Chapter 17
Approach to Respiratory Abnormalities on Blood Gas in the ICU

17.1 Introduction

Respiratory abnormalities are prevalent in critically ill patients and are often unveiled through arterial blood gas (ABG) analysis. Accurate interpretation of ABGs is essential for diagnosing and managing a variety of respiratory conditions. This chapter provides a comprehensive approach to assessing respiratory acidosis and alkalosis, emphasizing the alveolar-arterial (A–a) gradient to differentiate underlying causes and guide appropriate management. Understanding the physiological mechanisms, compensation processes, and clinical implications enhances the clinician's ability to make informed decisions [1, 2]. [Ref: Algorithm 17.1].

17.2 Physiological Basis of Respiratory Acid-Base Disorders

The respiratory system plays a pivotal role in maintaining acid-base balance by regulating carbon dioxide (CO_2) levels through ventilation. CO_2 is a volatile acid; its accumulation leads to respiratory acidosis, while excessive elimination results in respiratory alkalosis.

- Respiratory Acidosis: Occurs when alveolar hypoventilation leads to CO_2 retention. Causes include impaired respiratory drive, neuromuscular dysfunction, or obstructive lung diseases.
- Respiratory Alkalosis: Results from alveolar hyperventilation causing excessive CO_2 elimination. Common triggers are hypoxemia-induced hyperventilation, central nervous system stimulation, or mechanical overventilation.

S. B. Mishra et al., *Mastering ICU Care*,
https://doi.org/10.1007/978-981-95-0179-3_17

17.3 Initial Classification: Acidosis vs. Alkalosis

Begin by evaluating the arterial pH:

- Acidosis: pH < 7.38
- Alkalosis: pH > 7.42

Determine whether the abnormality is acute or chronic from patient history:

Acute respiratory acidosis: Change in pH = 0.008*(40-$PaCO_2$).
Chronic respiratory acidosis: Change in pH = 0.003*(40-$PaCO_2$).
Acute respiratory alkalosis: Change in pH = 0.008*(40-$PaCO_2$).
Chronic respiratory alkalosis: Change in pH = 0.02*(40-$PaCO_2$).

Assess $PaCO_2$ to determine if the primary disorder is respiratory:

- Respiratory Acidosis: Elevated $PaCO_2$ (>45 mm Hg)
- Respiratory Alkalosis: Decreased $PaCO_2$ (<35 mm Hg)

17.4 Compensation Mechanisms

The body attempts to restore normal pH through compensatory mechanisms:

- Acute Respiratory Disorders: Limited renal compensation occurs over hours, with minimal changes in bicarbonate (HCO_3^-).
- Chronic Respiratory Disorders: Renal adaptation over days increases or decreases HCO_3^- reabsorption to buffer pH changes.

Compensatory Changes:

- Respiratory Acidosis:
  - Acute: HCO_3^- increases by ~1 mEq/L for every 10 mm Hg rise in $PaCO_2$.
  - Chronic: HCO_3^- increases by ~3.5 mEq/L for every 10 mm Hg rise in $PaCO_2$.
- Respiratory Alkalosis:
  - Acute: HCO_3^- decreases by ~2 mEq/L for every 10 mm Hg drop in $PaCO_2$.
  - Chronic: HCO_3^- decreases by ~5 mEq/L for every 10 mm Hg drop in $PaCO_2$.

17.5 Calculating the A–a Gradient

The A–a gradient assesses the efficiency of gas exchange:

$$PaO_2 = FiO2^* \left[\left(Patm - PH_2O\right)\right] - PaCO_2 / RQ$$

$$A - a\,gradient = PaO_2 - PaO_2$$

Where:

At sea level on room air:

- PaO_2: Measured arterial oxygen tension
- FiO_2: Fraction of inspired oxygen (0.21 on room air)
- Patm: Atmospheric pressure (760 mm Hg at sea level)
- PH_2O: Water vapor pressure (47 mm Hg)
- RQ: Respiratory quotient (~0.8)

17.6 Key Clinical Considerations

Age-Related Changes in A–a Gradient

- The A–a O_2 tension difference increases by approximately 2 mm Hg per decade of life.
- Alternative formula: A–a O_2 difference = (Age/4) + 4.

Normal A–a Gradient

Increases with age:

- Young adults: <10 mm Hg
- Elderly (>60 years): <20 mm Hg

An elevated A–a gradient indicates impaired oxygen transfer due to ventilation-perfusion mismatch, diffusion defects, or shunting.

17.7 Diagnostic Algorithm

Step 1: Determine Primary Disorder

- Acidosis or Alkalosis: Based on arterial pH.
- Respiratory or Metabolic: Analyze $PaCO_2$ and HCO_3^-.

Step 2: Calculate Expected Compensation

- Use formulas for compensatory changes to assess if the compensation is appropriate.
- Inappropriate compensation suggests a mixed disorder.

Step 3: Calculate the A–a Gradient

- Determine if the gradient is normal or elevated.

Step 4: Analyze Causes Based on A–a Gradient

Respiratory Acidosis

- **Normal A–a Gradient**
  - **Acute Causes:**
    - Depression of the central respiratory center (e.g., drugs, stroke)
    - Cerebral disease (e.g., encephalitis or trauma)
    - Drugs (e.g., narcotics, barbiturates, benzodiazepines)
  - **Chronic Causes:**
    - Neuromuscular diseases (e.g., myasthenia gravis, amyotrophic lateral sclerosis, Guillain-Barré syndrome, muscular dystrophy)
    - Kyphoscoliosis
- **High A–a Gradient**

  Acute Causes:

  - Airway obstruction (e.g., asthma exacerbation, pneumonia)

  Chronic Causes:

  - Chronic obstructive pulmonary disease (COPD)

Respiratory Alkalosis

- **Normal A–a Gradient**
  - **Acute Causes:**
    - Pain, anxiety, fever
    - Stroke, meningitis, trauma
    - Severe anemia, salicylate toxicity
  - **Chronic Causes:**
    - Pregnancy, hyperthyroidism, hepatic failure
- **High A–a Gradient**
- **Acute Causes:**
  - Pneumonia, pulmonary edema, pulmonary embolism, aspiration, congestive heart failure, sepsis
- **Chronic Causes:**
  - Pulmonary embolism in pregnancy, liver failure with aspiration pneumonia

17.8 Clinical Case Examples

Case 1: Respiratory Acidosis with Elevated A–a Gradient
Presentation: A 68-year-old male with a history of COPD presents with increasing dyspnea and confusion.

ABG Results:

- pH: 7.25
- $PaCO_2$: 60 mm Hg
- PaO_2: 55 mm Hg
- HCO_3^-: 26 mEq/L

Analysis:

- Acidosis: pH <7.35
- $PaCO_2$ Elevated: Indicates respiratory acidosis.
- Compensation: HCO_3^- slightly elevated, suggesting partial renal compensation.
- A–a Gradient: Elevated, indicating impaired gas exchange.

Diagnosis
Acute-on-chronic respiratory acidosis due to COPD exacerbation.

Case 2: Respiratory Alkalosis with Normal A–a Gradient
Presentation: A 25-year-old female experiences palpitations and tingling in her fingers after a panic attack.

ABG Results:

- pH: 7.55
- $PaCO_2$: 28 mm Hg
- PaO_2: 95 mm Hg
- HCO_3^-: 22 mEq/L

Analysis:

- Alkalosis: pH >7.45

PaCO₂ Decreased: Indicates respiratory alkalosis.
Compensation: Minimal change in HCO_3^- suggests acute condition.
A–a Gradient: Normal.

Diagnosis
Acute respiratory alkalosis due to hyperventilation from anxiety.

17.9 Addressing Mixed Acid-Base Disorders

Mixed disorders occur when more than one primary acid-base disturbance is present. Indicators include:

- Inappropriate Compensation: The expected compensatory response is absent or exaggerated.
- Normal pH with Abnormal $PaCO_2$ and HCO_3^-: Suggests opposing disorders balancing pH.

  Example:

- pH: 7.40 (normal)
- $PaCO_2$: 60 mm Hg (elevated)
- HCO_3^-: 36 mEq/L (elevated)

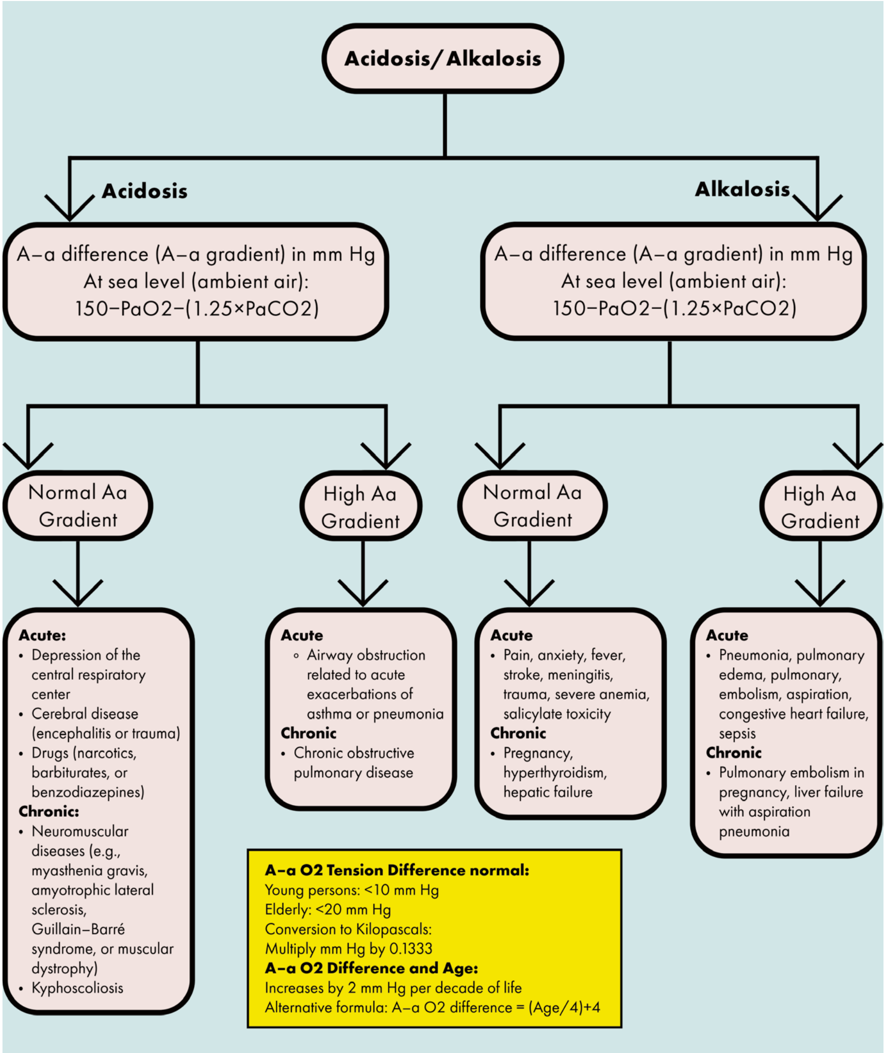
  Interpretation:

- Elevated $PaCO_2$: Respiratory acidosis
- Elevated HCO_3^-: Metabolic alkalosis
- Normal pH: Mixed disorder.

17.10 Conclusion

A systematic approach to interpreting ABGs enhances the clinician's ability to diagnose and manage respiratory abnormalities effectively. By understanding the underlying pathophysiology, compensation mechanisms, and clinical presentations, clinicians can identify the causes of acidosis and alkalosis, recognize mixed disorders, and implement appropriate interventions. Utilizing tools like the A–a gradient and diagnostic algorithms streamlines the decision-making process, ultimately improving patient outcomes.

Algorithm 17.1: Approach to respiratory abnormalities on blood gas in the ICU



Bibliography

1. Berend K, de Vries AP, Gans RO. Physiological approach to assessment of acid-base disturbances. N Engl J Med. 2014;371(15):1434–45.
2. Blum F, Lund ET, Hall H, Tachauer A, Chedrawy EG, Zilberstein J. Reevaluation of the utilization of arterial blood gas analysis in the intensive care unit: effects on patient safety and patient outcome. J Crit Care. 2015;30(2):438.e1-.e5.