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A GRAPHICAL REPRESENTATION FOR AIDING ARTERIAL BLOOD GAS INTERPRETATION USING NON-RESPIRATORY AND RESPIRATORY pH

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ABSTRACT

Arterial blood gas analyser is one of the most important point of care testing in intensive care unit for the management of critically ill patients. The understanding of arterial blood gas (ABG) analysis and interpretation is challenging and at times an arduous task. The graphical representation will serve as a supporting tool for teaching purposes especially for nursing students, critical care nurses and junior doctors but only few research studies are available for the same. The parameters like pH, pCO_2, bicarbonate and Standard base excess are routinely utilized for interpretation but standard bicarbonate is not commonly utilized and some researchers consider it as an obsolete parameter. The understanding of non-respiratory hydrogen ion concentration plays an essential part in arterial blood gas interpretation, but often it is not discussed in detail due to non-availability of its relationship with other ABG parameters. In a recently published research study, calculation of Non-respiratory hydrogen ion concentration from standard bicarbonate, its relationship with other commonly utilized ABG parameters and its clinical application were discussed with the postulates of the acid-base balance theory. The current research study is the extension of previously published work. The aim of the present study is to increase in depth the understanding of ABG interpretation by graphical representation using the metabolic and respiratory components involved in changing pH. The parameters derived from standard bicarbonate namely non-respiratory and predicted respiratory pH plays a vital role in understanding of acid-base disturbances.

KEYWORDS: Non-respiratory hydrogen ion concentration, predicted respiratory pH.

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.[1] The technological innovations has resulted in the development of Point-of-care devices which 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.[1] A rise in patients suffering from chronic diseases like chronic obstructive pulmonary diseases (COPD), asthma, heart failure, kidney failure and uncontrolled diabetes and an increase in the number of patients being treated in intensive care units and emergency department necessitate the increased requirement of blood gas analysers.[2,3] However, **complexity** involved in the **interpretation of blood gas analysis data** act as a restraining factor for the same.[3] The understanding of arterial blood gas (ABG) analysis and interpretation is sometimes confusing, challenging and at times an arduous task yet timely management results in life saving in emergency conditions.[4,5]

The **graphical** representation will serve as a **supporting tool** for teaching purposes especially for nursing students, critical care nurses and junior doctors for better understanding of the arterial blood gas interpretation.[6] A plenty of theoretical information is available and many methods exist in literature to guide the arterial blood gas interpretation.[4] But only few research articles discuss it in a graphical visualization method. There are only few graphical tools available depicting the respiratory and metabolic acid–base disturbances but are rarely used in clinical setting.[7]

The parameters like pH, pCO_2, bicarbonate and Standard base excess are routinely utilized for interpretation. **Base excess** is defined as the amount of strong acid that must be added to each litre of fully oxygenated blood to return the pH to 7.40 at a temperature of 37°C and a pCO_2 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 at haemoglobin concentration of 5 g/dl.[8]

Standard bicarbonate is not commonly utilized and some researchers consider it as an obsolete parameter.[9]

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).[8] The actual bicarbonate and the standard bicarbonate concentrations are approximately equal under normal ventilation (at pCO_2 40 mm of Hg) but the two values deviate from each other depending on the changes in the concentration of pCO_2. The bicarbonate value is increased in respiratory acidosis and decreased in respiratory alkalosis. The ratio **(HCO_3 – standard HCO_3)/H_2CO_3** is greater positive for respiratory acidosis and greater negative for respiratory alkalosis. In a previous research study, based on this concept a **four quadrant graphical tool** was constructed for ABG interpretation using standard base excess and the ratio (HCO_3 – standard HCO_3)/H_2CO_3 in the two axes that **demarcates** the various **acid base disturbances**.[7]

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 ABG interpretation because it is not routinely applied at the clinical practice due to the lack of simple formulae to calculate the same and non-availability of its inter-relationship with the other acid-base parameters.[10] In the recently published research study, **calculation** of Non-respiratory hydrogen ion concentration **from standard bicarbonate**, its relationship with other commonly utilized ABG parameters were discussed with the **postulates of the acid-base balance theory**.[11]

The **predicted respiratory pH** is usually calculated by **pCO_2 variance**. This calculation is slightly different for higher(>40 mm of Hg) and lower(<40 mm of Hg) pCO_2 levels. The **difference between** the predicted respiratory pH and the measured pH reflects the **metabolic pH change**.[12] In the current research study, the predicted respiratory pH is calculated by using a newly derived formulae which is common for all pCO_2 values.

The aim of the current research study is to aid for ABG interpretation by graphical representation using non-respiratory and respiratory pH for better understanding of the metabolic and respiratory components involved in the changes in total pH. The present research study is the extension of my previously published work.

MATERIALS AND METHODS

188 arterial blood gas sample data's 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.[13] The main parameters like measured **pH**, **pCO_2**, **HCO_3**, **Standard HCO_3** and **Standard base excess** values were noted. **Carbonic acid** concentration was calculated from pCO_2. The difference between bicarbonate and standard bicarbonate was calculated. The ratio **(HCO_3- Standard HCO_3) /H_2CO_3** was calculated.[7]

Calculation of NRH^+ (Non-Respiratory hydrogen ion concentration)

The 'non-respiratory' hydrogen ion concentration is calculated by the given formulae which is recently published.[11]

NRH^+ = 960 / Std HCO3

Calculation of ΔRpH (pH-NRpH)

The formulae to calculate the changes in pH due to respiratory influence is given below.[11]

[pH – NRpH] = 1.6 + log {(HCO3/ Std HCO3) / pCO2}

Where NRpH denotes the non-respiratory pH.

pH = 9 – log [H^+] ;

NRpH = 9 – log [NRH^+] ;

pH – NRpH = 9 – log [H^+] - 9 + log [NRH^+]

= log [NRH^+]/[H^+] or **- log [H^+]/ [NRH^+]**

The **magnitude** and **direction** (positive or negative) of the changes in the parameter **ΔRpH** (pH-NRpH) denotes the respiratory influence in causing changes in pH. The value is **negative** for **acidic** effect and **positive** for **alkaline** effect. At pCO_2 **40 mm of Hg**, pH - NRpH is **zero**.[11]

Net changes in total pH

The net changes in **total pH** (Actual pH) includes both the changes in **respiratory** and **nonrespiratory** (metabolic) component affecting the pH.[11,14,15]

Δ pH = ΔRpH + ΔNRpH

pH - 7.4 = ΔRpH + NRpH – 7.4

Where ΔNRpH (NRpH – 7.4) denotes the changes in pH due to metabolic component.[11,15]

Predicted Respiratory pH

pH = 7.4 + ΔRpH + ΔNRpH

7.4 + ΔRpH - pH = - ΔNRpH

Pr RpH - pH = - ΔNRpH {Pr RpH (Predicted respiratory pH) = 7.4 + ΔRpH}

The predicted respiratory pH is the **pH** at which the **changes in pH** due to **metabolic** component is **zero**. **(ΔNRpH is zero).**

The difference between the **predicted respiratory pH** and **actual pH** denotes the changes in pH due to metabolic component.[12] The **magnitude** and **direction** (positive or negative) of the changes in the parameter **ΔNRpH** (NRpH-7.4) is 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.[11] If the **actual pH** is **less** than the **predicted Respiratory pH**, **Δ NRpH** is **negative**. If the **actual pH** is **greater** than the **predicted Respiratory pH**, **Δ NRpH** is **positive**.

NRPH-7.4

NRPH – 7.4 = 9 – log $[NRH^+]$ - {9- log [40]

= 9- log $[NRH^+]$ - 9 + log [40]

= **log {[40]/ $[NRH^+]$ Or - log {$[NRH^+]$/[40]}**

7.4 + ΔRpH

7.4 + ΔRpH = {9- log [40] + 9 – log $[H^+]$ - 9 + log $[NRH^+]$

= 9 + log{$[NRH^+]$/ {$[H^+]$*[40]}

{ΔRpH (pH – NRpH) = 9 – log $[H^+]$ - 9 + log $[NRH^+]$}

= log {$[NRH^+]$/$[H^+]$}or - log {$[H^+]$$[NRH^+]$}

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

Net Changes in total Hydrogen ion concentration

The sum total changes in the hydrogen ion concentration **(Δ H^+= $[H^+]$- [40])** in the blood includes both the changes due to respiratory **(ΔRH^+ = $[H^+]$ – $[NRH^+]$)** and non-respiratory (metabolic) component **(Δ NRH^+ = $[NRH^+]$ - [40])**.[11,14]

[ΔRH^+/ H^+] = [H^+ - NRH^+]/ $[H^+]$ = **1 – {$[NRH^+]$/ $[H^+]$}**

[ΔNRH^+/ 40] = (NRH^+ - 40)/40 or

- [ΔNRH^+/ 40] = (40 - NRH^+)/40

= 1- {(NRH^+ /40)}

40 is the hydrogen ion concentration at **pH 7.4** which denotes the **homeostatic set point** of acid base balance.[16]

RESULTS

Table 1: Non-respiratory and Respiratory components (newly derived from standard bicarbonate) of ABG and their significance.

S.No	Parameter	Clinical significance
1.	**NRH^+:** Non-respiratory hydrogen ion concentration NRH^+ = 960 / Std HCO3	↑ in Metabolic acidosis and ↓ in Metabolic alkalosis
2.	**(40 - NRH^+)/40:** = 1- {(NRH^+ /40)}	This value is positive for base excess and negative for base deficit.
3.	**NRpH:** Non-respiratory pH NRpH = 9 – log [NRH+]	↓ in Metabolic acidosis and ↑ in Metabolic alkalosis
4.	**ΔRpH** (pH-NRpH): Delta respiratory pH ΔRpH = 1.6 + log {(HCO_3/ Std HCO_3) / pCO_2}	↓(negative) in Respiratory acidosis and ↑(positive) in Respiratory alkalosis
5.	**$[NRH^+]$/$[H^+]$**	↓ (<1) in Respiratory acidosis and ↑ (>1) in Respiratory alkalosis
6.	**[ΔRH^+/ H^+]:** (H^+ - NRH^+)/ H^+ or 1- {$[NRH^+]$/$[H^+]$}	positive for respiratory acidosis and negative for respiratory alkalosis
7.	**Pr RpH: Predicted Respiratory pH** Pr RpH = 7.4 + ΔRpH	**pH** at which the **changes in pH** due to **metabolic** component is **zero**
8.	**ΔNRpH (NRpH-7.4):** Delta non respiratory pH **Pr RpH - pH = - ΔNRpH**	Changes in pH due to metabolic component. negative for acidic effect and positive for alkaline effect

Table 2: Examples of ABG data showing metabolic and respiratory components involved in net changes in total pH. {Δ pH(pH - 7.4) = ΔRpH (pH-NRpH) + ΔNRpH(NRpH – 7.4)}.

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
Comment: changes in **net pH(acidic)** is **mainly** due to **metabolic** component, **partly opposed** by **respiratory** component (**alkaline effect**).								
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
Comment: changes in **net pH(alkaline)** is mainly due to **metabolic** component.								
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
Comment: changes in **net pH** is **normal**.								
6.	7.02	61	15.8	12.5	-0.38	-0.08	-0.30	7.32
Comment: changes in **net pH(acidic)** is **mainly** due to **metabolic** component and **partly** due to **respiratory** component.								
7.	7.5	57	44.5	39.3	0.1	-0.10	0.20	7.30
Comment: changes in **net pH(alkaline)** is **mainly** due to **metabolic** component, **partly opposed** by **respiratory** component (**acidic effect**).								
8.	7.4	72	44.6	36.1	0	-0.17	0.17	7.23
Comment: changes in **net pH** is **zero**. The changes in pH due to **metabolic** and **respiratory** component is **equal** and **opposite**. So, it is **cancelled out each other** and the net change is zero.								

9.	7.17	76	27.7	23.3	-0.23	-0.21	-0.02	7.19
Comment: changes in **net pH(acidic)** is **mainly** due to **respiratory** component.								
10.	7.6	12	11.8	19.5	0.2	0.30	-0.10	7.70
Comment: changes in **net pH(alkaline)** is **mainly** due to **respiratory** component, **partly opposed** by **metabolic** component (**acidic effect**).								
11	7.02	14	3.6	4.1	-0.38	0.40	-0.78	7.80
Comment: changes in **net pH(acidic)** is **mainly** due to **metabolic** component, **partly opposed** by **respiratory** component (**alkaline effect**).								

Table 3: Comparison of Predicted Respiratory pH calculation (one by previous method using pCO_2 variance and the other by newly derived formulae).

Predicted Respiratory pH calculation using pCO_2 variance (Previous method)		
PARAMETER	**pCO_2> 40 mm of Hg**	**pCO_2< 40 mm of Hg**
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 same for all the values of PCO2	
ΔRpH	[pH – NRpH] = 1.6 + log {(HCO_3/ Std HCO_3) / pCO_2}	
Predicted Respiratory pH	7.4 + ΔRpH	

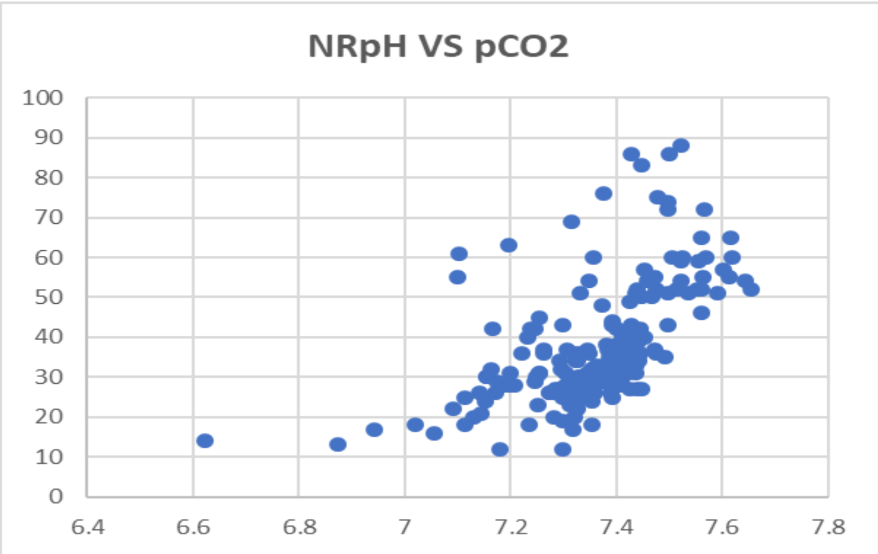

Figure 1: X: axis NRpH VS Y: axis pCO_2.

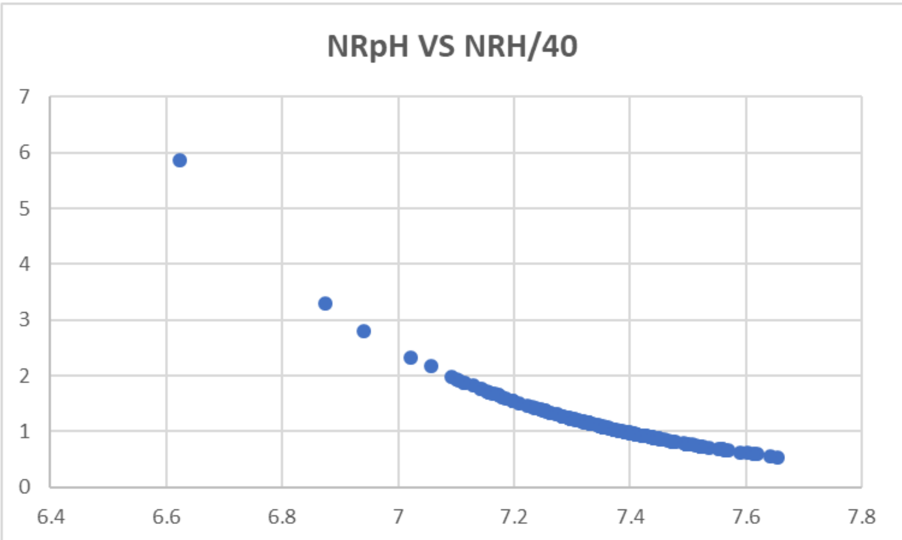

Figure 2: X: axis NRpH VS Y: axis NRH/40.

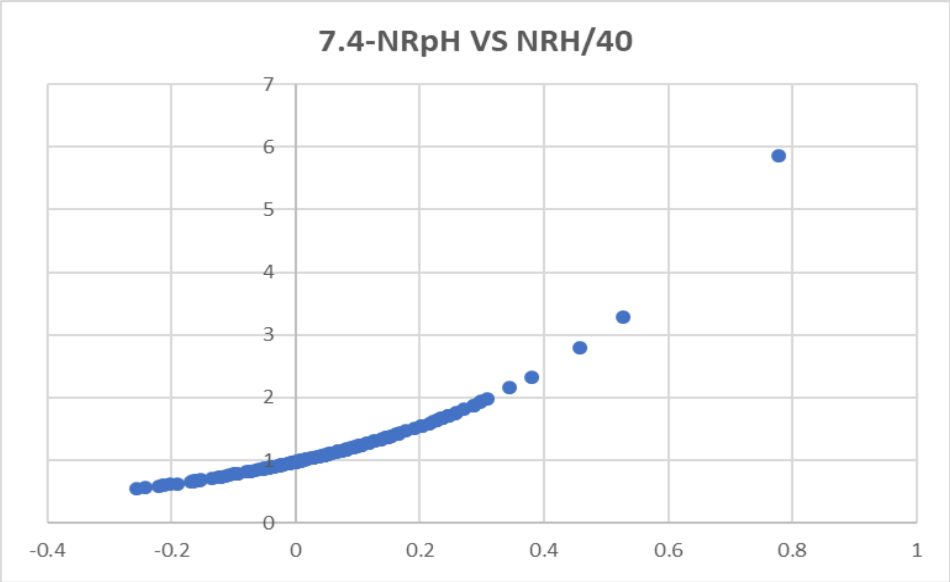

Figure 3: X: axis 7.4-NRpH VS Y: axis NRH/40.

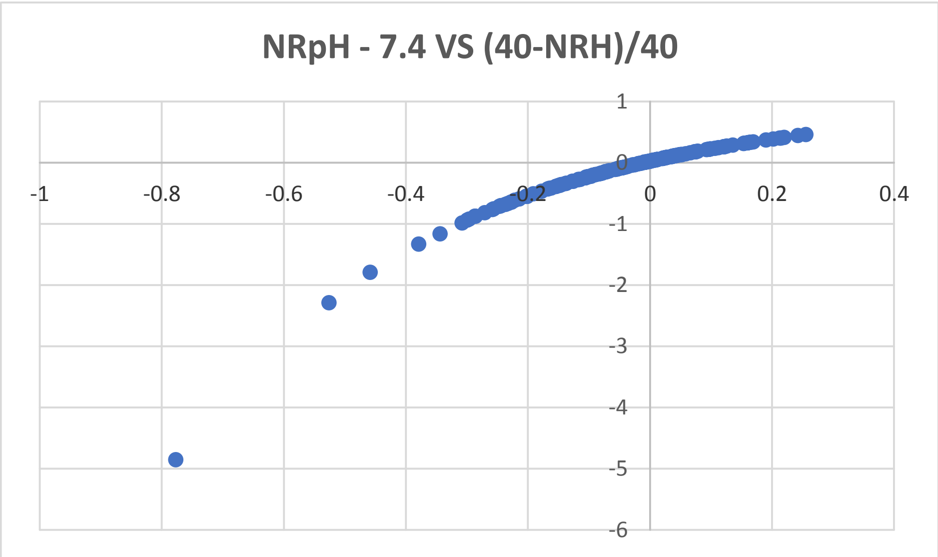

Figure 4: X: axis NRpH-7.4 VS Y: axis (40-NRH)/40.

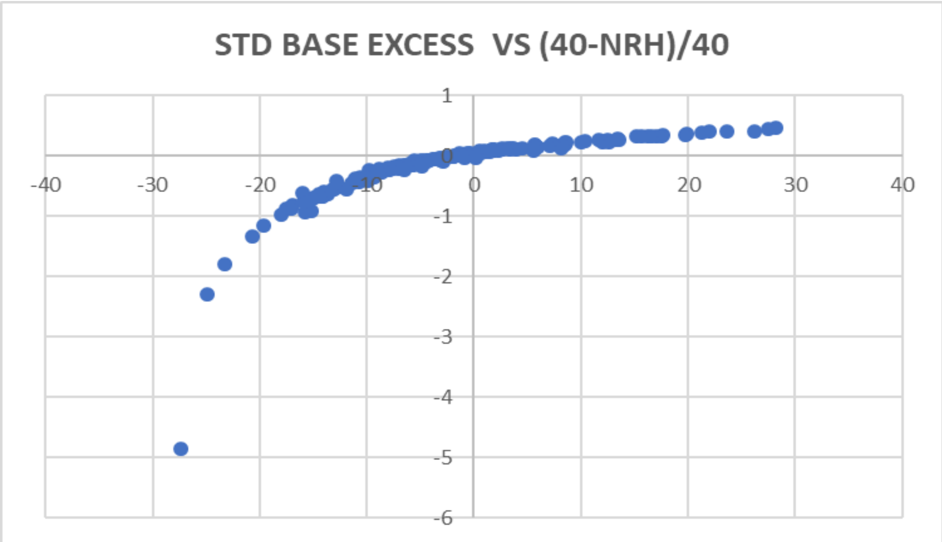

Figure 5: X: axis STD BASE EXCESS VS Y: axis (40-NRH)/40.

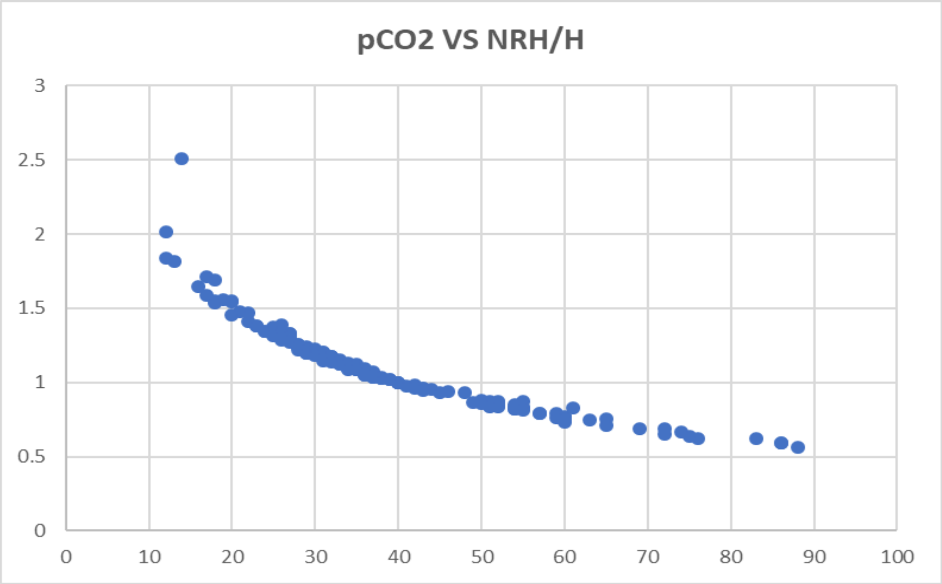

Figure 6: X: axis pCO_2 VS Y: axis [NRH]/[H].

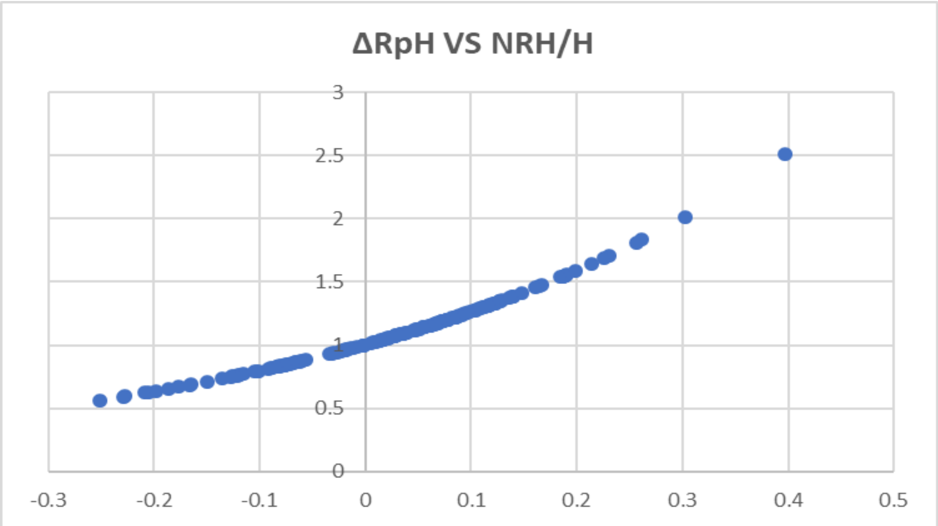

Figure 7: X: axis Δ RpH VS Y: axis [NRH]/[H].

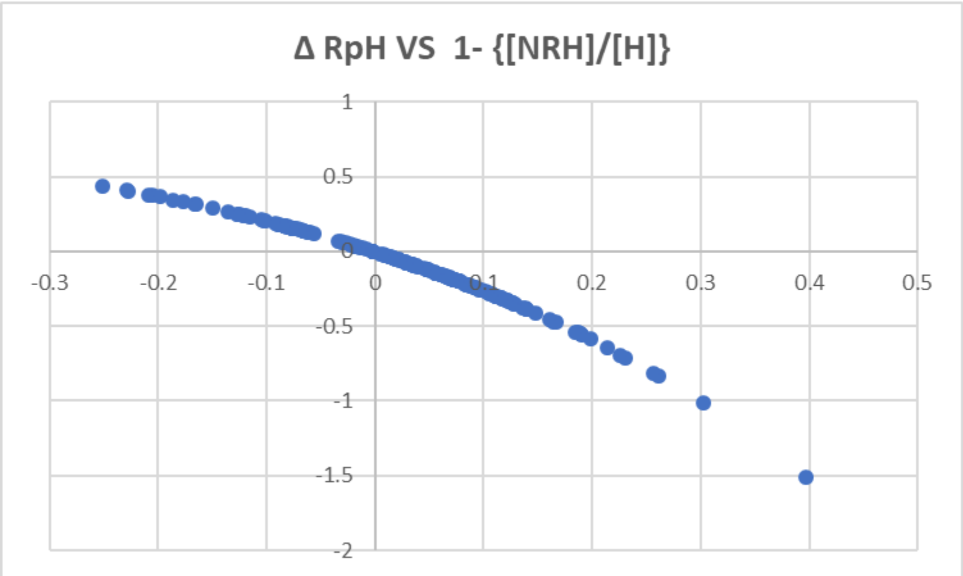

Figure 8: X: axis Δ RpH VS Y: axis 1- {[NRH]/[H]}.

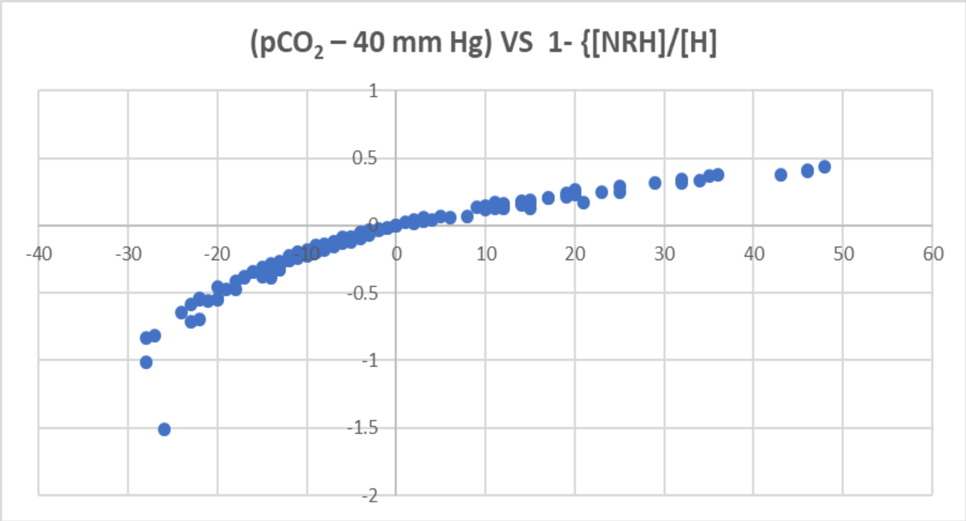

Figure 9: X: axis (pCO_2 – 40 mm Hg) VS Y: axis 1- {[NRH]/[H].

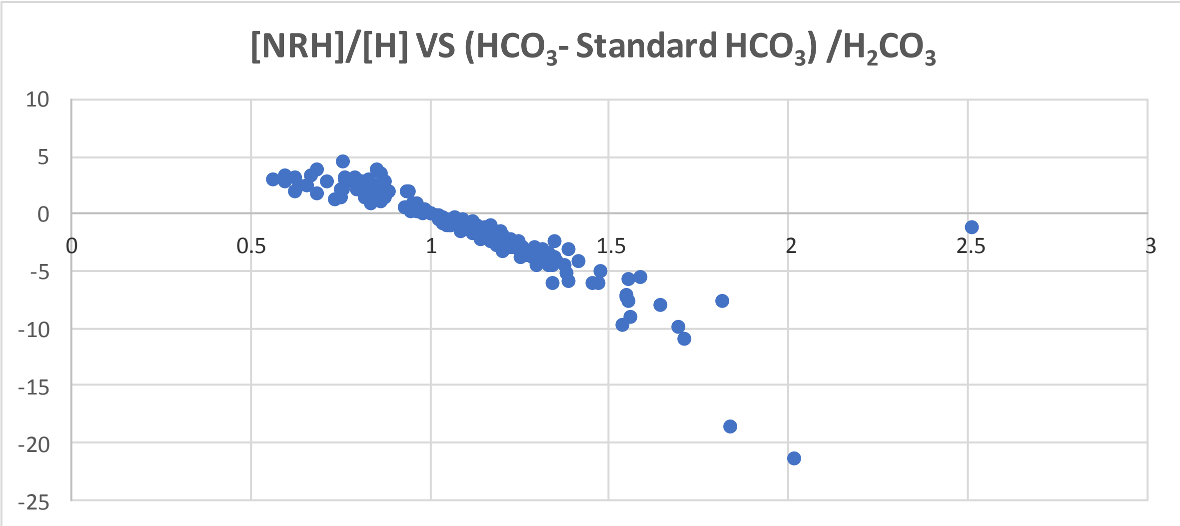

Figure 10: X: axis [NRH]/[H] VS Y: axis (HCO_3- Standard HCO_3) /H_2CO_3.

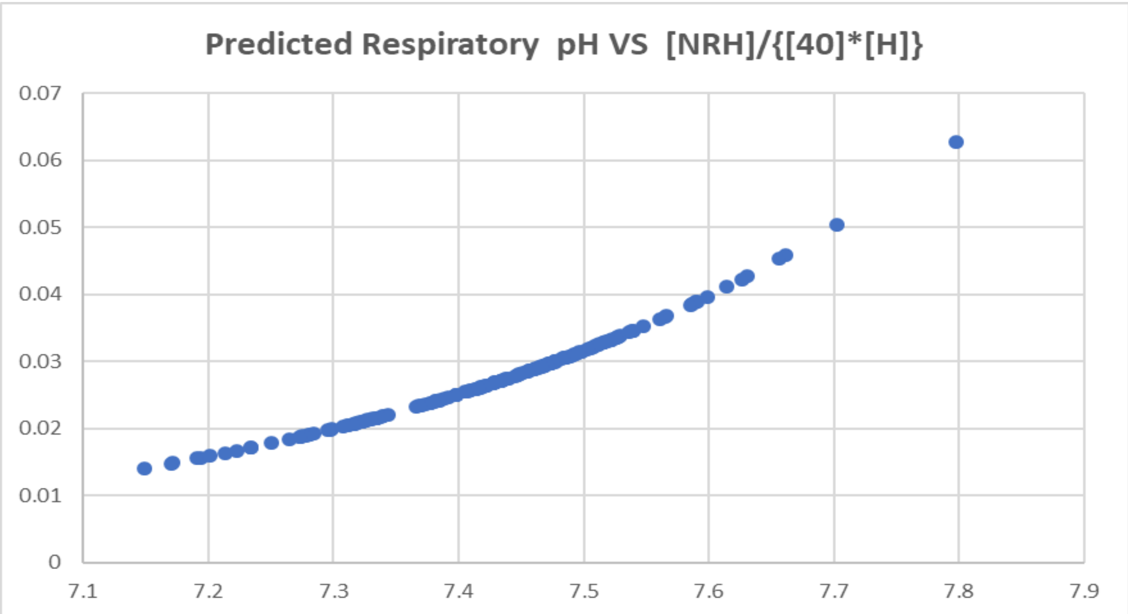

Figure 11: X: axis Predicted Respiratory pH VS Y: axis [NRH]/{[40]*[H]}.

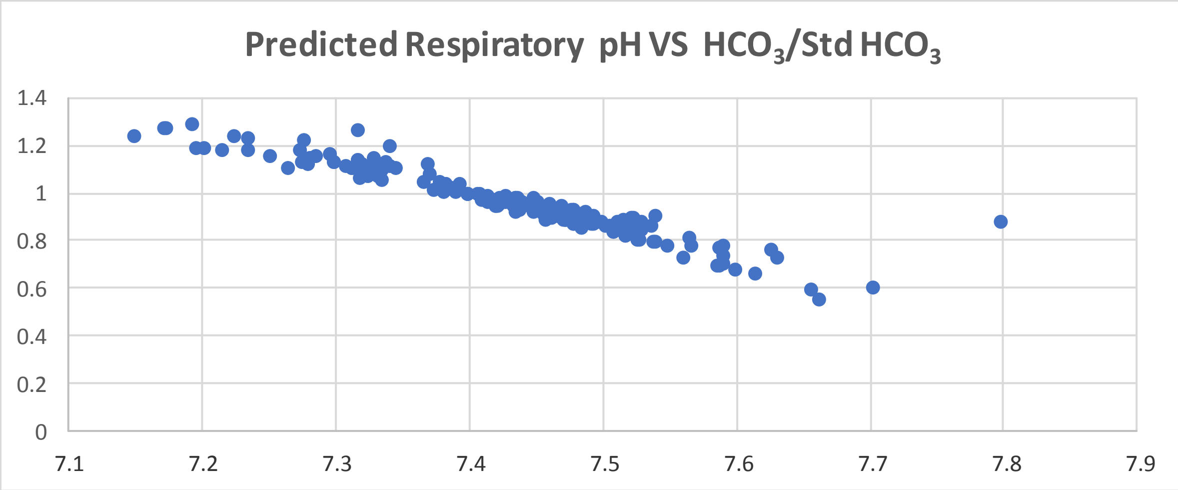

Figure 12: X: axis Predicted Respiratory pH VS Y: axis HCO_3/Std HCO_3.

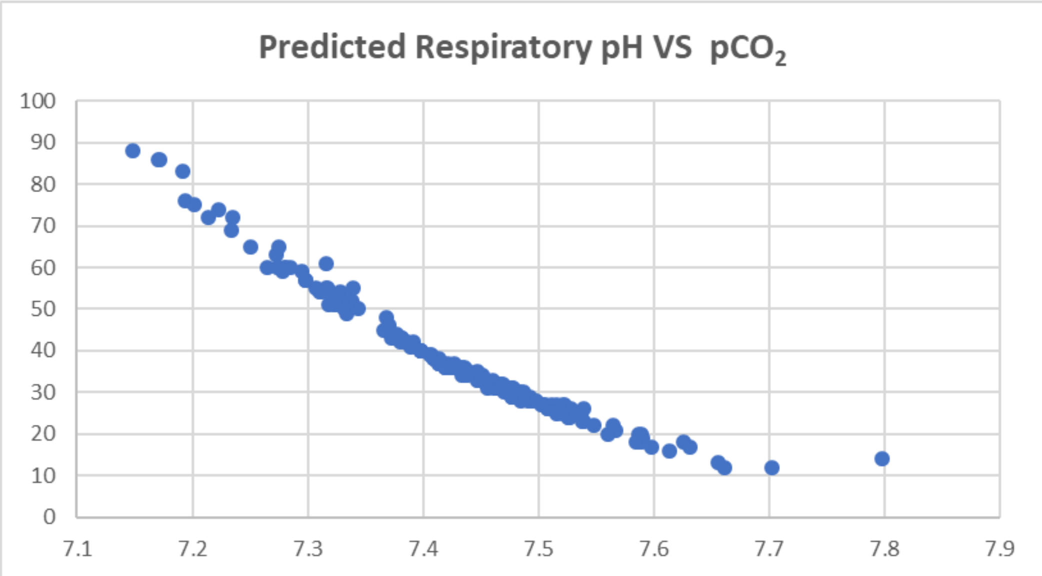

Figure 13: X: axis Predicted Respiratory pH VS Y: axis pCO_2.

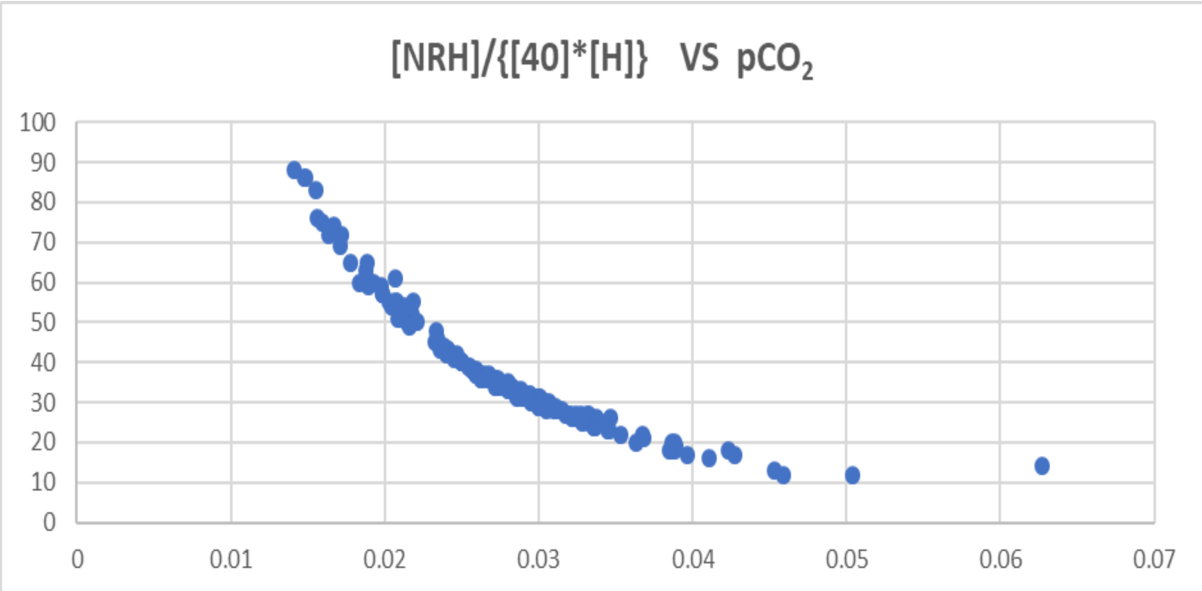

Figure 14: X: axis [NRH]/{[40]*[H]} VS Y: axis pCO_2.

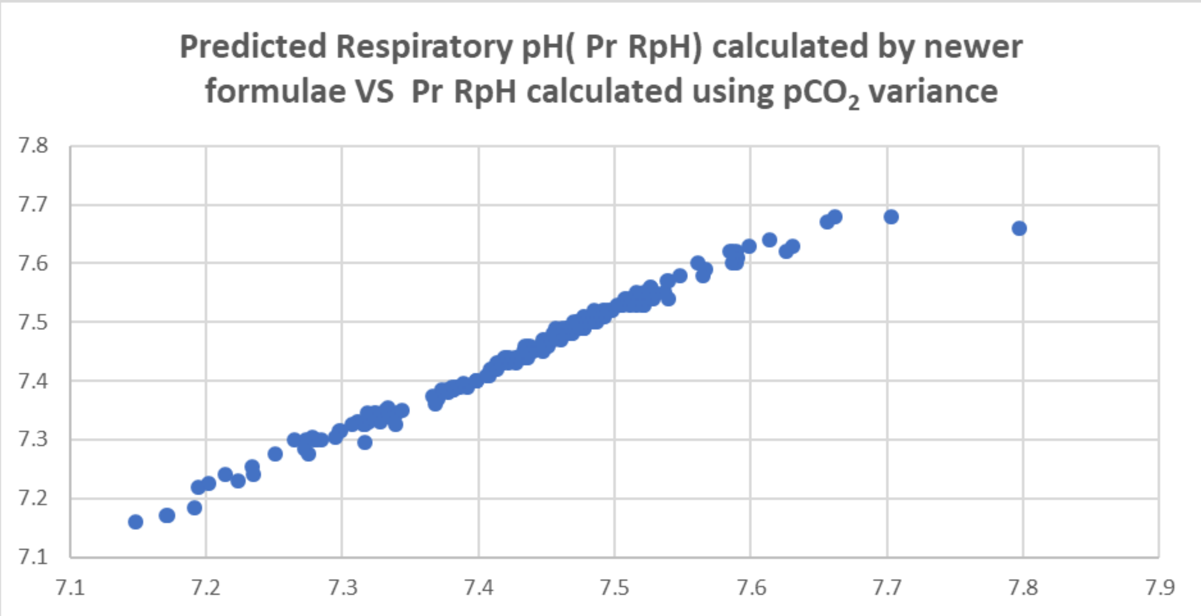

Figure 15: X: axis Predicted Respiratory pH(Pr RpH) calculated by newer formulae VS Y: axis Pr RpH calculated using pCO_2 variance.

DISCUSSION

The understanding of non-respiratory hydrogen ion concentration (NRH^+) plays a central role in ABG interpretation.[10,11] The calculation of NRH^+ from standard bicarbonate and it's interrelationship with other commonly utilized ABG parameters was discussed in the previous research study which enumerates the postulates of the acid-base balance theory. The first two postulates of this theory relates the net changes in pH and the sum total changes in the hydrogen ion concentration to their individual changes in respiratory and non-respiratory (metabolic) component respectively.[11] **Non-respiratory** and **Respiratory components** derived from **standard bicarbonate** are tabulated with their clinical significance in arterial blood gas interpretation in **table 1**. In the current study, 188 sample data's were utilized for the construction of various figures(graphs) representing the relationship between the respiratory and non-respiratory components involved in changing pH with other commonly used ABG parameters. In **table 2**, ABG data citing with 11 examples are given. The **net changes** in **total pH** is **compared** with the **individual changes** in pH due to **respiratory** and **non-respiratory** components. This will help in understanding the alterations in pH in different acid-base disturbances. The magnitude of the changes in pH and its acidic or alkaline effect due to the respiratory, metabolic or both components can be easily assessed.

From the **figure 1**, it is very clear that there is no correlation between non-respiratory pH(NRpH) and pCO_2 values because NRpH is calculated for pCO_2 value of 40 mm of Hg. The relation between changes in the non-respiratory hydrogen ion concentration(NRH^+) and its pH(NRpH) is shown in the **figures 2,3** and **4**. The relation ship between standard base excess and changes in the non-respiratory hydrogen ion concentration is shown in the **figure 5**.

From these graphs, it is easy to observe that $\mathbf{NRH^+}$ is increased in Metabolic acidosis and decreased in Metabolic alkalosis. Similarly, **NRpH** is decreased in Metabolic acidosis and increased in Metabolic alkalosis.

The relationship of the changes in pH due to respiratory influence is clearly shown in the **figures 6,7,8,9** and **10**. It is very easy to observe that the parameter $\mathbf{[NRH^+]/[H^+]}$ is **decreased** (<1) in Respiratory acidosis and **increased** (>1) in Respiratory alkalosis. The parameter NRH/H denotes the changes in pH due to respiratory influence. The parameter **ΔRpH** (pH-NRpH) is decreased (**negative**) in Respiratory acidosis and increased(**positive**) in Respiratory alkalosis. At pCO_2 40 mm of Hg, bicarbonate and standard bicarbonate value is same so the value of the ratios namely HCO_3/Std HCO_3 and [NRH]/[H] is one. The relation between $\mathbf{pCO_2}$ and the ratio $\mathbf{\Delta RH^+/ H^+}$ is clearly shown in the **figure 9**. It is **positive** for respiratory acidosis and **negative** for respiratory alkalosis. In this graph **central zero point** denotes $\mathbf{pCO_2}$ **of 40 mm of Hg** because the parameter ($\mathbf{pCO_2 - 40}$ mm of Hg) is taken in the **x: axis**.

$$\Delta RH^+/ H^+ = [H^+ - NRH^+]/ [H^+] \text{ or } 1 - \{[NRH^+]/ [H^+]\}$$

From the **figures 11,12,13** and **14**, the relationship of predicted Respiratory pH is obviously seen. At Predicted Respiratory pH value of 7.4, the value of the parameter **[NRH]/{[40]*[H]}** is **0.025**.(because the ratio [NRH]/[H] is one at pH 7.4 and the value of 1/40 is 0.025.

The Comparison of **Predicted Respiratory pH** calculation one by **previous method** using $\mathbf{pCO_2}$ **variance** and the other by **newly derived formulae** is shown in the **table 3**. Their graphical relationship is clearly shown in the **figure 15**.

The formulae to calculate the predicted respiratory pH is as follows.

Pr RpH (Predicted Respiratory pH) = 7.4 + ΔRpH

Where **ΔRpH** (pH-NRpH) =1.6 + log {(HCO_3/ Std HCO_3) / pCO_2}

In the newly derived formulae, pCO_2, bicarbonate and standard bicarbonate values are included but in the other method only pCO_2 values are considered. The actual bicarbonate and the standard bicarbonate values are more or less similar, but in the presence of respiratory disturbances, the two values will deviate from each other.[7] Hence, the alteration in these two values due to the respiratory influence has to be corrected. Also, this newly derived formulae is very simple because it can be used for all the pCO_2 values compared to other method which is different for higher(>40 mm of Hg) and lower(< 40 mm of Hg) pCO_2 values.

In a **previous study**, a novel **four quadrant graph method** was developed using **standard base excess** in x: axis and the ratio **(HCO_3- Standard HCO_3) /H_2CO_3** values in y: axis. This newer graphical tool may provide a rough guide and help in easier and quicker interpretation of ABG reports.[7] A **minor drawback** of this graphical tool is that, as the pCO_2 increases, ratio (HCO_3- Standard HCO_3) /H_2CO_3 also increases and afterwards the curve flattens. This may not clearly demarcate the different higher levels of pCO_2 values. Although the ratio (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 **corrected (rectified)** in **3-dimensional graph** if **pCO_2** values are included in the **third axis**(z:axis). The parameter (pCO_2- 40 mm of Hg) should be taken in the third axis, because the ratio **(HCO_3- Standard HCO_3) /H_2CO_3** is **zero** at **pCO_2 40 mm of Hg**, so that the zero central point is common to all the 3 parameters of the three axes. Alternatively, a similar 4 quadrant graph method can be constructed by the same concept but using different parameter the **ratio (H^+ - NRH^+)/ H^+**. This ratio is **positive** for **respiratory acidosis** and **negative** for **respiratory alkalosis** which is **similar** to the ratio **(HCO_3- Standard HCO_3) /H_2CO_3**.

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** may serve as a **supporting tool** for teaching purposes, when properly correlated with clinical conditions and other ABG parameters results in better understanding and quicker interpretation of ABG reports.

CONCLUSION

Arterial blood gas analysis test is one of the most commonly employed point of care testing in intensive care units, yet the understanding of acid-base disturbances and interpretation of ABG reports is 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 pCO_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.

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None.

REFERENCES

1. 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.
2. Blood Gas and Electrolyte Analyzer Market Size, Share & Trends https://www.transparencymarketresearch.com/blood-gas-electrolyte-analyzers.html.
3. Blood Gas and Electrolyte Analyzers Market Analysis,2017-23 https://www.alliedmarketresearch.com.
4. Pramod Sood, Gunchan Paul, and Sandeep Puri Interpretation of arterial blood gas Indian J Crit Care Med, 2010 Apr-Jun; 14(2): 57–64.
5. Barnette, L. & Kautz, D.D. Creative ways to teach arterial blood gas interpretation. Dimensions of Critical Care Nursing (DCCN), 2013; 32(2): 84-87.
6. 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.
7. 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.
8. O. Siggaard-Andersen, N. Fogh-Andersen Base excess or buffer base (strong ion difference) as measure of a non-respiratory acid-base disturbance Acta Anaesthesiol Scand, 1995; 39: Supplementum 106, 123-128.
9. Krapf R Standard bicarbonate and base excess--obsolete parameter Ther Umsch, 2000 Jun; 57(6): 386-90.
10. J. T. Suero The Usefulness Of Non-Respiratory Hydrogen Ion Concentration And Its Relationship

To The Traditional Acid-Base Parameters Clin. Biochem, 1969; 2: 177-185.
11. 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.
12. Munjal YP, Surendra K Sharm API Textbook of Medicine, Ninth Edition, 2012, section 7 critical care medicine Chapter 4, acid base disorders pages 239-241.
13. Rajini Samuel, Ilanchezian, Balaji Rajagopalan Application of Modified Henderson Equation In ABG Interpretation Int. J. Pharm. Sci. Rev. Res, 2016; 37(2): 169-177.
14. Whitehead TP. Acid-base status, pH, and PCO2. Lancet, 1965; 2: 1015–6.
15. Michael J. Bookallil Description of pH or Acid-Base Status in Blood, pH of the Blood: AcidBase Balance available online: www.anaesthesia.med.usyd.edu.au/ resources/lectures/acidbase_mjb/acidbase.html.
16. Siggaard-Andersen O. Acid-base balance. In: Boston GEO, editor. Encyclopedia of respiratory medicine. Amsterdam: Academic Press, 2006; 5–10.