Acid-Base Disturbances

Goal

- Provide an approach to determine complex acid-base disorders
- Discuss the approach to determine primary disturbances, compensation, Anion gap and Delta gap

pH

- Reflects total amount of Hydrogen ions [H+]
- Henderson-Hasselbalch Equation
  \[ \text{pH} = pK + \log_{10} \left( \frac{[A^-]}{[H_+]^n} \right) \]
- Summation of:
  - amount of acid produced, bicarb produced, acid excreted and buffered
pH
- Lower pH has more H+
- Curve is exponential

Normal pH is 7.35-7.45
- pH < 7.35 = acidemia
- pH > 7.45 = alkalemia
- Acidosis/alkalosis is underlying process
  - Lactic acidosis
- Acidemia/alkalemia is overall effect on blood pH
  - a pH of 7.2 is acidemic

Daily acid production
- 12,000-15,000 mEq/d volatile acids produced
- pH acts as an acid
  - Excreted by lungs
- 1 mEq/kg per day of nonvolatile acids
  - Excreted by kidney tubules
Buffer

• Substance that can donate or receive a proton
• Used to rapidly minimize changes in pH during an acid load
  – Exercise induced lactic acidosis

Buffer Systems help minimize pH changes in the body

• Phosphate
• Protein
• Carbonic acid-Bicarbonate
• All are in equilibrium with each other

Tests needed

BMP (Basic Metabolic Panel) Blood Gas

• Sodium (Na⁺)
• Potassium (K⁺)
• Chloride (Cl⁻)
• CO₂
  – Bicarb
  – HCO₃⁻

• pH
• pCO₂
5 Step Method for Acid-Base Analysis

• 1. Check the Numbers/Internal Integrity
• 2. Primary Disturbance
  – Assess pH
  – Respiratory or Metabolic
• 3. Limits of compensation
  – Look for additional disturbances
• 4. Anion Gap
• 5. Delta Gap

Case 1

• 68 yr male with severe oxygen dependent COPD in hospital for cholecystectomy, kept on vent overnight
Labs

- Na+ 150, K+ 2.5, Chloride 130, CO₂ 16, Creat .2
- pH 7.34/68/65/33

Lack of Internal Integrity

- Na+ 150, K+ 2.5, Chloride 130, CO₂ 16, Creat .2
- pH 7.34/68/65/33

Rearranged Henderson-Hasselbalch equation

- [H+] = 24 \frac{[\text{A}^-]}{[\text{HA}]}
- [H+] = 24 \frac{[\text{HCO}_3^-]}{[\text{CO}_2]}

Calculated bicarb is incorrect only if either [H+] or pCO₂ is incorrect

Lack of Internal Integrity

- No interpretation can be accurately performed
- Na+ 150, K+ 2.5, Chloride 130, CO₂ 16, Creat .2
- pH 7.34/68/65/33

Bicarb on the gas and BMP do not match up
- Specimens may have been drawn at different times
- One of the specimens is off
  - (short draw, contaminated)
Repeat lab draw

• Na+ 141, K+ 3.7, Chloride 94, CO₂ 34
• pH/CO₂/paO₂/HCO₃⁻

5 Step Method

• 1. Check the Numbers/Internal Integrity
• 2. Primary Disturbance
• 3. Limits of compensation
• 4. Anion Gap
• 5. Delta Gap

Repeat Lab Draw
Internal Integrity

• Na+ 141, K+ 3.7, Chloride 94, CO₂ 34
• pH/CO₂/paO₂/HCO₃⁻

[H⁺]= 24 (carbonic acid, bound, unbound)
4 Primary Acid-Base Disturbances

Metabolic disturbances
Deals with the bicarb/CO₂
• Metabolic acidosis - drop in bicarb/CO₂
• Metabolic Alkalosis - increase in bicarb/CO₂

Respiratory disturbances
Deals with pCO₂
• Respiratory acidosis - increase in pCO₂
• Respiratory Alkalosis - decrease in pCO₂

Primary Disturbance

• Na⁺ 141, K⁺ 3.7, Chloride 94, CO₂ 34
• 7.34/68/65/33
  pH/pCO₂/paO₂/HCO₃⁻

• Respiratory Acidosis

• Look at pH, is it higher or lower than 7.4ish
  • Look at bicarb and pCO₂
  • Then look at bicarb and pCO₂

• 1. Check the numbers
• 2. Primary Disturbance
• 3. Limits of compensation
• 4. Anion Gap
• 5. Delta Gap
Primary Disturbance

• Respiratory acidosis
  – Due to COPD

• 1. Check the numbers
• 2. Primary Disturbance
• 3. Limits of compensation
• 4. Anion Gap
• 5. Delta Gap

Normal balance

Acid  Base
pH 7.4
Uncompensated Respiratory Acidosis

pH 7.0

Compensated Respiratory Acidosis

pH 7.34

Compensation/Compensatory response

- Kidneys raise or lower the bicarb to compensate for lung issues
- Lungs raise or lower pCO₂ to compensate for metabolic issues
Normal balance
pH 7.4

Primary Respiratory alkalosis-Uncompensated
pH 7.55

Primary Respiratory alkalosis-compensated
pH 7.48
Normal balance
pH 7.4

Primary Metabolic Acidosis-Uncompensated
pH 7.0

Primary Metabolic Acidosis-Compensated
pH 7.2
Normal balance
pH 7.4

Primary Metabolic Alkalosis-Uncompensated
pH 7.55

Primary Metabolic Alkalosis-Compensated
pH 7.45
Rules of Thumb for Compensatory response

- **Metabolic Acidosis**
  - $pCO_2 = 1.5[HCO_3^-] + 8 \pm 2$
  - $\Delta pCO_2 = \Delta HCO_3^-$

- **Metabolic Alkalosis**
  - $40 + 0.6 (\Delta [HCO_3^-]) \pm 4$
  - $\Delta pCO_2 = 0.5 HCO_3^-$

- **Resp Acidosis**
  - **Acute**:
    - $\Delta [HCO_3^-] = 0.1 \times \Delta pCO_2$
  - **Chronic**:
    - $\Delta [HCO_3^-] = 0.35 \times \Delta pCO_2$

- **Resp Alkalosis**
  - **Acute**:
    - $\Delta [HCO_3^-] = 0.2 \times \Delta pCO_2$
  - **Chronic**:
    - $\Delta [HCO_3^-] = 0.5 \times \Delta pCO_2$

Compensation for Chronic Respiratory Acidosis

- $\Delta [HCO_3^-] = 0.35 \times \Delta pCO_2$
- $\Delta [HCO_3^-] = 0.35 \times 28$
- $\Delta [HCO_3^-] = 9.8$
- $Pt pCO_2 = 68$
- $Normal pCO_2 = 40$
- $Change in pCO_2 is 28$

Chronic Respiratory Acidosis with Appropriate metabolic compensation

- **Normal HCO_3^- 24**
- **Pt HCO_3^- 34**
- $\Delta [HCO_3^-] = 9.8$
- **Expected HCO_3^- 34**
Management

- Pt stable on vent
- Do NOT correct pCO₂ to 40
- Target should be around patient’s baseline pCO₂
  - Can determine this by \( \Delta [HCO_3^-] = 0.35 \times \Delta pCO₂ \)
  - Use the bicarb from a prior BMP and solve for pCO₂

Case 2

- 65 yr male admitted with CHF exacerbation
- Lasix 40 mg q 6 H for several days
- Now, with increased FiO₂ requirements

Labs

- Na⁺ 135, K⁺ 3.3, Cl⁻ 97, CO₂ 38, Creat 1.8
- 7.52/48/70/37  NRB
  \( pH = pCO₂ - pO₂ + HCO_3^- \)
5 Step Method

• 1. Check the Numbers/Internal Integrity
• 2. Primary Disturbance
• 3. Limits of compensation
• 4. Anion Gap
• 5. Delta Gap

Internal Integrity

• Na+ 135, K+ 3.3, Cl- 97, CO2 38, Creat 1.8
• 7.52/48/70/37 NRB
• pH=CO2/paO2/HCO3

[H+] = 24(\frac{\text{HCO}_3}{\text{H}_2\text{CO}_3})

• CO2
  – Measures bicarb in all of its forms (carbonic acid, bound, unbound

• Na+ 135, K+ 3.3, Cl- 97, CO2 38, Creat 1.8
• 7.52/48/70/37 NRB
• pH=CO2/paO2/HCO3

• 1. Check the numbers
• 2. Primary Disturbance
• 3. Limits of compensation
• 4. Anion Gap
• 5. Delta Gap
4 Primary Acid-Base Disturbances

**Metabolic disturbances**
Deals with the bicarb/CO₂
- **Metabolic acidosis**: drop in bicarb/CO₂
- **Metabolic Alkalosis**: increase in bicarb/CO₂

**Respiratory disturbances**
Deals with pCO₂
- **Respiratory acidosis**: increase in pCO₂
- **Respiratory Alkalosis**: decrease in pCO₂

Primary Disturbance

- Na⁺ 135, K⁺ 3.3, Cl⁻ 97, CO₂ 38, Creat 1.8
- 7.52/48/70/37 NRB pH/pCO₂/oaO₂/HCO₃⁻
  - **Metabolic Alkalosis**
- Look at pH, is it higher or lower than 7.4ish
  - Alkalemia
- Then look at bicarb and pCO₂
  - Bicarb is high
  - metabolic

Primary Disturbance

(First disturbance)

- **Metabolic Alkalosis**
• 1. Check the numbers
• 2. Primary Disturbance
• 3. Limits of compensation
• 4. Anion Gap
• 5. Delta Gap

Compensation/Compensatory response
• Kidneys raise or lower the bicarb to compensate for lung issues
• Lungs raise or lower pCO₂ to compensate for metabolic issues

Primary Metabolic Alkalosis-Uncompensated

pH 7.55
Primary Metabolic Alkalosis-Compensated

\[ \text{pH} > 7.45 \]

Compensation

Lungs compensate for kidney problems
Kidneys compensate for lung problems

- **Primary Respiratory acidosis**—high \( pCO_2 \)
  - Bicarb goes up
- **Primary Respiratory alkalosis**—Low \( pCO_2 \)
  - Bicarb goes down
- **Primary Metabolic acidosis**—low bicarb
  - \( pCO_2 \) goes down
- **Primary Metabolic alkalosis**—high bicarb
  - \( pCO_2 \) goes up

Rules of Thumb

for Compensatory response

- **Metabolic Acidosis**
  - \( pCO_2 = 1.5 \times \left[ HCO_3^- \right] +6 +/-.2 \)
  - \( \Delta pCO_2 = \Delta HCO_3^- \)
- **Metabolic Alkalosis**
  - \( 40 + 0.6 \times \left[ \Delta \left[ HCO_3^- \right] \right] \pm 4 \)
  - \( \Delta pCO_2 = \Delta HCO_3^- \times .5 \)

- **Resp Acidosis**
  - acute:
    - \( \Delta \left[ HCO_3^- \right] = 0.1 \times \Delta pCO_2 \)
  - chronic:
    - \( \Delta \left[ HCO_3^- \right] = 0.35 \times \Delta pCO_2 \)

- **Resp Alkalosis**
  - acute:
    - \( \Delta \left[ HCO_3^- \right] = 0.2 \times \Delta pCO_2 \)
  - chronic:
    - \( \Delta \left[ HCO_3^- \right] = 0.5 \times \Delta pCO_2 \)
Limits of compensation/compensatory response

- Primary Disturbance: Metabolic alkalosis
- Pt bicarb is 38
- Normal bicarb is 24
- Δ bicarb is 14
- \( pCO_2 = 40 + 0.6 (\Delta[HCO_3^-]) \)
- \( pCO_2 = 40 + 0.6 (\Delta 14) \)
- \( pCO_2 = 40 + 8 = 48 \)
- Expected \( pCO_2 = 48 \)

Limits of compensation for Metabolic Alkalosis

- Expected \( pCO_2 = 48 \)
- Patient \( pCO_2 = 47 \)
- Appropriate respiratory compensation
  - Compensated respiratory acidosis

Case 2 Summary

Metabolic alkalosis and a compensatory respiratory acidosis

- Diuresis induced a metabolic alkalosis
- Patient hypoventilated to raise \( pCO_2 \) to improve pH
- Hypoventilation worsened hypoxemia and increased \( \text{FiO}_2 \) requirements
- Diurese with Diamox to drop bicarb. This resolves metabolic alkalosis, associated hypoventilation and improves oxygenation
Causes of Metabolic Alkalosis

- Volume depletion
- Hypokalemia
- Aldosterone excess
- Hypomagnesemia
- Barter's/Liddle's syndrome

Review

1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap

Case 3

- 45 yr male found down
- BMP: Na+ 136, K+ 5.5, Cl- 106, CO₂ 8
- ABG: 7.44/12/100/7
1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap

Check the numbers/Internal integrity

- BMP: Na+ 136, K+ 5.5, Cl− 106, CO2 8
- ABG: 7.44/12/100/7

\[ [\text{H}^+] = 24 \left( \frac{\text{Na}^+}{\text{K}^+} \right) \]
\[ [\text{H}^+] = 24 \left( \frac{\text{pCO}_2}{\text{HCO}_3^-} \right) \]

Case 3

- BMP: Na+ 136, K+ 5.5, Cl− 106, CO2 8
- ABG: 7.44/12/100/7

1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap
Case 3 - Primary disturbance

- BMP: Na+ 136, K+ 5.5, Cl- 106, CO2 8
- ABG: 7.44/12/100/7
  pH, pCO2, paO2, HCO3-
- Respiratory Alkalosis

- Look at pH, is it higher or lower than 7.4ish
  - pH is high
- Then look at bicarb and pCO2
  - pCO2 is low Respiratory

Primary Disturbance

- Respiratory Alkalosis

1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap
Normal balance
pH 7.4

Primary Respiratory alkalosis-Uncompensated
pH 7.55

Primary Respiratory alkalosis-compensated
pH 7.48
Rules of Thumb

- **Metabolic Acidosis**
  - \( \text{pCO}_2 = 1.5(\text{HCO}_3^-) + 8 \pm 2 \)
  - \( \Delta \text{pCO}_2 = \Delta \text{HCO}_3^- \)
- **Metabolic Alkalosis**
  - \( 40 + 0.6 (\Delta \text{HCO}_3^-) \pm 4 \)
  - \( \Delta \text{pCO}_2 = 0.5 \times \Delta \text{HCO}_3^- \)
- **Resp Acidosis**
  - acute:
    - \( \Delta \text{HCO}_3^- = 0.1 \times \Delta \text{pCO}_2 \)
  - chronic:
    - \( \Delta \text{HCO}_3^- = 0.35 \times \Delta \text{pCO}_2 \)
- **Resp Alkalosis**
  - acute:
    - \( \Delta \text{HCO}_3^- = 0.2 \times \Delta \text{pCO}_2 \)
  - chronic:
    - \( \Delta \text{HCO}_3^- = 0.5 \times \Delta \text{pCO}_2 \)

Limits of compensation

- **Primary Disturbance:** Respiratory alkalosis
  - Normal \( \text{pCO}_2 = 40 \)
  - Pt \( \text{pCO}_2 = 12 \)
  - \( \Delta \text{pCO}_2 = 28 \)
  - \( \Delta \text{HCO}_3^- = 0.2 \times \Delta \text{pCO}_2 \)
  - Expected drop in bicarb is 6 for normal renal compensation
  - Normal bicarb is 24
  - Drop it by 6
  - Expected Pt bicarb is 18

Limits of compensation for Respiratory Alkalosis

- \( \Delta \text{HCO}_3^- = 5.6 \)
- Expected drop in bicarb is 6 for normal renal compensation
- Normal bicarb is 24
  - Drop it by 6
  - Expected Pt bicarb is 18
- Pt bicarb is 8
  - This is lower than expected
- Metabolic acidosis
**Normal balance**

pH 7.4

**Primary Respiratory alkalosis-Uncompensated**

pH 7.55

**Primary Respiratory alkalosis -compensated**

Metabolic Acidosis

pH 7.48
Primary Respiratory alkalosis
Metabolic Acidosis

Acid-Base Disturbances present

- Acute Respiratory Alkalosis
- Metabolic Acidosis

- 1. check the numbers
- 2. Primary Disturbance
- 3. Limits of compensation
- 4. Anion Gap
- 5. Delta Gap
Anion Gap

Sodium - (Chloride + Bicarbonate)
normal 10 +/- 2

Alkalinosis, lactates

Anion Gap

• BMP: Na+ 136, K+ 5.5, Cl- 106, CO2 8
• AG=Sodium - (Chloride + Bicarbonate)
• AG=136 - (106+ 8)
• Pt AG=22
• Normal AG is 8-12
• Anion Gap Metabolic Acidosis

Anion Gap Metabolic Acidosis

Na+ HCO3- Cl-
Anion Gap

Normal anion gap
Elevated anion gap
Causes of Anion gap

- Methanol
- Uremia
- DKA
- Paraldehyde
- INH/Ibuprofen/Iron
- Lactic acid
- Ethylene glycol
- Salicylate

- Ethylene glycol
- Lactic acid
- Methanol
- Paraldehyde
- ASA
- Renal failure
- Ketoacidosis

Case 3 Summary

- Acute Respiratory Alkalosis
- Anion Gap Metabolic Acidosis
- Due to Aspirin overdose
- Treatment: Dialysis or bicarb drip

- Ethylene glycol
- Lactic acid
- Methanol
- Paraldehyde
- ASA
- Renal failure
- Ketoacidosis

Case 4

- 30 female with rheumatoid arthritis presents for review of recent lab exam
- Na+ 138, K+ 3.1, Cl- 118, CO2 10
- 7.28/22/89/10
  \[\text{pH} + \text{PCO}_2 + \text{HCO}_3^-\]
• Na+ 138, K+ 3.1, Cl- 118, CO2 10
• pH 7.28/22/89/10

1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap

Primary Disturbance

• Look at pH, is it higher or lower than 7.4ish
  • pH is low: Acidoemia
• Then look at bicarb and pCO2
  • Bicarb is low: Metabolic
  • Bicarb is normal: Respiratory
Primary Disturbance

- Metabolic acidosis

- Na+ 138, K+ 3.1, Cl- 118, HCO3- 10
- 7.28/22/89/10
  pH/pCO2/paO2/HCO3-

1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap

Rules of Thumb

- Metabolic Acidosis
  - pCO2=1.5[HCO3-]x+8 +/- 2
  - ∆pCO2= ∆HCO3-
- Metabolic Alkalosis
  - 40 +/- 6 (Δ[HCO3-]) ± 4
  - ∆pCO2=5 ∆HCO3 X .5

- Resp Acidosis
  - acute:
    - pCO2 = 0.1 X ∆pCO2
    - ∆HCO3=
  - chronic:
    - 0.35 X ∆pCO2
    - Resp Alkalosis
      - acute:
        - ∆HCO3= 0.2 X ∆pCO2
      - chronic:
        - 0.5 X ∆pCO2
Limits of Compensation
Metabolic Acidosis

- Pt bicarb is 10
- pCO₂ = 1.5(HCO₃⁻) + 8 +/- 2
- pCO₂ = 1.5(10) + 8 +/- 2
- pCO₂ = 15 + 8 +/- 2
- Expected pCO₂ = 23 +/- 2
- Pt pCO₂ is 22
  - This is as expected
  - Appropriate Respiratory Compensation

Normal balance
pH 7.4
Primary Metabolic Acidosis-Uncompensated

pH 7.0

- Check the numbers
- Primary Disturbance
- Limits of compensation
- Anion Gap
- Delta Gap

Primary Metabolic Acidosis-Compensated

pH 7.2
Anion Gap

- Na⁺ 138, K⁺ 3.1, Cl⁻ 118, CO₂ 10
- AG = Sodium - (Chloride + Bicarbonate)
- AG = 138 - (118 + 10)
- Pt AG = 10
- Normal AG is 8-12
- Non-anion Gap Metabolic Acidosis

Non-Gap metabolic acidosis

Anion Gap

Non-anion gap
Anion Gap Metabolic Acidosis

- Normal anion gap
- Elevated anion gap

Non-Anion Gap Metabolic Acidosis

- Normal anion gap
- Elevated anion gap
- Non-gap

Causes of Non-gap Metabolic Acidosis

- Kidney
  - RTA I, II, IV
  - cholestyramine
- Gut
  - diarrhea
  - ileostomy
  - pancreatic fistula
  - TPN
Case 4 Summary

• Non-anion gap metabolic acidosis with appropriate respiratory compensation
• Pt has a renal tubular acidosis (RTA)
• Impaired ability of the kidney to excrete acid

RTA type I
• associated with autoimmune diseases
• Classic is 30s female with nephrocalcinosis
• Treatment: oral bicarb tx-potassium citrate

Non-Anion Gap Metabolic Acidosis
Review

• 1. Check the numbers
• 2. Primary Disturbance
• 3. Limits of compensation
• 4. Anion Gap
  - Anion-Gap and Non-Anion Gap Metabolic Acidosis
• 5. Delta Gap

Case 5

• 62 yr male with cirrhosis presents with 3 days of chills, sweats, fever, decreased PO intake. Now with decreased LOC and hypoxemia.
• CXR shows pneumonia. WBC 25,000
• Na+ 133, Cl− 100, K+ 5.7, CO₂ 16, Creat 2.8
• 7.18/44/88/16

Case 5

• Na+ 133, Cl− 100, K+ 5.7, CO₂ 16
• 7.18/44/88/16
Case 5

- Na⁺ 133, Cl⁻ 100, K⁺ 5.7, CO₂ 16
- pH/pCO₂/pO₂/HCO₃⁻

1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap

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Case 5 - Primary Disturbance

- Na⁺ 133, Cl⁻ 100, K⁺ 5.7, CO₂ 16
- pH/pCO₂/pO₂/HCO₃⁻

- Respiratory Acidosis
  - Look at pH, is it higher or lower than 7.4ish
    - pH is low - Acidemia
    - Then look at bicarb and pCO₂
      - pCO₂ is high - Respiratory

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Primary Disturbance

- Respiratory acidosis-acute
• 1. Check the numbers
• 2. Primary Disturbance
• 3. Limits of compensation
• 4. Anion Gap
• 5. Delta Gap

Rules of Thumb

• Metabolic Acidosis
  - pCO₂=1.5[HCO₃⁻]+8 +/- 2
  - Δ pCO₂= Δ HCO₃⁻
• Metabolic Alkalosis
  - 40 ± 0.6 (Δ[HCO₃⁻]) ± 4
  - Δ pCO₂=Δ HCO₃⁻ X .5

• Resp Acidosis
  - acute:
    - Δ[HCO₃⁻]=0.1 X ΔpCO₂
  - chronic:
    - Δ[HCO₃⁻]=0.35 X ΔpCO₂
• Resp Alkalosis
  - acute:
    - Δ[HCO₃⁻]=0.2 X ΔpCO₂
  - chronic:
    - Δ[HCO₃⁻]=0.5 X ΔpCO₂

Limits of Compensation

Acute Respiratory Acidosis

• Normal pCO₂ is 40
• Pt pCO₂ is 44
  - Δ[HCO₃⁻]=0.1 X ΔpCO₂
  - Δ[HCO₃⁻]=0.1 X 4
  - Δ[HCO₃⁻]=0.4
Limits of Compensation

- $\Delta [HCO_3^-] = 0.4$
- Expected increase in bicarb is 0.4 for normal renal compensation
- Expected pt bicarb is 24
  $24 - 0.4 = 23.6$ (ish)
- Pt bicarb is 16
  - This is lower than expected
- Metabolic acidosis

Normal balance

Uncompensated Respiratory Acidosis
Compensated Respiratory Acidosis
pH 7.34

Respiratory Acidosis
pH 7.0

Respiratory Acidosis and Metabolic Acidosis
pH 6.8
• Respiratory acidosis
• Metabolic acidosis

Case 5 again

• Na+ 133, Cl- 100, K+ 5.7,
  HCO₃⁻ 16
• 7.18/44/88/16
  pH<CO₂/po₂/HCO₃⁻

Which disturbance is primary when a respiratory acidosis AND metabolic acidosis are present?

Case 5-Primary Disturbance

• Na+ 133, Cl- 100, K+ 5.7, CO₂
  16
• 7.18/44/88/16
  pH<CO₂/po₂/HCO₃⁻
• Metabolic Acidosis

• Look at pH, is it higher or lower than 7.4ish
  – pH is low Acidosis
• Then look at bicarb and pCO₂
  – CO₂ is low Metabolic
Primary Disturbance

- Metabolic acidosis

Rules of Thumb

- Metabolic Acidosis
  - $pCO_2=1.5[HCO_3^-]+8 +/- 2$
  - $\Delta pCO_2=\Delta HCO_3^-$
- Metabolic Alkalosis
  - $40 + 0.6(\Delta[HCO_3^-]) \pm 4$
  - $\Delta pCO_2=0.5 HCO_3^- \times 0.5$

- Resp Acidosis
  - $\Delta[HCO_3^-]=0.1 \times \Delta pCO_2$

  - $\Delta[HCO_3^-]=0.35 \times \Delta pCO_2$ (chronic)

- Resp Alkalosis
  - $\Delta[HCO_3^-]=0.2 \times \Delta pCO_2$

  - $\Delta[HCO_3^-]=0.5 \times \Delta pCO_2$ (chronic)
Limits of Compensation
Metabolic Acidosis

• Pt bicarb is 16
  • pCO₂ = 1.5(HCO₃⁻) + 8 +/- 2
  • pCO₂ = 1.5(16) + 8 +/- 2
  • pCO₂ = 24 + 8 +/- 2
  • Expected pCO₂ = 32 +/- 2

Limits of Compensation
Metabolic Acidosis

• Expected pCO₂ = 32 +/- 2
  • Pt pCO₂ is 44
    - This is higher than expected
  • Respiratory Acidosis
    - Uncompensated respiratory acidosis

• Acute respiratory acidosis
• Metabolic acidosis
1. check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Δelta Gap

Anion Gap Metabolic Acidosis

AG = Sodium - (Chloride + Bicarbonate)

Na+ 133, Cl- 100, K+ 5.7, HCO3- 16

AG = 133 - (100 + 16)
Pt AG = 17
Normal AG is 8-12
Anion Gap Metabolic Acidosis
Causes of Anion gap

- Methanol
- Uremia
- Dka
- Paraldehyde
- INH/ibuprofen/iron
- Lactic acid
- Ethylene glycol
- Salicylate
- Ethylene glycol
- Lactic acid
- Methanol
- Paraldehyde
- ASA
- Renal failure
- Ketoacidosis

Case 5 Summary

Pt had a pneumonia and sepsis causing renal failure (anion gap metabolic acidosis), decompensated liver failure causing hepatic encephalopathy causing decreased LOC and respiratory failure (respiratory acidosis)

Review

1. Check the numbers
2. Primary Disturbance
   - can use any disturbance and the primary
3. Limits of compensation
4. Anion Gap
   - Anion-Gap and Non-Anion Gap Metabolic Acidosis
5. Delta Gap
Case 6

- 21 yr old diabetic presents with 2 days of nausea, vomiting, decreased PO intake, not checking sugars
- Na⁺ 124, K⁺ 5.1, Cl⁻ 95, CO₂ 7, Glucose 702
- 7.23/17/105/6
  pH,HCO₃/\text{PaO}_₂/HCO₃

1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap
Case 6-Primary Disturbance

- Na+ 124, K+ 5.1, Cl- 95, CO₂ 7, Glucose 702
- pH=7.23/17/105/6/pCO₂/paO₂/HCO₃⁻
- Metabolic Acidosis

- Look at pH, is it higher or lower than 7.4ish
  - pH is low - acidemia
- Then look at bicarb and pCO₂
  - Bicarb is low - Metabolic

1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap

Normal balance
pH 7.4
Primary Metabolic Acidosis - Uncompensated

\[
pH = 7.0
\]

\[
pCO_2
\]

\[
\text{HCO}_3^-
\]

Primary Metabolic Acidosis - Compensated

\[
pH = 7.2
\]

\[
pCO_2
\]

\[
\text{HCO}_3^-
\]

Rules of Thumb

- **Metabolic Acidosis**
  - \( pCO_2 = 1.5 \times (\text{HCO}_3^-) + 8 \pm 2 \)
  - \( \Delta pCO_2 = \Delta \text{HCO}_3^- \)
- **Metabolic Alkalosis**
  - \( 40 + 0.6 \times (\Delta [\text{HCO}_3^-]) \pm 4 \)
  - \( \Delta pCO_2 = 5 \times \text{HCO}_3^- \times 0.5 \)

- **Resp Acidosis**
  - acute:
    - \( \Delta [\text{HCO}_3^-] = 0.35 \times \Delta pCO_2 \)
  - chronic:
    - \( \Delta [\text{HCO}_3^-] = 0.5 \times \Delta pCO_2 \)
- **Resp Alkalosis**
  - acute:
    - \( \Delta [\text{HCO}_3^-] = 0.2 \times \Delta pCO_2 \)
  - chronic:
    - \( \Delta [\text{HCO}_3^-] = 0.8 \times \Delta pCO_2 \)
Limits of Compensation
Metabolic Acidosis

- Pt bicarb is 7
  - $pCO_2 = 1.5(HCO_3^-) + 8 +/- 2$
  - $pCO_2 = 1.5(7) + 8 +/- 2$
  - $pCO_2 = 11 + 8 +/- 2$
  - Expected $pCO_2 = 19 +/- 2$

- Expected $pCO_2 = 19 +/- 2$
  - Pt $pCO_2$ is 17
    - This is as expected
  - Appropriate Respiratory Compensation

- 1. Check the numbers
- 2. Primary Disturbance
- 3. Limits of compensation
- 4. Anion Gap
- 5. Delta Gap
Sodium correction

- Sodium correction for hyperglycemia: add 1.6 to the sodium for each 100 above 100
- Baseline of 100
- 602 above this
  - 6.100s above
  - 6 X 1.6=9.6 (10)
  - Corrected sodium is 134

Anion Gap

- AG=Sodium - (Chloride + Bicarbonate)
- AG=134 - (95+ 7)
- Pt AG=32
- Normal AG is 8-12
- Anion Gap Metabolic Acidosis

Causes of Anion gap

- Methanol
- Uremia
- Dka
- Paraldehyde
- INH/ibuprofen
- Lactic acid
- Ethylene glycol
- Salicylate
- Ethylene glycol
- Lactic acid
- Methanol
- Paraldehyde
- ASA
- Renal failure
- Ketoacidosis
• 1. Check the numbers
• 2. Primary Disturbance
• 3. Limits of compensation
• 4. Anion Gap
• 5. Delta Gap
  – Tells us if more than one metabolic disturbance is present

**Anion Gap Metabolic Acidosis**

<table>
<thead>
<tr>
<th>Na⁺</th>
<th>Cl⁻</th>
<th>HCO₃⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal anion gap</td>
<td>Elevated anion gap</td>
<td>Anion Gap</td>
</tr>
</tbody>
</table>

**Delta Gap-Change in the Gap**

Measured Anion Gap-normal Anion Gap

<table>
<thead>
<tr>
<th>Na⁺</th>
<th>Cl⁻</th>
<th>HCO₃⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal anion gap</td>
<td>Elevated anion gap</td>
<td>Total Anion Gap</td>
</tr>
</tbody>
</table>

Each additional unmeasured anion decreases HCO₃⁻ by 1
Delta Gap
Measured gap - normal gap
• Pt anion gap=32
• Normal anion gap =10
• Delta Gap=32-10=22
  – Increase of anion gap over baseline # of extra anions
  – Number of extra anions

Delta Gap=22
• Normal HCO$_3^-$ is 24
• Dropping by 22 gives an expected HCO$_3^-$ of 2

Delta Gap
• expected HCO$_3^-$ is 2
• Pt HCO$_3^-$ is 7
• Metabolic Alkalosis
  – When HCO$_3^-$ is higher than expected
  – Metabolic alkalosis is due to volume depletion from osmotic diuresis from hyperglycemia
Primary Metabolic Acidosis-Compensated

Case summary

- Anion-Gap Metabolic acidosis from DKA
  - DKA from insulin omission
- Appropriate respiratory compensation
- Metabolic Alkalosis due to volume depletion

Treatment

- insulin and fluids
- Fluid resolves metabolic alkalosis
- On the next BMP, the anion-gap may decrease suggesting an improvement in the DKA but the Bicarb may drop as well making it look like the patient is worse
  - Be aware the bicarb dropped because the metabolic alkalosis resolved
Case 7

• 55 yr female with acute on 7 days of watery diarrhea, vomiting, and shock. Labored respirations so intubated due to respiratory distress
• Volume A/C: rate 18, tidal volume 400

Case 7

• Sodium 140, K+ 3.8, Bicarb 6, chloride 115, Creatinine 2
• 6.8/40/150/6
  pH/pCO2/paO2/HCO3-

Case 7

• Na+ 140, K+ 3.8, Bicarb 6, chloride 115, Creatinine 4
• 6.8/40/150/6
  pH/pCO2/paO2/HCO3-

• 1. Check the numbers
• 2. Primary Disturbance
• 3. Limits of compensation
• 4. Anion Gap
• 5. Delta Gap
Case 7

- Na+ 140, K+ 3.8, Bicarb 6, chloride 115, Creatinine 4
- 6.8/40/150/6 pH/pCO₂/pO₂/HCO₃⁻

1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap

Case 7-Primary Disturbance

- Metabolic Acidosis

1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap

- Look at pH, is it higher or lower than 7.4ish
  - pH is low-acidemia
- Then look at bicarb and pCO₂
  - bicarb is low-metabolic
**Rules of Thumb**

- **Metabolic Acidosis**
  - $pCO_2 = 1.5(HCO_3^-) + 8 \pm 2$
  - $pCO_2 = \Delta HCO_3^-$

- **Metabolic Alkalosis**
  - $40 + 0.6(\Delta[HCO_3^-]) \pm 4$
  - $pCO_2 = 1.5 HCO_3^- \times 0.5$

- **Resp Acidosis**
  - Acute: $\Delta[HCO_3^-] = 0.1 \times \Delta pCO_2$
  - Chronic: $\Delta[HCO_3^-] = 0.35 \times \Delta pCO_2$

- **Resp Alkalosis**
  - Acute: $\Delta[HCO_3^-] = 0.2 \times \Delta pCO_2$
  - Chronic: $\Delta[HCO_3^-] = 0.5 \times \Delta pCO_2$

**Limits of Compensation**

**Metabolic Acidosis**

- Pt $HCO_3^-$ is 6
- $pCO_2 = 1.5(HCO_3^-) + 8 \pm 2$
- $pCO_2 = 9 \pm 8 \pm 2$
- $pCO_2 = 17 \pm 2$

**Expected $pCO_2 = 17 \pm 2$**

- Pt $pCO_2$ is 40
  - This is higher than expected
- **Respiratory Acidosis**
  - Uncompensated respiratory acidosis
- Can happen in any metabolic acidosis
  - DKA
1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap

Anion Gap

- Na+ 140, K+ 3.8, Bicarb 6, chloride 115, Creatinine 4
- AG = Sodium - (Chloride + Bicarbonate)
- AG = 140 - (115 + 6)
- PtAG = 19
- Normal AG is 8-12
- Anion Gap Metabolic Acidosis

Causes of Anion gap

- Methanol
- Uremia
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- Paraldehyde
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- Lactic acid
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- Ethylene glycol
- Lactic acid
- Methanol
- Paraldehyde
- ASA
- Renal failure
- Ketoacidosis
Acid-Base Disorders so far

- Lactate 6.7
- Anion-gap Metabolic acidosis
  - Lactic acidosis
  - Some due to renal failure
- Acute respiratory acidosis
  - Inadequately set Minute Ventilation

1. Check the numbers
2. Primary Disturbance
3. Limits of compensation
4. Anion Gap
5. Delta Gap
  - Tells us if more than one metabolic disturbance is present

Anion Gap Metabolic Acidosis
Delta Gap
Measured Anion Gap - normal Anion Gap

- Delta Gap
  - Measured gap - normal gap
  - Pt anion gap = 19
  - Normal anion gap = 10
  - Delta Gap = 19 - 10 = 9
    - Increase of anion gap over baseline
    - # of extra anions
    - Number of extra anions
- Normal HCO$_3^-$ is 24
- Dropping by 9 gives an expected HCO$_3^-$ of 15
Delta Gap

• expected $\text{HCO}_3^-$ is 15
• Pt $\text{HCO}_3^-$ is 6
• Metabolic Acidosis-Non-Gap
  – When $\text{HCO}_3^-$ is lower than expected

Causes of Non-gap Metabolic Acidosis

• Kidney
  – RTA I, II, IV
  – cholestyramine

• Gut
  – diarrhea
  – ureterosigmoidostomy
  – pancreatic fistula
  – TPN

Case summary

• Anion-Gap Metabolic acidosis
  – Due to Lactate and renal failure

• Acute Respiratory Acidosis
  – From inadequate set Minute Ventilation on ventilator

• Non-Gap Metabolic Acidosis
  – Due to diarrhea
  – Due to renal tubular dysfunction
    • Can’t excrete $\text{NH}_4^+$
Treatment

- Fix the vent setting
- Fluids
- Bicarb
  - Not for the lactic acidosis
  - For the Non-Gap metabolic acidosis

Review

1. Check the numbers
2. Primary Disturbance
   - can use any disturbance and the primary
3. Limits of compensation
4. Anion Gap
   - Anion Gap and Non-Anion Gap Metabolic Acidosis
5. Delta Gap
   - Tells us if more than one metabolic disturbance is present
   - Tells us how many extra anions are present
   - Each anion drops bicarb by about 1

pH

- Reflects total amount of Hydrogen ions [H+]
- Henderson-Hasselbalch Equation
  \[ pH = pK + \log_{10} \left( \frac{A^-}{[H^+]} \right) \]
- Summation of:
  - All acid base disturbances in the body
Recommended Reading

- Understanding Acid Base
  - Benjamin Abelow
  - ISBN-10: 0683182722

Normal balance
pH 7.4

ROOT SLIDE
pH 7.4