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APPLICATION OF MODIFIED BICARBONATE/STANDARD BICARBONATE RATIO IN ARTERIAL BLOOD GAS INTERPRETATION

Biochemistry

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ABSTRACT

In arterial blood gas interpretation (ABG), bicarbonate (HCO3) 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 denotes the respiratory influence. This concept was applied in a previous research study for the development of a novel four quadrant graphical method for ABG interpretation. Their ratio was also applied for an equation inter-relating the total changes in pH to the changes in both the respiratory and non-respiratory component affecting the pH.

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 apply a modified bicarbonate/ Standard bicarbonate ratio in various acid base disturbances.

KEYWORDS

bicarbonate, standard bicarbonate, non-respiratory hydrogen ion

INTRODUCTION:

Arterial blood gas (ABG) analysis and interpretation is a challenging task but plays a vital role in the management of critically ill patients.[1] **Bicarbonate** concentration, calculated using the modified Henderson equation and routinely utilized for ABG interpretation is a useful parameter under normal ventilation, but in patients with abnormal respiration it may not reflect the true status. As **pCO_2** increases, it results in the formation of more **carbonic acid** (H_2CO_3) which dissociates into **hydrogen** and **bicarbonate** ions. So, the concentration of bicarbonate increases as pCO_2 also increases.[2] **Standard bicarbonate** is the concentration of bicarbonate in the plasma from blood which is equilibrated with a normal pCO_2 (40 mmHg) and a normal pO_2 (over 100 mmHg) at a normal temperature (37°C).[2,3] Under normal ventilation, the **standard bicarbonate** and the **actual bicarbonate** values are equal but in abnormal conditions like hypoventilation or hyperventilation their values differ depending on the alterations in the partial pressure of carbon-dioxide (pCO_2). [4,5]

The **ratios** namely 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 which may help in discriminating various acid base disorders.[5] A novel **four quadrant graphical method** developed by **Rajini Samuel** (current research study author) using standard base excess and the ratio (HCO_3 – standard HCO_3)/H_2CO_3 values may provide a rough guide for easier and quicker ABG interpretation.[4] A minor drawback 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.[6]

The ratio bicarbonate/standard bicarbonate value was also applied for a derived equation that states that the **net changes** in **total pH** is due to both the changes in **respiratory** and **non-respiratory(metabolic)** component affecting the pH.[6,7]The ratio between non-respiratory hydrogen ion concentration(**NRH^+**) and hydrogen ion concentration (**H^+**) is directly proportional to the parameter **ΔRpH (pH - NRpH)** which denotes the respiratory component affecting the net changes in total pH. The **non-respiratory hydrogen ion concentration** is calculated using standard bicarbonate and hydrogen ion concentration is calculated using bicarbonate values.

The aim of the current research study is to graphically analyse the relationship between these ratios for its correct application in various acid base disorders.

MATERIALS AND METHODS:

A total of 250 ABG analysis sample data's were utilized. The consistency of the ABG report was checked by using the modified Henderson equation.[8] The samples were analysed using ABG Analyser GEM PREMIER 3000. The main parameters like measured pH, pCO_2, HCO_3, and standard HCO_3 (Std HCO_3) values were noted.

Calculation of Carbonic acid Concentration:

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

H_2CO_3=0.03 X pCO_2

Then the bicarbonate/carbonic acid and standard bicarbonate/carbonic acid ratios were calculated.[5]

Calculation of Ratio 1: (HCO_3 /Std HCO_3)

The ratio 1 denotes the ratio between bicarbonate and standard bicarbonate value.[5]

Calculation of Ratio 2: (HCO_3 - Std HCO_3) / H_2CO_3

Ratio 2 denotes the difference between bicarbonate/carbonic acid and standard bicarbonate/carbonic acid ratio.[5]

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

Calculation of Ratio 3: {(HCO_3/ Std HCO_3)} X {(HCO_3 - Std HCO_3) / H_2CO_3 }

Ratio 3 is calculated by multiplying ratio 1 and ratio 2.

Calculation of NRH^+/H^+:

H^+ = {24 X pCO_2} / HCO_3 {H^+ - Hydrogen ion concentration}
NRH^+ = (24 X pCO_2)/ Std HCO_3
= (24 X 40)/ Std HCO_3 or 960 / Std HCO_3

The calculated hydrogen ion concentration equivalent of standard bicarbonate is called as the 'non-respiratory' hydrogen ion concentration (NRH^+) which is the hydrogen ion concentration at non-respiratory pH (at pCO_2 40 mm of Hg).[6,7,9]

[NRH^+]/ [H^+] = {(24 X 40)/ Std HCO_3 }/{(24 X pCO_2)/ HCO_3}
= **40 X {(HCO_3/ Std HCO_3)/ pCO_2}**

The value of the ratio **[NRH^+]/ [H^+]** is **one** at **pCO_2 40 mm of Hg** because bicarbonate and standard bicarbonate values are equal. At **higher pCO_2** levels (> 40 mm of Hg), the value of [NRH^+]/ [H^+] is **less than one** which denotes the **acidic influence** of increased pCO_2.At **lower pCO_2** levels (<40 mm of Hg), the value of [NRH^+]/ [H^+] is **more than one** which denotes the **alkaline influence** of decreased pCO_2.[6,7] Obviously, **1- [NRH^+]/ [H^+]** is greater positive for acidic influence and lesser negative for alkaline influence.[6]

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 various groups are **Group I** (Normal: **25** cases), **Group II** {Missellaneous (**59** cases) further divided into Sub-groups **II A** with **11** cases, **IIB** with **20** cases & **II C** with **28** cases}, **Group III** (Metabolic acidosis with **47** cases divided into **III A**(**16** cases with normal pCO2) and **III B**(**31** cases with decreased pCO_2), **Group IV** (Metabolic alkalosis with **34** cases divided into **IV A** (**12** cases with normal pCO_2) and **IV B**(**22** cases with increased pCO_2) **Group E**(Respiratory acidosis:**32** cases) and **Group F** (Respiratory alkalosis: **53** cases).

The metabolic and respiratory acid-base disorders are further divided based on their pH and pCO_2 values. The normal level 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. Out of the 250 samples, **25** ABG data's are **cited as examples** with calculated ratios shown in the **table 1.** The following ratios like **ratio 1**((HCO_3 /Std HCO_3), **ratio 2** (HCO_3 - Std HCO_3) / H_2CO_3), **ratio 3** {(HCO_3/ Std HCO_3)X (HCO_3 - Std HCO_3) / H_2CO_3}, **[** NRH^+**]/ [**H^+**]** and **1- [** NRH^+**]/ [**H^+**]** values are calculated for all the cases and the results are tabulated with their mean and standard deviation in the **tables 2, 3** and **4**.

The relationship between the **ratio 2**, **ratio 3** and **1- [** NRH^+**]/ [**H^+**]** were graphically analysed for various acid base disorders and shown in the **figures 1** to **9**.

TABLE1: Examples of ABG Data sample values with calculated ratios

S. NO	pH	pCO_2	$H2CO_3$	HCO_3	Std HCO_3	Ratio 1	Ratio 2	Ratio 3	$[NRH^+]/[H^+]$	$1-[NRH^+]/[H^+]$
1	7.37	43	1.29	24.9	24.3	1.025	0.465	0.477	0.953	0.047
2	7.02	48	1.44	12.4	10.4	1.192	1.389	1.656	0.994	0.006
3	7.4	59	1.77	36.5	32.6	1.120	2.203	2.467	0.759	0.241
4	7.42	26	0.78	16.1	18.8	0.856	-3.462	-2.964	1.318	-0.318
5	7.27	16	0.48	7.3	11.1	0.658	-7.917	-5.206	1.644	-0.644
6	7.23	25	0.75	10.5	12.8	0.820	-3.067	-2.516	1.313	-0.313
7	7.31	31	0.93	15.6	17.6	0.886	-2.151	-1.906	1.144	-0.144
8	7.36	25	0.75	14.1	17.4	0.810	-4.400	-3.566	1.297	-0.297
9	7.15	42	1.26	14.6	14.4	1.014	0.159	0.161	0.966	0.034
10	7.36	35	1.05	19.8	21	0.943	-1.143	-1.078	1.078	-0.078
11	7.44	44	1.32	29.9	28.9	1.035	0.758	0.784	0.941	0.059
12	7.48	43	1.29	32	30.9	1.036	0.853	0.883	0.963	0.037
13	7.45	52	1.56	36.1	31.9	1.132	2.692	3.047	0.871	0.129
14	7.52	55	1.65	44.9	40.2	1.117	2.848	3.182	0.812	0.188
15	7.22	60	1.8	24.6	22.3	1.103	1.278	1.410	0.735	0.265
16	7.28	67	2.01	31.5	27	1.167	2.239	2.612	0.697	0.303
17	7.36	52	1.56	29.4	27	1.089	1.538	1.675	0.838	0.162
18	7.44	12	0.36	8.2	14.9	0.550	-18.61	-10.24	1.834	-0.834
19	7.45	29	0.87	20.2	22.8	0.886	-2.989	-2.648	1.222	-0.222
20	7.45	31	0.93	21.5	23.7	0.907	-2.366	-2.146	1.171	-0.171
21	7.48	24	0.72	17.9	22.2	0.806	-5.972	-4.815	1.344	-0.344
22	7.47	33	0.99	24	25.2	0.952	-1.212	-1.154	1.154	-0.154
23	7.51	20	0.6	16	20.6	0.777	-7.667	-5.955	1.553	-0.553
24	7.54	27	0.81	23.1	26.1	0.885	-3.704	-3.278	1.311	-0.311
25	7.49	32	0.96	24.4	25.9	0.942	-1.563	-1.472	1.178	-0.178

TABLE 2: Normal cases, metabolic acid base disorder cases with normal pCO2
Total: 53 cases

	RATIO 1	RATIO 2	RATIO 3	NRH/H	1-NRH/H
Group I (Normal: **25** cases)					
Mean	0.986	-0.325	-0.308	1.025	-0.025
Std Dev	0.025	0.531	0.522	0.047	0.047
Group III (Metabolic acidosis- **total 47** cases **) – 16 cases** with **normal** pCO_2					
Group III: Decreased pH with normal pCO_2 **- 12 cases**					
Mean	0.987	-0.263	-0.240	1.011	-0.011
Std Dev	0.037	0.585	0.571	0.046	0.046
Group III: **Normal pH with normal** pCO_2 **- 4 cases**					
Mean	0.951	-0.975	-0.926	1.057	-0.057
Std Dev	0.007	0.141	0.127	0.017	0.017
Group IV (Metabolic alkalosis-**total 34** cases)**- 12 cases** with **normal** pCO_2					
Group IV : **Normal pH with normal** pCO_2 **- 4 cases**					
Mean	1.013	0.287	0.296	0.984	0.016
Std Dev	0.018	0.399	0.411	0.035	0.035
Group IV: **Increased pH with normal** pCO_2**- 8 cases**					
Mean	0.994	-0.166	-0.145	1.064	-0.064
Std Dev	0.029	0.762	0.773	0.055	0.055

TABLE 3: Acid base disorder cases with increased pCO2
Total: 85 cases

	RATIO 1	RATIO 2	RATIO 3	NRH/H	1-NRH/H
Group E(Respiratory acidosis)**- 32 cases**					
Group E: Decreased pH with Increased pCO_2 **- 28 cases**					
Mean	1.180	2.178	2.610	0.683	0.317
Std Dev	0.066	0.713	0.972	0.091	0.091
Group E: **Normal pH with Increased** pCO_2 **- 4 cases**					
Mean	1.088	1.507	1.653	0.835	0.165
Std Dev	0.032	0.486	0.586	0.029	0.029
Group IV (Metabolic alkalosis **total 34** cases)**- 22** cases with **increased** pCO_2					
Group IV: **Normal pH with Increased** pCO_2 **- 7 cases**					
Mean	1.126	2.565	2.904	0.816	0.184
Std Dev	0.030	0.563	0.698	0.045	0.045
Group IV: **Increase pH with Increased** pCO_2 **- 15 cases**					
Mean	1.122	2.848	3.224	0.836	0.164
Std Dev	0.039	0.844	1.069	0.058	0.058
Group II {Missellaneous **II A**) Decreased pH ,increased pCO_2 with decreased HCO_3 **- 11 cases**					
Mean	1.192	1.431	1.725	0.829	0.171
Std Dev	0.071	0.330	0.472	0.095	0.095
Group II {Missellaneous **II B**) Normal pH, increased pCO_2 with Increased HCO_3 - **20 cases**					
Mean	1.139	2.474	2.857	0.756	0.244
Std Dev	0.051	0.812	1.039	0.083	0.083

TABLE 4: Acid base disorder cases with decreased pCO2
Total: 112 cases

	RATIO 1	RATIO 2	RATIO 3	NRH/H	1-NRH/H
Group F (Respiratory alkalosis) - **53 cases**					
Group F: Normal pH & Decreased pCO_2 (20 to < 30) **- 6 cases**					
Mean	0.845	-4.243	-3.560	1.303	-0.303
Std Dev	0.029	0.969	0.679	0.064	0.064
Group F: Normal pH & Decreased pCO_2< 20 **- 1 single case**					
Group F: Normal pH & Decreased pCO_2 (30-34) **- 5 cases**					
Mean	0.919	-2.037	-1.857	1.165	-0.165
Std Dev	0.027	0.719	0.617	0.033	0.033
Group F: (7.46-7.48) Increased pH & Decreased pCO_2(<30) **- 9 cases**					
Mean	0.841	-4.653	-3.851	1.351	-0.351
Std Dev	0.045	1.603	1.115	0.106	0.106
Group F: (7.46-7.48) Increased pH & Decreased pCO_2(30 -34) **- 9 cases**					
Mean	0.934	-1.733	-1.609	1.168	-0.168
Std Dev	0.018	0.510	0.443	0.035	0.035
Group F: (≥7.49) Increased pH & Decreased pCO_2 (≤ 20) **- 5 cases**					
Mean	0.722	-11.760	-8.194	1.706	-0.706
Std Dev	0.068	5.518	2.767	0.189	0.189

Group F (≥7.49) Increased pH & Decreased pCO_2 (21 to <30) - 10 cases					
Mean	0.875	-3.962	-3.439	1.336	-0.336
Std Dev	0.032	1.077	0.788	0.071	0.071
Group F: (≥7.49) Increased pH & Decreased pCO_2 (30 - 34) - 8 cases					
Mean	0.934	-1.859	-1.732	1.183	-0.183
Std Dev	0.012	0.404	0.356	0.038	0.038
Group III (Metabolic acidosis**: Total** 47 cases) **- 31 cases with decreased pCO_2**					
Group III: Decreased pH & decreased pCO_2 (≤20) - 6 cases					
Mean	0.674	-6.677	-4.473	1.599	-0.599
Std Dev	0.048	1.059	0.576	0.121	0.121
Group III: Decreased pH & decreased pCO_2 (21 <30) - 15 cases					
Mean	0.838	-3.041	-2.514	1.306	-0.306
Std Dev	0.039	0.964	0.686	0.082	0.082
Group III: Decreased pH & decreased pCO_2(30 -34) - 7 cases					
Mean	0.901	-1.757	-1.578	1.163	-0.163
Std Dev	0.018	0.420	0.357	0.020	0.020
Group III: Normal pH & decreased pCO_2 - 3 cases					
Mean	0.882	-2.580	-2.210	1.174	-0.174
Std Dev	0.062	1.580	1.177	0.109	0.109
Group II {Missellaneous **IIC**} Normal pH, Decreased pCO_2 & Decreased HCO_3 - 28 cases					
Mean	0.876	-3.053	-2.589	1.232	-0.232
Std Dev	0.054	1.698	1.144	0.101	0.101

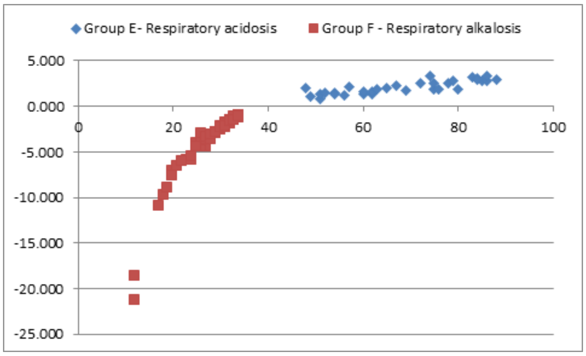

FIGURE 1: Ratio 2 for Respiratory acid base disorders (X: axis pCO_2 VS Y: axis Ratio 2)

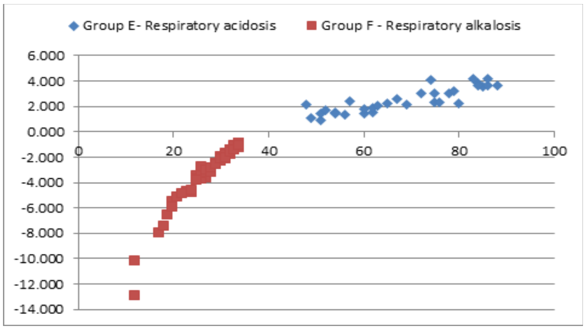

FIGURE 2: Ratio 3 for Respiratory acid base disorders (X: axis pCO_2 VS Y: axis Ratio 3)

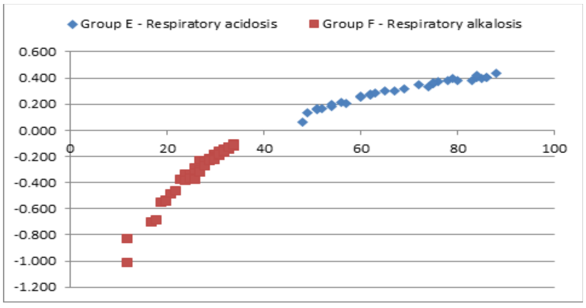

FIGURE 3: 1- {[NRH$^+$]/ [H$^+$]} values for Respiratory acid base disorders (X: axis pCO_2 VS Y: axis 1- {[NRH$^+$]/ [H$^+$]}

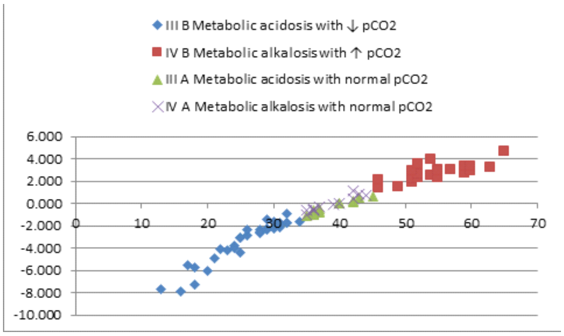

FIGURE 4: Ratio 2 for Metabolic acid base disorders (X: axis pCO2 VS Y: axis Ratio 2)

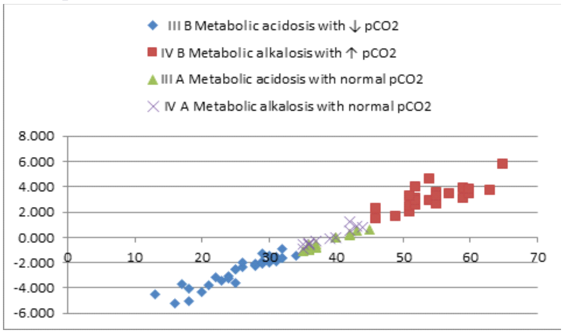

FIGURE 5: Ratio 3 for Metabolic acid base disorders (X: axis pCO2 VS Y: axis Ratio 3)

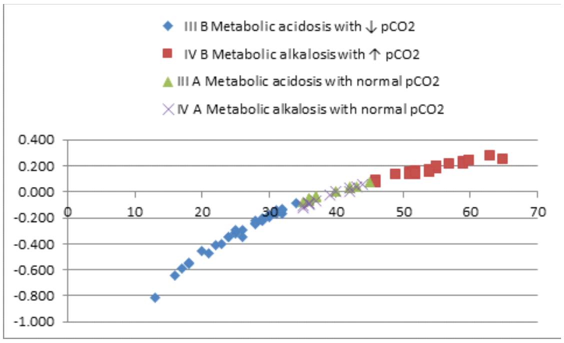

FIGURE 6: 1- {[NRH+]/ [H+]} values for Metabolic acid base disorders (X: axis pCO2 VS Y: axis 1- {[NRH+]/ [H+]}

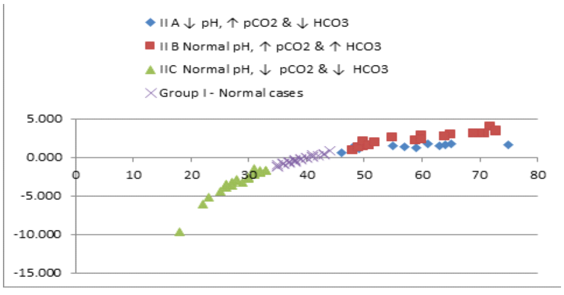

FIGURE 7: Ratio 2 for Normal and Missellaneous cases (X: axis pCO2 VS Y: axis Ratio 2)

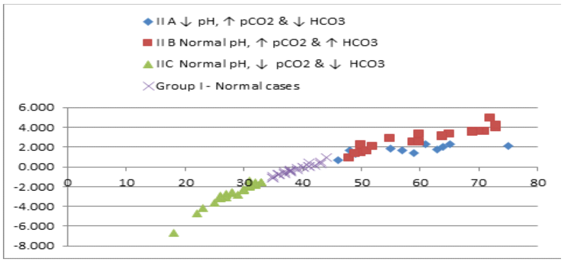

FIGURE 8: Ratio 3 for Normal and Missellaneous cases (X: axis pCO2 VS Y: axis Ratio 3)

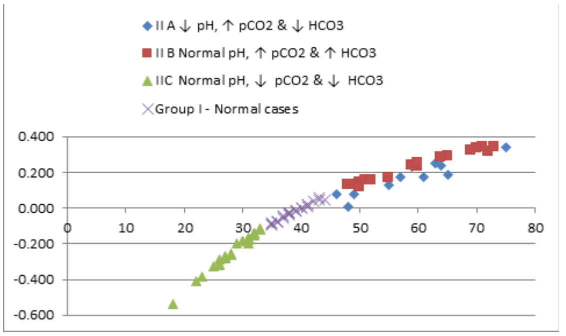

FIGURE 9: 1- {[NRH+]/ [H+]} values for Normal and Missellaneous cases
(X: axis pCO2 VS Y: axis 1- {[NRH+]/ [H+]})

DISCUSSION:

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.[4] 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.[4,5]

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.[6]

The ratio **[NRH^+/H^+]** is directly proportional to the parameter **ΔRpH (pH - NRpH)** which denotes the respiratory influence of pCO_2. The respiratory influence of pCO_2 in changing pH **through bicarbonate** is a variable one (**ratio HCO_3/ Std HCO_3**) depending on the **acute or chronic conditions** or compensations.[6,7] The parameter **1- {[NRH^+]/ [H^+]}** is positive for respiratory acidosis and negative for respiratory alkalosis **similar** to the **ratios 2** and **3**.[6]

The relation between **pCO_2** and the **ratio 2 (HCO_3 - Std HCO_3) / H_2CO_3** is shown for the various acid base disorders in the **figures 1, 4** and **7**. At pCO_2 40 mmHg, both the bicarbonate and standard bicarbonate values are equal and so the difference is zero. Ratio 2 values are negative for pCO_2 lesser than 40 mmHg and positive for pCO_2 greater than 40 mmHg. As the pCO_2 increases, the ratio 2 also increases and afterwards the curve flattens. The **flattening** of the curve is **more prominent** for the **respiratory acidosis** and **missellaneous** cases with **increased pCO_2** values. But this **flattening** is **reduced** and the curve is slightly steeper **if ratio 3** is utiltized by multiplying ratio 2 with ratio 1 (bicarbonate/standard bicarbonate ratio) which is clearly shown in the **figures 2, 5** and **8**.The **figures 3, 6** and **9** clearly shows the relationship between **pCO_2** and **1- {[NRH^+]/ [H^+]}** for the various acid-base disorders.

In the current research study, the relationship between pCO_2, ratio 1(HCO_3/ Std HCO_3), ratio 2{(HCO_3 - Std HCO_3) / H_2CO_3}, ratio 3 (ratio 1 X ratio 2) and 1- {[NRH^+]/ [H^+]} parameters were analysed and tabulated for the various acid-base disorders . Normal cases, metabolic acid base disorder cases with **normal pCO_2** are shown in the **table 2**. The values for the acid base disorder cases with **increased pCO_2** and acid base disorder cases with **decreased pCO_2** are shown in the **tables 3** and **4** respectively.

In **purely metabolic acid-base disorder** (without respiratory compensation) the bicarbonate and standard bicarbonate values **do not deviate** and the values are more or less similar. But if it is **compensated by respiratory** mechanisms, then the two **values deviate** from each other. These newly derived ratios not only render some clues that may help in discriminating various acid base disorders but also utilized for a newly developed recently published four quadrant graphical method for ABG interpretation.

CONCLUSION:

The study concludes that application of the relationship of these ratios derived using bicarbonate and standard bicarbonate values in various acid base disorders provide a better understanding for the interpretation of arterial blood gas reports and may serve as a supporting tool for teaching purposes.

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