International Journal of Clinical Chemistry and Laboratory Medicine (IJCCLM)
Volume 5, Issue 3, 2019, PP 19-29
ISSN No. (Online) 2455-7153
DOI: http://dx.doi.org/10.20431/2455-7153.0503003
www.arcjournals.org

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

Dr. T. Rajini Samuel M.D*

Assistant Professor of Biochemistry, Shri Sathya Sai Medical College and Research institute, Sri Balaji Vidyapeeth Deemed to be University, Guduvancherry-thiruporur main road Ammapettai, kancheepuram district, Tamilnadu, India.

Corresponding Author:** ***Dr. T. Rajini Samuel M.D, *Assistant Professor of Biochemistry, Shri Sathya Sai Medical College and Research institute, Sri Balaji Vidyapeeth Deemed to be University, Guduvancherry-thiruporur main road Ammapettai, kancheepuram district, Tamilnadu, India.*

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 {(HCO3 - Standard HCO3) /carbonic acid} in the y axis. A minor problem with the ratio {(HCO3 - Standard HCO3) /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 and portability 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. [I]

The measured parameters like pH, PCO_2 and calculated parameters like bicarbonate and Standard base excess are routinely utilized for interpretation. In ABG analysis, **PCO_2** denotes the respiratory component and **bicarbonate** and **standard base excess** represents the metabolic component in physiological and base excess approach respectively. [V,VI]

As PCO_2 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 PCO_2 values. So, the concentration of bicarbonate increases with increase in PCO_2 and it decreases as the PCO_2 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 $PaCO_2$ (40 mmHg) and a normal pO_2 (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 PCO_2.

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 PCO_2 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

$$\mathbf{pH = pKa_{H2CO3} + Log[HCO_3^-]/[H_2CO_3]}$$

pH is the acidity in the blood, $pK_{a\ H2CO3}$ is the negative logarithm (base 10) of the acid dissociation constant of carbonic acid. It is equal to 6.1 at normal body temperature.

$$pH = 6.1 + Log_{10}[HCO_3^-]/[H_2CO_3]\{ [H_2CO_3] = k_{H\ CO2} \text{ X } _{PCO2} \}= 6.1 + Log_{10}[HCO_3^-]/[0.03 \text{ X } _{PCO2}]$$

$[HCO_3^-]$ is the concentration of bicarbonate in the blood (mEq/L or mmol/L) ***$PaCO_2$*****(PCO_2)** is the partial pressure of carbon dioxide in the arterial blood(mm of Hg)

$[H_2CO_3]$ is the concentration of carbonic acid in the blood(mmol/L).

$k_{H\ CO2}$ is a constant including the solubility of carbon dioxide in blood. The solubility coefficient of CO_2 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:

$$\mathbf{pH = pKa_{H2CO3} + Log[HCO_3^-]/[H_2CO_3]}$$

The above equation is in logarithm form.

$$\mathbf{pH = - \log [H^+ \text{ nanomoles/L}] \quad ; \quad pK_a = - \log[K_a] \quad ; \quad K' = 10^{-pKa}}$$

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

$$[H+] = \{K' *(0.03 \text{ X } _{PCO2})\}/[HCO_3^-]$$

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 HCO_3^- 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:

H^+ (Hydrogen ion concentration) = {24 X PCO_2}/ 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^+ (Hydrogen ion concentration at actual pH) = {24 X PCO_2}/ HCO_3

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

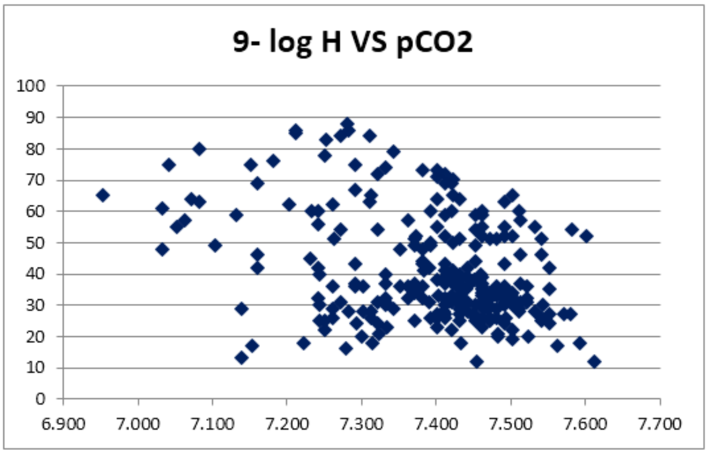
pH = - log[H^+ nanomoles/L]

= **-** log [H^+ x 10^{-9} moles/L]

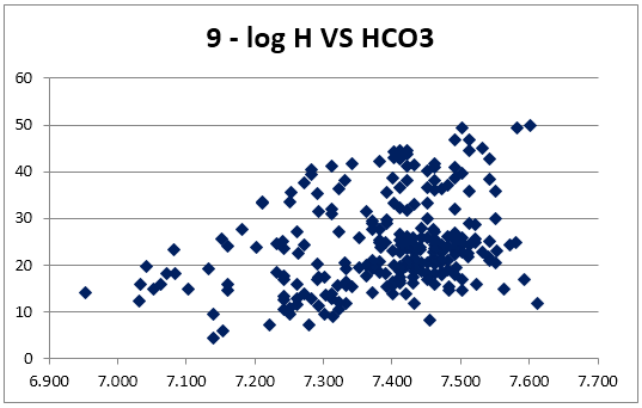
= **-** log [H^+] –log[10^{-9}]   { nanomoles/L =10^{-9} moles/L }

pH = 9 – log [H^+]

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



GRAPH1. *X: axis 9- log H VS Y: axis PCO_2*



GRAPH2. *X: axis 9 - log H VS Y: axis HCO3*

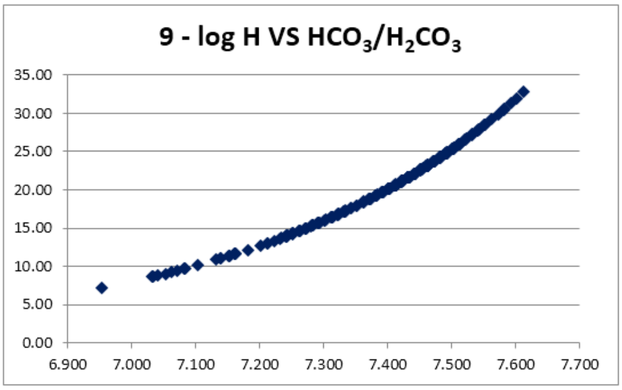
It is found there is no clear relationship between pH and partial pressure of carbon dioxide (PCO_2) values (shown in **graph 1**) and pH and bicarbonate concentration values (shown in **graph 2**).[X]

2.4. Calculation of Bicarbonate/Carbonic Acid Ratio

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

H_2CO_3=0.03 X PCO_2

The ratio between HCO_3 and carbonic acid (HCO_3/H_2CO_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]



GRAPH3. *X: axis 9 - log H VS Y: axis HCO_3/H_2CO_3*

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]

Ratio 1 = HCO_3/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]

Ratio 2 = (HCO_3/H_2CO_3) - (Std HCO_3/H_2CO_3) = (HCO_3 - Std HCO_3) / H_2CO_3

The ratio between (HCO_3- Standard HCO_3) and carbonic acid was calculated and represented by (HCO_3- Standard HCO_3) /H_2CO_3. A Newer parameter that denotes the respiratory influence of PCO_2 in changing pH is given below. [XII]

[HCO_3 / Std HCO_3] - (H_2CO_3 -1.2)/H_2CO_3

2.8. Calculation of Ratio 3:

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

Ratio 3 = {(HCO_3/ Std HCO_3)} X {(HCO_3 - Std HCO_3) / H_2CO_3}

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]

cBase(ecf) = cHCO_3 - 24.8 + 16.2 × (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 **PCO_2** 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, PCO_2, 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**.

TABLE1. *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($PCO_2 > 45 \leq 60$ mm of Hg)	11 cases
	Respiratory acidosis 2($PCO_2 > 60 \leq 80$ mm of Hg)	14 cases
	Respiratory acidosis 3($PCO_2 > 80$ mm of Hg)	7 cases
Group III	**Respiratory alkalosis**	**53 cases**
	Respiratory alkalosis 1: PCO_2 31 to 34 mm of Hg	16 cases
	Respiratory alkalosis 2: PCO_2 26 to 30 mm of Hg	22 cases
	Respiratory alkalosis 3: PCO_2 21 to 25 mm of Hg	8 cases
	Respiratory alkalosis 4: $PCO_2 \leq 20$ mm of Hg	7 cases

TABLE2. *Metabolic Acid-base Disorder and Missellaneous Groups*

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

Table3. *Samples of Normal and Respiratory acid base disorder Case Values*

S.no	pH	PCO_2	PCO_2 - 40	H_2CO_3	$(H_2CO_3$-1.2)/ H_2CO_3	HCO_3	Std HCO_3	STD BE	Ratio 1	Ratio 2	Ratio 3
	Normal										
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	-5	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	0.024	26	25.5	1.36	1.020	0.407	0.414
	Respiratory acidosis 1($PCO_2 > 45 \leq 60$ 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	1.944	2.180
3	7.36	52	12	1.56	0.231	29.4	27	3.95	1.089	1.538	1.675
	Respiratory acidosis 2($PCO_2 > 60 \leq 80$ 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($PCO_2 > 80$ 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 to 34 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 to 30 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 to 25 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: $PCO_2 \leq 20$ mm of Hg										

1	7.44	12	-28	0.36	-2.333	8.2	14.9	-15.95	0.550	-18.611	-10.242
2	7.47	20	-20	0.6	-1.000	14.6	18.9	-9.07	0.772	-7.167	-5.536
3	7.58	18	-22	0.54	-1.222	16.9	22.2	-4.98	0.761	-9.815	-7.472

Table4. *Samples of Metabolic acid base disorder Case Values*

S.no	pH	PCO_2	PCO_2 - 40	H_2CO_3	$(H_2CO_3-1.2)/H_2CO_3$	HCO_3	Std HCO_3	STD BE	Ratio 1	Ratio 2	Ratio 3
Metabolic acidosis 1(HCO_3 >18≤ 22 mmol/L)											
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
Metabolic acidosis 2(HCO_3 > 15≤ 18 mmol/L)											
1	7.35	32	-8	0.96	-0.250	17.7	19.4	-7.91	0.912	-1.771	-1.616
2	7.28	36	-4	1.08	-0.111	16.9	17.9	-9.84	0.944	-0.926	-0.874
3	7.23	42	2	1.26	0.048	17.6	17.3	-9.95	1.017	0.238	0.242
Metabolic acidosis 3(HCO_3 > 10≤ 15 mmol/L)											
1	7.36	25	-15	0.75	-0.600	14.1	17.4	-11.35	0.810	-4.400	-3.566
2	7.23	30	-10	0.9	-0.333	12.6	14.1	-14.95	0.894	-1.667	-1.489
3	7.15	42	2	1.26	0.048	14.6	14.4	-14.25	1.014	0.159	0.161
Metabolic acidosis 4(HCO_3 ≤ 10 mmol/L)											
1	7.3	18	-22	0.54	-1.222	8.9	12.8	-17.52	0.695	-7.222	-5.022
2	7.24	22	-18	0.66	-0.818	9.4	12.1	-17.99	0.777	-4.091	-3.178
3	7.13	29	-11	0.87	-0.379	9.6	10.8	-19.57	0.889	-1.379	-1.226
Metabolic alkalosis 1(HCO_3 >40 mmol/L)											
1	7.59	52	12	1.56	0.231	49.9	44.4	28.18	1.124	3.526	3.962
2	7.45	60	20	1.8	0.333	41.7	36.4	17.71	1.146	2.944	3.373
3	7.49	65	25	1.95	0.385	49.5	40.4	26.16	1.225	4.667	5.718
Metabolic alkalosis 2(HCO_3 > 30 ≤ 40 mmol/L)											
1	7.5	46	6	1.38	0.130	35.9	34	12.72	1.056	1.377	1.454
2	7.49	52	12	1.56	0.231	39.6	35.6	16.26	1.112	2.564	2.852
3	7.44	54	14	1.62	0.259	36.7	32.6	12.55	1.126	2.531	2.849
Metabolic alkalosis 3(HCO_3 > 26≤ 30 mmol/L)											
1	7.48	35	-5	1.05	-0.143	26.1	27.1	2.60	0.963	-0.952	-0.917
2	7.54	35	-5	1.05	-0.143	29.9	30.5	7.37	0.980	-0.571	-0.560
3	7.45	40	0	1.2	0.000	27.7	27.7	3.71	1.000	0.000	0.000

Table5. *Samples of Missellaneous acid base disorder Case Values*

S.no	pH	PCO_2	PCO_2 - 40	H_2CO_3	$(H_2CO_3-1.2)/H_2CO_3$	HCO_3	Std HCO_3	STD BE	Ratio 1	Ratio 2	Ratio 3
Missellaneous 1: Decreased pH ,increased PCO_2 with decreased HCO_3											
1	7.15	46	6	1.38	0.130	16	15.1	-12.85	1.060	0.652	0.691
2	7.07	63	23	1.89	0.365	18.3	15.5	-11.85	1.181	1.481	1.749
3	7.03	75	35	2.25	0.467	19.8	16	-10.99	1.238	1.689	2.090
Missellaneous 2: Normal pH, increased PCO_2 with Increased HCO_3											
1	7.38	50	10	1.5	0.200	29.6	27.6	4.48	1.072	1.333	1.430
2	7.4	59	19	1.77	0.322	36.5	32.6	11.70	1.120	2.203	2.467
3	7.42	64	24	1.92	0.375	41.5	36.3	17.02	1.143	2.708	3.096
Missellaneous 3: Normal pH, Decreased PCO_2 & Decreased HCO_3											
1	7.38	18	-22	0.54	-1.222	11.7	16.9	-13.42	0.692	-9.630	-6.667
2	7.4	25	-15	0.75	-0.600	16.2	19.5	-8.60	0.831	-4.400	-3.655
3	7.42	26	-14	0.78	-0.538	15.4	18.4	-9.08	0.837	-3.846	-3.219

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 log$PaCO_2$ as derived by the Henderson-Hasselbalch equation. But the major disadvantage of the chart is that it cannot diagnose many pairs of pH- PCO_2 values that have not been adopted in the everyday clinical practice. [XIV – XVI]

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 PCO_2 values derived using the Henderson hasselbach equation. Each isopleth PCO_2 curved line has a

fixed PCO_2 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 **PCO_2** 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]

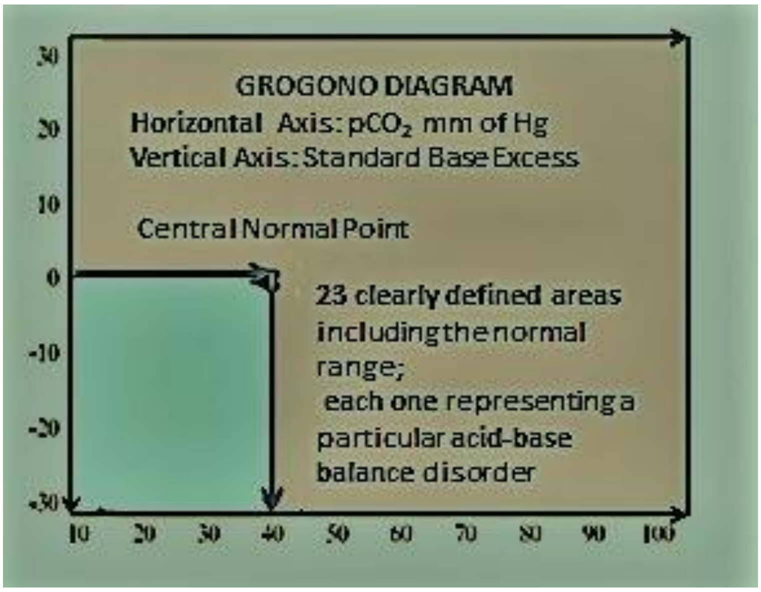


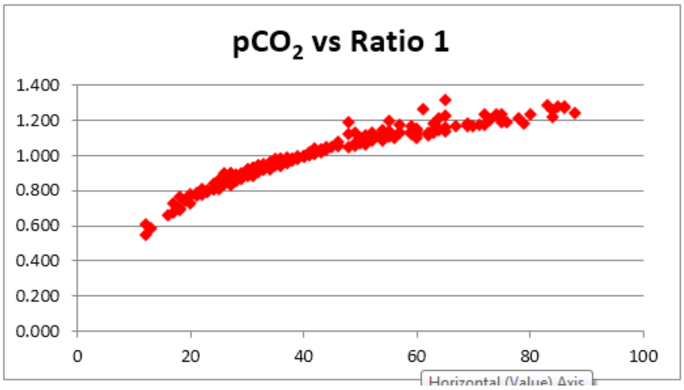
FIGURE1. *Grogono Diagram*

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]

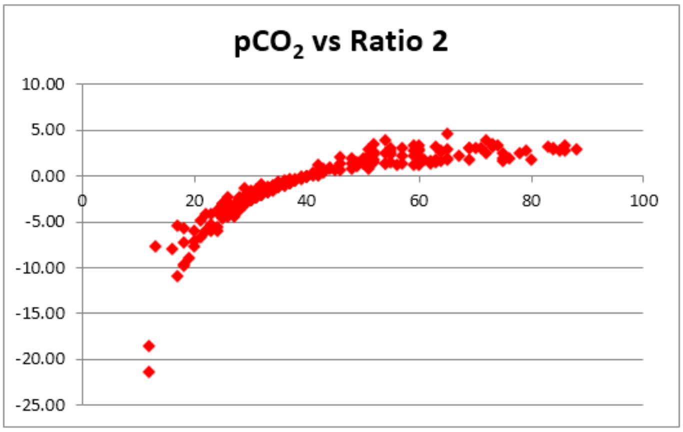
Recently a novel **graphical tool** was developed by **Rajini Samuel** (Current Author) for ABG interpretation to analyse the various acid-base disturbances in a four quadrant graphical method by using bicarbonate, standard bicarbonate, carbonic acid and standard base excess values. [VIII] The calculated bicarbonate concentration derived from Modified Henderson equation is a **variable parameter** because it changes with alterations in the values of PCO_2. [VII – IX]

In respiratory acidosis (due to hypoventilation) PCO_2 retention occurs and in respiratory alkalosis (due to hyperventilation) PCO_2 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 PCO_2 and the ratio 1 (HCO_3 / Std HCO_3) depicted in the **graph 4** clearly shows that as the PCO_2 increases, the ratio 1 also increases and afterwards the curve slightly flattens.[VII] The correlation between PCO_2 and the ratio 2 (HCO_3 - Std HCO_3) / H_2CO_3 depicted in the **graph 5** clearly shows that as the PCO_2 increases, the ratio 2 also increases and afterwards the curve flattens.[VII,VIII] At PCO_2 40 mmHg, both the bicarbonate and standard bicarbonate values are equal and so the difference is zero.



GRAPH4. *X axis: PCO_2 VS Y axis: Ratio 1(HCO_3/ Std HCO_3)*

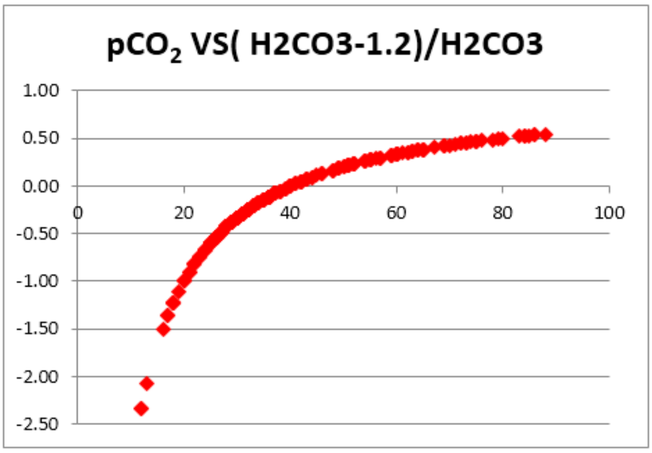


GRAPH5. *X axis: PCO_2 VS Y axis: Ratio 2*

The ratio 1(**HCO_3 / Std HCO_3**) values are **greater (>1)** for increased PCO_2 and **lesser (<1)** for decreased PCO_2. 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 PCO_2 (lesser than 40 mmHg) and **positive** for higher PCO_2 (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 $PCO_{2\ in}$ changing pH is given by the following relation. [XII]

[HCO_3 / Std HCO_3] – (H_2CO_3 -1.2)/H_2CO_3

From the **graph 4,** the first part of the above relation (**HCO_3 / Std HCO_3**) is very clear that the respiratory influence of PCO_2 in changing pH through bicarbonate is a **variable one** depending on acute or chronic conditions or compensations. [XII] The second part of the relation (**(H_2CO_3 -1.2)/H_2CO_3**) denotes that the respiratory influence of PCO_2 in changing the pH through carbonic acid is a **constant** which is clearly depicted in the **graph 6**.



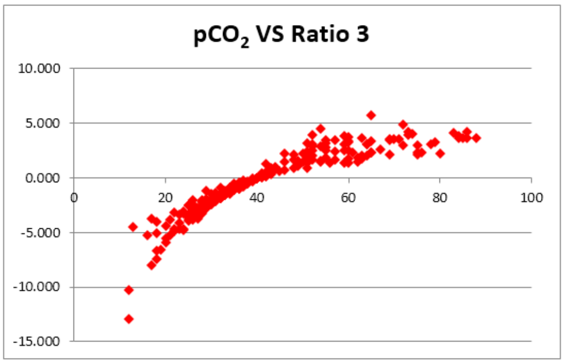
GRAPH6. *X axis: PCO_2 VS Y axis: (H_2CO_3 -1.2)/H_2CO_3*

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** (HCO_3 **-** Std HCO_3) / H_2CO_3 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*

Various acid-base disorders plotted will occupy any of the 4 quadrant.				
PLOTTED AREA	**Quadrant in the Graphical Tool**			
	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 are negative	**4th quadrant** x axis negative and y axis positive
Towards **X: Axis**	Metabolic Alkalosis	Metabolic Alkalosis	Metabolic Acidosis	Metabolic Acidosis
Towards **Y: Axis**	Respiratory Acidosis	Respiratory Alkalosis	Respiratory Alkalosis	Respiratory Acidosis
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 PCO_2 values. [I, XIX] Although the ratio2 (HCO_3- Standard HCO_3) /H_2CO_3 differentiate the respiratory acidosis and respiratory alkalosis, it may not clearly differentiate the different PCO_2 levels. But this can be **rectified** in **3-dimensional graph** if $\mathbf{PCO_2}$ values are included in the **third axis**. The parameter (**$\mathbf{PCO_2}$ - 40 mm of Hg**) should be taken in the third axis, because the ratio **($\mathbf{HCO_3}$- Standard $\mathbf{HCO_3}$) /$\mathbf{H_2CO_3}$** is **zero** at **$\mathbf{PCO_2}$ 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 PCO_2 increases, **ratio 2**{(HCO_3- Standard HCO_3) /H_2CO_3} 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**)



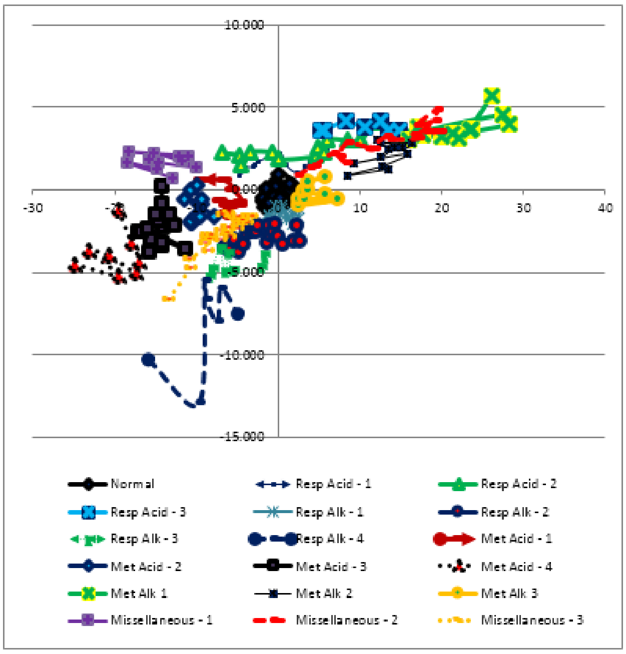
GRAPH7. *X axis: PCO_2 VS Y axis: Ratio 3*

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 missellaneous cases based on the values of pH, PCO_2, 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 PCO_2. Similarly, metabolic acidosis and alkalosis were classified into sub-groups based on the bicarbonate values. The missellanous cases were divided into subgroups based on the values of pH, PCO_2 and bicarbonate.

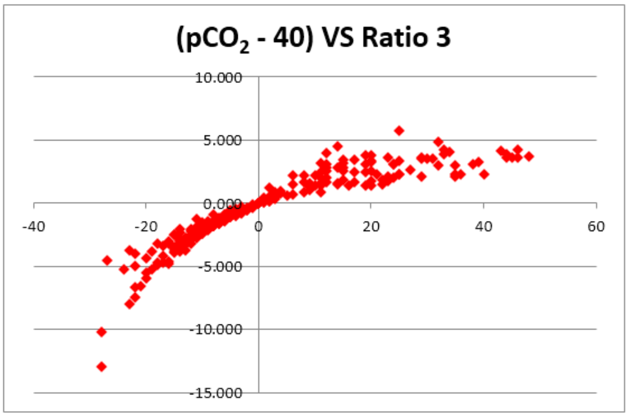
The revised graphical tool for ABG interpretation can be constructed in a 3-dimensional surface by using **standard base excess** values in the x axis, **ratio 3** values in the second axis and the parameter

(**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**.



GRAPH8. *Four Quadrant Graphical Tool - X axis: Std BE **VS** Y axis: Ratio 3*



GRAPH9. *X axis: (PCO_2 - 40) VS Y axis: Ratio 3*

A 3-dimensional graphical tool(**four quadrant** in **2-dimension** and it becomes **8** in **3-dimension**) can be constructed by the combination of the **graphs 8** and **9** using **standard base excess, ratio 3** and (**PCO_2 - 40 mm of Hg**) values of the various acid-base disturbances in the three (x axis , y axis and z axis) perpendicular axis respectively to analyse the different acid -base disorder groups. The advancement in the field of diagnosis of acid base disorders were very minimal in the last decades. This recently proposed four quadrant graphical tool by the current author which is revised in this current research study article may fulfil the requirements for a graphical visualization method to be widely applied in clinical practice.

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.

REFERENCES

[1] Rajini Samuel A Graphical Representation For Aiding Arterial Blood Gas Interpretation Using Non-Respiratory And Respiratory pH WJPMR, 2018,4(12), 192-202

[2] Dheeraj Kapoor, Meghana Srivastava, and Pritam Singh, Point of care blood gases with electrolytes and lactates in adult emergencies Int J Crit Illn Inj Sci. 2014 Jul-Sep; 4(3): 216–222.

[3] Barnette, L. & Kautz, D.D. Creative ways to teach arterial blood gas interpretation. Dimensions of Critical Care Nursing (DCCN), 2013; 32(2): 84-87.

[4] Doig AK, Albert RW, Syroid ND, Moon S, Agutter JA. Graphical arterial blood gas visualization tool supports rapid and accurate data interpretation Comput Inform Nurs, 2011; 29(4): 53-60

[5] Pramod Sood, Gunchan Paul, and Sandeep Puri Interpretation of arterial blood gas Indian J Crit Care Med. 2010 Apr-Jun; 14(2): 57–64.

[6] Bartter TC, Abouzgheib WB, Pratter MR, Irwin RS. In: Irwin and Rippe's Intensive Care Medicine. 6th edi. Lippincott: Williams and Wilkins Publishers; 2008. Respiratory Failure-Part 1; pp. 485–9.

[7] Rajini Samuel T Application of standard bicarbonate/carbonic acid ratio in arterial blood gas analysis International Journal of Clinical Biochemistry and Research, 2018;5(2):314 – 320

[8] Samuel R. A Graphical Tool for Arterial Blood Gas Interpretation using Standard Bicarbonate and Base Excess. Indian J Med Biochem, 2018; 22(1): 85-89

[9] Rajini Samuel T Application Of Modified Bicarbonate/Standard Bicarbonate Ratio In Arterial Blood Gas Interpretation International Journal Of Scientific Research-2019 ; 8(3): 60-63

[10] Rajini Samuel, Ilanchezian, Balaji Rajagopalan .Application of Modified Henderson Equation in ABG Interpretation. Int. J. Pharm. Sci. Rev. Res., 2016; 37(2):169-177

[11] Rajini Samuel T, Balaji Rajagopalan, Uma Maheshwari. A novel contemporary perspective teaching method for interpretation of various acid base disorders citing with examples. International Journal of Contemporary Medical Research 2019;6(3):C10-C14.

[12] 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.

[13] Rajini Samuel,Vyshnavi, Vanaja, Ragashree, Balaji Rajagopalan Graphical Analysis of Arterial Blood Gas Analysis Using Standard Base Excess, Int. J. Pharm. Sci. Rev. Res., 2017; 46(1) : 223-228

[14] Siggaard-Andersen O. Acid-base balance. In: Boston GEO, editor. Encyclopedia of respiratory medicine. Amsterdam: Academic Press; 2006. p. 5–10

[15] H. G. MORGAN ACID-BASE BALANCE IN BLOOD BRITISH JOURNAL OF ANAESTHESIA (1969), 41: 196- 212

[16] N. THEAKOS, A. LOUKOS*, M. VASSILIOU**, M. MOUKAS*, M. ZAKA* and P.K. BEHRAKIS pH-logPaCO2 diagram for the diagnostic approach of simple acid-base disorders 2nd Mediterranean Congress on THORACIC DISEASES Athens, Greece 4-7 March 1998

[17] Davenport, Horace W. (1974). The ABC of Acid-Base Chemistry: The Elements of Physiological Blood-Gas Chemistry for Medical Students and Physicians (Sixth ed.). Chicago: The University of Chicago Press.

[18] Panagiotis Behrakis, Miltos Vasileiou, Loukos A., Theakos N. Latest developments in graphic diagnostic approach of arterial blood gases disturbances Pneumon 2004, 17(2):150-158.

[19] T. Rajini Samuel Chapter Who Is Balancing: Is It RBC or Acid-Base Status? Intech Open Publisher; pages 1-15 DOI: http://dx.doi.org/10.5772/intechopen.84768

Citation: *Dr.T. Rajini Samuel M.D (2019),. "Revised Graphical Tool for ABG Interpretation using Modified Bicarbonate/Standard Bicarbonate Ratio". International Journal of Clinical Chemistry and Laboratory Medicine (IJCCLM), 5(3), pp.19-29, DOI: http://dx.doi.org/10.20431/2455-7153.0503003.*