ABG Interpretation

ABG analysis assesses acid-base status, oxygenation, and ventilation, guiding diagnosis and management in acute settings.

Basics of ABG

pH: 7.35-7.45 (acid-base balance).

PaCO2: 35-45 mmHg (respiratory component, CO2).

HCO3-: 22-26 mEq/L (metabolic component, bicarbonate).

PaO2: 75-100 mmHg (oxygenation).

SaO2: 95-100% (oxygen saturation).

Base Excess (BE): -2 to +2 mEq/L (metabolic derangement).

Anion Gap (AG): 8-12 mEq/L (calculated as Na+ - [Cl- + HCO3-]).

Normal ABG Values Table

Parameter	Normal Range	Notes
pH	7.35-7.45	<7.35 = Acidosis; >7.45 = Alkalosis.
PaCO2	35-45 mmHg	>45 = Respiratory acidosis; <35 = Respiratory alkalosis.
HCO3-	22-26 mEq/L	<22 = Metabolic acidosis; >26 = Metabolic alkalosis.
PaO2	75-100 mmHg	<60 = Hypoxemia; adjust for age.
SaO2	95-100%	<90% = Desaturation.
Anion Gap	8-12 mEq/L	>12 = AG acidosis (e.g., DKA, lactate).

Stepwise ABG Interpretation

1. Determine pH:

pH <7.35 → Acidosis.

pH >7.45 → Alkalosis.

pH 7.35-7.45 → Normal or compensated.

2. Identify Primary Disorder:

Respiratory: PaCO2 drives pH (↑PaCO2 → ↓pH, acidosis; ↓PaCO2 → ↑pH, alkalosis).

Metabolic: HCO3- drives pH (↓HCO3- → ↓pH, acidosis; ↑HCO3- → ↑pH, alkalosis).

3. Check Compensation:

Respiratory Acidosis: HCO3- ↑ (1 mEq/L per 10 mmHg PaCO2 ↑, chronic).

Respiratory Alkalosis: HCO3- ↓ (2 mEq/L per 10 mmHg PaCO2 ↓, acute).

Metabolic Acidosis: PaCO2 ↓, use Winter's Formula (see detailed explanation below).

Metabolic Alkalosis: PaCO2 ↑ (0.7 mmHg per 1 mEq/L HCO3- ↑).

4. Calculate Anion Gap (AG):

Formula: AG = Na+ - (Cl- + HCO3-).

Normal: 8-12 mEq/L.

AG >12 → Anion gap metabolic acidosis (AGMA).

AG ≤12 → Non-anion gap metabolic acidosis (NAGMA).

5. Assess Oxygenation: PaO2 <60 mmHg → Hypoxemia; SaO2 <90% → Desaturation.

6. Look for Mixed Disorders: If compensation doesn't match, suspect secondary disorder (e.g., COPD + DKA).

Winter's Formula: Detailed Explanation

What It Is:

Winter's formula (PaCO2 = 1.5 × HCO3- + 8 ± 2) estimates the expected PaCO2 in primary metabolic acidosis, reflecting respiratory compensation (hyperventilation to "blow o" CO2). It helps confirm if the respiratory response is appropriate or if a secondary disorder exists.

When to Use It:

Use in primary metabolic acidosis (pH <7.35, HCO3- <22 mEq/L) to check respiratory compensation.

Use to identify mixed disorders: If measured PaCO2 doesn't match the expected PaCO2, a second disorder (e.g., respiratory acidosis or alkalosis) is present.

Example scenarios: Diabetic ketoacidosis (DKA), lactic acidosis, diarrhea.

How to Use It:

1. Confirm primary metabolic acidosis: pH <7.35, HCO3- <22 mEq/L.

2. Measure HCO3- from ABG (e.g., HCO3- = 15 mEq/L).

3. Calculate expected PaCO2:

PaCO2 = (1.5 × HCO3-) + 8 ± 2.

Example: HCO3- = 15 → PaCO2 = (1.5 × 15) + 8 = 22.5 + 8 = 30.5 ± 2 (range: 28.5-32.5 mmHg).

4. Compare with measured PaCO2:

Matches range (e.g., PaCO2 32 mmHg) → Appropriate compensation.

Too high (e.g., PaCO2 40 mmHg) → Secondary respiratory acidosis (e.g., hypoventilation).

Too low (e.g., PaCO2 20 mmHg) → Secondary respiratory alkalosis (e.g., hyperventilation).

5. Interpret: Appropriate compensation suggests pure metabolic acidosis; mismatch indicates a mixed disorder.

Acid-Base Disorders Table

Disorder	Primary Change	Compensation	Causes
Respiratory Acidosis	↑ PaCO2	↑ HCO3- (1:10 chronic)	COPD, hypoventilation, opioid overdose.
Respiratory Alkalosis	↓ PaCO2	↓ HCO3- (2:10 acute)	Hyperventilation (anxiety, PE, sepsis).
Metabolic Acidosis	↓ HCO3-	↓ PaCO2 (Winter's: PaCO2 = 1.5 × HCO3- + 8 ± 2)	AG: DKA, lactate, methanol. Non-AG: Diarrhea, RTA.
Metabolic Alkalosis	↑ HCO3-	↑ PaCO2 (0.7:1)	Vomiting, diuretics, NG suction.
Mixed (e.g., COPD + DKA)	Multiple	Partial compensation	COPD (↑ PaCO2) + DKA (↓ HCO3-, ↑ AG).

Metabolic Acidosis: AGMA vs. NAGMA

Type	AG	Causes	Key Features
AGMA	>12	- DKA: Diabetic ketoacidosis (ketones). - Lactic Acidosis: Sepsis, shock, cocaine use. - Toxins: Methanol, ethylene glycol. - Renal Failure: Uremia (late).	Kussmaul breathing, high lactate/ketones, substance use (cocaine).
NAGMA	≤12	- Diarrhea: Bicarbonate loss. - RTA: Type 1 (distal), Type 2 (proximal). - Alcohol: Early alcoholic ketoacidosis. - IV Fluids: Hyperchloremic (0.9% NS excess).	Normal AG, urine pH >5.5 in RTA Type 1, history of diarrhea.

Clinical Presentation

Respiratory Acidosis: Dyspnea, confusion (e.g., COPD).

Respiratory Alkalosis: Lightheadedness, tetany (e.g., anxiety).

Metabolic Acidosis: **AGMA:** Kussmaul breathing (e.g., DKA). **NAGMA:** Fatigue (e.g., diarrhea).

Metabolic Alkalosis: Muscle cramps (e.g., vomiting).

Hypoxemia: Cyanosis (PaO_2 <60 mmHg).

Substance Use: Opioids (respiratory acidosis), cocaine (AGMA, lactate), alcohol (NAGMA).

Diagnostic Workup

ABG:

pH, $PaCO_2$, HCO_3^-, PaO_2, SaO_2.

Labs:

Electrolytes: Na^+, Cl^-, HCO_3^- for AG; K^+.

Lactate: ↑ in AGMA (sepsis, cocaine).

Glucose, Ketones: AGMA (DKA).

Creatinine: AGMA (renal failure); NAGMA (RTA).

Urine pH: NAGMA (RTA Type 1: pH >5.5).

Urine Drug Screen: Opioids, cocaine, alcohol.

Imaging:

CXR (COPD, PE).

Key Tip:

Use Winter's formula for metabolic acidosis; calculate AG to dierentiate AGMA vs. NAGMA.

Examples

1. Case 1: COPD Exacerbation (Respiratory Acidosis)

ABG: pH 7.30, $PaCO_2$ 60 mmHg, HCO_3^- 29 mEq/L, PaO_2 55 mmHg.

Interpretation: Respiratory acidosis (↑ $PaCO_2$, ↓ pH), partial compensation (HCO_3^- ↑), hypoxemia (PaO_2 <60).

Management: BiPAP, bronchodilators, O_2 (target SaO_2 88-92%).

2. Case 2: DKA (AGMA)

ABG: pH 7.20, $PaCO_2$ 25 mmHg, HCO_3^- 10 mEq/L, PaO_2 90 mmHg.

Labs: Na^+ 140, Cl^- 100, HCO_3^- 10 (AG = 140 - [100 + 10] = 30), glucose 600 mg/dL, ketones positive.

Interpretation: Metabolic acidosis (↓ HCO_3^-, ↓ pH). Apply Winter's Formula:

Expected $PaCO_2$ = (1.5 × HCO_3^-) + 8 ± 2 = (1.5 × 10) + 8 = 15 + 8 = 23 ± 2 (range: 21-25 mmHg).

Measured $PaCO_2$ = 25 mmHg, matches → Appropriate compensation.

AG 30 → AGMA (DKA).

Management: IV fluids, insulin, monitor K^+.

3. Case 3: Diarrhea (NAGMA)

ABG: pH 7.28, $PaCO_2$ 32 mmHg, HCO_3^- 15 mEq/L, PaO_2 95 mmHg.

Labs: Na^+ 138, Cl^- 110, HCO_3^- 15 (AG = 138 - [110 + 15] = 13, adjusted for albumin ~12).

Interpretation: Metabolic acidosis (↓ HCO_3^-, ↓ pH). Apply Winter's Formula:

Expected $PaCO_2$ = (1.5 × HCO_3^-) + 8 ± 2 = (1.5 × 15) + 8 = 22.5 + 8 = 30.5 ± 2 (range: 28.5-32.5 mmHg).

Measured $PaCO_2$ = 32 mmHg, matches → Appropriate compensation.

AG ~12 → NAGMA (diarrhea).

Management: IV fluids (NS), bicarbonate if pH <7.1, treat diarrhea.

4. Case 4: Anxiety Attack (Respiratory Alkalosis)

ABG: pH 7.50, $PaCO_2$ 28 mmHg, HCO_3^- 22 mEq/L, PaO_2 98 mmHg.

Interpretation: Respiratory alkalosis (↓ $PaCO_2$, ↑ pH), acute (HCO_3^- normal).

Management: Reassurance, breathing exercises.

Treatment

Respiratory Acidosis: Improve ventilation (BiPAP, reverse opioids with naloxone).

Respiratory Alkalosis: Treat cause (e.g., O2 for PE, anxiolytics).

Metabolic Acidosis: AGMA: Treat cause (insulin for DKA, fluids for lactate). **NAGMA:** Bicarbonate if pH <7.1 (e.g., 50-100 mEq IV), address cause (e.g., fluids for diarrhea).

Metabolic Alkalosis: Replace volume (NS for vomiting), stop diuretics.

Hypoxemia: Supplemental O2 (target SaO2 >90%, or 88-92% in COPD).

Key Pearls

pH first, then PaCO2/HCO3- to identify primary disorder.

Winter's formula (PaCO2 = 1.5 × HCO3- + 8 ± 2) for metabolic acidosis compensation.

AG = Na+ - (Cl- + HCO3-); >12 → AGMA; ≤12 → NAGMA.

PaO2 <60 mmHg → Hypoxemia; address urgently.

References

UpToDate: "Arterial Blood Gas Interpretation" (2025).

AARC Guidelines: ABG Analysis (2023).

NEJM: "Acid-Base Disorders" (Adrogue, 2009).