Analyzing & Interpreting Arterial Blood Gases

AARC Approved for 1.5 CRCE Credit Hours

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Learner Objectives

Describe	Describe collection methods for arterial blood gases
Discuss	Discuss avoidance strategies for pre-analytical errors
List	List the process steps for ABG analysis
Discuss	Discuss the causes of metabolic acidosis & alkalosis
Discuss	Discuss the causes of respiratory acidosis & alkalosis
Identify	Identify the role of ABG analysis with mechanical ventilation

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Alternatives to Traditional Arterial Sampling

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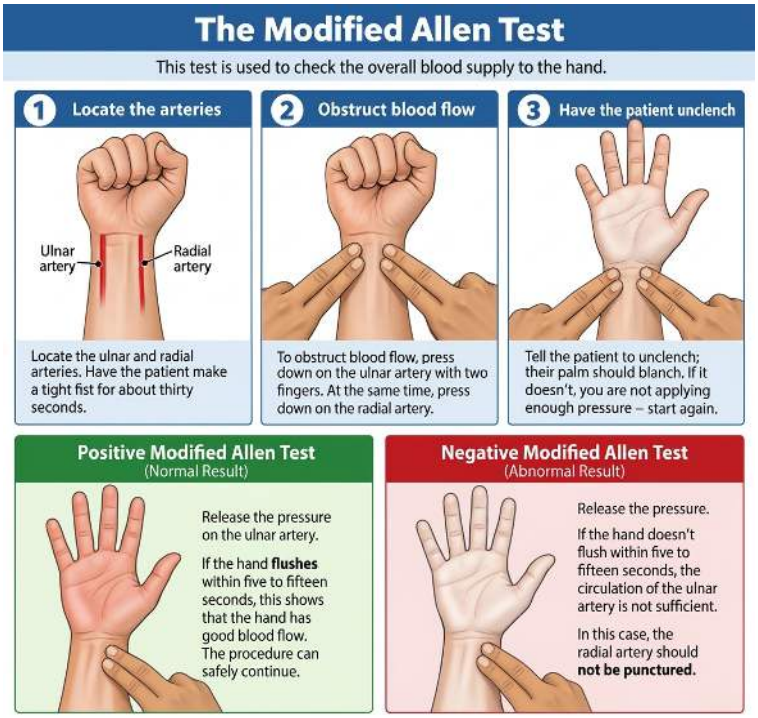


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References: 1, 2, 9

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References: 1, 2, 7, 8, 9

5



References: 2, 7, 8, 9

6

Influencing Factors

- Room Air
- Leukocytes
- Hypo/hyperthermic

References: 1, 7, 8, 9

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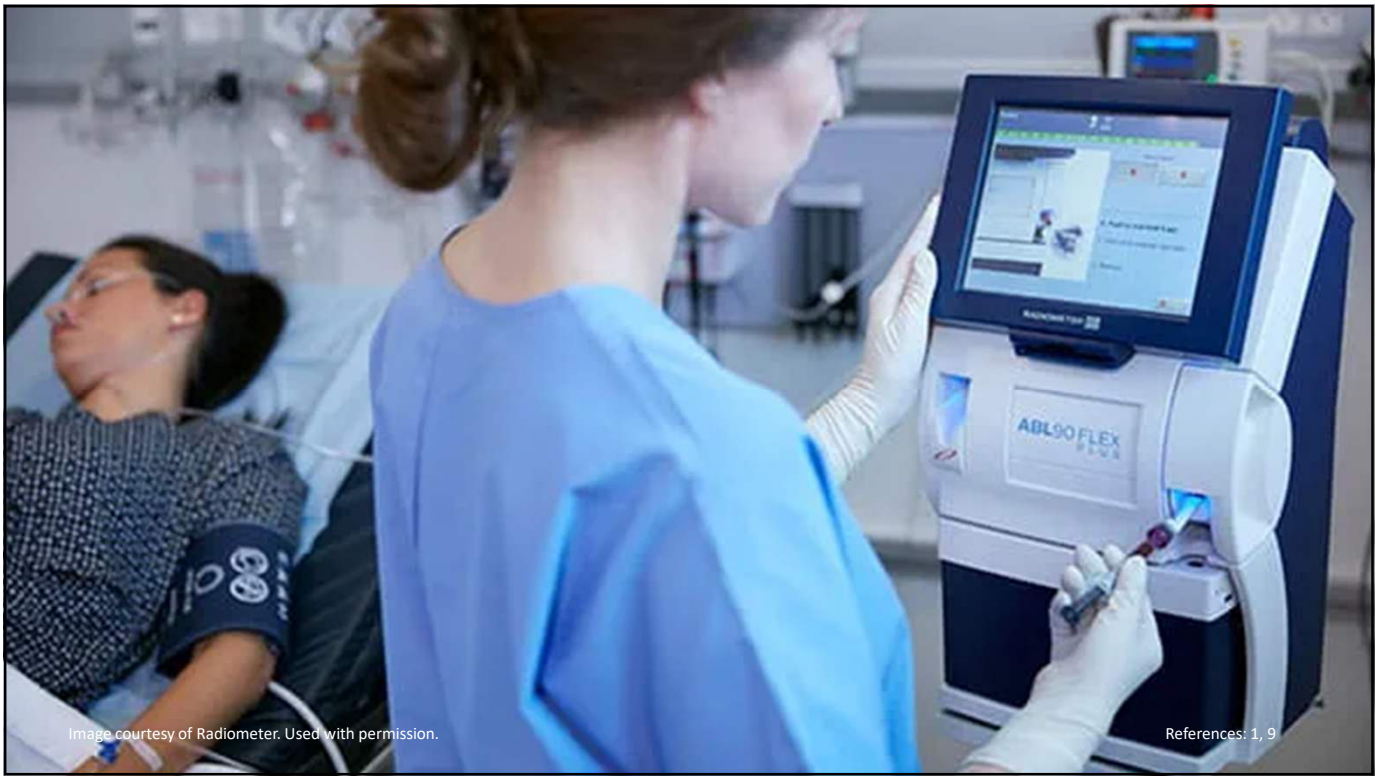


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References: 1, 9

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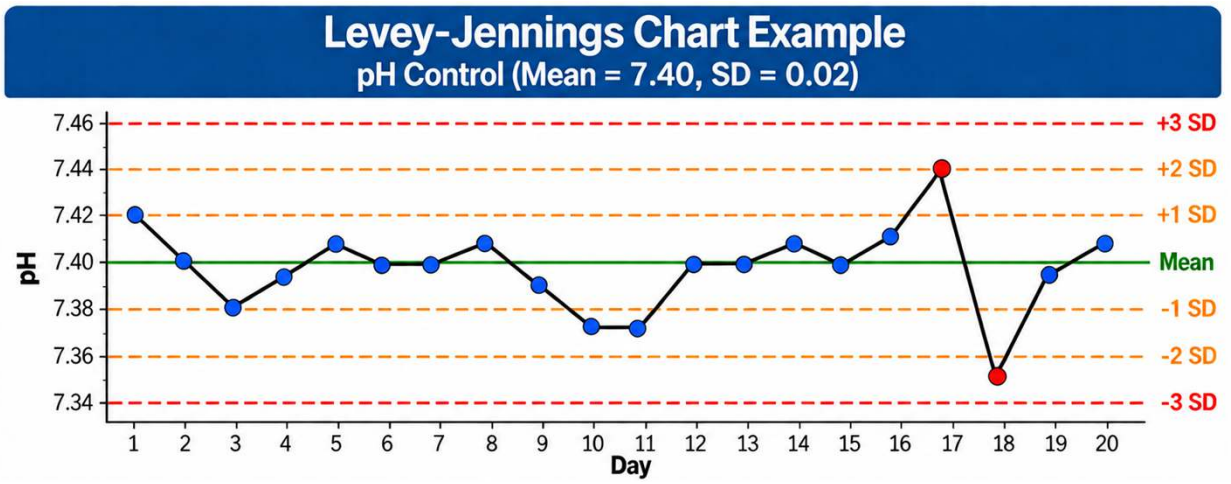
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References: 9

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Review unexpected QC patterns using the laboratory's established QC rules.

References: 9

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What Can a Blood Gas Analyzer Tell Us?

Blood gases	Acid-base status, ventilation, and oxygenation
Co-oximetry	Hemoglobin, oxygen saturation, and dyshemoglobins
Electrolytes	Clinically important ions
Metabolites	Markers of metabolism and tissue perfusion

Available measurements depend on the analyzer and its configuration.

References: 1, 9

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Interpretation

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carbonic anhydrase

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

Acid-base processes

Acidosis	↑ H^+, tends to lower pH
Alkalosis	↓ H^+, tends to raise pH

Regulatory systems

Lungs	regulate CO_2
Kidneys	regulate HCO_3^- and H^+ excretion

Acidosis/alkalosis describe the processes.
Acidemia/alkalemia describe the actual blood pH.

References: 3, 4, 5

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Henderson-Hasselbalch Concept

$$pH = pK_a + \log \frac{[\text{conjugate base}]}{[\text{weak acid}]} \quad \text{(for weak acid)}$$

In the bicarbonate buffer system:
HCO_3^- reflects the metabolic component
CO_2 reflects the respiratory component

pH rises when HCO_3^- increases relative to CO_2
pH falls when CO_2 increases relative to HCO_3^-

References: 3, 4, 5

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ABG Shortcut
pH Reflects the $HCO_3^-/PaCO_2$ Balance

$$pH \propto \frac{HCO_3^-}{PaCO_2}$$

Bicarbonate HCO_3^-
Metabolic component

Carbon Dioxide $PaCO_2$
Respiratory component

Ask: which side of the ratio changed?

References: 3, 4, 5

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Normal ABG Values and Reporting Order

Parameter	Normal range	What it tells you
pH	7.35–7.45	Overall acid-base status
$PaCO_2$	35–45 mm Hg	Respiratory component
PaO_2	80–100 mm Hg	Oxygenation
HCO_3^-	22–26 mmol/L	Metabolic component
Base excess	–2 to +2 mmol/L	Metabolic component

Report in order: pH → $PaCO_2$ → PaO_2 → HCO_3^- → base excess

References: 1, 3, 4

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Extreme pH Values Signal High Risk

pH < 6.8
Severe acidemia
High risk

7.35 -7.45
Normal range
Usual arterial pH

pH > 7.8
Severe alkalemia
High risk

Risk increases as pH moves farther from normal.
These are warning thresholds, not absolute survival limits.

References: 3, 4, 5

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Respiratory Acidosis

pH < 7.35

$PaCO_2$ **> 45**

Acute or Chronic

References: 3, 4, 5

19

Acute Respiratory Acidosis

Headache

Confusion

Drowsiness

Heart Contraction

Catecholamines

Medications

References: 3, 4, 5

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Acute Respiratory Acidosis

- Ventilation chain defect
- Increased CO_2 production

Arterial Blood Gas (ABG)	
pH	7.27
HCO_3^- (mEq/L)	24
$PaCO_2$ (mm Hg)	55

Calculation (Henderson–Hasselbalch)

$$pH = 6.1 + \log \frac{24}{0.03 \times 55}$$

$$pH = 6.1 + \log(14.55)$$

$$pH \approx 7.27$$

References: 3, 4, 5

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Chronic Respiratory Acidosis

- Increased $PaCO_2$
- Increased HCO_3^-
- Normal pH

Arterial Blood Gas (ABG)	
pH	7.39
HCO_3^- (mEq/L)	33
$PaCO_2$ (mm Hg)	55

Calculation (Henderson–Hasselbalch)

$$pH = 6.1 + \log \frac{33}{0.03 \times 55}$$

$$pH = 6.1 + \log(20.00)$$

$$pH \approx 7.39$$

References: 3, 4, 5

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Respiratory Alkalosis

$PaCO_2 < 35$

pH > 7.45

References: 3, 4, 5

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Respiratory Alkalosis

- Pain
- Fear
- Hypoxia
- Increased metabolic demand

Arterial Blood Gas (ABG)	
pH	7.52
HCO_3^- (mEq/L)	24
$PaCO_2$ (mm Hg)	25

Calculation (Henderson-Hasselbalch)

$$pH = 6.1 + \log \frac{24}{0.03 \times 25}$$

$$pH = 6.1 + \log(32.00)$$

$$pH \approx 7.52$$

References: 3, 4, 5

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Respiratory Alkalosis

Numbness	Tingling	Confusion
Blurred vision	Muscle spasms	Dysrhythmias

References: 3, 4, 5

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Metabolic Acidosis

- HCO_3^- < 22
- pH < 7.35

Arterial Blood Gas (ABG)	
pH	7.26
HCO_3^- (mEq/L)	16
$PaCO_2$ (mm Hg)	40

Calculation (Henderson–Hasselbalch)

$$pH = 6.1 + \log \frac{16}{0.03 \times 40}$$

$$pH = 6.1 + \log(13.33)$$

$$pH \approx 7.26$$

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Metabolic Acidosis

- Diarrhea
- Renal failure
- DKA
- Anaerobic Metabolism
- Starvation
- Salicylates
- Renal tubular acidosis
- Toxic alcohols

References: 3, 4, 5, 6

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Metabolic Acidosis

- Headache
- Confusion
- Coma
- Dysrhythmias
- Kussmaul Breathing (DKA)
- Nausea
- Vomiting

References: 3, 4, 5, 6

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Metabolic Alkalosis

- HCO_3^- > 26
- pH > 7.45

Arterial Blood Gas (ABG)	
pH	7.60
HCO_3^- (mEq/L)	38
$PaCO_2$ (mm Hg)	40

Henderson-Hasselbalch Calculation

$$pH = 6.1 + \log \frac{HCO_3^-}{0.03 \times PaCO_2}$$

$$pH = 6.1 + \log \frac{38}{0.03 \times 40}$$

$$pH = 6.1 + \log(38 \div 1.2)$$

$$pH = 6.1 + \log(31.67)$$

$$pH = 6.1 + 1.50$$

$$pH \approx 7.60$$

References: 3, 4, 5, 6

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Metabolic Alkalosis

- Excess Alkali/Antacids
- Bicarbonate
- Gastric Suctioning
- Vomiting
- Diuretics

References: 3, 4, 5, 6

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Metabolic Alkalosis

- Hypoventilation (compensation)
- Dizziness
- Seizures
- Coma
- Muscle twitching
- Cramps
- Nausea
- Vomiting

References: 3, 4, 5, 6

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Mixed Respiratory Metabolic

References: 3, 5, 6

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Classification of Hypoxemia by PaO_2

80-100 Normal → **60-79 Mild** → **40-59 Moderate** → **< 40 Severe**

References: 1, 3

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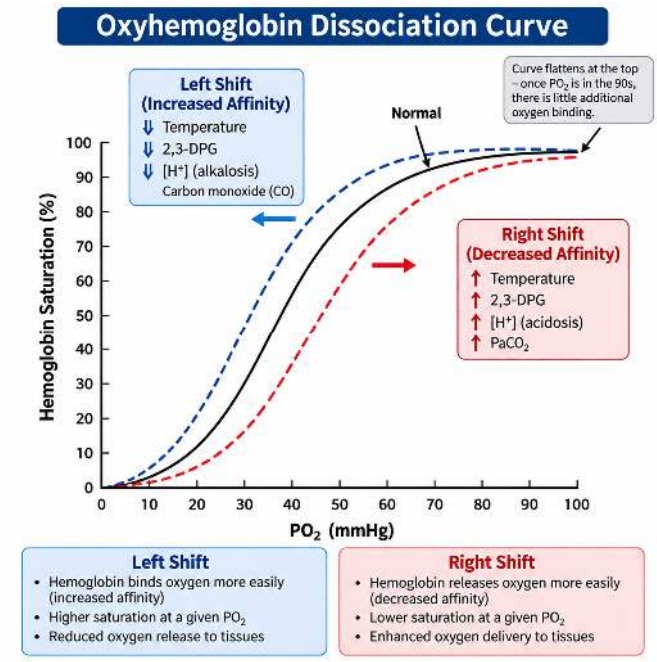


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References: 3, 4

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HOT ACID goes RIGHT.

References: 3, 4

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Arterial Oxygen Content (CaO_2)

$$CaO_2 = (1.34 \times Hb \times SaO_2) + (PaO_2 \times 0.003)$$

Most oxygen content comes from hemoglobin-bound oxygen.

Example:

Hb = 15 SaO_2 = 0.98 PaO_2 = 100 mmHg

CaO_2 = (1.34 x 15 x 0.98) + (100 x 0.003)

CaO_2 = 19.7 + 0.3 = **20.0 mL O_2/dL**

Severe anemia can reduce oxygen content even when PaO_2 and SaO_2 look normal.

References: 1, 3

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Mixed Venous Oxygen Saturation (SvO_2)

Arterial blood → **Tissue oxygen extraction** → **Mixed venous blood**

SaO_2 near 100% → tissues extract oxygen → SvO_2 ~65–75%

Low SvO_2 may suggest:
Increased demand · reduced delivery · impaired delivery/consumption balance

High SvO_2 does not always mean adequate tissue oxygen use.

References: 3

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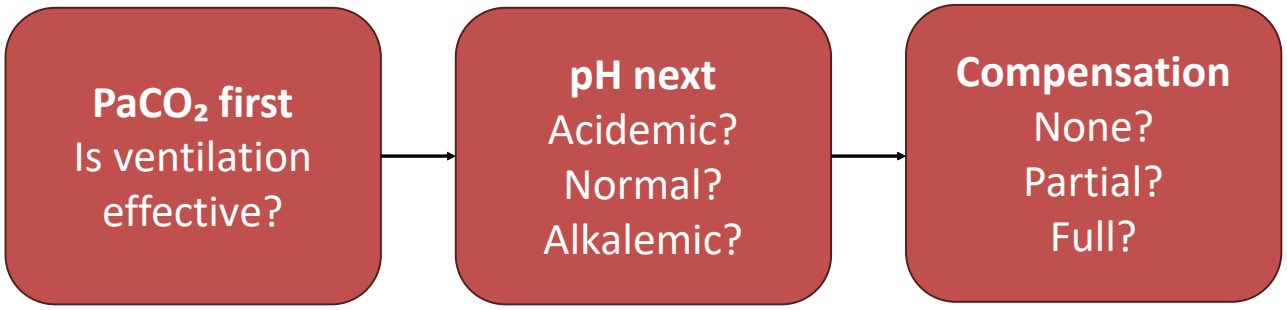
Base Excess

Normal +/- 2 mEq/L

References: 3, 4, 5

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ABG Interpretation Framework



High $PaCO_2$ with near-normal pH may suggest chronic compensation.

References: 3, 5, 6

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Quick Practice: Interpret the ABG.



pH	$PaCO_2$	PaO_2	HCO_3^-
7.30	50	65	24
7.36	54	65	30
7.49	30	65	22
7.30	32	80	15

30 Seconds

References: 3, 5, 6

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Quick Practice: Interpret the ABG.

pH **7.30 /** $PaCO_2$ **50 /** PaO_2 **65 /** HCO_3^- **24** →

Acute respiratory acidosis

pH **7.36 /** $PaCO_2$ **54 /** PaO_2 **65 /** HCO_3^- **30** →

Chronic compensated respiratory acidosis

pH **7.49 /** $PaCO_2$ **30 /** PaO_2 **65 /** HCO_3^- **22** →

Acute respiratory alkalosis

pH **7.30 /** $PaCO_2$ **32 /** PaO_2 **80 /** HCO_3^- **15** →

Metabolic acidosis with appropriate respiratory compensation



References: 3, 5, 6

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Example #1

58-year-old male, 5'9", 295 lb, stroke-like symptoms

History: CVA, diabetes, obesity

Vent: A/C 16 / VT 450 / PEEP 5 / FiO_2 50%

ABG: pH **7.37 /** $PaCO_2$ **47.1 /** PaO_2 **72.4 /** HCO_3^- **26.4 /** BE **+1.3**

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Example #2

22-year-old male, 6' 1", 146 lbs., AMS & acute encephalopathy

Hx: Asthma

Vent: A/C 16/400/5 FiO_2 50%

ABG: pH **7.20 /** $PaCO_2$ **60 /** PaO_2 **254 /** HCO_3^- **23 /** BE **–5**

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Example #3

64-year-old male, 5' 7", 160 lbs., admitted w/ sepsis and respiratory failure

Failed NIV

Vent: A/C 14/450/5 FiO_2 40%

ABG: pH **7.42 /** $PaCO_2$ **44.5 /** PaO_2 **79.4 /** HCO_3^- **28.4 /** BE **+4**

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Example #4

46-year-old female, 5’ 0”, 130 lbs., 8 days SOB & COVID+

Vent: AC-PC f 26, Pi 23, Ti 1.0, PEEP 5, FiO_2 100%

ABG: pH **7.29 /** $PaCO_2$ **62.8 /** PaO_2 **53.1 /** HCO_3^- **29 /** BE **+1.6**

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Example #5

44-year-old male, 5’ 6”, 223 lbs., urinary retention and lower-extremity edema.

Hx: Significant CHF, EF 20-25%, hypertension, OSA, obesity, and prediabetes

BiPAP 24/5 FiO_2 40%

ABG: pH **7.54 /** $PaCO_2$ **43.1 /** PaO_2 **96.8 /** HCO_3^- **37.1 /** BE **+12.8**

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Anion Gap

140 – (104 + 24) = 12 mEq/L

References: 3, 5, 6

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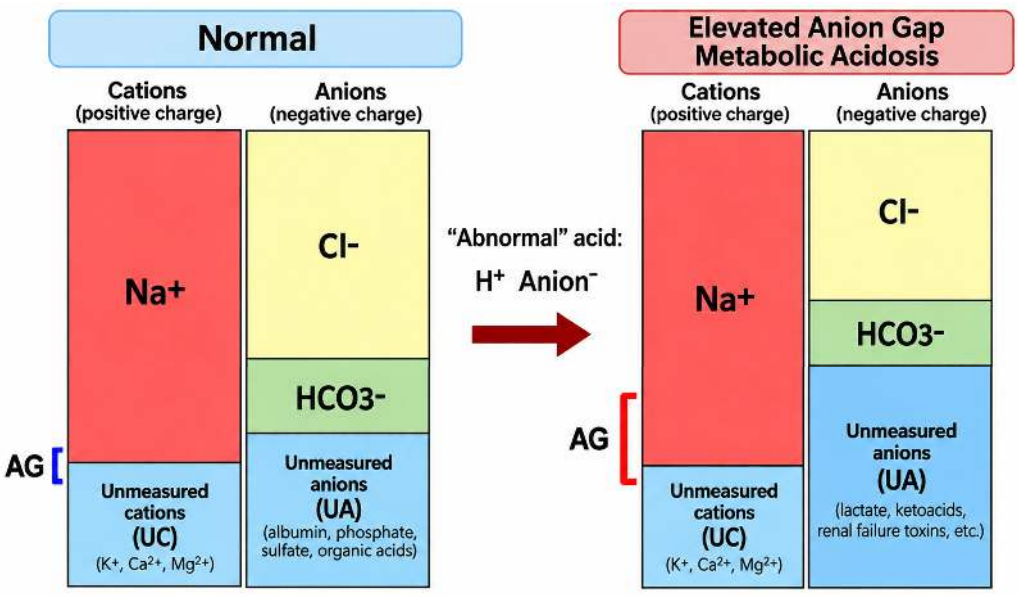
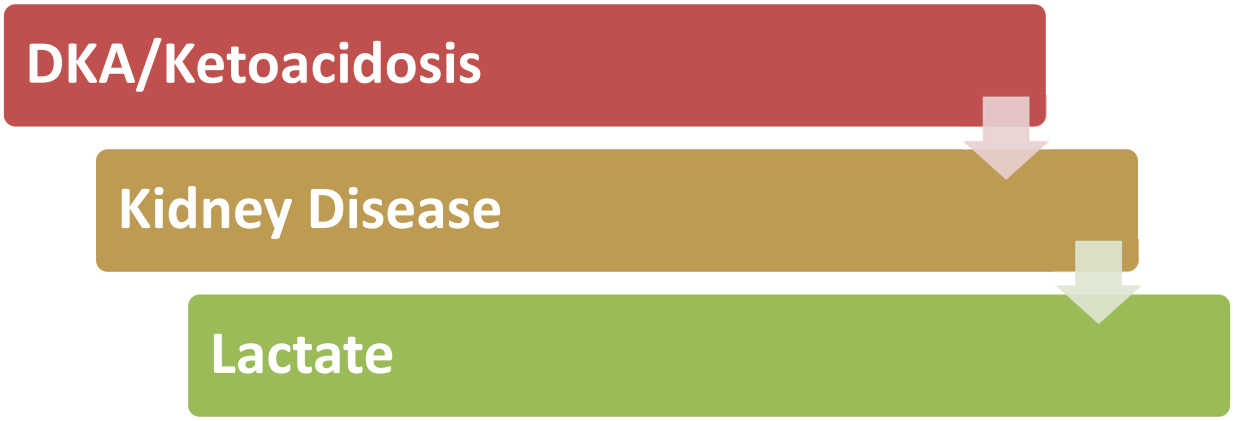


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References: 3, 5, 6

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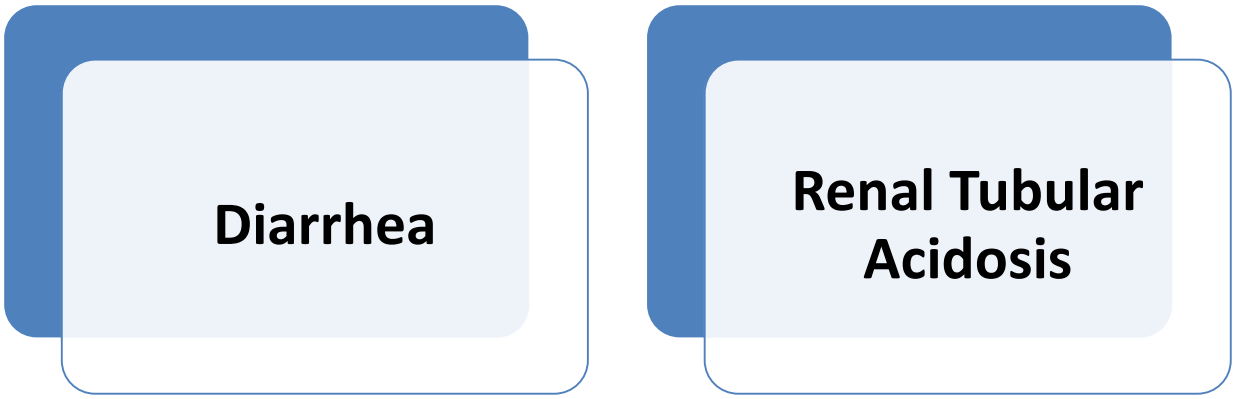
Elevated Anion Gap



References: 3, 5, 6

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Normal Anion Gap



References: 3, 5, 6

50

Low Anion Gap

Low Albumin

References: 3, 5, 6

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Example #1

58-year-old male, 5'9", 295 lb, stroke-like symptoms

History: CVA, diabetes, obesity

Vent: A/C 16 / VT 450 / PEEP 5 / FiO_2 50%

ABG: pH **7.37 /** $PaCO_2$ **47.1 /** PaO_2 **72.4 /** HCO_3^- **26.4 / BE +1.3**

Sodium (Na^+) 141

Potassium (K^+) 3.4

Chloride (Cl^-) 104

141 – (104 + 26.4) =
141-130.4=
AG = 10.6 mEq/L

References: 3, 5, 6

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Example #2

22-year-old male, 6' 1", 146 lbs., AMS & acute encephalopathy

Hx: Asthma

Vent: A/C 16/400/5 FiO_2 50%

ABG: pH **7.20 /** $PaCO_2$ **60 /** PaO_2 **254 /** HCO_3^- **23 / BE –5**

Na^+ 140

Cl^- 109

140 – (109 + 23) =
140-132=
AG = 8 mEq/L

References: 3, 5, 6

53

Example #3

64-year-old male, 5' 7", 160 lbs., admitted with sepsis and respiratory failure

Earlier laboratory results:

ABG: pH **7.28 /** $PaCO_2$ **30 /** PaO_2 **70 /** HCO_3^- **14**

Na^+ 138

Cl^- 102

138 – (102 + 14) =
138-116=
AG = 22 mEq/L

References: 3, 5, 6

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Delta-Delta Gap

References: 3, 5, 6

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Delta Ratio

Does the anion gap rise match the bicarbonate fall?

$$\textbf{Delta-delta} = \frac{(\boldsymbol{Calculated\ AG - Expected\ AG})}{(\boldsymbol{24 - HCO_3^-})}$$

Use only after identifying high-anion-gap metabolic acidosis.

Ratio	What it suggests
< 0.4	Predominantly normal-gap metabolic acidosis
0.4–0.8	Mixed high-gap + normal-gap metabolic acidosis
0.8–2.0	High-gap acidosis without clear additional metabolic process
> 2.0	High-gap acidosis with metabolic alkalosis or elevated baseline HCO_3^-

Ranges vary by reference. Use the ratio as a clue, not a diagnosis.

References: 3, 5, 6

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Example #1

64-year-old male, 5’ 7”, 160 lbs., admitted with sepsis and respiratory failure

Na^+ **138**
Cl^- **102**
HCO_3^- **14**
AG = 22 mEq/L

Delta-Delta = (AG – 12) ÷ (24 – HCO_3^-)
= (22 – 12) ÷ (24 – 14)
= 10 ÷ 10
= 1.0

References: 3, 5, 6

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Example #2

52-year-old female admitted with DKA and diarrhea

Na^+ **138**
Cl^- **109**
HCO_3^- **10**
AG = 19 mEq/L

Δ/Δ = (19 – 12) ÷ (24 – 10)
= 7 ÷ 14
= 0.5

References: 3, 5, 6

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Example #3

27-year-old female admitted with DKA and persistent vomiting

Na^+ **140**
Cl^- **94**
HCO_3^- **16**
AG = 30 mEq/L

Δ/Δ = (30 − 12) ÷ (24 − 16)
= 18 ÷ 8
= 2.25

References: 3, 5, 6

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Calculations help you notice patterns, but they don't replace clinical judgment.

Reference values vary

Cutoffs differ by source and facility.

Patient factors matter

Albumin and other conditions can affect the anion gap and delta-delta.

Use the whole clinical picture

Investigate results that don't fit the patient.

References: 3, 5, 6

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ABG Interpretation: The Big Picture

1. $PaCO_2$ — Ventilation
Eliminating CO_2 appropriately?

2. pH — Acid-base status
Acidemic, normal, or alkalemic?

3. HCO_3^- / BE — Metabolic component
Metabolic disturbance or compensation?

4. Compensation — Does it fit?
Consider mixed disorder if not.

5. PaO_2 + FiO_2 — Oxygenation
Interpret PaO_2 with delivered oxygen.

6. Anion gap / delta-delta — Dig deeper
Look for another metabolic process.

A normal pH does not guarantee a normal ABG. Treat the patient who produced it.

References: 1, 3, 5, 6

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References

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The End

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