Revised Graphical Tool for ABG Interpretation using Modified Bicarbonate/Standard Bicarbonate Ratio

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Abstract: Arterial Blood Gas analyser is one of the most important point of care testing in intensive care unit that has immense clinical value in the management of critically ill patients. The technological innovations in Point-of-care devices offer rapid analysis at the patient bed side which produce quick and accurate results. The advancement in the innovations of blood gas analysers that has occurred in the last decades has not brought a respective advance in the field of diagnosis. There are only few graphical visualization tools available for Arterial blood Gas (ABG) interpretation depicting the respiratory and metabolic acid-base disturbances. Davenport or Bicarbonate-pH diagram is a graphical tool to depict the respiratory and metabolic acid-base disturbances which is rarely used in clinical setting, Grogono diagram, despite its higher diagnostic agreement compared to the classic Siggaard-Andersen diagram, is not superior to the Oxygen Status Algorithm software program.

The parameters like pH, pCO2, bicarbonate and Standard base excess are routinely utilized for interpretation. The bicarbonate concentration parameter is useful only in patients with normal respiration because it is a variable parameter highly influenced by the changes in the concentration of carbon-dioxide (pCO2). This is solved by measuring Standard bicarbonate. The deviation between these two values denote the respiratory influence. The ratio between bicarbonate and standard bicarbonate value and the differences between bicarbonate/carbonic acid and standard bicarbonate/carbonic acid ratio values render some clues in discriminating various acid base disorders. This concept was applied in a previous research study for the development of a novel four quadrant graphical method for ABG interpretation by the current author using standard base excess values in the x axis and the ratio \( \frac{[\text{HCO}_3^\text{-} - \text{HCO}_3^\text{standard}]}{\text{carbonic acid}} \) in the y axis. A minor problem with the ratio \( \frac{[\text{HCO}_3^\text{-} - \text{HCO}_3^\text{standard}]}{\text{carbonic acid}} \) is that as the pCO2 increases, this ratio also increases but afterwards the curve flattens and may not clearly differentiate the different higher levels of pCO2 values. The aim of the current research study is to rectify this problem by the construction of the revised four quadrant graphical tool for ABG interpretation.

Keywords: Revised Graphical Tool, ABG Interpretation

1. INTRODUCTION

Arterial blood gas analyser is one of the most important point of care testing in intensive care unit and plays a vital role in management of critically ill patients. [I, II] The technological innovations in Point-of-care devices offer rapid analysis at the patient bed side due to its ease-of-use, short turnaround time which produce quick and accurate results. An increase in the number of patients in critical care units and a rise in the burden of chronic diseases like diabetes mellitus, chronic obstructive pulmonary diseases (COPD), asthma, coronary heart disease and renal failure enhanced the requirement of blood gas analysers but the complexity involved in the interpretation of blood gas analysis data act as a restraining factor for the same. [I - IV]

The graphical methods will serve as a supporting tool for teaching purposes for better understanding of the arterial blood gas interpretation. [III, IV] A plenty of methods exist in literature to guide the arterial blood gas(ABG) interpretation. But only few graphical methods are available depicting the respiratory and metabolic acid–base disturbances. [II]
The measured parameters like pH, PCO₂ and calculated parameters like bicarbonate and Standard base excess are routinely utilized for interpretation. In ABG analysis, PCO₂ denotes the respiratory component and bicarbonate and standard base excess represents the metabolic component in physiological and base excess approach respectively. [V,VI]

As PCO₂ increases, it reacts with water molecules to form carbonic acid which dissociates into hydrogen and bicarbonate ions, the reaction catalysed by the enzyme carbonic anhydrase present inside the Red blood cells (RBC). The hydrogen ions are buffered by non-bicarbonate buffers like haemoglobin, albumin and phosphate buffer system. So, the concentration of bicarbonate changes with PCO₂ values. So, the concentration of bicarbonate increases with increase in PCO₂ and it decreases as the PCO₂ value decreases. The measurement of standard bicarbonate helps to solve this problem. Standard bicarbonate is the concentration of bicarbonate in the plasma from blood which is equilibrated with a normal PaCO₂ (40 mmHg) and a normal pO₂ (over 100 mmHg) at a normal temperature (37°C).[VII-IX]

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.

The ratios derived using bicarbonate, standard bicarbonate and carbonic acid values render some clues in discriminating various acid base disturbances. These ratios are greatly altered in respiratory disorders and also in metabolic acid-base disturbances associated with respiratory compensations. The alteration of ratio values are minimal in purely metabolic acid-base disturbances without respiratory compensation. [VII]

A novel four quadrant graphical tool was developed by Rajini Samuel (current author) based on this concept for ABG interpretation using standard base excess and the ratios derived using standard bicarbonate, bicarbonate and carbonic acid that demarcates the various acid base disturbances.[VIII] A minor drawback of this graphical tool is that this may not clearly demarcate the different higher levels of PCO₂ values.[I] The aim of the current research article is to construct a revised four quadrant graphical tool to rectify this problem.

2. MATERIALS AND METHODS

2.1. Henderson Hasselbalch Equation

\[ \text{pH} = \text{pK}_a\text{HCO}_3^- + \log[\text{HCO}_3^-]/[\text{H}_2\text{CO}_3] \]

pH is the acidity in the blood, pKₐ[HCO₃⁻] is the negative logarithm (base 10) of the acid dissociation constant of carbonic acid. It is equal to 6.1 at normal body temperature.

\[ \text{pH} = 6.1 + \log(\text{HCO}_3^-/[\text{H}_2\text{CO}_3]) \]

\[ [\text{H}_2\text{CO}_3^-] \text{ is the concentration of bicarbonate in the blood (mEq/L or mmol/L) }, \text{ PaCO}_2 \text{(PCO}_2 \text{) is the partial pressure of carbon dioxide in the arterial blood (mm of Hg)} \]

\[ k_{\text{HCO}_2} \text{ is a constant including the solubility of carbon dioxide in blood. The solubility coefficient of CO}_2 \text{ value is approximately 0.03 (mmol/L)/mmHg. The normal bicarbonate and carbonic acid ratio is 20. The ratio is changed under abnormal conditions. [X]} \]

2.2. Derivation of the Kassirer-Bleich Approximation:

\[ \text{pH} = \text{pK}_a\text{HCO}_3^- + \log[\text{HCO}_3^-]/[\text{H}_2\text{CO}_3] \]

The above equation is in logarithm form.

\[ \text{pH} = -\log[H^+ \text{ nanomoles/L}] ; \text{ pK}_a = -\log(K_a) ; \text{ K}' = 10^{pK_a} \]

Where K’ is the dissociation constant from the pKₐ of carbonic acid, 6.1, which is equal to 800nmol/L (since K’ = 10^{pK_a} = 10^{-(6.1)} ≈ 8.00X10^{-7}mol/L = 800nmol/L)

\[ [H^+] = \{K' \times(0.03 \times \text{PCO}_2)/[\text{HCO}_3^-] \}

The Henderson Equation, which is derived from the Law of Mass Action, can be modified with respect to the bicarbonate buffering system to yield a simpler equation that provides a quick approximation of the H⁺ or HCO₃⁻ concentration without the need to calculate logarithms. [X]

By multiplying K’ (nmol/L) and 0.03, the product value is 24. (800 X 0.03)

The equation is simplified to:
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\[ H^+ (\text{Hydrogen ion concentration}) = \{24 \times \text{PCO}_2\}/ \text{HCO}_3^- \]

The concentration of bicarbonate is calculated using this **Modified Henderson Equation** in the ABG analyser. [X, XI, XII]

### 2.3. Calculation of PH from Calculated [H+]

\[ H^+ (\text{Hydrogen ion concentration at actual pH}) = \{24 \times \text{PCO}_2\}/ \text{HCO}_3^- \]

This is calculated using **Modified Henderson Equation**. [X, XI, XII]

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

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

Using this relationship, the pH can be calculated from the hydrogen ion concentration. [XI, XII]

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**GRAPH1.** X: axis 9- \( \log H \) VS Y: axis \( \text{PCO}_2 \)

**GRAPH2.** X: axis 9 - \( \log H \) VS Y: axis \( \text{HCO}_3^- \)

It is found there is no clear relationship between pH and partial pressure of carbon dioxide (PCO\(_2\)) values (shown in graph 1) and pH and bicarbonate concentration values (shown in graph 2). [X]

### 2.4. Calculation of Bicarbonate/Carbonic Acid Ratio

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

\[ \text{H}_2\text{CO}_3 = 0.03 \times \text{PCO}_2 \]

The ratio between HCO\(_3^-\) and carbonic acid (HCO\(_3^-/\text{H}_2\text{CO}_3\)) was found. The pH values and the bicarbonate/ carbonic acid ratio is directly related. As the bicarbonate/ carbonic acid ratio increases, the pH also increases and as the bicarbonate/ carbonic acid ratio decreases, the pH also decreases which is shown in the graph 3. The changes in pH and hydrogen ion concentration depends only on the changes in the bicarbonate/carbonic acid ratio. [X]
2.5. Newly Derived Ratios

The bicarbonate/carbonic acid and standard bicarbonate/carbonic acid ratios were calculated. [VII, VIII, IX]

2.6. Calculation of Ratio 1: (HCO3 /Std HCO3)

The ratio 1 denotes the ratio between the bicarbonate/carbonic acid and standard bicarbonate/carbonic acid ratios which is numerically the same as the ratio between bicarbonate and standard bicarbonate value. [VII]

\[ \text{Ratio 1} = \frac{\text{HCO}_3}{\text{Std HCO}_3} \]

2.7. Calculation of Ratio 2: (HCO3 - STD HCO3) / H2CO3

Ratio 2 denotes the difference between bicarbonate/carbonic acid and standard bicarbonate/carbonic acid ratio. [VIII]

\[ \text{Ratio 2} = \left( \frac{\text{HCO}_3}{\text{H}_2\text{CO}_3} \right) - \left( \frac{\text{Std HCO}_3}{\text{H}_2\text{CO}_3} \right) = \left( \frac{\text{HCO}_3}{\text{H}_2\text{CO}_3} \right) - \left( \frac{\text{Std HCO}_3}{\text{H}_2\text{CO}_3} \right) \]

The ratio between (HCO3/ Standard HCO3) and carbonic acid was calculated and represented by (HCO3/ Standard HCO3) /H2CO3. A Newer parameter that denotes the respiratory influence of PCO2 in changing pH is given below. [XII]

\[ \left( \frac{\text{HCO}_3}{\text{Std HCO}_3} \right) - \left( \frac{\text{H}_2\text{CO}_3 - 1.2}{\text{H}_2\text{CO}_3} \right) \]

2.8. Calculation of Ratio 3:

Ratio 3 is calculated by multiplying ratio 1 and ratio 2. [IX]

\[ \text{Ratio 3} = \left( \frac{\text{HCO}_3}{\text{Std HCO}_3} \right) \times \left( \frac{\text{HCO}_3 - \text{Std HCO}_3}{\text{H}_2\text{CO}_3} \right) \]

2.9. Calculation of Standard Base Excess:

The standard base excess(SBE) or the base excess of the extracellular fluid(cBase(ecf)) measured in mmol/L or mEq/L is calculated by the following formula which is widely used in most Arterial Blood Gas analyser. [VIII, XIII]

\[ \text{cBase(ecf)} = \text{chCO}_3 - 24.8 + 16.2 \times (\text{pH} - 7.40) \]

3. RESULTS

A total of 250 Arterial Blood Gas sample data’s were utilized and classified into various acid-base disorder groups based on their normal ranges. The normal reference for arterial blood pH is 7.35 to 7.45, for PCO2 is 35-45 mm of Hg and for bicarbonate is 22-26 mEq/L or mmol/L. The various groups are tabulated in the tables 1 and 2.

The values of pH, PCO2, bicarbonate and standard bicarbonate values were noted. The standard base excess, carbonic acid and the ratios 1, 2 and 3 derived using bicarbonate, standard bicarbonate and carbonic acid values all were calculated. The samples of each acid base disturbance groups citing with few examples are tabulated. The table 3 shows the samples of Normal and Respiratory acid base disorder cases, table 4 showing the samples of Metabolic acid base disorder cases and the samples of Missellaneous acid base disorder cases are shown in the table 5.
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#### TABLE 1. Normal and Respiratory Acid-base Disorder Groups

| GROUP | Type of Acid Base Disorder | Number of Cases |
|-------|-----------------------------|-----------------|
| Group I | Normal: | 25 cases |
| Group II | Respiratory acidosis | 32 cases |
| | Respiratory acidosis 1(\(PCO_2 > 45 \leq 60 \text{ mm of Hg}\)) | 11 cases |
| | Respiratory acidosis 2(\(PCO_2 > 60 \leq 80 \text{ mm of Hg}\)) | 14 cases |
| | Respiratory acidosis 3(\(PCO_2 > 80 \text{ mm of Hg}\)) | 7 cases |
| Group III | Respiratory alkalosis | 53 cases |
| | Respiratory alkalosis 1: \(PCO_2 31 \text{ to } 34 \text{ mm of Hg}\) | 16 cases |
| | Respiratory alkalosis 2: \(PCO_2 26 \text{ to } 30 \text{ mm of Hg}\) | 22 cases |
| | Respiratory alkalosis 3: \(PCO_2 21 \text{ to } 25 \text{ mm of Hg}\) | 8 cases |
| | Respiratory alkalosis 4: \(PCO_2 \leq 20 \text{ mm of Hg}\) | 7 cases |

#### TABLE 2. Metabolic Acid-base Disorder and Miscellaneous Groups

| GROUP | TYPE OF ACID BASE DISORDER | Number of Cases |
|-------|-----------------------------|-----------------|
| Group IV | Metabolic acidosis | 47 cases |
| | Metabolic acidosis 1(\(HCO_3^- > 18 \leq 22 \text{ mmol/L}\)) | 10 cases |
| | Metabolic acidosis 2(\(HCO_3^- > 15 \leq 18 \text{ mmol/L}\)) | 12 cases |
| | Metabolic acidosis 3(\(HCO_3^- > 10 \leq 15 \text{ mmol/L}\)) | 17 cases |
| | Metabolic acidosis 4(\(HCO_3^- \leq 10 \text{ mmol/L}\)) | 8 cases |
| Group V | Metabolic alkalosis | 34 cases |
| | Metabolic alkalosis 1(\(HCO_3^- > 40 \text{ mmol/L}\)) | 12 cases |
| | Metabolic alkalosis 2(\(HCO_3^- > 30 \leq 40 \text{ mmol/L}\)) | 12 cases |
| | Metabolic alkalosis 3(\(HCO_3^- > 26 \leq 30 \text{ mmol/L}\)) | 10 cases |
| Group VI | Miscellaneous further divided into Sub-groups | 59 cases |
| | Miscellaneous 1: Decreased pH, increased \(PCO_2\) with decreased \(HCO_3^-\) | 11 cases |
| | Miscellaneous 2: Normal pH, increased \(PCO_2\) with decreased \(HCO_3^-\) | 20 cases |
| | Miscellaneous 3: Normal pH, decreased \(PCO_2\) & Decreased \(HCO_3^-\) | 28 cases |

#### Table 3. Samples of Normal and Respiratory acid base disorder Case Values

| S.no | \(pH\) | \(PCO_2\) | \(PCO_2/40\) | \(H_2CO_3\) | \(HCO_3^- 1/2\)/ \(H_2CO_3\) | \(HCO_3^-\) | Std \(HCO_3^-\) | STD BE | Ratio 1 | Ratio 2 | Ratio 3 |
|------|--------|---------|--------------|-----------|-------------------------------|-----------|-------------|--------|--------|--------|--------|
| 1    | 7.37   | 43      | 3            | 1.29      | 0.070                         | 24.9      | 24.3        | -0.39  | 1.025  | 0.465  | 0.477  |
| 2    | 7.43   | 35      | -3           | 1.05      | -0.143                        | 23.2      | 24.4        | -1.11  | 0.951  | -1.143 | -1.087 |
| 3    | 7.4    | 37      | -3           | 1.11      | -0.081                        | 22.9      | 23.7        | -1.90  | 0.966  | -0.721 | -0.696 |
| 4    | 7.41   | 41      | 1            | 1.23      | 0.048                         | 26        | 25.5        | 1.36   | 1.020  | 0.407  | 0.414  |

Respiratory acidosis 1(\(PCO_2 > 45 \leq 60 \text{ mm of Hg}\))

1. 7.25  51  11  1.53  0.216  22.4  21.1  -4.83  1.062  0.850  0.902
2. 7.34  48  8   1.44  0.167  25.9  23.1  0.13  1.121  1.044  1.280
3. 7.36  52  12  1.56  0.231  29.4  27.7  3.95  1.089  1.538  1.675

Respiratory acidosis 2(\(PCO_2 > 60 \leq 80 \text{ mm of Hg}\))

1. 7.17  76  36  2.28  0.474  27.7  23.3  -0.83  1.189  1.930  2.294
2. 7.25  62  22  1.86  0.355  27.2  24.1  -0.03  1.129  1.667  1.881
3. 7.32  74  34  2.22  0.459  38.1  30.8  12.00  1.237  3.288  4.068

Respiratory acidosis 3(\(PCO_2 > 80 \text{ mm of Hg}\))

1. 7.2   85  45  2.55  0.529  33.2  26   5.16  1.277  2.824  3.605
2. 7.27  86  46  2.58  0.535  39.5  31   12.59  1.274  3.295  4.198
3. 7.3   84  44  2.52  0.524  41.3  33.8  14.88  1.222  2.976  3.637

Respiratory alkalosis 1: \(PCO_2 31 \text{ to } 34 \text{ mm of Hg}\)

1. 7.45  31  -9  0.93  -0.290  21.5  23.7  -2.49  0.907  -2.366  -2.146
2. 7.51  32  -8  0.96  -0.250  25.5  27.2  -2.48  0.938  -1.771  -1.660
3. 7.49  34  -6  1.02  -0.176  25.9  27.1  -2.56  0.956  -1.176  -1.124

Respiratory alkalosis 2: \(PCO_2 26 \text{ to } 30 \text{ mm of Hg}\)

1. 7.45  30  -10 0.9  -0.333  20.9  23.3  -3.09  0.897  -2.667  -2.392
2. 7.53  30  -10 0.9  -0.333  25.1  27.2  -2.41  0.923  -2.333  -2.153
3. 7.57  27  -13 0.81  -0.481  24.7  27.5  -2.65  0.898  -3.457  -3.105

Respiratory alkalosis 3: \(PCO_2 21 \text{ to } 25 \text{ mm of Hg}\)

1. 7.44  25  -15 0.75  -0.600  17   20.1  -7.15  0.846  -4.133  -3.496
2. 7.49  22  -18 0.66  -0.818  16.8  20.8  -6.54  0.808  -6.061  -4.895
3. 7.53  25  -15 0.75  -0.600  20.9  24.3  -1.79  0.860  -4.533  -3.899

Respiratory alkalosis 4: \(PCO_2 \leq 20 \text{ mm of Hg}\)

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| S.no | pH   | PCO₂  | HCO₃⁻ | H₂CO₃ | H₂CO₃/HCO₃-1.2 | HCO₃⁻ | Std HCO₃ | Std BE | Ratio 1 | Ratio 2 | Ratio 3 |
|------|------|-------|-------|-------|-----------------|-------|----------|--------|---------|---------|---------|
| 1    | 7.36 | 34    | -6    | 1.02  | -0.176          | 19.2  | 20.8     | -6.25  | 0.923   | -1.569  | -1.448  |
| 2    | 7.32 | 37    | -3    | 1.11  | -0.081          | 19.1  | 19.9     | -7.00  | 0.960   | -0.721  | -0.692  |
| 3    | 7.22 | 45    | 5     | 1.35  | 0.111           | 18.4  | 17.6     | -9.32  | 1.045   | 0.593   | 0.620   |

**Table 4. Samples of Metabolic acid base disorder Case Values**

| S.no | pH   | PCO₂  | HCO₃⁻ | H₂CO₃ | H₂CO₃/HCO₃-1.2 | HCO₃⁻ | Std HCO₃ | Std BE | Ratio 1 | Ratio 2 | Ratio 3 |
|------|------|-------|-------|-------|-----------------|-------|----------|--------|---------|---------|---------|
| 1    | 7.36 | 34    | -6    | 1.02  | -0.176          | 19.2  | 20.8     | -6.25  | 0.923   | -1.569  | -1.448  |
| 2    | 7.32 | 37    | -3    | 1.11  | -0.081          | 19.1  | 19.9     | -7.00  | 0.960   | -0.721  | -0.692  |
| 3    | 7.22 | 45    | 5     | 1.35  | 0.111           | 18.4  | 17.6     | -9.32  | 1.045   | 0.593   | 0.620   |

**Table 5. Samples of Miscellaneous acid base disorder Case Values**

| S.no | pH   | PCO₂  | HCO₃⁻ | H₂CO₃ | H₂CO₃/HCO₃-1.2 | HCO₃⁻ | Std HCO₃ | Std BE | Ratio 1 | Ratio 2 | Ratio 3 |
|------|------|-------|-------|-------|-----------------|-------|----------|--------|---------|---------|---------|
| 1    | 7.48 | 35    | -5    | 1.05  | -0.143          | 26.1  | 27.1     | 2.60   | 0.963   | -0.952  | -0.917  |
| 2    | 7.45 | 35    | -5    | 1.05  | -0.143          | 29.9  | 30.5     | 7.37   | 0.980   | -0.571  | -0.560  |
| 3    | 7.44 | 40    | 0     | 1.2    | 0.000           | 27.7  | 27.7     | 3.71   | 1.000   | 0.000   | 0.000   |

4. DISCUSSION

Arterial blood gas (ABG) analysis plays a vital role in the management of critically ill patients but the interpretation is sometimes an arduous task if the acid-base disturbances are complex. Siggaard-Andersen chart (S-A chart) developed by Siggaard-Andersen is considered the standard diagram for the diagnosis of acid-base balance disorder. It is a two-axial diagram that plots pH as a linear function of logPaCO₂ as derived by the Henderson-Hasselbalch equation. But the major disadvantage of the chart is that it cannot diagnose many pairs of pH-PCO₂ values that have not been adopted in the everyday clinical practice. [XIV – XVII]

Davenport or Bicarbonate-pH diagram is a graphical tool used to depict the respiratory and metabolic acid-base disturbances in a three dimensional surface. [XVII] The x-axis represents pH and the y-axis represents plasma bicarbonate concentration and the curved lines known as isopleths, represent the PCO₂ values derived using the Henderson hasselbach equation. Each isopleth PCO₂ curved line has a
fixed PCO₂ value for a given variable pH and bicarbonate Concentration calculated using the modified Henderson equation. The Davenport diagram is rarely used in the clinical setting. [XVII]

Grogono diagram is a new two-axial diagram consists of 23 clearly defined areas, each one representing a particular acid-base balance disorder. The PCO₂ representing the respiratory component of the acid base disorder is plotted in the horizontal axis and the standard base denoting the metabolic component of the acid base disorder in plotted in the vertical axis is shown in the figure 1. This newer diagrammatic approach to the diagnosis of acid-base balance disorders although superior to the S-A chart, cannot be safely used for the diagnosis of acid-base balance disorders in everyday clinical practice, because it has been shown to provide inaccurate diagnoses in at least 25% of the cases. Grogono diagram, despite its higher diagnostic agreement compared to the classic Siggaard-Andersen diagram, is not superior to the Oxygen Status Algorithm software program. [XVIII]

![Grogono Diagram](image)

**FIGURE1. Grogono Diagram**

The Oxygen-Status-Algorithm (OSA) Software was developed by the Radiometer-Copenhagen Company on the basis of the diagram and work done by Siggaard-Andersen. This software was installed in all blood gas analysers manufactured by Radiometer-Copenhagen. [XVIII] Nevertheless, the enormous technological advance in laboratory methods and instruments that has occurred in the last decades has not brought a respective advance in the field of diagnosis. [XVIII]

Recently a novel graphical tool was developed by Rajini Samuel (Current Author) for ABG interpretation to analyse the various acid-base disturbances in a four quadrant graphical method by using bicarbonate, standard bicarbonate, carbonic acid and standard base excess values. [VIII] The calculated bicarbonate concentration derived from Modified Henderson equation is a variable parameter because it changes with alterations in the values of PCO₂. [VII – IX]

In respiratory acidosis (due to hypoventilation) PCO₂ retention occurs and in respiratory alkalosis (due to hyperventilation) PCO₂ value is decreased. 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 close. If the metabolic disorder is compensated by respiratory mechanisms, then the two values alter and deviate from each other. [VII – IX]

The relation between PCO₂ and the ratio 1 (HCO₃⁻/ Std HCO₃⁻) depicted in the graph 4 clearly shows that as the PCO₂ increases, the ratio 1 also increases and afterwards the curve slightly flattens.[VII] The correlation between PCO₂ and the ratio 2 (HCO₃⁻ - Std HCO₃⁻) / H₂CO₃ depicted in the graph 5 clearly shows that as the PCO₂ increases, the ratio 2 also increases and afterwards the curve flattens.[VII, VIII] At PCO₂ 40 mmHg, both the bicarbonate and standard bicarbonate values are equal and so the difference is zero.
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**GRAPH 4.** X axis: PCO₂ VS Y axis: Ratio 1 (HCO₃⁻ / Std HCO₃⁻)

**GRAPH 5.** X axis: PCO₂ VS Y axis: Ratio 2

The ratio $\frac{\text{HCO}_3^-}{\text{Std HCO}_3^-}$ values are greater ($>1$) for increased PCO₂ and lesser ($<1$) for decreased PCO₂. The ratio 2 values are positive for greater ratio 1 values and negative for lesser ratio 1 values. Obviously, the value of ratio 2 is zero if the ratio 1 value is one. Ratio 2 values are negative for lower PCO₂ (lesser than 40 mmHg) and positive for higher PCO₂ (more than 40 mmHg). These newer ratios derived using bicarbonate, standard bicarbonate and carbonic acid values render some clues regarding the disturbances affecting the acid-base homeostasis. [VII]

A Newer parameter that denotes the respiratory influence of PCO₂ in changing pH is given by the following relation. [XII]

$$\frac{\text{HCO}_3^-}{\text{Std HCO}_3^-} - \frac{(\text{H}_2\text{CO}_3 - 1.2)}{\text{H}_2\text{CO}_3}$$

From the graph 4, the first part of the above relation ($\frac{\text{HCO}_3^-}{\text{Std HCO}_3^-}$) is very clear that the respiratory influence of PCO₂ in changing pH through bicarbonate is a variable one depending on acute or chronic conditions or compensations. [XII] The second part of the relation $\left(\frac{(\text{H}_2\text{CO}_3 - 1.2)}{\text{H}_2\text{CO}_3}\right)$ denotes that the respiratory influence of PCO₂ in changing the pH through carbonic acid is a constant which is clearly depicted in the graph 6.

**GRAPH 6.** X axis: PCO₂ VS Y axis: $\frac{(\text{H}_2\text{CO}_3 - 1.2)}{\text{H}_2\text{CO}_3}$
A novel four quadrant graphical tool was developed by the Current Author for ABG interpretation using standard base excess in the x axis and the ratio 2 (HCO₃⁻ - Std HCO₃⁻) / H₂CO₃ values in the y axis to analyse the various acid-base disturbances in a graphical method.[VIII] 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). The acid-base disorders can be classified and plotted in the 4 quadrant graph. Each acid-base disorders will occupy any of the 4 quadrant and the normal arterial blood gas analysis reports will be seen around the centre of the graph.[VIII] This novel four quadrant graphical method will serve as a newer graphical tool that may provide a rough guide and help in easier and quicker interpretation of ABG reports which is clearly shown in the table 6.

**TABLE6. ACID BASE DISORDERS IN A FOUR QUADRANT GRAPHICAL TOOL**

| PLOTTED AREA | Quadrant in the Graphical Tool |
|--------------|--------------------------------|
| **Towards X: Axis** | 1st quadrant both x axis and y axis are positive | 2nd quadrant x axis positive and y axis negative | 3rd quadrant both x axis and y axis negative | 4th quadrant x axis negative and y axis positive |
| Metabolic Alkalosis | Metabolic Alkalosis | Metabolic Acidosis | Metabolic Acidosis |
| **Towards Y: Axis** | Respiratory Acidosis | Respiratory Alkalosis | Respiratory Alkalosis | Respiratory Alkalosis |

Normal Cases around the centre of the graph.

**Simple acid base disorders:** Towards Single Axis (either x axis or y axis)  
**Combined acid base disturbances** (compensations or mixed disorders): In between them (x axis and y axis)

A minor drawback of this graphical tool is that this may not clearly demarcate the different higher levels of PCO₂ values. [I, XIX] Although the ratio2 (HCO₃⁻ - Standard HCO₃⁻) / H₂CO₃ differentiate the respiratory acidosis and respiratory alkalosis, it may not clearly differentiate the different PCO₂ levels. But this can be rectified in 3-dimensional graph if PCO₂ values are included in the third axis. The parameter (PCO₂ - 40 mm of Hg) should be taken in the third axis, because the ratio (HCO₃⁻ - Standard HCO₃⁻) / H₂CO₃ is zero at PCO₂ 40 mm of Hg, so that the zero central point is common to all the 3 parameters of the three axes,[I, XIX] As the PCO₂ increases, ratio 2{(HCO₃⁻ - Standard HCO₃⁻) / H₂CO₃} also increases and afterwards the curve flattens.[IX] But this flattening is slightly reduced and the curve is slightly steeper if ratio 3 ( multiplying ratio 1 with ratio 2) is utilized instead of ratio 2. (shown in the graph 7 which can be compared with graph 5)

![Graph 7](image)

**GRAPH7. X axis: PCO₂ VS Y axis: Ratio 3**

In the current study, 250 arterial blood gas sample cases were classified into various acid base disorders namely normal, respiratory acidosis, respiratory alkalosis, metabolic acidosis, metabolic alkalosis and miscellaneous cases based on the values of pH, PCO₂, bicarbonate and base excess which are clearly shown in the tables 1 and 2. The respiratory acidosis and alkalosis were divided into sub-groups based on the values of PCO₂. Similarly, metabolic acidosis and alkalosis were classified into sub-groups based on the bicarbonate values. The miscellaneous cases were divided into subgroups based on the values of pH, PCO₂ and bicarbonate.

The revised graphical tool for ABG interpretation can be constructed in a 3-dimensional surface by using standard base excess values in the x axis, ratio 3 values in the second axis and the parameter
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(PCO$_2$ - 40 mm of Hg) in the third axis to analyse the various acid-base disturbances. For practical convenience, in this research article, the 3-dimensional graph is represented in two graphs (2-dimensional graph).

A graphical tool constructed using standard base excess in the x axis and the ratio 3 values in the y axis for the various acid base disorder groups (250 cases divided into 18 different acid base disorder groups) is clearly shown in the graph 8. The relation between the parameter (PCO$_2$ - 40 mm of Hg) and the ratio 3 value is clearly shown in the graph 9.

5. CONCLUSION

The study concludes that this revised novel diagnostic graphical tool which clearly demarcates the various acid-base disorders in different quadrants may serve as a supporting tool for better understanding and quicker interpretation to overcome the challenging and arduous task of Arterial Blood Gas (ABG) interpretation.
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