Acid-Base Disorders: Student Handout

Andrew Bland, MD, FACP, FAAP

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Acid-Base Disorders: A Student Guide to Blood Gas Interpretation

Learning Objectives

- Interpret arterial blood gases systematically
- Distinguish primary disorders from compensation
- Calculate anion gap and identify mixed disorders
- Apply Winter's formula and other compensation rules
- Approach complex acid-base cases confidently

Fundamental Concepts

pH Basics

- **Acidemia:** pH <7.40
- **Alkalemia:** pH >7.40
- **Acidosis:** The underlying PROCESS causing acidemia
- **Alkalosis:** The underlying PROCESS causing alkalemia

Critical: You can have acidosis WITHOUT acidemia (if something else compensates)

The Bicarbonate System (Foundation of Everything)

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Key insight: This is an OPEN system - Lungs eliminate CO_2 (respiratory component) - Kidneys excrete/retain HCO_3^- (metabolic component) - When system becomes CLOSED (respiratory failure), severe acidosis develops rapidly

Normal Values

- **pH:** 7.35-7.45
- **PCO_2:** 35-45 mmHg (respiratory control)
- **HCO_3^-:** 22-26 mEq/L (metabolic control)

The Systematic ABC Approach

Step A: Assess pH

- Is it <7.40 (acidemia) or >7.40 (alkalemia)?
- This tells you the DIRECTION of the primary problem

Step B: Identify Primary Disorder

Check **HCO_3☐ and PCO_2** together to determine what matches the pH direction:

If ACIDEMIA (pH <7.40), look for: - ☐ HCO_3☐ (<22) = **Metabolic acidosis** (primary) - ☐ PCO_2 (>45) = **Respiratory acidosis** (primary)

If ALKALEMIA (pH >7.40), look for: - ☐ HCO_3☐ (>26) = **Metabolic alkalosis** (primary) - ☐ PCO_2 (<35) = **Respiratory alkalosis** (primary)

Critical rule: Compensation is ALWAYS INCOMPLETE. If compensation appears complete or excessive, suspect a SECOND disorder.

Step C: Assess Compensation (Use Formulas!)

For **Metabolic Acidosis** ☐ Respiratory Compensation (Winter's Formula):

$$\text{Expected } PCO_2 = 1.5 \times [HCO_3^-] + 8 \pm 2$$

Example: HCO_3☐ = 10 - Expected PCO_2 = 1.5(10) + 8 ± 2 = 23 ± 2 ☐ 21-25 mmHg - If actual PCO_2 is 28 ☐ inadequate respiratory compensation (concurrent respiratory problem) - If actual PCO_2 is 18 ☐ appropriate compensation ☐

For **Metabolic Alkalosis** ☐ Respiratory Compensation:

$$PCO_2 \text{ increases by } 0.7 \text{ mmHg per } 1 \text{ mEq/L rise in } HCO_3^-$$

For **Respiratory Acidosis** (☐PCO_2) ☐ Metabolic Compensation: - **Acute:** HCO_3☐ rises by 1 mEq/L per 10 mmHg rise in PCO_2 - **Chronic:** HCO_3☐ rises by 3.5 mEq/L per 10 mmHg rise in PCO_2

For **Respiratory Alkalosis** (☐PCO_2) ☐ Metabolic Compensation: - **Acute:** HCO_3☐ drops by 2 mEq/L per 10 mmHg drop in PCO_2 - **Chronic:** HCO_3☐ drops by 5 mEq/L per 10 mmHg drop in PCO_2

Remember: Respiratory changes happen in MINUTES. Renal compensation takes DAYS.

Step D: Calculate Anion Gap

Formula:

$$AG = Na^+ - (Cl^- + HCO_3^-)$$

Normal: 8-12 mEq/L (varies by lab; check YOUR lab's normal)

Elevated AG (>12): Means unmeasured anions present (organic acids accumulating)

Narrow AG (<8): Unusual; suggests hypoalbuminemia, myeloma, or specific toxins

Clinical pearl: Albumin correction - Each 1 g/dL drop in albumin below 4 g/dL ☐ AG decreases by ~2.5 mEq/L - In ICU (hypoalbumemic patients) ☐ ALWAYS correct AG for albumin

High-Yield Disorders: Anion Gap Metabolic Acidosis

MUDPILES Mnemonic

- **M:** Methanol
- **U:** Uremia (kidney failure)
- **D:** DKA (Diabetic ketoacidosis)
- **P:** Propylene glycol (from IV Ativan!)
- **I:** Isoniazid, Iron
- **L:** Lactic acidosis
- **E:** Ethylene glycol
- **S:** Salicylates (aspirin overdose)

Most Common in Practice

1. **Lactic acidosis** (shock, sepsis, hypoxemia)
2. **DKA** (diabetes out of control)
3. **Uremia** (kidney failure)
4. **Methanol/ethylene glycol** (toxic ingestions)

Non-Anion Gap Metabolic Acidosis

When AG is normal but HCO_3☐ is low ☐ the body is losing bicarbonate or retaining acid

Diagnosis: Check URINARY ANION GAP (UAG)

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UAG = (Urine Na⁺ + Urine K⁺) − Urine Cl⁻
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Interpretation: - **Negative UAG:** Kidney producing ammonia appropriately (losing ammonium) ☐ extrarenal cause - **Positive UAG:** Kidney NOT producing ammonia (renal cause)

USED CARP Mnemonic

Negative UAG (kidney works fine, GI problem): - **U:** Ureterosigmoidostomy - **S:** Small bowel fistula - **E:** Extra chloride (NS administration) - **D:** Diarrhea (most common)

Positive UAG (kidney problem): - **C:** Chronic renal failure - **A:** Acetazolamide, Addison's disease - **R:** Renal tubular acidosis (RTA) - **P:** Protein overfeeding

Detecting Mixed Disorders

The Delta/Delta Ratio

Used when you suspect MULTIPLE metabolic problems in anion gap acidosis:

```
Δ AG = Measured AG − Normal AG (10)
Δ HCO₃⁻ = Normal HCO₃⁻ (24) − Measured HCO₃⁻
Ratio = Δ AG / Δ HCO₃⁻
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Interpretation: - **Ratio <1:** HCO_3□ dropped MORE than expected □ concurrent non-AG acidosis - **Ratio 1-2:** Pure AG acidosis (appropriate) - **Ratio >2:** HCO_3□ didn't drop as much as expected □ concurrent metabolic alkalosis

Potential Bicarbonate Method

Alternative approach:

$$\text{Potential } HCO_3^- = \text{Measured } HCO_3^- + (\text{Measured AG} - 10)$$

Interpretation: - **<22:** Suggests concurrent NAGMA - **22-26:** Pure AG acidosis - **>26:** Suggests concurrent metabolic alkalosis

SGLT2 Inhibitor-Associated DKA (Emerging!)

Know this for exams: - SGLT2 inhibitors can cause DKA at mild-moderate hyperglycemia - DKA without severe hyperglycemia (glucose <200) - High anion gap with normal HCO_3□ initially - Risk factors: Type 1 diabetes, surgery, illness - Management: Hold SGLT2i, treat with IV fluids + insulin

Clinical Cases: Putting It Together

Case 1: Severe Sepsis with Shock

ABG: pH 7.15, PCO_2 22, HCO_3□ 8, Lactate 8

Analysis: 1. pH 7.15 □ **Acidemia** 2. HCO_3□ 8 (low) □ **Metabolic acidosis** (primary) 3. Winter's formula: Expected $PCO_2 = 1.5(8) + 8 \pm 2 = 20 \pm 2$ □ 18-22 mmHg - Actual 22 □ **appropriate respiratory compensation** □ 4. AG = 140 - (110 + 8) = 22 (**elevated**) 5. **Diagnosis:** High AG metabolic acidosis with appropriate respiratory response 6. **Cause:** Likely lactic acidosis from shock 7. **Management:** Aggressive fluid resuscitation, antibiotics, vasopressors

Case 2: DKA with Concurrent Infection

ABG: pH 7.10, PCO_2 28, HCO_3□ 9, Glucose 450, β-hydroxybutyrate 4.2

Analysis: 1. **Acidemia** (pH 7.10) 2. **Metabolic acidosis** (HCO_3□ 9) 3. Winter's formula: Expected $PCO_2 = 1.5(9) + 8 \pm 2 = 21.5 \pm 2$ □ 19-24 mmHg - Actual 28 □ **inadequate respiratory compensation** (higher than expected!) 4. **Interpretation:** There's a **concurrent respiratory acidosis** or the respiratory center is depressed 5. **Possible causes:** Concurrent pneumonia, pulmonary edema, CNS depression 6. **Management:** Aggressive insulin, fluids, monitor respiratory status closely

Quick Reference: What Changes With Each Disorder

Disorder	pH	HCO_3□	PCO_2
Met Acidosis	□	□	□ (compensate)
Met Alkalosis	□	□	□ (compensate)
Resp Acidosis	□	□ (compensate)	□
Resp Alkalosis	□	□ (compensate)	□

Disorder	pH	HCO_3☐	PCO_2

Practice Questions

Q1: ABG shows pH 7.32, HCO_3☐ 15, PCO_2 38. Calculate if compensation is appropriate.

Answer

Using Winter's formula: Expected $PCO_2 = 1.5(15) + 8 \pm 2 = 30.5 \pm 2$ ☐ 28-33 mmHg. Actual PCO_2 is 38, which is HIGHER than expected. This indicates inadequate respiratory compensation, suggesting a concurrent respiratory acidosis or respiratory problem. The patient has metabolic acidosis PLUS respiratory acidosis = mixed disorder.

Q2: A patient with advanced COPD has pH 7.25, HCO_3☐ 28, PCO_2 65. What's happening?

Answer

Respiratory acidosis (PCO_2 high). HCO_3☐ is 28 (elevated), which is appropriate renal compensation for chronic hypercapnia. However, with pH still 7.25, the patient is acidemic—the compensation isn't enough. This is chronic respiratory acidosis from COPD exacerbation. Treatment: oxygen, bronchodilators, consider BiPAP, treat infection.

Q3: ABG: pH 7.28, HCO_3☐ 12, PCO_2 20, AG 18. What's the diagnosis?

Answer

AG metabolic acidosis with appropriate respiratory compensation. Delta/delta ratio: (18-10) / (24-12) = 8/12 = 0.67, which is <1. This suggests a CONCURRENT non-AG acidosis (like diarrhea or saline administration). So the patient has HIGH AG + NON-AG acidosis = mixed metabolic acidosis. Look for both DKA/lactic acidosis AND diarrhea/renal tubular disease.

Key Takeaways

- **Always follow the ABC approach** systematically
- **Winter's formula** predicts respiratory response to metabolic acidosis
- **Compensation is incomplete** ☐ if appears complete, suspect mixed disorder
- **Anion gap** separates high-AG from non-AG acidosis
- **Albumin matters** ☐ correct AG for hypoalbuminemia
- **Respiratory changes happen fast, renal slow** ☐ temporal clue to acuity
- **Delta/delta ratio** identifies mixed metabolic disorders
- **MUDPILES for high AG** causes
- **USED CARP for non-AG** causes

Memory aid: "ABC = Always Be Calculating" — Use formulas, don't guess at compensation!

Exam strategy: If ABG doesn't make sense, calculate Winter's formula. It catches mixed disorders most students miss.

See Also

Related Student Handouts

- Hyperkalemia Management
- Hypokalemia Management
- Hyponatremia Management
- Hypernatremia and SIADH
- AKI Workup and Diagnosis

Clinical Content (01-Clinical-Medicine/Nephrology)

- Electrolyte Disorders Hub
- Acid-Base Disorders Clinical Reference
- Essential Renal Laboratory Tests

Atomic Notes (ZK)

- RAAS System and Electrolyte Regulation

Butler-COM Resources

- Butler COM - Nephrology Deep Dive

Clinical Resources

- Clinical Review: Acid Base Guide — Comprehensive clinical review with PubMed references
- Clinical Review: Acid Base Formal Review — Comprehensive clinical review with PubMed references