# Acid Base Disorders

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# Objectives

- To provide a simple, systematic approach to interpreting arterial blood gas (ABG) samples.

- Multiple formulas and rules exist to help guide us through the forest of diagnoses and complex problems
- All that is needed is a little clinical information obtained from a history and physical examination, a few readily available laboratory tests, and the knowledge of five simple steps.

- Getting in the routine of performing these steps on each patient in which an ABG and electrolytes are performed will help decrease the rate of missed complex acid-base disturbances and hopefully improve patient care

# Five Steps of Acid-Base Analysis1-5

- **Step 1: _Acidemia_ (pH <7.38) or _alkalemia_ (pH >7.42)?**
- **Step 2**: **Primary respiratory or metabolic disturbance? (Look at PCO2 and pH)**
- **Step 3**: **Is there appropriate compensation for the primary disorder?**

  Metabolic acidosis: $PCO_2 = [1.5 \times (\text{serum } HCO_3)] + 8\ (\pm 2)$

  Metabolic alkalosis: $PCO_2$ =patient bicarbonate –24(normal bicarbonate ) ×.06

  Respiratory acidosis: ↑$PCO_2$ 10, ↑ $HCO_3$ by 1 (acute) or 4 (chronic)

  Respiratory alkalosis: ↓$PCO_2$ 10, ↓ $HCO_3$ by 2 (acute) or 5 (chronic)
- **Step 4**: **Is there an anion gap metabolic acidosis (AGMA)?** $AG = Na - (HCO_3 + Cl)$. If > 12, an AGMA is present.
- **Step 5**: **If metabolic acidosis, is there another concomitant metabolic disturbance?** 1- If AGMA, then calculate $\Delta Gap = \Delta AG - \Delta\ HCO_3 = (AG - 12) - (24 - HCO_3)$
- If # between 6 and -6 no combined others metabolic

  If the $\Delta$Gap is > 6, there is a combined AGMA and Metabolic Alkalosis.

  If the $\Delta$Gap is < -6, there is a combined AGMA and NAGMA.

  2- If NAGMA, for every 1 mEq/L ↑Cl, there should be a 1 mEq/L ↓ $HCO_3$ (+5).

  If $HCO_3$ decrease is less than predicted, then NAGMA and metabolic alkalosis.

# Five Steps of Acid-Base Analysis1-5

- **Step 1**: Acidemia (pH <7.38) or alkalemia (pH >7.42)?

# Five Steps of Acid-Base Analysis1-5

- **Step 2**: Primary respiratory or metabolic disturbance?
  (Look at PCO2 and pH.)

  If pH and PCO2 going in same direction
  Metabolic

  If pH and PCO2 going in different direction
  Respiratory

# Five Steps of Acid-Base Analysis1-5

- **Step 3**: Is there appropriate compensation for the primary disorder?
- **Metabolic acidosis**: PCO2 = [1.5 x (serum HCO3)] + 8 (±2)
- **Metabolic alkalosis**: ↑PCO2 = 0.6 x ↑HCO3 (±2)
- **Respiratory acidosis**: ↑PCO2 10, ↑ HCO3 by 1 (acute) or 4 (chronic)
- **Respiratory alkalosis**: ↓PCO2 10, ↓ HCO3 by 2 (acute) or 5 (chronic)

# Five Steps of Acid-Base Analysis1-5

- **Step 4**: Is there an anion gap metabolic acidosis (AGMA)?
- AG = Na - ($HCO_3$ + Cl).
- If > 12, an AGMA is present

# Five Steps of Acid-Base Analysis1-5

- **Step 5**: If metabolic acidosis, is there another concomitant metabolic disturbance?
- 1- If AGMA, then calculate $\Delta$Gap = $\Delta$AG – $\Delta$ HCO3 = (AG -12) – (24 – HCO3)
- If the $\Delta$Gap is > 6, there is a combined AGMA and metabolic alkalosis
- If the $\Delta$Gap is < -6, there is a combined AGMA and NAGMA.

# Five Steps of Acid-Base Analysis1-5

- 2-If NAGMA, for every 1 mEq/L ↑Cl, there should be a 1 mEq/L ↓ $HCO_3$ (+5).
- If $HCO_3$ decrease is less than predicted, then NAGMA and metabolic alkalosis

# Metabolic Acidosis

- In the presence of a pH < 7.38, metabolic acidosis is diagnosed as a primary condition when the pCO2 is < 40 mmHg or the bicarbonate is < 24 mEq/L.
- Metabolic acidosis can be further classified based on the presence of an anion gap.
- The anion gap reflects the balance between positively and negatively charged particles in the blood.

- Sodium is the only significant positively charge particle that is measured, while the measured anions are chloride and bicarbonate.
- Therefore, the anion gap is calculated by the formula:

  $Na - (Cl + HCO3)$.

- One potential pitfall in the measurement of the anion gap is patients with low albumin.
- Albumin has several negative charges on it and therefore, in a patient with a low albumin level, their “normal” anion gap might be much lower than 12.
- For every 1 gram drop in serum albumin level, the anion gap decreases by 2.5.
- A patient with a calculated anion gap of 10 and a 2 gram drop in their albumin may actually have an anion gap metabolic acidosis (recalculated AG 15).

- Anion Gap Metabolic Acidosis (AGMA) Detection of an AGMA is important because only a few conditions commonly cause it.
- In addition, in mixed acid-base disorders, an elevation in the anion gap may be the only signal that a metabolic acidosis is present.
- The causes of an AGMA are divided into four main categories:

  renal failure, ketoacidosis, toxins, and lactic acidosis

# Metabolic acidosis

- **<u>A CAT MUDPILES</u>**:
- Analgesics (massive NSAID, acetaminophen) o
- Cyanide, Carbon monoxide
- Arsenic, Alcoholic ketoacidosis
- Toluene o Methanol, Metformin o
- Uremia o Diabetic ketoacidosis
- Paraldehyde, Phenformin
- Iron, Isoniazid
- Lactic acidosis
- Ethylene glycol
- Salicylates

- In any patient with an AGMA, calculate an osmol gap.
- Osmol gaps are a clue to a potentially life-threatening toxic alcohol ingestion (ie. ethylene glycol and methanol).
- The osmol gap is determined by subtracting the calculated osmolality from the measured osmolality.
- Calculated osmolality = 2(Na) + Glc/18 + BUN/2.4 + ETOH/4.6

***32 year old man with depression and alcohol abuse presents with altered* mental status.**

- ABG: pH 6.9, $pCO_2$ 29, $pO_2$ 100
- Metabolic panel: Na 140, Cl 101, $HCO_3$ 5

- **Step 1**: Acidosis
- **Step 2**: Metabolic
- **Step 3**: $pCO2 = 1.5(HCO3) + 8 = 15$, but the patient's pCO2 is higher than 15. Therefore, a respiratory acidosis is also present, possibly secondary to CNS depression.
- **Step 4**: AG = 140 – (101 + 5) = 34
- **Step 5**: Delta gap = (34-12) – (24-5) = 3. No additional metabolic disorders other than AGMA.
- **Answer: Anion gap metabolic acidosis and respiratory acidosis. The patient had an osmol gap of 174 and a methanol level of 510 mg/dL**.

## Non-Anion Gap Metabolic Acidosis (NAGMA)

- A NAGMA is due to either GI or renal losses of bicarbonate.
- If desired, GI mediated and renally mediated losses can be distinguished by obtaining urine electrolytes (ie. Na, K, and Cl) and calculating the urine anion gap.
- The urine anion gap : Na + K - Cl
- The urine anion gap is the difference between the spot urine positive ions and spot urine negative ions.
- If an excess of negatively charged ions is present, the acidemia is due to the kidney

- **A 68 year old man who recently took antibiotics for a skin infection presents with 10 episodes of watery diarrhea per day for the last 5 days**.
- ABG: pH 7.34, $pCO_2$ 34, $pO_2$ 80
- Metabolic panel: Na 135, Cl 108, $HCO_3$ 18

**Step 1**: Acidosis

- **Step 2**: Metabolic
- **Step 3**: $pCO_2 = 1.5(HCO_3) + 8 = 35$
- **Step 4**: AG = 135 – (108 + 18) = 9
- **Step 5**: Cl ↑ by 8 and $HCO_3$ ↓ by 6; therefore there is no metabolic alkalosis.
- **Answer: NAGMA due to diarrhea**

# Respiratory acidosis

- Respiratory acidosis is characterized by an elevation in the $pCO_2$ and a decrease in blood pH due most commonly to hypoventilation.
- It results from conditions that decrease the ability of the lungs to excrete carbon dioxide at a rate to keep up with the body's production.

- **A differential diagnosis includes**:
- Central nervous system depression (sedatives, CNS disease, sleep apnea)
- Pleural disease (large pneumothorax or pleural effusion)
- Lung disease (ARDS, COPD, pulmonary edema, severe pneumonia)
- Acute airway obstruction (laryngospasm, sleep apnea)
- Neuromuscular disorders (GBS, myasthenia gravis, botulism)
- Thoracic cage injury (flail chest)
- Ventilator dysfunction

- The kidney compensates for primary respiratory acidosis by retaining bicarbonate.
- This compensation occurs over hours to days and is generally at a maximum within four days.
- The rate of onset of respiratory acidosis can be determined by the degree of renal compensation (increase in HCO3) as listed above in step 3.

- Alternatively, the chronicity of the respiratory acidosis can be predicted by the change in the pH.
- In acute respiratory acidosis, the pH decreases by 0.08 units for each increase of 10 mmHg in the $pCO_2$ from its baseline of 40 mmHg.
- Chronic respiratory acidosis is marked by a decrease in the pH of 0.03 units for every increase of 10 mmHg in the $pCO_2$.

- Differentiating acute from chronic respiratory conditions can have important clinical implications that may alert the clinician to a patient that is rapidly spiraling downward and might require emergent intubation, from a patient who has chronic disease, but is in less danger of imminent decompensation

- ***A 70 year-old smoker presents with an acute onset of shortness of breath.***
- ABG: pH 7.30, $pCO_2$ = 60 mmHg, $pO_2$ 60 mmHg
- Metabolic panel: Na 135, Cl 100, $HCO_3$ 30

- **Step 1**: Acidosis
- **Step 2**: Respiratory
- **Step 3**: Acute on chronic. $pCO_2$ increased by 20, therefore the $HCO_3$ should increase by 2 if acute and 8 if chronic. Because the $HCO_3$ increased from 24 to 30 (6), an acute on chronic respiratory acidosis is present.
- **Step 4:** AG = 135-(100+26) = 9. No anion gap metabolic acidosis
- **Step 5**: XX
- **Answer: Acute on chronic respiratory acidosis due to COPD exacerbation**

# Metabolic alkalosis

- Metabolic alkalosis is characterized by an increase in the serum bicarbonate concentration.
- **The causes of metabolic alkalosis are :**
- Volume contraction (vomiting, NG suction, loop or thiazide diuretics).
- Excess glucocorticoids or mineralocorticoids (eg, Cushing’s syndrome).
- Hypokalemia
- Bartter’s syndrome.
- Alkali ingestion/infusion.
- Post-hypercapnic alkalosis

- To differentiate the most common cause  of metabolic alkalosis which is volume depletion from other causes you need to measure urine chloride
- If urine chloride lees than 10 this due to volume depletion(saline respnce)
- If urine chloride more than 10 this due to other causes (saline resistance)

- ***Example 4:***
- ***A 20 year old student presents with excessive vomiting after binge drinking.***
- ABG: pH 7.50, $pCO_2$ 44, $pO_2$ 100
- Metabolic panel: Na 138, Cl 100, $HCO_3$ 30

- **Step 1**: Alkalosis
- **Step 2**: Metabolic
- **Step 3**: Increase in $pCO_2$ should equal 0.6 multiplied by the elevation of the $HCO_3$ ±2.
- The increase of the $pCO_2$ of 4 is within two of 6(0.6) or 3.6; therefore there is appropriate compensation.
- **Step 4**: AG = 138 – (100 + 30) = 8
- **Step 5**: XX
- **Answer: Metabolic alkalosis secondary to vomiting**

# Respiratory alkalosis

- Respiratory alkalosis is characterized by a decrease in the $pCO_2$ and an elevation in the blood pH.
- The $pO_2$ can be used to distinguish between disease of the lungs and other causes of hyperpnea (eg, fever)

- **<u>The causes of a primary respiratory alkalosis include:</u>**
- CNS disease (CVA) o Toxins (Salicylates)
- High altitude
- Severe anemia
- Pregnancy
- Lung disease/hypoxia (asthma, pneumonia, PE, pulmonary edema, pulmonary fibrosis)
- Anxiety o Cirrhosis of the liver
- Fever (Sepsis)
- Ventilator dysfunction

- ***A 22 year-old woman presents with 4 hours of numbness in both hands typical***
- of previous episodes of anxiety.
- ABG: pH 7.48, $pCO_2$ 30 mmHg, $pO_2$ 86 mmHg
- Metabolic panel: Na 140, Cl 110, $HCO_3$ 22

- **Step 1**: Alkalosis
- **Step 2**: Respiratory
- **Step 3**: Acute. Drop in the $pCO_2$ by 10 corresponds to a drop in the $HCO_3$ by 2 if acute and 5 if chronic. 24-22 = 2 and therefore, as would be expected by the clinical history, an acute disorder is diagnosed.
- **Step 4**: AG 140-(110+22) = 8
- **Step 5**: XX
- **Answer: Acute respiratory alkalosis secondary to a panic attack**

# Practice Cases

- CASE 1
- 40 Year old male Patient Complaining of Abdominal Pain
- pH 7.42 pCO2 33
- Na 141 HCO3 24
- Cl 90

- CASE 2
- Chronic alcoholic is brought to emergency department vomiting and abdominal pain
- $Na^+$ =137 PH = 7.40
- $K^+$ = 3.8 $PCO_2$ = 41
- $Cl^-$ = 90 $HCO_3$ = 22

- CASE 3
- A diabetic presents with diarrhea and cough.
- CXR reveals an infiltrate.
- pH 7.31 pCO2 10
- Na 123 HCO3 5
- Cl 99

- CASE 4
- An alcoholic presents with vomiting.
- pH 7.20    $pCO_2$ 25
- Na 130    $HCO_3$ 10
- Cl 80

- CASE 5
- A man with arthritis presents with confusion, shortness of breath, and diaphoresis.
- pH 7.30 pCO2 18
- Na 147 HCO3 16
- Cl 108

- CASE 6
- A patient with COPD presents with shortness of breath.
- pH 7.18      $pCO_2$ 80
- Na 135      $HCO_3$ 30
- Cl 93

- CASE 7
- A woman with Crohn’s disease presents with fever, vomiting, and diarrhea.
- pH 7.36 $pCO_2$ 22
- Na 147 $HCO_3$ 14
- Cl 121

- CASE 8
- A noncompliant patient with diabetes and cirrhosis presents with vomiting.
- pH 7.46     $pCO_2$ 17
- Na 133      $HCO_3$ 15
- Cl 84

**Case 9 A health care professional present with dizziness**

| | |
|---|---|
| Na = 123 | pH = 7.55 |
| k+ = 3.1 | $pCO_2$ = 50 |
| Cl- = 67 | $HCO_3$ = 43 |
| $HCO_3$ = 42 | |
| Glu = 125 | |
| BUN = 25 | |

Case 10

A 25 year old man is brought to ED comatose by paramedic. There was no response in the field to D50 and Narcan

| | |
|---|---|
| $Na^+ = 141$ | pH = 4.40 |
| $K^+ = 4.0$ | $pCO_2 = 40$ |
| Cl = 103 | $pO_2 = 84$ |
| $HCO_3 = 25$ | $HCO_3 = 25$ |
| Glu = 90 | |
| Bun = 14 | |

Urine Dip : large ketone

Measured Osmolarity of 338

QUESTION