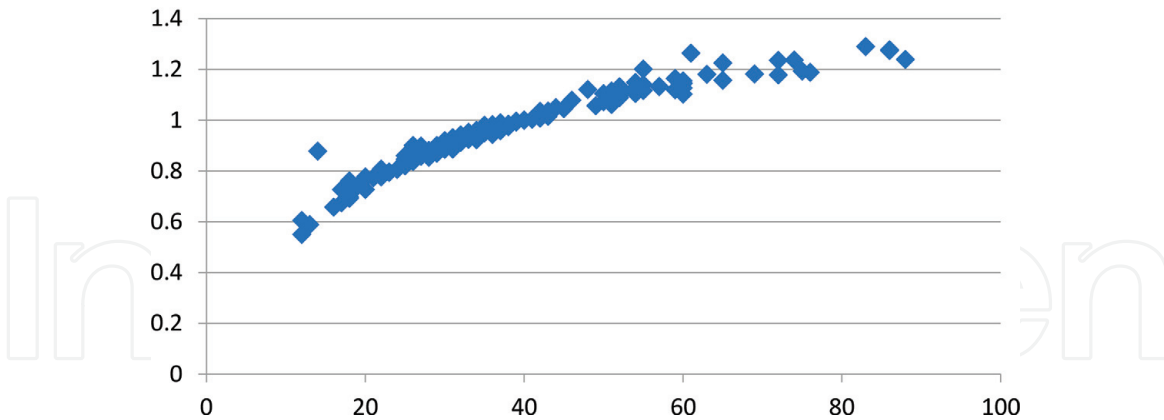


Figure 2.
Relation between pCO_2 and $HCO_3 / Std HCO_3$.

and the ratio of $(HCO_3 - \text{standard } HCO_3) / H_2CO_3$ in the two axes that demarcate the various acid-base disturbances which are shown in **Figure 3** [1].

The aim of the manuscript is to increase in depth the understanding of the acid-base balance which is a challenging and at times an arduous task, yet it has immense

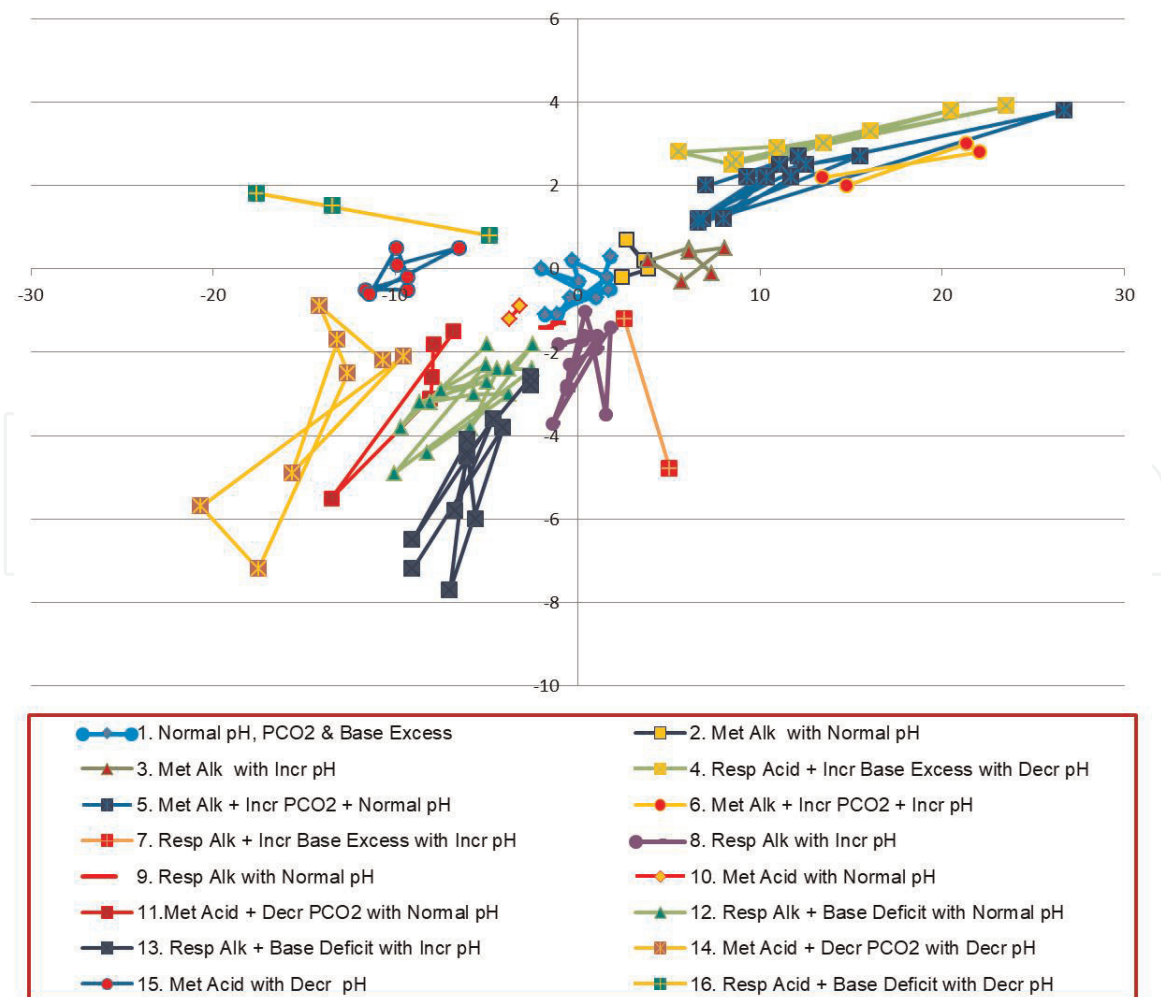


Figure 3.
Analysis of various acid-base disturbances using standard base excess (x-axis) and the ratio of $(HCO_3 - \text{standard } HCO_3) / H_2CO_3$ (y-axis) in the four-quadrant graph.

clinical value. The relationship of the formation of bicarbonate from $p\text{CO}_2$ with the help of carbonic anhydrase enzyme present inside the RBC plays a significant role in maintaining the acid-base balance. The application of standard bicarbonate in the calculation of non-respiratory hydrogen ion concentration and development of a novel four quadrant graphical method for arterial blood gas interpretation may help us for better understanding.

3. Materials and methods

About 188 arterial blood gas sample data were utilized. Strict precautions were taken to avoid pre-analytical errors, and the consistency of the ABG report was checked by using the modified Henderson equation [2].

The main parameters like measured $p\text{H}$, $p\text{CO}_2$, HCO_3 , standard HCO_3 , and standard base excess values were noted. Carbonic acid concentration was calculated from $p\text{CO}_2$. The difference between bicarbonate and standard bicarbonate was calculated. The ratio of $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3$ was calculated [1].

Calculation of H^+ :

H^+ —hydrogen ion concentration at actual pH

(Calculated using modified Henderson equation)

H^+ (hydrogen ion concentration) = $\{24 \times p\text{CO}_2\}/\text{HCO}_3$

$p\text{H} = -\log[\text{H}^+ \text{ nanomoles/L}]$

= $-\log [\text{H}^+ \times 10^{-9} \text{ moles/L}]$

= $-\log [\text{H}^+] - \log [10^{-9}]$ {nanomoles/L = 10^{-9} moles/L}

$p\text{H} = 9 - \log [\text{H}^+]$

Calculation of NRH^+ (non-respiratory hydrogen ion concentration):

NRH^+ —hydrogen ion concentration at non-respiratory pH

(At $p\text{CO}_2$ of 40 mmHg)

This calculated hydrogen ion concentration equivalent of standard bicarbonate has thus been called the “non-respiratory” hydrogen ion concentration or NRH^+ [13, 14]. It has a unique value for a given standard bicarbonate concentration, and the relationship is clearly shown in **Figure 4**:

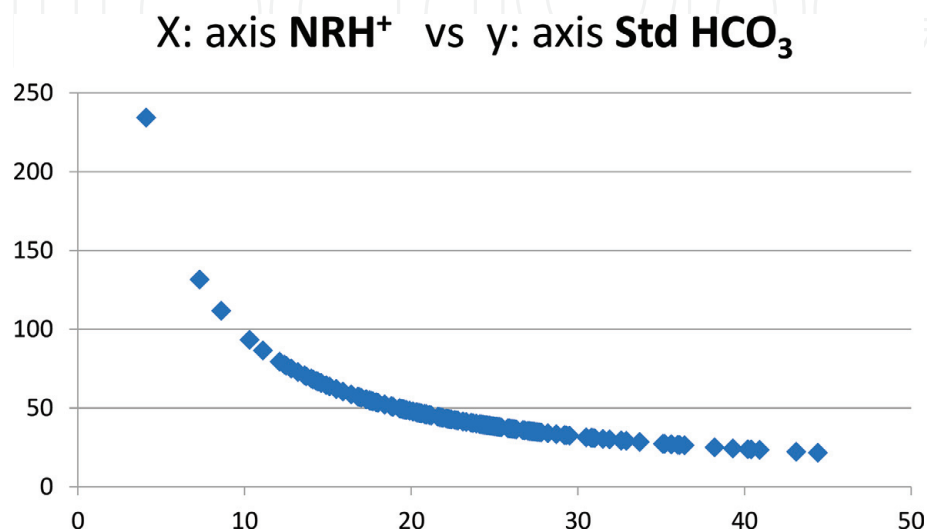


Figure 4.
 Relation between NRH^+ and Std HCO_3 .

$$\begin{aligned}
 \text{NRH}^+ &= \{24 \times \text{pCO}_2\} / \text{Std HCO}_3 \\
 &= \{24 \times 40\} / \text{Std HCO}_3 \quad (\text{pCO}_2 \text{ is } 40 \text{ mmHg}) \\
 \text{NRH}^+ &= 960 / \text{Std HCO}_3 \\
 \text{NRpH} &= 9 - \log [\text{NRH}^+]
 \end{aligned}$$

Calculation of ΔRpH :

$$\begin{aligned}
 \text{pH} &= 9 - \log [\text{H}^+] \\
 \text{NRpH} &= 9 - \log [\text{NRH}^+] \\
 \text{pH} - \text{NRpH} &= 9 - \log [\text{H}^+] - 9 + \log [\text{NRH}^+] \\
 &= \log [\text{NRH}^+ / \text{H}^+] \text{ or } -\log [\text{H}^+ / \text{NRH}^+] \\
 \text{H}^+ \text{ (hydrogen ion concentration)} &= \{24 \times \text{pCO}_2\} / \text{HCO}_3 \\
 \text{NRH}^+ \text{ (non-respiratory hydrogen ion concentration)} &= \{24 \times 40\} / \text{Std HCO}_3 \\
 [\text{NRH}^+] / [\text{H}^+] &= \{24 \times 40\} / \text{Std HCO}_3 / \{24 \times \text{pCO}_2\} / \text{HCO}_3 \\
 &= 40 \times \{(\text{HCO}_3 / \text{Std HCO}_3) / \text{pCO}_2\}
 \end{aligned}$$

Or in terms of carbonic acid [$\text{pCO}_2 = \text{H}_2\text{CO}_3 / 0.03$], this can be written as

$$= 1.2 \times \{(\text{HCO}_3 / \text{Std HCO}_3) / \text{H}_2\text{CO}_3\}$$

$$\begin{aligned}
 \text{pH} - \text{NRpH} &= \log [\text{NRH}^+ / \text{H}^+] \\
 \text{pH} - \text{NRpH} &= \log 40 + \log (\text{HCO}_3 / \text{Std HCO}_3) - \log (\text{pCO}_2) \\
 [\text{pH} - \text{NRpH}] &= 1.6 + \log \{(\text{HCO}_3 / \text{Std HCO}_3) / \text{pCO}_2\}
 \end{aligned}$$

At pCO_2 of 40 mmHg, $\text{pH} - \text{NRpH}$ is zero (because bicarbonate and standard bicarbonate values are equal, log 1 is zero, and log 40 is 1.6). At higher pCO_2 levels (>40 mmHg), the value of $[\text{pH} - \text{NRpH}]$ is negative which denotes the *acidic influence* of increased pCO_2 . At lower pCO_2 levels (<40 mmHg), the value of $[\text{pH} - \text{NRpH}]$ is positive which denotes the *alkaline influence* of decreased pCO_2 :

$$\begin{aligned}
 [\text{pH} - \text{NRpH}] &= 1.6 + \log \{(\text{HCO}_3 / \text{Std HCO}_3) / \text{pCO}_2\} \\
 \text{where NRpH denotes the non-respiratory pH.} \\
 \text{pH} &= 9 - \log [\text{H}^+] \\
 \text{NRpH} &= 9 - \log [\text{NRH}^+] \\
 \text{pH} - \text{NRpH} &= 9 - \log [\text{H}^+] - 9 + \log [\text{NRH}^+] \\
 &= \log [\text{NRH}^+ / \text{H}^+] \text{ or } -\log [[\text{H}^+] / [\text{NRH}^+]]
 \end{aligned}$$

The *magnitude* and *direction* (positive or negative) of the changes in the parameter ΔRpH ($\text{pH} - \text{NRpH}$) denote the respiratory influence in causing changes in pH. The value is *negative* for *acidic* effect and *positive* for *alkaline* effect. At pCO_2 of 40 mmHg, $\text{pH} - \text{NRpH}$ is zero [14].

3.1 Net changes in total pH

The net changes in *total pH* (actual pH) include both the changes in *respiratory* and *non-respiratory* (metabolic) components affecting the pH [14]:

$$\begin{aligned}
 \Delta\text{pH} &= \Delta\text{RpH} + \Delta\text{NRpH} \\
 \text{pH} - 7.4 &= \Delta\text{RpH} + \text{NRpH} - 7.4
 \end{aligned}$$

where ΔNRpH ($\text{NRpH} - 7.4$) denotes the changes in pH due to metabolic component.

3.2 Predicted respiratory pH

$$\begin{aligned}
 \text{pH} &= 7.4 + \Delta\text{RpH} + \Delta\text{NRpH} \\
 7.4 + \Delta\text{RpH} - \text{pH} &= -\Delta\text{NRpH} \\
 \text{Pr RpH} - \text{pH} &= -\Delta\text{NRpH} \quad \{\text{Pr RpH (predicted respiratory pH)} = 7.4 + \Delta\text{RpH}\}
 \end{aligned}$$

The predicted respiratory pH is the *pH* at which the *changes in pH* due to *metabolic* component are *zero* ($\Delta NRpH$ is zero).

The difference between the *predicted respiratory pH* and *actual pH* denotes the changes in pH due to metabolic component. The *magnitude* and *direction* (positive or negative) of the changes in the parameter $\Delta NRpH$ ($NRpH - 7.4$) are due to the accumulation of acids other than carbonic acid or bases. The value is *negative* for *acidic* effect and *positive* for *alkaline* effect. This is one of the postulates of the acid-base balance theory recently published. If the *actual pH* is *less* than the *predicted respiratory pH*, $\Delta NRpH$ is *negative*. If the *actual pH* is *greater* than the *predicted respiratory pH*, $\Delta NRpH$ is *positive* [15–18].

NRPH-7.4:

$$\begin{aligned} NRPH-7.4 &= 9 - \log [NRH^+] - \{9 - \log [40]\} \\ &= 9 - \log [NRH^+] - 9 + \log [40] \\ &= \log \{[40]/[NRH^+]\} \text{ or } -\log \{[NRH^+]/[40]\} \end{aligned}$$

7.4 + ΔRpH :

$$\begin{aligned} 7.4 + \Delta RpH &= \{9 - \log [40] + 9 - \log [H^+] - 9 + \log [NRH^+]\} \\ &= 9 + \log [NRH^+]/\{[H^+] \times [40]\} \\ \{\Delta RpH (pH - NRpH) &= 9 - \log [H^+] - 9 + \log [NRH^+]\} \\ &= \log \{[NRH^+]/[H^+]\} \text{ or } -\log \{[H^+]/[NRH^+]\} \end{aligned}$$

Pr Resp Ph related to $[NRH^+]/\{[H^+] \times [40]\}$

3.3 Net changes in total hydrogen ion concentration

The sum total changes in the hydrogen ion concentration ($\Delta H^+ = [H^+] - [40]$) in the blood include both the changes due to respiratory ($\Delta RH^+ = [H^+] - [NRH^+]$) and non-respiratory (metabolic) components ($\Delta NRH^+ = [NRH^+] - [40]$):

$$\begin{aligned} [\Delta RH^+/H^+] &= [H^+ - NRH^+]/[H^+] = 1 - \{[NRH^+]/[H^+]\} \\ [\Delta NRH^+/40] &= (NRH^+ - 40)/40 \text{ or} \\ -[\Delta NRH^+/40] &= (40 - NRH^+)/40 \\ &= 1 - \{(NRH^+/40)\}. \end{aligned}$$

The hydrogen ion concentration is 40 at *pH 7.4* which denotes the *homeostatic set point* of acid-base balance [14, 18].

4. New graphical tool

This new graphical tool developed for ABG interpretation contains four quadrants. In the x-axis, standard base excess values were taken, and in the y-axis, the ratio of $(HCO_3 - \text{standard } HCO_3)/H_2CO_3$ values was taken to analyze the various acid-base disturbances which are clearly shown in the four-quadrant graph (**Figure 3**).

In the *first 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 *second 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 *third 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 *fourth 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 [1].

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 of $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3$. Each acid-base disorder 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. [1] This newer graphical tool may provide a rough guide and help in easier and quicker interpretation of ABG reports. A minor drawback of this graphical tool is that, as the $p\text{CO}_2$ increases, the *ratio of* $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3$ also increases and afterward the curve flattens. This may not clearly demarcate the different higher levels of $p\text{CO}_2$ values. Although the ratio of $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3$ differentiates the respiratory acidosis and respiratory alkalosis, it may not clearly differentiate the different $p\text{CO}_2$ levels. But this can be *corrected (rectified)* in a three-dimensional graph if $p\text{CO}_2$ values are included in the third axis (z-axis). The parameter $(p\text{CO}_2 - 40 \text{ mmHg})$ should be taken in the third axis, because the ratio $(\text{HCO}_3 - \text{standard HCO}_3)/\text{H}_2\text{CO}_3$ is zero at $p\text{CO}_2$ of 40 mmHg , so that the *zero central point is common* to all the three parameters of the three axes [18].

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.

The concept of non-respiratory hydrogen ion concentration plays a key role in understanding of ABG interpretation, yet often it is not discussed in detail during

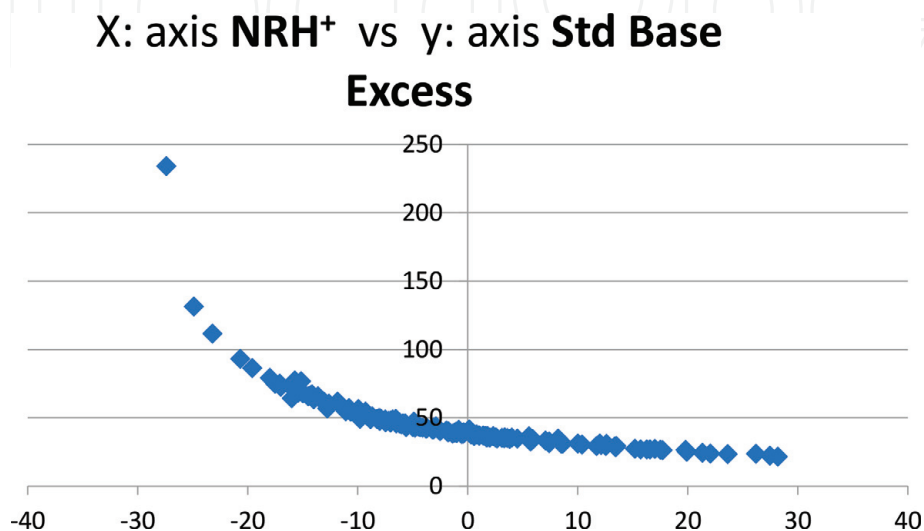


Figure 5.
Relation between NRH^+ and Std base excess.

x: axis[40- NRH⁺] vs y: axis Std Base Excess

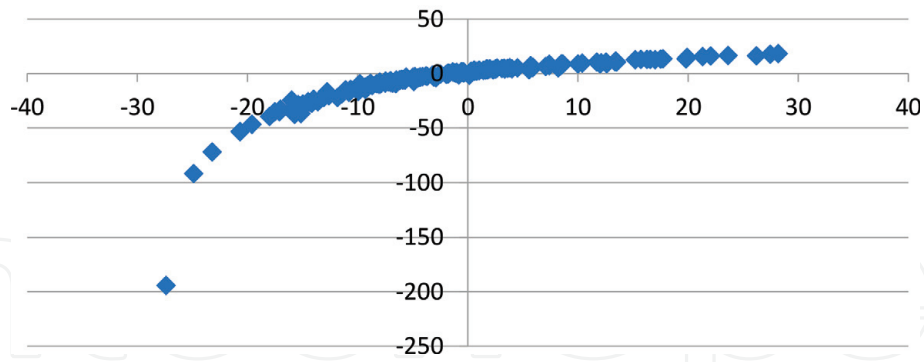


Figure 6.
Relation between $[40 - NRH^+]$ and Std base excess.

pCO₂ VS NRH/H

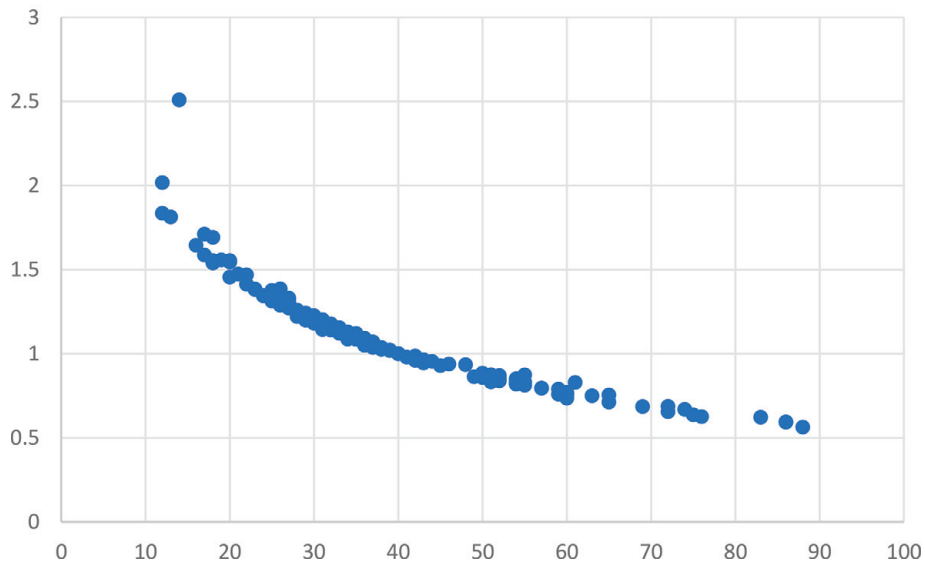


Figure 7.
X-axis pCO₂ vs. y-axis $[NRH]/[H]$.

ΔRpH VS NRH/H

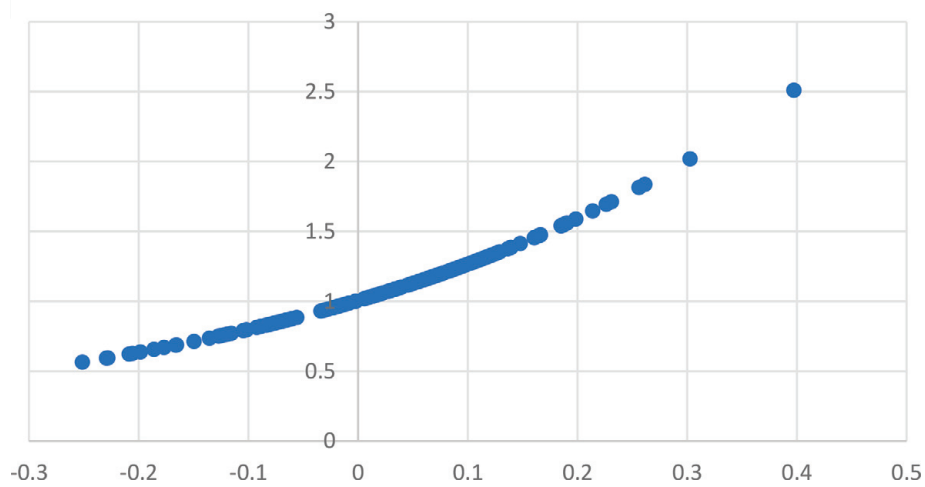


Figure 8.
X-axis ΔRpH vs. y-axis $[NRH]/[H]$.

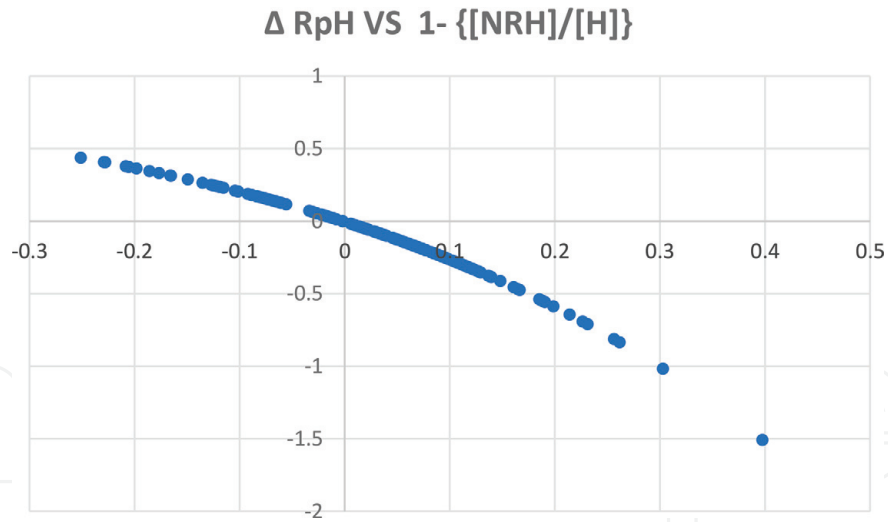


Figure 9.
X-axis ΔRpH vs. y-axis $1 - \{[NRH]/[H]\}$.

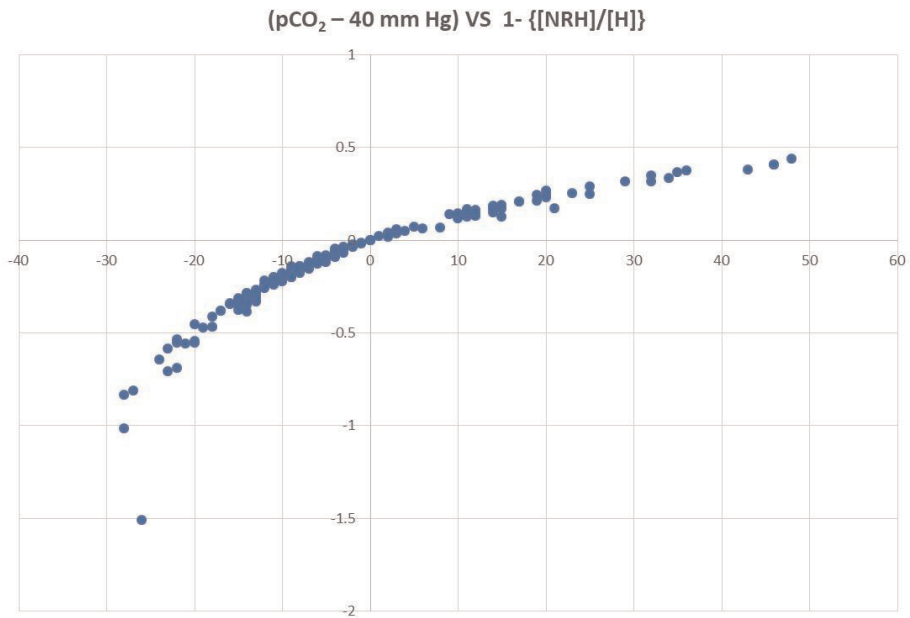


Figure 10.
X-axis $(pCO_2 - 40 \text{ mmHg})$ vs. y-axis $1 - \{[NRH]/[H]\}$.

| S. no | pH | pCO ₂ | HCO ₃ | Std HCO ₃ | pH-7.4 | ΔRpH | ΔNRpH | NRPH-7.4 | Pr RpH 7.4 + ΔRpH |
|---------------------------------------------------------------------------------------------------------------------------------------------|------|------------------|------------------|----------------------|--------|-------|-------|----------|-------------------|
| 1. | 7.26 | 31 | 13.9 | 15.5 | -0.14 | 0.06 | -0.20 | | 7.46 |
| <i>Comment: changes in net pH (acidic) are mainly due to metabolic component, partly opposed by respiratory component (alkaline effect)</i> | | | | | | | | | |
| 2. | 7.5 | 37 | 28.9 | 29.2 | 0.1 | 0.03 | 0.07 | | 7.43 |
| 3. | 7.48 | 43 | 32 | 30.9 | 0.08 | -0.02 | 0.10 | | 7.38 |
| <i>Comment: changes in net pH (alkaline) are mainly due to metabolic component</i> | | | | | | | | | |
| 4. | 7.41 | 37 | 23.5 | 24.3 | 0.01 | 0.02 | -0.01 | | 7.42 |
| 5. | 7.39 | 38 | 23 | 23.6 | -0.01 | 0.01 | -0.02 | | 7.41 |
| <i>Comment: changes in net pH are normal</i> | | | | | | | | | |
| 6. | 7.02 | 61 | 15.8 | 12.5 | -0.38 | -0.08 | -0.30 | | 7.32 |
| <i>Comment: changes in net pH (acidic) are mainly due to metabolic component and partly due to respiratory component</i> | | | | | | | | | |

| S. no | pH | pCO ₂ | HCO ₃ | Std HCO ₃ | pH-7.4 | ΔRpH | ΔNRpH | NRPH-7.4 | Pr RpH | 7.4 + ΔRpH |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|------------------|------------------|----------------------|--------|-------|-------|----------|--------|------------|
| 7. | 7.5 | 57 | 44.5 | 39.3 | 0.1 | -0.10 | | 0.20 | | 7.30 |
| <i>Comment: changes in net pH (alkaline) are mainly due to metabolic component, partly opposed by respiratory component (acidic effect)</i> | | | | | | | | | | |
| 8. | 7.4 | 72 | 44.6 | 36.1 | 0 | -0.17 | | 0.17 | | 7.23 |
| <i>Comment: changes in net pH are zero. The changes in pH due to metabolic and respiratory component are equal and opposite. So, they cancelled out each other and the net change is zero</i> | | | | | | | | | | |
| 9. | 7.17 | 76 | 27.7 | 23.3 | -0.23 | -0.21 | | -0.02 | | 7.19 |
| <i>Comment: changes in net pH (acidic) are mainly due to respiratory component</i> | | | | | | | | | | |
| 10. | 7.6 | 12 | 11.8 | 19.5 | 0.2 | 0.30 | | -0.10 | | 7.70 |
| <i>Comment: changes in net pH (alkaline) are mainly due to respiratory component, partly opposed by metabolic component (acidic effect)</i> | | | | | | | | | | |
| 11. | 7.02 | 14 | 3.6 | 4.1 | -0.38 | 0.40 | | -0.78 | | 7.80 |
| <i>Comment: changes in net pH (acidic) are mainly due to metabolic component, partly opposed by respiratory component (alkaline effect)</i> | | | | | | | | | | |

Table 1.
 Examples of ABG data showing metabolic and respiratory components involved in net changes in total pH.

ABG interpretation because it is not routinely applied at the clinical practice due to the lack of simple formulae to calculate the same and nonavailability of its interrelationship with the other acid-base parameters. In the recently published research study, calculation of non-respiratory hydrogen ion concentration from standard bicarbonate and its relationship with other commonly utilized ABG parameters were discussed with the postulates of the acid-base balance theory and shown in **Figures 5–10** and *tabulated in Table 1* [14, 18].

5. Predicted respiratory pH

The predicted respiratory pH is usually calculated by pCO₂ variance. This calculation is slightly different for higher (>40 mmHg) and lower (<40 mmHg) pCO₂

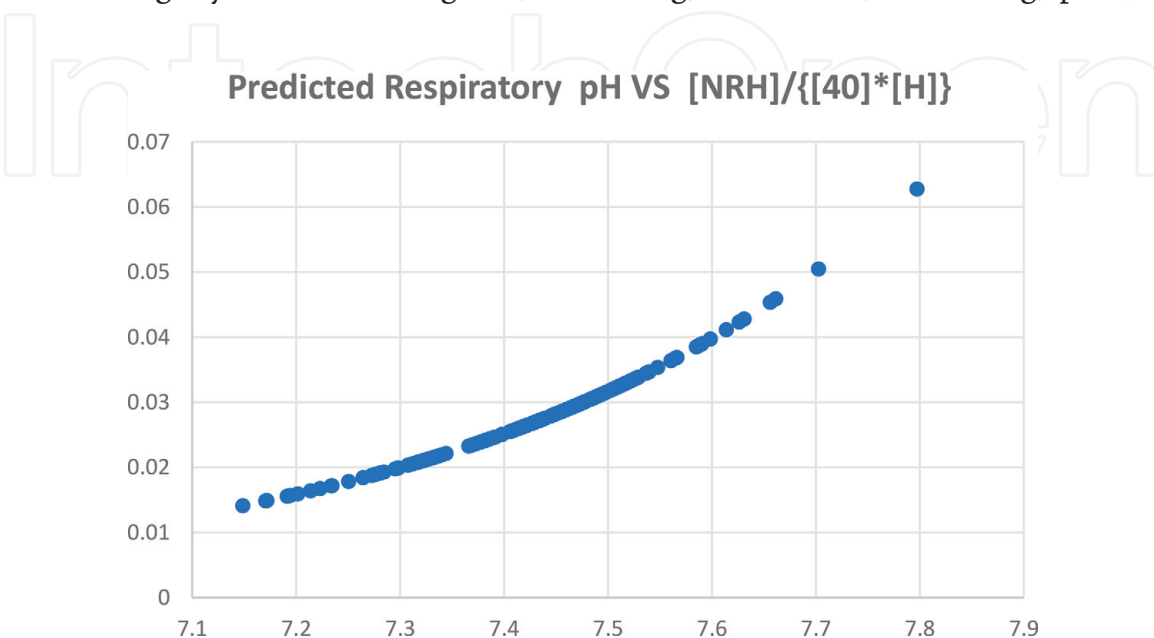


Figure 11.
 X-axis predicted respiratory pH vs. y-axis $[NRH]/\{[40]*[H]\}$.

Predicted Respiratory pH VS pCO₂

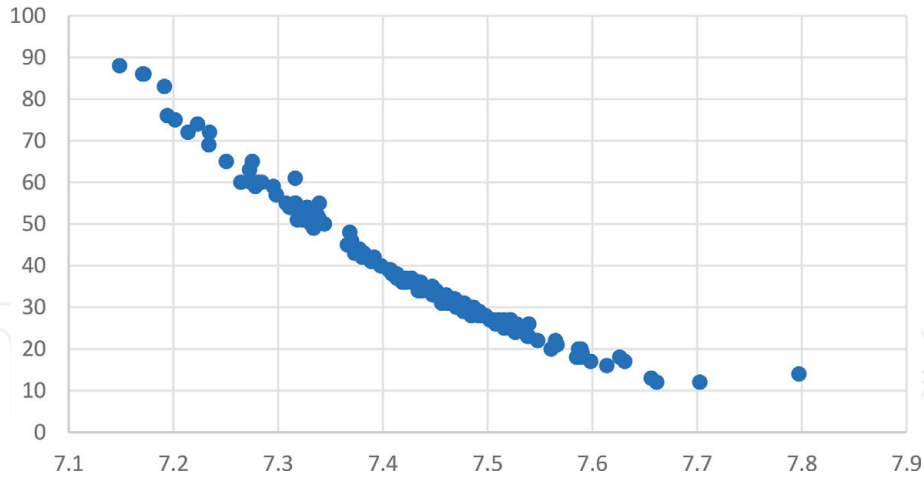


Figure 12.
X-axis predicted respiratory pH vs. y-axis pCO₂.

Predicted Respiratory pH(Pr RpH) calculated by newer formulae VS Pr RpH calculated using pCO₂ variance

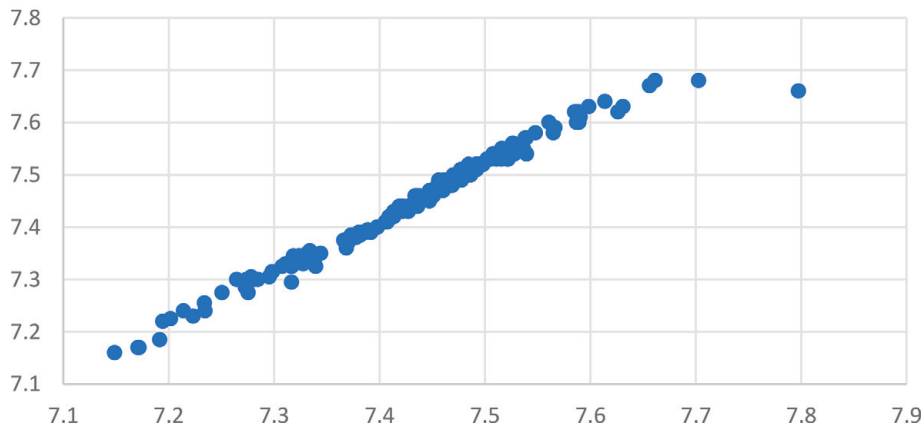


Figure 13.
X-axis predicted respiratory pH(Pr RpH) calculated by newer formulae vs. y-axis Pr RpH calculated using pCO₂ variance.

| Predicted respiratory pH calculation using pCO ₂ variance (previous method) | | |
|----------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|-----------------------------------|
| Parameter | pCO ₂ > 40 mmHg | pCO ₂ < 40 mmHg |
| pCO ₂ variance | (pCO ₂ - 40)/100 | (40 - pCO ₂)/100 |
| Predicted respiratory pH | 7.4 - (pCO ₂ variance)/2 | 7.4 + (pCO ₂ variance) |
| Predicted respiratory pH calculation using newly derived formulae | | |
| Formulae is the same for all the values of PCO ₂ | | |
| ΔRpH | [pH - NRpH] = 1.6 + log {(HCO ₃ /Std HCO ₃)/pCO ₂ } | |
| Predicted respiratory pH | 7.4 + ΔRpH | |

Table 2.
Comparison of predicted respiratory pH calculation (one by previous method using pCO₂ variance and the other by newly derived formulae).

levels. The difference between the predicted respiratory pH and the measured pH reflects the metabolic pH change. [15] The predicted respiratory pH is calculated by using a newly derived formula which is common for all $p\text{CO}_2$ values [18]. The graphical relationship is shown in **Figures 11–13** and tabulated in **Table 2**.

6. Postulates of the acid-base balance theory

The postulates of the acid-base balance theory are listed below [14]:

1. The net changes in pH of the blood reflect the sum total changes in the hydrogen ion concentration in the blood. The net changes in total or actual pH [ΔpH ($\text{pH} - 7.4$)] are due to both the changes in respiratory [ΔRpH ($\text{pH} - \text{NRpH}$)] and non-respiratory (metabolic) components [ΔNRpH ($\text{NRpH} - 7.4$)] affecting the pH.
2. The sum total changes in the hydrogen ion concentration ($\Delta\text{H}^+ = [\text{H}^+] - [40]$) in the blood include both the changes due to respiratory ($\Delta\text{RH}^+ = [\text{H}^+] - [\text{NRH}^+]$) and non-respiratory (metabolic) components ($\Delta\text{NRH}^+ = [\text{NRH}^+] - [40]$).
3. The non-respiratory hydrogen ion concentration [NRH^+] has a unique value for a given standard bicarbonate concentration represented by the relation $\text{NRH}^+ = 960/\text{Std bicarbonate}$.
4. The concentration of hydrogen ion excess given by [$\text{NRH}^+ - 40$] is directly proportional to the base deficit. This quantity with opposite sign [$40 - \text{NRH}^+$] is directly proportional to the base excess. Standard base excess is the base excess at hemoglobin concentration of 5 g/dl.
5. The changes in the dependent variable non-respiratory hydrogen ion concentration [NRH^+] representing the non-respiratory (metabolic) component are due to the changes by the independent variables, namely, strong ion difference (SID) and the total concentration of weak nonvolatile acids, namely, albumin and phosphate [ATOT].
6. The changes in the dependent variable [HCO_3^-] are a marker of metabolic acid-base disturbances and not its causative mechanism.
7. The magnitude and direction (positive or negative) of the changes in the parameter ΔNRpH ($\text{NRpH} - 7.4$) are due to the accumulation of acids other than carbonic acid or bases. The value is negative for acidic effect and positive for alkaline effect.
8. The magnitude and direction (positive or negative) of the changes in the parameter ΔRpH ($\text{pH} - \text{NRpH}$) denote the respiratory influence in causing changes in pH represented by the relation $\text{pH} - \text{NRpH} = 1.6 + \log\{(\text{HCO}_3^-/\text{Std HCO}_3^-)/p\text{CO}_2\}$. The value is negative for acidic effect and positive for alkaline effect.
9. The ratio [NRH^+/H^+] is directly proportional to the parameter ΔRpH ($\text{pH} - \text{NRpH}$) which denotes the respiratory influence of $p\text{CO}_2$.

10. The respiratory influence of $p\text{CO}_2$ in changing pH through bicarbonate is a variable one (ratio of $\text{HCO}_3^-/\text{Std HCO}_3^-$) depending on the acute or chronic conditions or compensations and through carbonic acid is a constant one given by $(\text{H}_2\text{CO}_3 - 1.2)/\text{H}_2\text{CO}_3$.

7. Conclusion

Arterial blood gas analysis test is one of the most commonly employed point-of-care testings in intensive care units, yet the understanding of acid-base disturbances and interpretation of ABG reports are sometimes a challenging task especially for critically ill patients with multiorgan failure. The graphical relationship between the metabolic and respiratory components of the net changes in pH and the total changes in hydrogen ion concentration with other ABG parameters like standard base excess, bicarbonate, standard bicarbonate, and $p\text{CO}_2$ will help in better understanding of the arterial blood gas interpretation which results in proper, quicker, and better management of the patient's critical conditions. 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.

Although, standard bicarbonate value is not routinely utilized for ABG interpretation, the parameters derived from standard bicarbonate plays a vital role in the understanding of acid-base disturbances. The application of these newly derived parameters and the four-quadrant graphical tool may serve as a supporting tool for teaching and diagnostic purposes, which when properly correlated with clinical conditions and other ABG parameters results in better understanding and quicker interpretation of ABG reports.

Conflict of interest

Nil.


Author details

T. Rajini Samuel

Shri Sathya Sai Medical College and Research Institute, Sri Balaji Vidyapeeth
Deemed to be University, Kancheepuram District, Tamilnadu, India

*Address all correspondence to: samuel.biochemistry@gmail.com;
samuel.rajini@gmail.com

IntechOpen

© 2019 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. 

References

- [1] Samuel RA. Graphical tool for arterial blood gas interpretation using standard bicarbonate and base excess. *Indian journal of Medical Biochemistry*. 2018; **22**(1):85-89
- [2] Samuel R, Ilanchezian, Rajagopalan B. Application of modified Henderson equation in ABG interpretation. *International Journal of Pharmaceutical Sciences Review and Research*. 2016; **37**(2):169-177
- [3] Arterial Blood Gases—Indications and Interpretation. 2010. Available from: Patient.info/doctor [Accessed: February, 10 2013]
- [4] Baillie K. Arterial Blood Gas Interpreter. Online: Arterial Blood Gas Analysis. Available from: prognosis.org [Accessed: July 05, 2007]
- [5] Marino PL. Arterial Blood Gas Interpretation. 2nd ed. Philadelphia: Lippincott/Williams and Wilkins Publishers; 1998. pp. 582-605
- [6] Narins RG, Emmett M. Simple and mixed acid-base disorders: A practical approach. *Medicine*. 1980; **59**:161-187
- [7] Adrogue HJ. Mixed acid-base disturbances. *Journal of Nephrology*. 2006; **19**(Suppl 9):S97-S103
- [8] Siggaard-Andersen O, Fogh-Andersen N. Base excess or buffer base (strong ion difference) as measure of a non-respiratory acid-base disturbance. *Acta Anaesthesiologica Scandinavica*. 1995; **39**(Supplementum 106):123-128
- [9] Mizock BA. Utility of standard base excess in acid-base analysis. *Critical Care Medicine*. 1998; **26**(7):1146-1147
- [10] Siggaard-Andersen O. Acid-base balance. In: Boston GEO, editor. *Encyclopedia of Respiratory Medicine*. Amsterdam: Academic Press; 2006. pp. 5-10
- [11] Jørgensen K, Astrup P. Standard bicarbonate, its clinical significance, and a new method for its determination. *Scandinavian Journal of Clinical & Laboratory Investigation*. 1957; **9**(2): 122-132
- [12] Krapf R. Standard bicarbonate and base excess-obsolete parameter. *Therapeutische Umschau*. 2000; **57**(6): 386-390
- [13] Suero JT. The usefulness of non-respiratory hydrogen ion concentration and its relationship to the traditional acid-base parameters. *Clinical Biochemistry*. 1969; **2**:177-185
- [14] Rajini Samuel T. Application and inter-relationship of non-respiratory hydrogen ion concentration in acid-base balance theory. *International Journal of Clinical Chemistry and Laboratory Medicine (IJCCLM)*. 2018; **4**(3):1-13
- [15] Munjal YP, Surendra K, Sharm API. Section 7: Critical care medicine. Chapter 4: Acid base disorders. In: *Textbook of Medicine*. Ninth ed. 2012. pp. 239-241
- [16] Whitehead TP. Acid-base status, pH, and PCO₂. *Lancet*. 1965; **2**:1015-1016
- [17] Bookallil MJ. Description of pH or Acid-Base Status in Blood, pH of the Blood: Acid Base Balance. Available from: www.anaesthesia.med.usyd.edu.au/resources/lectures/acidbase_mjb/acidbase.html
- [18] Samuel R. A graphical representation for aiding arterial blood gas interpretation using non-respiratory and respiratory pH. *World Journal of Pharmaceutical and Medical Research*. 2018; **4**(12):192-202