Arterial Blood Gas Interpretation

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Disclosures

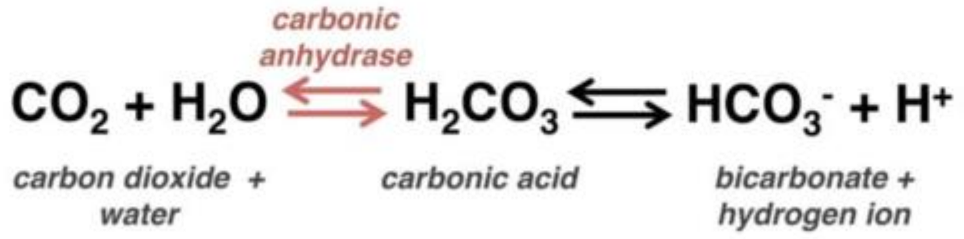
- None

Objectives

1. Recall the six steps in interpreting an ABG
2. Understand how to tell which disorder is the primary disorder in a mixed acid-base disorder when the PaC02 and HC03 change in the same direction
3. Describe the evaluation of a high anion gap acidosis and know several causes of high AG acidosis using the mnemonic GOLD MARRK. Understand the importance of correcting the anion gap for albumin and measuring a serum osmolar gap
4. Describe the evaluation of a normal anion gap acidosis and list several causes
5. Describe the uses of the urinary anion gap and know when the urine anion gap is unreliable
6. Describe the evaluation metabolic alkalosis and list several causes

Introduction

- Homeostasis: Acid base status is tightly regulated and is fundamental for maintaining normal biochemical reactions and organ function
- Abnormalities are extremely common in hospitalized patients with a higher incidence in critically ill with more complex pictures
- A standard approach to analysis can help guide diagnosis and treatment



Acidemia	Alkalemia
A state of low blood pH (< 7.35)	A state of high blood pH (> 7.45)
Acidosis	**Alkalosis**
A process tending to acidify body fluids	A process tending to alkalinize body fluids
Metabolic	**Respiratory**
Relating to gain/loss of acid or bicarbonate (HCO_3^-)	Relating to gain/loss of carbon dioxide (CO_2)
Acute	**Chronic**
Occurring over minutes to hours	Occurring over days

Steps for Interpretation of Acid base disorders

1. Is there Acidemia or Alkalemia (pH)?
2. Is the PCO2 explain the change in pH? (Same direction=Metabolic)
3. Does this change fully explain the pH? (Evaluate compensation)
4. Is there an anion gap?
5. What is the Delta-Delta gap?
6. What is the osmolar Gap?
7. Interpretation

Example 1

pH	PCO2	$HCO3^-$
7.32	60	25

1. Is there Acidemia or Alkalemia (pH)?

Acidemia

2. Does the PCO2 explain the change in pH? (same direction=metabolic)

Opposite = Respiratory Acidosis

Example 2

pH	PCO2	$HCO3^-$
7.50	46	34

1. Is there Acidemia or Alkalemia (pH)?

Alkalemia

2. Does the PCO2 explain the change in pH? (same direction=metabolic)

Same direction = Metabolic Alkalosis

Example 3

pH	PCO2	$HCO3^-$
7.15	30	10

1. Is there Acidemia or Alkalemia (pH)?

Acidemia

2. Does the PCO2 explain the change in pH? (same direction=metabolic)

Same direction = Metabolic Acidosis

Step 3: Compensation

Disorder	**Compensation**
Metabolic Acidosis ↓ $HCO3^-$ → ↓ pH	Respiratory Alkalosis (rapid) ↑ Minute ventilation→ ↓PCO2→ ↑pH
Metabolic Alkalosis ↑ $HCO3^-$ → ↑ pH	Respiratory Acidosis (rapid) ↓ Minute ventilation→ ↑PCO2→ ↓pH
Respiratory Acidosis ↑PCO2→ ↓pH	Metabolic Alkalosis (slow) ↑ $HCO3^-$ → ↑ pH
Respiratory Alkalosis ↓PCO2→ ↑pH	Metabolic Acidosis (slow) ↓ $HCO3^-$ → ↓ pH

Compensation Calculation

Disorder	Compensation Formula
Metabolic Acidosis	Expected PCO_2 (± 2) = 1.5 $[HCO_3^-]$ + 8 (Winter's formula)
Metabolic Alkalosis	Exp. PCO_2 (± 2) = $[0.7 \times (HCO_3^- - 24)] + 40$
Respiratory Acidosis	Acute: $[HCO_3^-] \approx 24 + \{ (PaCO_2 - 40) / 10 \}$ Chronic: $[HCO_3^-] \approx 24 + 4 \{ (PaCO_2 - 40) / 10 \}$
Respiratory Alkalosis	Acute: $[HCO_3^-] \approx 24 - 2 \{ (40 - PaCO_2) / 10 \}$ Chronic: $[HCO_3^-] \approx 24 - 5 \{ (40 - PaCO_2) / 10 \}$

Metabolic Disorders: Simpler Compensation

- $PaCO_2$ (mmHg) is approximately the same as two digits of the pH after the decimal
- This is a good estimation compared to the formulae used for compensation and much easier to use at the bed side

pH	PCO2	HCO_3^-
7.27	26	12

pH	PCO2	HCO_3^-
7.50	49	33

Respiratory Disorders: Simpler Compensation

	HCO3 (Baseline 24 mmol/L)	
Every **10 mmHg** change in PaCO2 from *baseline* 40 mmHg	ACUTE	CHRONIC
↑PaCO2	**1**	**4**
↓PaCO2	**2**	**5**

Example 4

55-year-old male with COPD and Obesity hypoventilation syndrome

pH	PCO2	$HCO3^-$
7.33	60	32

	HCO3 (Baseline 24 mmol/L)	
Every **10 mmHg** change in PaCO2 from *baseline* 40 mmHg	ACUTE	CHRONIC
↑PaCO2	**1**	**4**
↓PaCO2	**2**	**5**

1. Is there Acidemia or Alkalemia (pH)?

Acidemia

2. Does the PCO2 explain the change in pH? (same direction=metabolic)

Different direction = Respiratory Acidosis

3. Does this change fully explain the pH? (Evaluate compensation)

YES

24 +8 = 32. Expected HCO3- increase for Chronic respiratory acidosis by 8

Respiratory Acidosis with metabolic compensation

Example 5

pH	PCO2	$HCO3^-$
7.25	35	12

1. Is there Acidemia or Alkalemia (pH)?

Acidemia

2. Does the PCO2 explain the change in pH? (same direction=metabolic)

Same direction = Metabolic Acidosis

3. Does this change fully explain the pH? (Evaluate compensation)

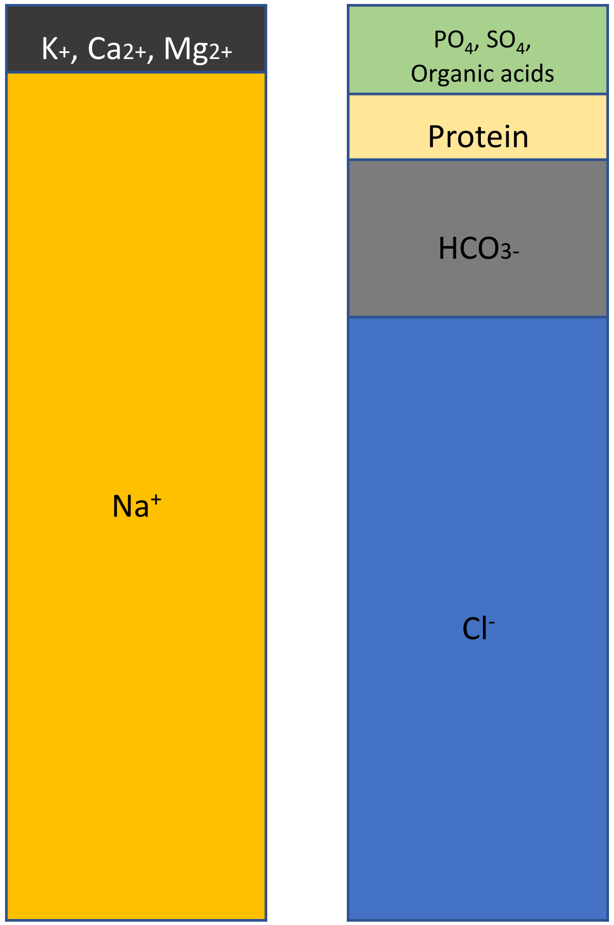
(1.5 [12]) + 8 = 26 (expected PCO_2) NO

2nd disorder : Respiratory Acidosis

Metabolic and Respiratory Acidosis

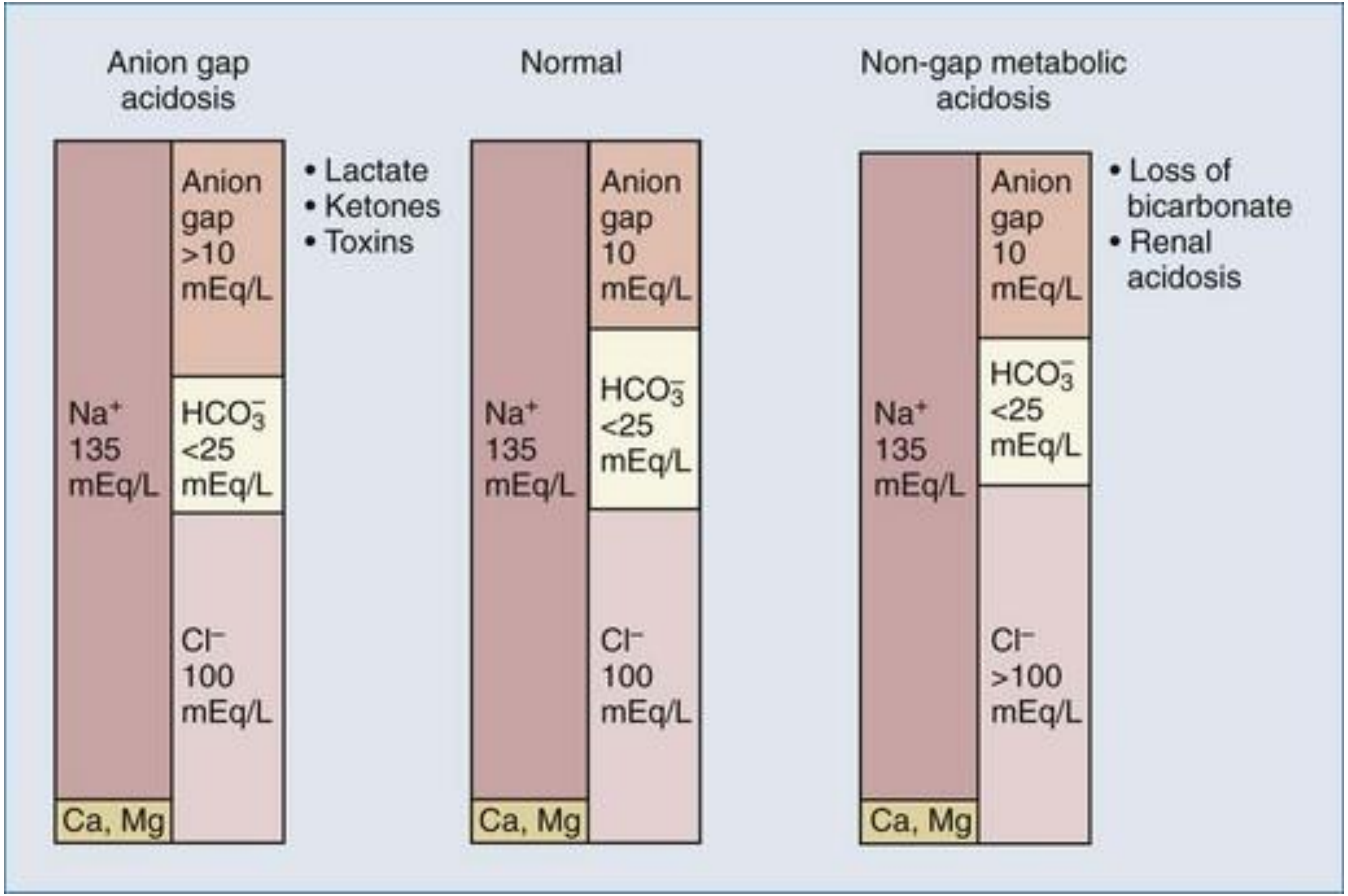
Step 4: Anion Gap

Cations	mEq/L	Anions	mEq/L
Na^{+}	138	Cl^{-}	100
K^{+}	4	HCO_3^{-}	25
Ca^{2+}	4	Protein	15
Mg^{2+}	2	Phosphate	2
		Sulfate	1
		Organic acids	5
Total cations	~148	Total anions	~148



Anion Gap (normal 6-12 mEq/l) : $Na^{+} - Cl^{-} + HCO_3^{-}$

Adjusted AG = AG + 2.5 (4 - Albumin)



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High Anion Gap Metabolic Acidosis (HAGMA)

M: methanol
U: uremia
D: diabetic ketoacidosis (DKA)
P: phenformin, paraldehyde
I : INH, iron
L: lactic acid
E: ethanol, ethylene glycol
S: salicylates

G: glycols (propylene glycol and ethylene glycol)
O: 5-oxoproline (associated with acetaminophen use)
L : L-lactate
D: D-lactate (short bowel syndrome)
M: methanol
A: aspirin
R: renal failure
K: ketoacidosis (diabetic/alcohol/starvation)

Example 6

pH	PCO2	HCO_3^-
7.28	24	12

Sodium	128
Potassium	3.8
Chloride	94
Bicarbonate	12
Albumin	4
Glucose	120

1. Is there Acidemia or Alkalemia (pH)?

Acidemia

2. Does the PCO2 explain the change in pH? (same direction=metabolic)

Same direction = Metabolic Acidosis

3. Does this change fully explain the pH? (Evaluate compensation) YES. 1.5 x 12 +8 = 26

4. Is there an anion gap?

YES AG= Na – (Cl- + HCO3-) = 22

Anion Gap Metabolic Acidosis

Step 5: Delta-Delta gap

Delta gap = $\frac{\Delta AG - \Delta HCO_3^-}{\quad}$

Or

$\Delta AG + HCO_3^- = 24\ (\pm 6)$

- Assumes that as AG increases, bicarbonate drops in a 1:1 ratio
- Tries to back track in time to when the patient did not have an anion gap that was high
- Used to diagnose concurrent metabolic disorders but tends to over diagnose metabolic alkalosis and underdiagnose non-anion gap metabolic acidosis

Example 7

76 yo F presents to ED with fever and severe diarrhea. HR 135, BP 80/40, RR 36 Temp 39 C

pH	PCO2	$HCO3^-$
7.23	24	10

Sodium	128
Potassium	3.2
Chloride	100
Bicarbonate	10
Albumin	4
Glucose	110

1. Is there Acidemia or Alkalemia (pH)?

Acidemia

2. Does the PCO2 explain the change in pH? (same direction=metabolic)

Same direction = Metabolic Acidosis

3. Does this change fully explain the pH? (Evaluate compensation)

YES. 1.5 x 10 +8 = 23 (expected PCO2)

4. Is there an anion gap?

YES, AG = Na – (Cl^- + $HCO3^-$) = 18

5. What is the delta gap?

Delta Gap: ΔAG + HCO3- = 24 (± 6)

(18-12) + 10 = 16

metabolic acidosis prior to AGMA

7. Anion Gap metabolic acidosis and Non-Anion Gap Metabolic Acidosis

Step 6: Serum Osmolar Gap

- Usually check unexplained AGMA, suspected toxic ingestion or coma
- Measured – Calculated osmolarity = >10 mOsm/kg
- Calculated Osmolarity = 2(Na) + glucose/18 + BUN/2.8 + (ethanol/3.8)

- >10 mOsm/kg is suspicious for presence of toxic alchol ingestion such as methanol, ethylene glycol or propylene glycol

Example 8

42 y/o alcoholic M is found down soiled in vomit.

pH	PCO2	$HCO3^-$
7.17	65	22

Sodium	136
Potassium	3.4
Chloride	98
Bicarbonate	22
Albumin	2
Glucose	85
Osmolarity	307
Blood alcohol level	0
BUN	30

1. Is there Acidemia or Alkalemia (pH)?

Acidemia

2. Does the PCO2 explain the change in pH? (same direction=metabolic)

Opposite direction = Respiratory Acidosis

3. Does this change fully explain the pH? (Evaluate compensation)

No. assuming acute process expect HCO3 is 26. Metabolic acidosis

4. Is there an anion gap?

YES, AG = Na – (Cl^- + $HCO3^-$) = 16

Corrected AG = Meas AG +2.5 (4-alb) - >16 + 5= 21. AGMA

5. What is the delta gap?

Delta Gap: ΔAG + HCO3- = 24 (± 6)

(21-12) + 22 = 31 Metabolic Alkalosis

6. What is the osmolar gap? Calculated Osmolarity = 2(Na) + glucose/18 + BUN/2.8 + (ethanol/3.8)

2 x 136 + 85/18 + 30/2.8 = **287** 307 – 287= 20

7. Respiratory acidosis, Anion-gap metabolic acidosis and metabolic alkalosis. High osmolar gap suspicious for toxic alcohol ingestion

Urine Anion Gap (UAG)

- Used to identify cause of non-anion gap metabolic acidosis
- Used as a surrogate to measure urinary ammonium
- Urine Anion Gap = $[Na^+] + [K^+] – [Cl^-]$
  - Normally negative but become positive with excretion of urinary $NH4^+$
- Unreliable in polyuria, urine pH>6.5, penicillin derived abx, ASA and if Urine Na is <20. Can use urine osmolar gap in these cases to estimate urinary ammonium

Non-anion Gap Metabolic Acidosis

UAG negative

- GI causes such as diarrhea, laxative abuse
- Ureteral diversion
- Type 2 (proximal) RTA

UAG positive

- Type 1 (distal) RTA
- Type 4 (aldosterone) RTA
- CKD

Questions/Comments?

Example

pH	PCO2	HCO3$^-$
7.56	22	22

Sodium	142
Potassium	3.2
Chloride	100
Bicarbonate	22

A 76-year-old man is evaluated in the ED for confusion, unsteady gait, tinnitus, nausea and vomiting. His family has noticed progressive functional decline over the past 2 weeks. History is significant for osteoarthritis. His only medication is aspirin.

On exam, the patient is tachypneic and obtunded. Temperature is normal, blood pressure is 140/68 mm Hg, pulse rate is 96/min, respiration rate is 30/min, and oxygen saturation is 99% breathing room air. The neuro exam is non-focal.

Steps

1. Is there acidemia or alkalemia?
    - Alkalemia: 7.56
- Does the $pC02$ explain the pH?
    - YES. The $pC02$ explains the pH.
    - Opposite directions: This is a respiratory alkalosis
- Is the bicarbonate expected for the degree of chronic respiratory alkalosis? i.e Assess compensation
    - For each 10 **decrease** in $pC02$, the $HC03$ **increases** by 4-5
    - $pC02$ 40 (normal) – $pC02$ 22 (measured) = 18
    - Normal bicarbonate – Expected compensation = Expected bicarbonate
    - 24 – (2x5) = 14
    - His serum bicarb is 22, (above expected 14) indicating a metabolic alkalosis in addition to respiratory alkalosis
- Is there an anion gap?
    - 142 – (100 + 22) = 20
    - YES, the anion gap is 20
- What is the delta gap?
    - Patient AG (20) – Normal AG (10) = 10
- What is the corrected bicarbonate (what was the bicarbonate before the anion gap acidosis occurred?)
    - Bicarb (22) + Delta gap (10) = 32
    - The bicarb was 32 before the AG metabolic acidosis occurred,
    - Therefore, was a metabolic alkalosis before the anion gap occurred
- Alternatively, $\Delta AG + HCO3^- = 24 (\pm 6)$
    - 10+22 = 32 which is 8 greater than 24 suggesting a metabolic alkalosis.

Interpretation

- Respiratory alkalosis combined with anion gap metabolic acidosis and metabolic alkalosis

- The respiratory alkalosis is likely due to tachypnea with stimulation of central nervous system respiratory center by salicylate toxicity. The anion gap metabolic acidosis is also due to salicylate toxicity, and the metabolic alkalosis is due to vomiting.