Complex Acid Base Disturbances

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Objectives

• Utilize a systematic approach to evaluate acid-base disturbances
• Identify acid-base disturbances
• Identify/recognize the etiology of acid base disorders
• Apply rules of compensation
• Identify/recognize complex (mixed, secondary, tertiary) acid base disorders
ABG’s

pH

??

Base Excess

Acidosis

Anion Gap

Alkalosis

Henderson-Hasselbalch

Metabolic

PaC02

HC03-

Henderson-Hasselbalch

Respiratory

SID

Δ/Δ

Respiratory

Metabolic
Stepwise Analysis

1) Do History and Physical – look for acid-base clues
2) Verify that the lab values are consistent
3) Is pH low, normal or high?
4) Is the primary disturbance metabolic or respiratory? If both are abnormal, pick the one that seems most severe at first glance.
5) Is the disturbance acute or chronic; Have compensatory changes occurred?
6) For Metabolic Acidosis, what is the AG? This will help develop your list of differentials.
7) Is there a secondary or tertiary disturbance present?
H & P Clues

- Vomiting – Metabolic Alkalosis
- History of Diabetes – Metabolic Acidosis
- History of smoking / COPD – Respiratory Acidosis
- History of Liver Disease – Respiratory Alkalosis
- Recent binge drinking – Metabolic Acidosis
- Diarrhea – Metabolic Acidosis
- Tachypnea – Respiratory Alkalosis
- Hypotension – Metabolic Acidosis
• Verify Consistency of Lab Values
  \[ HC03 \text{ (ABG)} = C02 \text{ (venous electrolytes)} \pm 2 \]
• Evaluate the pH – Is it acidicotic (< 7.35), normal (7.35 – 7.45) or alkalotic (> 7.45)?
• Is the primary disturbance metabolic or respiratory? If both are abnormal, pick the one that is most severe at first glance.
Acidemia

- Low HC03 High PC02
  - Mixed metabolic acidosis and respiratory acidosis
- Low Hc03 Low PC02
  - Predominant Metabolic Acidosis
- High HC03 High PC02
  - Predominant Respiratory Acidosis
- High HC03 Low PC02
  - Not possible; likely lab error

Apply Compensation Rules

- Measured PC02 too high
  - Mixed metabolic acidosis and respiratory acidosis
- Measured PC02 too low
  - Mixed metabolic acidosis and respiratory alkalosis
- Measured PC02 is appropriate
  - Simple metabolic acidosis
- Measured HC03 is too low
  - Mixed respiratory acidosis and metabolic acidosis
- Measured HC03 is too high
  - Mixed respiratory acidosis and metabolic alkalosis
- Measured HC03 is appropriate
  - Simple respiratory acidosis
Alkalemia

High HC03
Low PC02

Mixed metabolic alkalosis and respiratory alkalosis

High Hc03
High PC02

Predominant Metabolic Alkalosis

Low HC03
Low PC02

Predominant Respiratory Alkalosis

Low HC03
High PC02

Not possible; likely lab error

Apply Compensation Rules

Measured PC02 too high

Mixed metabolic alkalosis and respiratory acidosis

Measured PC02 too low

Mixed metabolic alkalosis and respiratory alkalosis

Measured PC02 is appropriate

Simple metabolic alkalosis

Measured HC03 is too low

Mixed respiratory alkalosis and metabolic acidosis

Measured HC03 is too high

Mixed respiratory alkalosis and metabolic alkalosis

Measured HC03 is appropriate

Simple respiratory alkalosis
Metabolic Acidosis

pH < 7.35 with normal or ↓ HC03

- Caused by one of four mechanisms
  - Decreased H⁺ excretion - Distal RTA
  - Diminished NH4⁺ production – Renal failure, Hypoaldosteronism (Type IV RTA)
  - Increased H⁺ load – lactate, DKA, toxins, Rhabdo
  - Bicarbonate loss – Diarrhea, Pancreatic Fistula, Ureteral Diversion. Renal bicarb loss (Proximal RTA)
  - Bicarbonate dilution

Metabolic Acidosis

• Threats to life
  – Hemodynamic Instability (↓myocardial contractility, ↓intravascular volume, ↓PVR)
  – Cardiac arrhythmias (hyper or hypokalemia)
  – Ventilatory failure
  – Presence of toxins
  – Nutritional deficiency (B vitamins, Wernicke’s)

Anion Gap

- \( AG = (Na^+) - (HCO_3^- + Cl^-) \)
- Three clinical applications
  1) Presence or absence of an AG assists in determining the cause of the metabolic acidosis.
  2) The AG is useful in determining the presence of a mixed acid/base disturbance by calculating the Delta Ratio.
  3) The AG can be useful in detecting selected disorders that occur with a low, not high AG. (Lithium toxicity, Multiple Myeloma with production of cationic paraproteins)

Anion Gap

A. NORMAL ION DISTRIBUTION
B. METABOLIC ACIDOSIS due to acid accumulation; decreased $\text{HCO}_3^-$, increased anion gap
C. METABOLIC ACIDOSIS due to $\text{HCO}_3^-$ loss; decreased $\text{HCO}_3^-$, normal anion gap, increased $\text{Cl}^-$

http://www.flickr.com/photos/dokidok/2369729114/in/photostream/
Adjusted Anion Gap

- Hypoalbuminemia can mask an increased concentration of gap ions and lowering the value of the AG.
- Adjusted AG =
  \[ \text{AG} + 2.5 \times (\text{normal albumin g/dL} - \text{albumin g/dL}) \]

Example: Pt. albumin 2.0g/dL and AG 15

\[
15 + 2.5 \times (4 - 2) = 15 + 5
\]

Adjusted AG = 20
Etiology of Anion Gap Metabolic Acidosis

- Excess endogenous or exogenous acid
- Mudpiles
  - U: Uremia
  - M: Methanol
  - D: Diabetic Ketoacidosis
  - P: Propofol (Paraldehyde)
  - I: Ischemia, INH
  - L: Lactic acidosis
  - E: ETOH ketoacidosis / Ethylene Glycol
  - S: Salicylates / starvation ketoacidosis
- Massive Rhabdomyolysis – release of intracellular phosphate and sulfate
GOLD MARK

G - Glycols – Ethylene glycol and methanol
O - Oxoproline
L - Lactic acidosis (Inadequate perfusion)
D - Lactic acidosis (Increased lactate production or decreased lactate utilization)

M - Methanol
A - Aspirin
R - Renal Failure
K - Ketoacidosis
Non-Gap Metabolic Acidosis

- GI Losses of HC03+ (Diarrhea, fistulas)
- Renal HC03+ loss (Type II RTA)
- Renal dysfunction (Hypoaldosteronism, Type IV RTA)
- Ingestions – ammonium chloride, hyperalimentation fluids

- Dilutional metabolic acidosis
  - Usually due to administration of large volume saline
A Word About NaHCO₃

• Direct treatment of acute metabolic acidosis with NaHCO₃ is **not** indicated, **unless**:
  – pH < 7.10
  – Overt physiologic compromise is present
  – Excessive work of breathing is required to maintain pH > 7.2

• NaHCO₃ is not indicated in DKA, even with pH < 7.10 due to the risks of developing rebound alkalosis or exacerbating hyperosmolarity.
Metabolic Alkalosis

- pH > 7.45 with normal or ↑HCO3
  1) Anion loss
     - Chloride responsive
     - Chloride unresponsive
     - Determined by measuring urine electrolytes
  2) Cation gain
     - Correction of long-standing respiratory acidosis with institution of invasive or non-invasive mechanical ventilation
     - Rarely, due to regulation of K⁺ by exchanging H⁺ ions for K⁺ in tissues and kidneys resulting in H⁺ wasting (Cushings, steroid therapy)
## Metabolic Alkalosis

<table>
<thead>
<tr>
<th>Chloride Responsive</th>
<th>Chloride Unresponsive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urine sodium low (&lt;20)</td>
<td>Urine sodium &gt; 20</td>
</tr>
<tr>
<td>Gastric loss (vomiting, NG suction)</td>
<td>Primary hyperaldosteronism</td>
</tr>
<tr>
<td>Urinary loss (diuresis, mannitol)</td>
<td>Corticosteroids</td>
</tr>
<tr>
<td>Renal response to hypercapnea (Cl(^{-}) loss at renal tubule as HC03(^{+}) is generated)</td>
<td>Correction of long-standing respiratory acidosis (institution of invasive or non-invasive mechanical ventilation)</td>
</tr>
</tbody>
</table>

Respiratory Acidosis

- pH ↓ 7.35 with normal or ↑PaCO2
- Decreased ventilation
  - Acute
    - Exacerbation of severe asthma
    - PNA
    - Pulmonary edema
    - Post cardiac-arrest
    - Drug overdose
    - Administration of O2 in setting of chronic hypercapnea.
  - Chronic: chronic obstructive lung diseases
Symptoms of Respiratory Acidosis

• Headache
• Blurred vision
• Restlessness
• Anxiety
• Tremors
• Asterixis
• Delirium
• Somnolence
• Hypotension when pH falls below 7.10
# Chronic Respiratory Acidosis

<table>
<thead>
<tr>
<th>Compensated</th>
<th>Uncompensated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevated PaCO2</td>
<td>Elevated PaCO2</td>
</tr>
<tr>
<td>Near Normal pH</td>
<td>pH &lt; 7.35</td>
</tr>
</tbody>
</table>
Respiratory Alkalosis

- pH ↑ 7.45 with normal or ↓ PaCO2
- Increased ventilation
  - CNS Disturbances
  - Pain
  - Inappropriate mechanical ventilation
  - Drugs (salicylates, catecholamines, theophylline)
  - Hypoxemia
  - Liver Disease
  - Pulmonary receptor stimulation / ↓ lung compliance (PNA, pulmonary embolism, asthma, pulmonary fibrosis, pulmonary edema)
  - Pregnancy
Respiratory Alkalosis

• Symptoms
  – Parasthesias, tetany, tremor
  – Chest pain, circumoral parasthesia, lightheadedness
  – anxiety
Compensation Basics

• Compensatory changes are dependent upon normal function of the compensating system
• Most compensation is incomplete
• Lack of adequate compensation may indicate the presence of a co-existing secondary disorder
• Different compensatory formulas are applied, depending upon the primary disturbance
• Humans have good buffering systems for acidosis but a reduced ability to buffer alkalosis
Respiratory Compensation

- PC02 changes in the same direction as the serum HC03
  - PC02 ↓ in metabolic acidosis
  - PC02 ↑ in metabolic alkalosis
- Respiratory compensation decreases the change in ratio of HC03:PC02, and therefore in the pH.
- Rapid onset of response, within 30 minutes
- Complete within 12-24 hours
- Respiratory compensation can occur to a physiologic max of PaC02 50 to 55; higher PaC02 in this situation indicates a concomitant Respiratory Acidosis

Renal Compensation

• HC03 changes in the same direction as the PC02
  – HC03 ↑ in respiratory acidosis due to increased H⁺ secretion
  – HCO3 ↓ in respiratory alkalosis due to decreased H⁺ secretion and urinary HC03 loss

• Slower onset of compensation, within hours

• Completion takes days to weeks for maximal effect

• Expected findings differ in acute (little or no renal compensation) and chronic (full renal compensation) respiratory acid-base disorders.

Acid-Base Nomogram

http://pic.pimg.tw/mulicia/1179210017.jpg
## Expected Compensation for Acid-Base Disorders

<table>
<thead>
<tr>
<th>Primary Disorder</th>
<th>Primary Change</th>
<th>Compensatory Change</th>
<th>Expected Compensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic Acidosis</td>
<td>↓ HC03⁻</td>
<td>↓ PaCO2</td>
<td>ΔPaCO2 = 1.2 Δ HC03⁻</td>
</tr>
<tr>
<td>Metabolic Alkalosis</td>
<td>↑ HC03⁻</td>
<td>↑ PaCO2</td>
<td>ΔPaCO2 = 0.9 Δ HC03⁻</td>
</tr>
</tbody>
</table>
| Respiratory Acidosis     | ↑ PaCO2        | ↑ HC03⁻             | ΔHC03⁻ = 0.10 Δ PaCO2  
ΔHC03⁻ = 0.35 Δ PaCO2 |
| Respiratory Alkalosis    | ↓ PaCO2        | ↓ HC03⁻             | ΔHC03⁻ = 0.2 Δ PaCO2  
ΔHC03⁻ = 0.5 Δ PaCO2 |

\[ \Delta \text{PaCO}_2 = 1.2 \times \Delta \text{HC03} \]

\[ \Delta \text{HC03} = 24 \text{ (optimal)} - \text{measured HC03} \]
\[ \Delta \text{PaCO}_2 = 40 \text{ (optimal)} - \text{calculated, expected change in PaCO}_2 \]

- pH 7.22 / 30 / 10
  \[ \Delta \text{HC03} = 24 - 10 = 14 \]
  \[ 1.2 \times 14 = 16.8 \]
  \[ \Delta \text{PaCO}_2 = 40 - 16.8 = 23.2 \]

  Expected PaCO2 = 23.2mmHg.

- Conclusion – Not completely compensated; because PaCO2 should be 23 but it is 30.
Compensation for Metabolic Acidosis

1) $\Delta \text{PaCO}_2 = 1.2 \Delta \text{HC0}_3$

2) pH = last two digits of PaCO2
   pH 7.25 $\rightarrow$ PaCO2 25

3) Winter’s Formula - Estimates the expected PCO2
   $(1.5 \times \text{HC0}_3) + 8 = \text{PaCO}_2 \pm 2$
Winter’s Formula *
(1.5 x HC03) + 8 = PaC02 ± 2

• ABG: 7.22 / 30 / 10
• Na 139, K 4.0, Cl 90, C02 10

(1.5 x 10) + 8 = 23

23 ± 2 is < measured PaC02 (30)
Expected PC02 = 23
Conclusion – Not completely compensated
Compensation Pearls for Chronic Metabolic Acidosis

- If PaCO2 is > expected, then the time for respiratory compensation has been too short; or a respiratory acidosis is also present.
- If the PaCO2 is < expected, then a concomitant respiratory alkalosis is also present
Compensation Formulas for Metabolic Alkalosis

1) \[ \Delta \text{PaCO}_2 = 0.9 \Delta \text{HC}03 \]

2) PaCO2 \[ \uparrow \] 0.7mmHg for every 1mEq elevation in the serum HC03 concentration

3) PaCO2 = 40 + .7 (measured HC03 – normal HC03)

4) PaCO2 = (0.9 x HC03) + 15
PaC02 = (0.9 x HCO3) + 15

ABG 7.56 / 44 / 70 / 38

• PaC02 = (0.9 x HCO3) + 15
  0.9 x 38 + 15 = 49.2

Expected PaC02 = 49.2

Conclusion - Not completely compensated
Compensatory Formulas for Respiratory Acidosis

• Acute
  1) \( HC03 \uparrow \ 1 \ / \ 10\text{mm Hg increase in PaC02} \)
  2) \( \Delta HC03 = 0.10 \ \Delta \text{PaC02} \)
  3) \( HC03 = (\text{PC02} - 40 \ / \ 10) + 24 \)

• Chronic
  1) \( HC03 \uparrow \ 3.5 \ / \ 10\text{mm Hg increase in PaC02} \)
  2) \( \Delta HC03 = 0.35 \ \Delta \text{PaC02} \)
  3) \( HC03 = (\text{PC02} - 40/ \ 5) + 24 \)
Acute

HC03 = (PC02 – 40 / 10) + 24

ABG: 7.22 / 70 / 25

HC03 = (PC02 – 40 / 10) + 24

70-40 = 30

30 /10 = 3

Expected HC03 is 3 + 24 = 27

Conclusion – Incomplete compensation
Chronic

HC03 = \( (PC02 - 40 / 5) + 24 \)

ABG: 7.30 / 90 / 38

HC03 = \( (PC02 - 40 / 5) + 24 \)

90 - 40 = 50

50 / 5 = 10

Expected HC02 is 10 + 24 = 34

Conclusion – Incomplete compensation
Compensatory Formula for Respiratory Alkalosis

• Acute
  1) \( \text{HC03} \downarrow 2 / 10 \text{ mmHg decrease in PC02} \)
  2) \( \Delta \text{HC03} = 0.20 \Delta \text{PaC02} \)
  3) \( \text{HC03} = 24 - (40 - \text{PaC02} / 5) \)

• Chronic
  1) \( \text{HC03} \downarrow 5 / 10 \text{ mmHg decrease in PC02} \)
  2) \( \Delta \text{HC03} = 0.5 \Delta \text{PaC02} \)
  3) \( \text{HC03} = 24 - (40 - \text{PaC02} / 2) \)
Acute

HC03 = 24 - (40 – PaC02 / 5)

ABG: 7.52 / 28 / 24
HC03 = (40 – PaC02) / 5
40 – 28 = 12
12 / 5 = 2.4 + 24 = 26.4
Expected HC03

Conclusion – Incomplete compensation
Chronic

$\text{HC}03 = 24 - (40 - \text{PaC}02 / 2$)

ABG 7.44 / 22 / 18

- $\text{HC}03 = 24 - (40 - \text{PaC}02 / 2$
  
  $40 - 22 / 2 = 9$
  
  $24 - 9 = 15$

Expected HC03 15

Conclusion – Incomplete compensation
# Easy Compensation Formulas

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<td></td>
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Finding Mixed Acid-base Disturbances

1) PCO2 and HC03 both adding to the pH change
   → mixed Acid-base disorder is present
2) Calculate corrected HC03 = HC03 + Δ AG
   Corrected HC03 > 28 → Alkalosis
   Corrected HC03 < 20 → Acidosis
3) Calculate the Delta Ratio (Δ / Δ)
   Δ Anion Gap/ Δ HC03⁻
Acidemia

Low HC03
High PC02

Mixed metabolic acidosis and respiratory acidosis

Low Hc03
Low PC02

Predominant Metabolic Acidosis

High HC03
High PC02

Predominant Respiratory Acidosis

High HC03
Low PC02

Not possible; likely lab error

Apply Compensation Rules

Measured PC02 too high
Mixed metabolic acidosis and respiratory acidosis

Measured PC02 too low
Mixed metabolic acidosis and respiratory alkalosis

Measured PC02 is appropriate
Simple metabolic acidosis

Measured HC03 is too low
Mixed respiratory acidosis

Measured HC03 is too high
Mixed respiratory acidosis and metabolic alkalosis

Measured HC03 is appropriate
Simple respiratory acidosis
Mixed Metabolic Acidosis Pearls

If the PaCO2 > expected HC03⁻, then the time for respiratory compensation has been too short; or a respiratory acidosis is also present.

If the PaCO2 < expected HC03⁻, then a concominant respiratory alkalosis is also present.
Delta Ratio

• Delta Ratio = Δ Anion Gap/ Δ HC03⁻
Δ / Δ = 1-2 → uncomplicated high AG metabolic acidosis
Δ / Δ < 1 → combined high AG metabolic acidosis and normal AG metabolic acidosis
Δ / Δ > 2 → combined high AG metabolic acidosis and concurrent metabolic alkalosis
Delta / Delta
ΔAG / ΔHC03−

1) ABG: 7.26 / 15 / 14
   BMP: Na 130, Cl 90, CO2 15, AG = 25
   25 - 10 / 24-15 = 15/9 = 1.66
   Δ/Δ 1-2 : Uncomplicated high AG metabolic Acidosis

2) ABG: 7.22 / 30 / 10
   BMP: Na 139, Cl 110, CO2 10, AG = 19
   19 – 10 / 24 – 10 = 9/14 = 0.64
   Δ/Δ : Combined high AG metabolic acidosis and normal AG metabolic acidosis
Summary of Key Points

• Systematic approach, use H&P clues
• Pick the most severe-appearing abnormality and start there
• The flow charts are your friends
• Apply compensation formulas – find the formulas that are easiest for you
• Use Delta / Delta to detect mixed disturbances
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