Different Interpretation Approaches To Acid Base Disturbances

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Mohamad Atef Radwan  Different Interpretation Approaches To Acid Base Disturbances
"If anyone killed a person not in retaliation of murder, or (and) to spread mischief in the land - it would be as if he killed all mankind, and if anyone saved a life, it would be as if he saved the life of all mankind"

Al-Maidah-32
Objectives

- Understanding basic concept of pH, and Hydrogen ion activity.
- Understanding different definitions of acidosis, alkalosis.
- Development of traditional approach using combination of Henderson-Haselblach equation, the base excess and its clinical application.
- Development of Stewart approach, its mathematical concept and its clinical application.
- Unification of acid-base physiology.
Introduction

- The body produces more acids than bases (food, protein, lipid metabolism,...).
- It's critical to keep hydrogen ion concentration in a certain range.
- Management of Acid-base disorders begins with accurate diagnosis.
- Main organs responsible for controlling hydrogen ion concentration are lungs, kidney, GIT, liver.
Traditional Approach

- Boston School “Henderson-Hasselbalch”
- Copenhagen School “Base Excess”

**Acid And Base**

- **Acid**: Proton donor
- **Base**: Proton acceptor
- **pH**: Negative logarithm of hydrogen ion concentration
Henderson-Hasselbalch equation

\[ pH = 6.1 + \log_{10} \frac{[HCO_3^-]}{0.03 \times PaCO_2} \]

Described six primary states of acid-base imbalance

- Chronic/Acute respiratory acidosis
- Chronic/Acute respiratory alkalosis
- Metabolic Acidosis
- Metabolic Alkalosis
Winters Rules

- Rules established interrelationships among the degree of primary reduction of the metabolic component
- The clinical question the rules are designed to answer in this situation is, “whether the patients respiratory compensation is within the range to be expected or whether there is an additional component of respiratory disturbance, too”

Winter Equation

\[ PCO2 = 1.54 \times [HCO_3^-] + 8 \pm 2 \]


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The term anion gap (AG) represents the concentration of all the unmeasured anions in the plasma.

\[ \text{Na}^+ - (\text{Cl}^- + \text{HCO}_3^-) = \text{UA} - \text{UC} = \text{Anion Gap} \]

- Value: 10 to 12 mEq/L
- Help differentiate between causes of a metabolic acidosis: high anion gap versus normal anion gap.
Acid-base disorders are classified as being of respiratory origin (primary change in PaCO2) or of metabolic origin (primary change in fixed acids). Some basic questions to be answered by any approach are:

- How can the magnitude of a respiratory disorder be determined?
- How can the magnitude of a metabolic disorder be determined?
Henderson persuaded his friend Van Slyke to place his equation on quantitative footing.

Van Slyke realized that the plot of $\log \text{PaCO}_2$ Vs Plasma pH was Linear.

By adding known amount of acid or base and reading value of pH vs log PaCO2, A line of "non respiratory pH" could be obtained which was known as "base excess".
Siggaard-Andersen Nomogram

1960, Ole Siggard Anderson, a 25-year-old rotating intern, helped to produce an alignment nomogram relating PaCO2 and pH to base excess.

- Point A: measured pH at high PaCO2
- Point B: measured pH at low PaCO2
- Point F: actual pH of the anaerobically drawn blood and allows the calculation of the actual PaCO2.
- Point C: the BE “Base Excess”
- Point D: the Buffer Base
**Definition**

The miliequivalents of strong acid or bases that is needed to titrate one liters (in vitro) of blood or plasma

- Has been equilibrated to PaCO2 = 40 mmHg
- At physiological pH of 7.4
- At temperature 37 C
- Full O2 saturation
By using the previous informations Siggard Anderson produced formula for calculating BE as re-expression of data and called it ”Van Slyke equation”

**BE**

$$\text{Base excess} = 0.93 \times ([\text{HCO}_3^-] - 24.4 + 14.8 \times (\text{pH} - 7.4))$$

**SBE**

$$SBE = 0.9287 \times (\text{HCO}_3^- - 24.4 + 14.83 \times ([\text{pH} - 7.4]))$$
Base excess using computing methods.

Interactive Acid-Base Diagram: PCO₂ vs. SBE

Instructions:
1. Drag the Mouse to Your Chosen pH and PCO₂: the diagram provides the corresponding text report.
2. Color change. The color of the spot changes: acid - red; alkaline - blue.
4. Other Zones: The gap between typical zones appear gray.
5. Numerical Values: As you move round in the graph, the boxes below show the corresponding values for Standard Base Excess, pH, and the components of the Modified Henderson Equation.
Algorithm

- Anticipate the acid base disturbance from the causes and history that may have effect.
- Check pH, PaCO2, HCO3, If one of these are abnormal:
  - Check pH
    - If pH less than 7.4, the primary disorder is acidosis
    - If pH more than or equal 7.4, The primary disorder is alkalosis
  - Metabolic Or Respiratory
    - If HCO3⁻ is responsible for changing the pH, the cause is Metabolic
    - If PaCO2 is responsible for changing pH, the cause is Respiratory
Check pH acceptance (pH range from 7.3 to 7.5):
- In respiratory disorder
  - If pH is accepted, it is chronic respiratory disorder
  - If pH is Unaccepted, it is acute respiratory disorder
- In metabolic disorder
  - Accepted pH, indicates compensated metabolic disorder
  - Unaccepted pH, without change in PaCO2 indicates uncompensated metabolic disorder
  - Unaccepted pH, with change in PaCO2 indicates partially compensated metabolic disorder

Check appropriateness using winter rules (for diagnosis of Mixed disorder)

Further analysis for specific disorders:

- In Metabolic acidosis, calculate Anion Gap
- In metabolic alkalosis, check chloride in urine.
What is the role of bicarbonate in acid-base balance?

The answer is simply:

None!
Stewart Approach

- Quantitative analysis of pH deviation
- How much each element of acid base controller substances will affect pH deviation

Variables

- Independent variables (PaCO2, SID, A\textsubscript{TOT})
- Dependent variables (pH, H, HCO3\textsuperscript{−},......)
Mathematical Concept Of Stewart Approach

The Simplest Acid-Base System: Pure water

\[ [H_2O] \rightleftharpoons H^+ + OH^- \]

\[ [H^+] \times [OH^-] = K_W \times [H_2O] \]

As \( K_W \) is highly temperature dependent and very small

\[ K'_W = K_W \times [H_2O] \]

\[ [H^+] \times [OH] = K'_W \]

\[ H^+ - OH^- = 0 \]

\[ H^+ = OH^- \]
Mathematical Concept Of Stewart Approach

Cont.

\[ [H^+] \times [H^+] = K'_W \]

\[ [H^+] = \sqrt{K'_W} \]

\[ [OH^-] = \sqrt{K'_W} \]

The following definitions were introduced:

1. Solution is acid-base neutral if the hydrogen ion concentration is equal to the square root of the \( K'_W \).
2. A solution is acidic if \([H^+]>\sqrt{(K'_W)}\)
3. A solution is basic if \([H^+]<\sqrt{(K'_W)}\)
Adding specified amount of NaCl to Water [H2O], so solution will only contain Na\(^+\), Cl\(^-\), H\(^+\) And OH\(^-\)

By application of electrical neutrality:

\[ Na^+ - Cl^- + H^+ - OH^- = 0 \]

\[ [H] \times [OH^-] = K'_W \]

By substitution of OH\(^-\) by \([K'_W]/[H]\)

\[ H^+ - (K'_W/H^+) + Na^+ - Cl^- = 0 \]

By multiplying the previous equation by H\(^+\) and rearrangement

\[ [H^+]^2 + [H^+][Na^+] - [Cl^-] - K'_W = 0 \]
ax^2 + bx + c = 0

The quadratic equation can be solved as

\[ [H^+] = \frac{-([Na^+]-[Cl^-])}{2} + \sqrt{\left(\frac{([Na^+]-[Cl^-])^2}{4} + K'_W\right)} \]

And by application to OH^-

\[ [OH^-] = \sqrt{\left(K'_W + SID^2/4\right)} - SID/2 \]
Reproduced from original Stewart textbook using JAVA programming language and Gnuplot
Strong Ion Difference

"The sum of all strong base cation concentration minus the sum of all strong anion concentration, all expressed in equivalents per Liter."

\[ SID = (\sum \text{StrongBaseCation}) - (\sum \text{StrongAcidAnions}) \]

Sodium minus Chloride = 40-42
What is really happening ???

- Adding HCL to water ??
  - Traditionally: $\text{H}^+$ ion was added .., so solution became more acidic.
  - Stewart: $\text{Cl}^-$ was added, SID decreased, so solution became more acidic.

Why !!
Adding Weak Acid

Weak electrolytes

Substance that partially dissociate when dissolved in water, i.e. the molecules of parent substance as well as the product of dissociation will exist.

Weak acid solution contains molecular species [HA] and [A\(^-\)].
Weak acid dissociation

\[ HA \rightleftharpoons H^+ + A^- \]

Water dissociation

\[ [H^+] \times [OH^-] = K'_W \]

Weak acid dissociation

\[ [H^+] \times [A^-] = K_A \times [HA] \]

Weak acid conversion

\[ [HA] + [A^-] = [ATOT] \]

For achieving electrical neutrality

\[ [H^+] + [OH^-] + [SID] + [A^-] = 0 \]
Cubic equation like

\[ f(x) = ax^3 + bx^2 + cx + d \]

\[ [H+]^3 + K_A + [SID] \times [H^+]^2 + K_A \]

\[ \times ([SID] - [A_{TOT}]) - K'_W \times [H^+] - K_A \times K'_W = 0 \]
pH VS SID plus $A_{TOT}$

With Weak Acid $A_{tot} = 0.02 \text{ Eq/l}, K_A = 2e-7$

No weak Acid $A_{tot} = 0$

Reproduced from original Stewart textbook using JAVA programming language and Gnuplot
pH VS SID plus A_{TOT}

With Weak Acid Atot = 0.02 Eq/l, KA = 2e-7
No weak Acid Atot=0

Reproduced from original Stewart textbook using JAVA programming language and Gnuplot
[SID] + [H⁺] − [OH⁻] − [HCO₃⁻] − [CO₃²⁻] = 0

by substituting and clearing, cubic equation like syntax will be produced

\[ H^3 + [SID] \times H^2 - (K_C \times P_C + K'_W) \times H - K_3 \times K_C \times P_C = 0 \]
Reproduced from original Stewart textbook using JAVA programming language and Gnuplot

PCO2 VS HCO3 & SID = 0.031
SID + $A_{TOT} + CO_2$

\[ SID + H^+ + HCO_3^- - A^- - CO_3^{2-} - OH^- = 0 \]

\[ H^4 + K_A + SID \times H^3 + K_A \times (SID) - A_{TOT} \]
\[- (K_C \times P_C + K_W') \times H^2 - K_A \times (K_C \times P_C + K_W' + K_3 \times K_C \times P_C + H - K_A \times K_3 \times K_C \times P_C = 0 \]

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Acid-base Balance:
is set of mechanisms by which parts of the body, notably lungs, kidneys, and gastrointestinal track, control the composition of circulating blood plasma, so its $H^+$ lies generally within range from $2 \times 10^{-7}$ to $1 \times 10^{-7}$ Eq/L or pH 7.7 to 7.0

Regulators
- Lung
- Kidney
- GIT
Lungs

$\text{CO}_2$ regulator
Alveolar ventilation could be changes in seconds.

Elevation of CO$_2$ level lead to elevation of H$^+$ value ”Respiratory Acidosis”.

Decrease of CO$_2$ level lead to decrease of H$^+$ value ”Respiratory Alkalosis”.

Sustained change in CO$_2$ level leads to change of S$D$ Value. Role which is played by the kidneys.
Kidney

\[ \text{SID} = (\text{Na}^+ + \text{K}^+) - \text{Cl}^- \]

1. Circulating plasma is perfusing the kidneys at an average rate of about 500 mL/min.
2. Every Cl\(^-\) filtered but not reabsorbed means corresponding increase in plasma SID.
3. Every Na\(^+\) or K\(^+\) not reabsorbed means a decrease in plasma SID.
Kidney

\[ \text{SID} = (\text{Na}^+ + \text{K}^+) - \text{Cl}^- \]

### Sustained change of PaCO$_2$ level

1. **Acute Respiratory Acidosis** = PaCO$_2$ up briefly, so plasma $H^+$ is up
2. **Acute Respiratory Alkalosis** = PaCO$_2$ down briefly, so plasma $H^+$ is down
3. **Chronic Respiratory Acidosis** = PaCO$_2$ up "sustained", SID up, $H^+$ up slightly
4. **Chronic Respiratory Alkalosis** = PaCO$_2$ down "sustained", SID down, $H^+$ down slightly
Cl\(^-\) is removed from the plasma circulating through the gastric mucosa and secreting into the lumen as gastric acid.

SID in the plasma is increasing (Na\(^+\)-Cl\(^-\)).

that effect on total circulating plasma is small, but detectable, the classic name for this phenomena is (Alkaline tide).

**Disturbance:**

- transferred Cl\(^-\) is lost from body and never returned to plasma.
- Plasma SID is elevated.
- Decrease of H\(^+\) ”Rise in pH”.
Figge and Fencl concentrated in their work on major species of weak acid and their conjugate base.

**Weak acids**
- phosphoric acid (phosphate system)
- Citric acid (citrate system)
- Dissociatable amino acid side chain of albumin

**Fencl Model**
\[
pH = f_{(pH)}\{SID, PCO_2, [Pi_{TOT}], [Albumin], [Citrate_{TOT}]\}
\]
Diagnosis of Metabolic Acid–Base Disturbances in Critically Ill Patients

VLADIMIR FENCL, ANTONÍN JABOR, ANTONÍN KAZDA, and JAMES FIGGE

Division of Pulmonary and Critical Care Medicine, Brigham and Women’s Hospital, and Departments of Medicine, Brigham and Women’s Hospital and Harvard Medical School, Boston, Massachusetts; Departments of Clinical Biochemistry, Hospital Kladno and Postgraduate Medical School, Prague, Czech Republic; Departments of Medicine, St. Peter’s Hospital, and Biomedical Sciences, State University of New York, Albany, New York

Important values to be calculated

SID And $A_{TOT}$
Albumin & Phosphorus participation:

\[
[Alb] = [Alb] \times (0.123 \times pH - 0.631)
\]

\[
[Pi] = [Pi] \times (0.309 \times pH - 0.469)
\]

New SID : SIDe

\[
SID = [HCO_3^-] + [Alb] + [Pi]
\]
Electrical neutrality

\[ \text{Na}^+ + \text{K}^+ + \text{Ca}^{+2} + \text{Mg}^{+2} = \text{HCO}_3^- + \text{Alb}^- + \text{Pi}^- + \text{Cl}^- + \text{XA}^- \]

**SIDa**

\[ \text{SIDa} = \text{Na}^+ + \text{K}^+ + \text{Ca}^{+2} + \text{Mg}^{+2} - \text{Cl}^- \]

**XA^-**

\[ \text{XA}^- = \text{SIDa} - \text{SIDe} = \text{SIG} \]
# Classification of disturbances

Mohamad Atef Radwan

## TABLE 1

<table>
<thead>
<tr>
<th></th>
<th>Acidosis</th>
<th>Alkalosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Respiratory</td>
<td>↑ Pco₂</td>
<td>↓ Pco₂</td>
</tr>
<tr>
<td>II. Nonrespiratory (metabolic)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Abnormal SID</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Water excess/deficit*</td>
<td>↓ SID, ↓ [Na⁺]</td>
<td>↑ SID, ↑ Na⁺</td>
</tr>
<tr>
<td>b. Imbalance of strong anions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>i. Chloride excess/ deficit†</td>
<td>↓ SID, ↑ [Cl⁻]</td>
<td>↑ SID, ↓ [Cl⁻]</td>
</tr>
<tr>
<td>ii. Unidentified anion excess‡</td>
<td>↓ SID, ↑ [XA⁻]</td>
<td>—</td>
</tr>
<tr>
<td>2. Nonvolatile weak acids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Serum albumin</td>
<td>↑ [Alb]§</td>
<td>↓ [Alb]</td>
</tr>
<tr>
<td>b. Inorganic phosphate</td>
<td>↑ [Pi]</td>
<td>↓ [Pi]</td>
</tr>
</tbody>
</table>

Algorithm

- Check history for detecting expected acid base deviation
- The following data are required for interpretation
  \[ \text{Na}^+, \text{Cl}^-, \text{K}^+, \text{Albumin}, \text{PCO}_2 \]
- Calculate corrected chloride "Corrected Cl" for assessment of volume status incorporation in acid base status
  \[ \text{Corrected Cl} = \text{Observed Cl} \times (\text{Normal Na}^+ / \text{Observed Na}^+) \]
- Calculate apparent SID "SIDa"
  \[ \text{SIDa} = (\text{Na}^+ + \text{K}^+ + 6) - \text{Cl}^- \]
  \[ (6) = \text{value for presentation of Ca}^{+2} \text{ and Mg}^{+2} \text{ value } \text{"provided they are normal"} \]
Calculated effective SID "SIDe"

\[ \text{SIDe} = \text{HCO}_3^- + 2.8 \times \text{Albumin in g/dL} + 2 \]

(2) in SIDe equation for substitution of phosphorus [Pi] value as it not routinely measured

\( \text{HCO}_3^- \) usually measured by arterial blood gas machine or it could be calculated using Hasselbalch equation

Calculate strong ion gap (SIG) or effect exerted by unknown anions "XA−"

\[ \text{SIG} = \text{XA}^- \text{ effect } = \text{SIDa} - \text{SIDe} \]

Make comparison for calculated data to its reference range
Stewart application using computing method

Available now: Stewart's Textbook of Acid-Base

If you have ever been confused by traditional acid-base teaching and/or want a deeper and practical understanding of the subject, this is the book for you! You will be rewarded!

What is the role of bicarbonate (HCO₃⁻) in acid-base balance? The answer is simply: none!

What then determines pH or [H⁺] in body fluids? Understanding acid-base balance means having clear answers to this question, and the quantitative analysis in this book supplies them. They are astonishingly simple! — Peter A. Stewart

Stewart's Textbook of Acid-Base
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• Front and back cover
• Table of contents
• List of authors
• Why and how to read
• Foreword by Prof. Gattinoni
• Preface
• Chapter 5
• Chapter 10
• Chapter 19
• Chapter 25
• Chapter 29
• Afterword by Prof. Story
Stewart application using computing method

acidbase analysis and database

required data

<table>
<thead>
<tr>
<th>pH</th>
<th>mmol/l</th>
<th>Mg</th>
<th>mmol/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE (base excess)</td>
<td>mEq/l</td>
<td>Ca (total, not ionized)</td>
<td>mmol/l</td>
</tr>
<tr>
<td>Na</td>
<td>mmol/l</td>
<td>phosphate</td>
<td>mmol/l</td>
</tr>
<tr>
<td>K</td>
<td>mmol/l</td>
<td>lactate</td>
<td>mmol/l</td>
</tr>
<tr>
<td>Cl</td>
<td>mmol/l</td>
<td>haemoglobin</td>
<td>mmol/l</td>
</tr>
<tr>
<td>PCO2</td>
<td>kPa</td>
<td>osmolality (freezing point method)</td>
<td>mosmol/l</td>
</tr>
<tr>
<td>albumin</td>
<td>g/l</td>
<td>glucose</td>
<td>mmol/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td>urea</td>
<td>mmol/l</td>
</tr>
</tbody>
</table>

Different Interpretation Approaches To Acid Base Disturbances
Stewart application using computing method

<table>
<thead>
<tr>
<th>SID&lt;sub&gt;apparent&lt;/sub&gt;</th>
<th>27.3 mEq/l</th>
<th>40 -- 46</th>
<th>a low apparent SID value - almost certainly due to high chloride values (Cl⁻ excess 12.3 mEq/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SID&lt;sub&gt;effective&lt;/sub&gt;</td>
<td>22.6 mEq/l</td>
<td>36 -- 40</td>
<td>a low effective SID value - at least partially (12.3 mEq/l) due to high chloride values</td>
</tr>
<tr>
<td>XA - unknown anions</td>
<td>4.7 mEq/l</td>
<td>2 -- 8</td>
<td>a normal value for unknown anions, virtually excluding more than ~4 mEq/l of non-chloride metabolic acidosis</td>
</tr>
<tr>
<td>unmeasured ion excess</td>
<td>-3.1 mEq/l</td>
<td>-3 -- 3</td>
<td>the UIX points to slight unknown anion metabolic acidosis</td>
</tr>
</tbody>
</table>
### Summary Database Interpretation

**shifts in pH attributable to the various components**

Red indicates shift towards acidosis, blue towards alkalosis.

Based on calculating what the pH had been, if only the variable in question had been normal, while all the others were unchanged, they do not completely add up to the observed pH deviation, though, the relation is non-linear (logarithmic, of course).

Find out about our rules of interpretation.

<table>
<thead>
<tr>
<th>Component</th>
<th>Change</th>
<th>Value</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall shift for the measured pH (7.190)</td>
<td>-0.21</td>
<td>7.190</td>
<td>moderate acidosis</td>
</tr>
<tr>
<td>XA (unknown anions)</td>
<td>0.040</td>
<td></td>
<td>no significant derangement</td>
</tr>
<tr>
<td>Chloride (corrected for sodium abnormalities)</td>
<td>-0.375</td>
<td></td>
<td>severe hyperchloremic metabolic acidosis</td>
</tr>
<tr>
<td>Albumin</td>
<td>-0.025</td>
<td></td>
<td>no significant derangement</td>
</tr>
<tr>
<td>PCO₂</td>
<td>0.145</td>
<td>3.5 kPa</td>
<td>slight respiratory alkalosis</td>
</tr>
</tbody>
</table>
It was long way for achieving accurate interpretation of acid base disorders.

Story started since 100 year ago by **Handerson-Haselblach** Equation.

Later **Boston school** tried to classify different disorder as respiratory and metabolic.

**BE** approach concentrated on metabolic element, Introduced **BE** and **Buffer base definitions**.

80s, **Stewart** presented his radical theory for explaining disturbances.

For rapid interpretation traditional approach may be used, for more detailed interpretation quantitative approach could be used.
Different Interpretation Approaches To Acid Base Disturbances
Thank You!

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