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METABOLIC COMPONENTS OF ACID BASE DISORDER IN ABG INTERPRETATION

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ABSTRACT The understanding of the different metabolic components involved in arterial blood gas (ABG) interpretation is difficult yet it plays a significant role in identifying, classifying and analysing the metabolic acid base disorders which may help in prompt treatment resulting in saving the life of the patients. The present study summarizes the relationship and the clinical significance of the various metabolic parameters like bicarbonate, standard base excess, strong ion difference and non-respiratory hydrogen ion concentration in the understanding of the metabolic acid base disorders.

KEYWORDS : Arterial Blood Gas Interpretation, Metabolic Component

INTRODUCTION:

The physiological approach using bicarbonate is the most commonly used metabolic component for Arterial Blood Gas (ABG) interpretation. This method is based on the bicarbonate-carbon dioxide buffer system which is very simple and easy but it does not quantify the metabolic component (non-respiratory) component and also it does not provide sufficient explanation for the causes of metabolic acid-base disturbances.[1,2] Base excess approach was applied to quantify the metabolic component but it represents the whole blood and so standard base excess or extracellular base excess was developed to represent the whole body behaviour(in-vivo base excess) which is the base excess at haemoglobin concentration of 5g/dl.[1,2,3] Stewart's physicochemical approach is used to understand complex acid base disorders. Strong ion difference and total concentration of dissociated weak acids (A^- or A^-_{tot}) are the metabolic components utilized in this approach that provides causative mechanism for the metabolic acid base disorders.[3,4,5]

The bicarbonate parameter is calculated from Modified Henderson equation. The bicarbonate concentration is changed by values of pCO_2 and this problem is solved by standard bicarbonate.[6] The hydrogen ion concentration calculated using standard bicarbonate denotes the 'Non-respiratory hydrogen ion concentration'(NRH).[6,7] In Arterial blood gas (ABG) interpretation various metabolic components are used to identify, classify and analyse the metabolic acid base disturbances. The present study summarizes the relationship and the clinical significance of the various metabolic parameters applied for the understanding of metabolic acid base disorders.

MATERIALS AND METHODS:

The delta ratio and delta gap are calculated using the following formulas which helps in diagnosis of mixed acid base disorders.[8-11]

Delta Ratio:

delta ratio = $\Delta\mathbf{AG}/\Delta\mathbf{HCO_3^-}$

$\Delta\mathbf{AG}$ = Calculated Anion Gap - Normal Anion Gap

$\Delta\mathbf{HCO_3^-} = \mathbf{24} - \Delta\mathbf{HCO_3^-}$

Delta Gap:

$\Delta AG/\Delta HCO_3^-$ = Delta Gap or Bicarbonate Gap

$\Delta AG + \text{Measured } HCO_3^- = 24$

Strong Ion Difference:

The difference between sum of the strong cations and strong anions is called **apparent strong ion difference (SIDa)**. [3,4,5,12]

SIDa = [sum of the strong cations] - [sum of the strong anions]

SIDa = $\{Na^+ + k^+\} - \{Cl^-\}$

Usually sodium, potassium and chloride are considered for calculation for strong ion difference because calcium, magnesium and lactate are not routinely measured. Sodium and chloride are the main strong ions. [3,4,5,12]

Main strong ion difference SIDm = $\{Na^+\} - \{Cl^-\}$

Buffer base **($[HCO_3^-] + [A^-]$)** is the **effective strong ion difference[SID_e].** $[A^-]$ or $[A^-tot]$ denotes the total concentration of dissociated non-volatile weak acids namely albumin (Alb) and phosphate (Pi). [3,4,5,12] The electric charge on albumin and inorganic phosphate are calculated by the given below equations. [3,5,12,13,14]

$[Alb^-] = [\text{Alb g/L}] \times (0.123 * pH - 0.631)\ \text{mEq/L}$

$[Pi^-] = [\text{Pi mmol/L}] \times (0.309 * pH - 0.469)\ \text{mmol/L}.$

$\mathbf{[A^-]\ or\ [A^-tot] = [Alb^-] + [Pi^-]}$

$\mathbf{SIDe = [HCO_3^-] + [Alb^-] + [Pi^-]}$

Strong Ion Gap (SIG):

SIG = SIDa - SIDe

$SIG = SIDa - HCO_3^- - A^-tot$

$\mathbf{HCO_3 = SIDa - A^-tot - SIG}$

Calculation of Anion Gap:

Anion gap = measured cations - measured anions OR

Anion gap = unmeasured anions - unmeasured cations

As the unmeasured anions increases, the anion gap increases. Based on the law of electrical neutrality, anion gap calculation is done. [5] If sodium, potassium, chloride and bicarbonate are considered for calculation then anion gap is calculated as follows. [5]

Anion gap (AG) = $\{Na^+ + k^+\} - \{Cl^- + HCO_3^-\}$

Strong ion gap (SIG) = $SIDa - HCO_3^- - A^-tot$

If SIDa = $\{Na^+ + k^+\} - \{Cl^-\}$

$SIG = \{Na^+ + k^+\} - \{Cl^-\} - HCO_3^- - A^-tot$
$SIG = AG - A^-tot$; **$AG = SIG + A^-tot$**

If sodium, chloride and bicarbonate are considered for calculation then anion gap is calculated as follows. [5]

Anion gap = $\{Na^+\} - \{Cl^- + HCO_3^-\}$
Strong ion gap (SIG) = $SIDa - HCO_3^- - A^-tot$
$SIDa = \{Na^+\} - \{Cl^-\}$ (if only main strong ions are included)
$SIG = \{Na^+\} - \{Cl^-\} - HCO_3^- - A^-tot$
$SIG = AG - A^-tot$ or **$AG = SIG + A^-tot$**

The above relationship between anion gap and strong ion gap will be valid only if that particular ions are considered for calculation and if some other ions (eg calcium, magnesium and lactate) are added for calculation then their relationship has to be adjusted.It is very clear that the anion gap value will be affected by the total concentration of dissociated non-volatile weak acids ($[A^-]$ or $[A^-tot]$) namely albumin (Alb) and phosphate (Pi). So the anion gap has to corrected (mainly for albumin) which is given below. [2,5,14]

Albumin corrected anion gap = anion gap + 0.25 *(44 – observed albumin g/L)

Fencl-Stewart approach (Semi-quantitative approach):
It calculates the effects of the individual ions on the base excess. The **semi-quantitative estimation** of **unmeasured ions** is the difference between base excess and the sum of effects of individual ions on the base excess.[1,2,5,8,13 & 14]

Individual ion effects on Base Excess:
Water effect or sodium effect = 0.3 X ($[Na^+]$ -140) mEq/L or mmol/L
Chloride effect = 102 - $\{[Cl^-]$ X (140 / $[Na^+])\}$ mEq/L
Albumin effect = [42 - albumin g/L] X (0.123×pH - 0.631) mEq/L
Phosphate effect = (1.15 - Pi) X (0.309×pH - 0.469) mmol/L.
Lactate effect = -1 X lactate mmol/L

unmeasured ions effect = SBE© - {SID Effect + non-volatile weak acid effect }

The unmeasured ions effect on base excess is estimated by subtracting the strong ion difference effect (sodium-chloride effect which includes both water and chloride effects) and the weak non-volatile acid effect (albumin and phosphate) from the corrected standard base excess SBE© value (correction done for albumin and phosphate). If lactate is not measured then it is included under unmeasured ions effect.[5]

Calculation of NRH^+ (Non-Respiratory hydrogen ion concentration):
$NRH^+ = 960 / Std\ HCO3$
$NRpH = 9 - \log [NRH^+]$

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]

Non-Respiratory Hydrogen ion and Stewart's parameters:
$SIDa - (A^-tot + SIG) = \{960 / NRH^+\}$ X HCO_3/ Std HCO_3
From the above equation it is very clear that Strong ion difference (SIDa) is inversely proportional but the total concentration of dissociated weak acids (A^- or A^-_{tot}) and the Strong ion gap (SIG) is directly proportional to the non-respiratory hydrogen ion concentration(NRH^+).[15,16]

DISCUSSION:
The bicarbonate concentration is a variable one and so it may not indicate the true metabolic status but it serves as a marker for metabolic acid base disorders. [6,7] Metabolic acidosis is classified into normal anion gap and high anion gap metabolic acidosis.The anion gap denotes the unmeasured anions. If a metabolic acid(HA) is added to extracellular fluid(ECF), it dissociates into H^+ and organic anion(A^-). H^+ reacts with a molecule of bicarbonate to form carbonic acid and unmeasured organic anion(A^-) will accumulate to increase anion gap. The changes in anion gap due to accumulation of unmeasured organic anion should be equal to the decrease in HCO_3^-.The difference between the patients anion gap and the normal anion gap is termed as the delta anion gap. [17,18] The ratio between delta anion gap and change in bicarbonate denote the delta ratio. For every unit increase in the anion gap, the bicarbonate should decrease by one unit.Thus if the calculated delta anion gap is added to the measured HCO_3^-, the result should be in the normal level for HCO_3^- and if the levels are elevated then it indicates the additional presence of metabolic alkalosis denoting mixed acid base disorder.[17,18]

The organic anion(A^-) cannot be transported easily through the cell membrane but these hydrogen ions are also buffered by intracellular protein and not only by HCO_3^-.So the change in anion gap will not be equal to the change in bicarbonate.In pure metabolic acidosis, the change in bicarbonate concentration is lesser than the anion gap, and delta ratio is between 1 & 2. A delta ratio above 2 indicates lesser fall in bicarbonate level and it may suggests a concurrent metabolic alkalosis or pre-existing high HCO_3^- levels due to chronic respiratory acidosis.[18]

Sodium and chloride ions provide major contribution to the strong ion difference. Their concentration can be changed by dehydration (concentrating) and over-hydration(diluting) which influences the strong ion difference.The dilution or concentration effects of changes by water can be identified by the deviations of plasma sodium level from a given standard value and the dilution effect of water on chloride has to be corrected using these sodium levels. The sodium-chloride effect which includes both water and chloride effects will provide the Fencl–Stewart estimate of the strong ion difference effect on base excess. [1-5, 12-15]

The effect of albumin on base excess is due to the anionic effect of albumin. A pH-dependent formula to calculate the anionic effect of albumin (electric charge on albumin) was developed by Figge and their colleagues. Changes in the concentration of albumin will cause changes in the anionic effect of albumin which in turn will change the base excess. [1-5, 12-15] As the albumin concentration is decreased the blood becomes more alkaline. Similarly, the effect of phosphate on base excess is due to the anionic effect of phosphate (electric charge on inorganic phosphate). The weak non-volatile acid effect is mainly contributed by albumin. The base excess is directly affected by the changes in strong ion difference effect and inversely affected by the changes in non-volatile weak acid concentration(albumin and phosphate) [1-5, 12-15]

The strong ion difference value is influenced by the ratio (HCO_3/ Std HCO_3) which varies with pCO_2 values. Strong ion difference is inversely proportional and the total concentration of dissociated weak acids (A^-or A^-tot) is directly proportional to the non-respiratory hydrogen ion concentration. Higher non-respiratory hydrogen ion concentration indicate metabolic acidosis and lower non-respiratory hydrogen ion concentration indicate metabolic alkalosis.[15,16]

Decreased strong ion difference and elevated unmeasured ions will result in low bicarbonate value indicating metabolic acidosis. High bicarbonate value can occur with higher strong ion difference that indicates metabolic alkalosis. The increased presence of unmeasured ions will not be clearly noticed if the concentration of dissociated weak acid (A^-tot) is very low, because sum of the parameters (A^-tot + SIG) will not change and so the bicarbonate value will be normal. The

presence of unmeasured ions is masked due to the alkalizing effect of decreased A'tot. The Strong ion gap or the albumin corrected anion gap will help to identify it. [5,15,16] The metabolic component non-respiratory pH(**NRpH**) directly correlates with the standard base excess parameter. Non-respiratory pH **(NRpH)** is decreased in Metabolic acidosis and increased in Metabolic alkalosis. The value of **ΔNRpH** (**NRpH -7.4**) is more negative for metabolic acidosis and more positive for metabolic alkalosis.[7,16]

CONCLUSION:

The understanding of the different metabolic components and its relationship plays an important role in decision making for critically ill patients because each of the various metabolic components involved in arterial blood gas interpretation has its own clinical significance to be applied at the bedside depending on the various types of clinical conditions.

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