Respiratory Failure in the Acute Care Setting

A Clinical Guide

Silya Mazigh, MD

Riverside Advanced Practice Provider Conference

02/08/2025

Disclosures

- I have no financial relationships to disclose.

Objectives

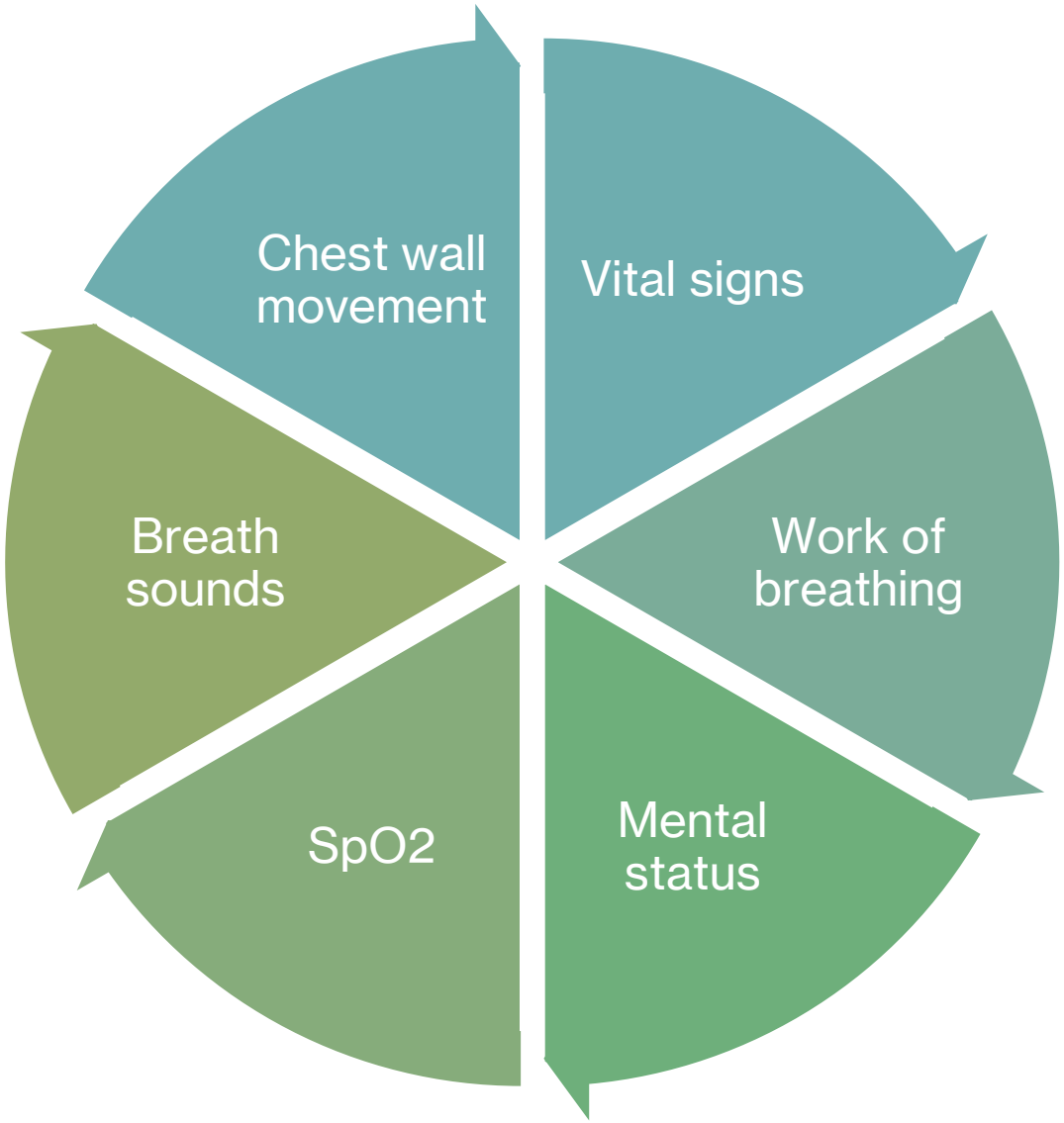
- Define respiratory failure and its types.
- Discuss the pathophysiology and common causes.
- Identify clinical signs and apply evidence-based diagnostic tools.
- Systematically interpret ABGs and identify respiratory failure patterns.
- Review management protocols in acute care.

Case presentation

- **Patient:** 68-year-old male
- **PMH:** severe COPD on 2L/min NC at baseline, OSA on CPAP (poor compliance)
- **Chief Complaint:** Increased shortness of breath
- **HPI:**
  - Increased sputum production (yellow/green), wheezing, and worsening dyspnea over 48 hours
  - Family reports new confusion and lethargy
  - No fever, chest pain, or leg swelling

Diagnostic Approach

Initial Assessment



Physical Exam

- **Vitals:** BP: 145/85 mmHg, HR: 98 bpm, RR: 28/min, SpO_2: 86% on 2L NC, Temp: 37.0°C

- **General:** Drowsy, but arousable
- **Respiratory:**
  - Labored breathing, accessory muscle use
  - Diffusely diminished breath sounds, expiratory wheezing
  - Prolonged expiratory phase
- **Neurologic:**
  - A&O x 2 (disoriented to place)
  - No focal deficits

Preliminary diagnoses

Definition and Classification of Respiratory Failure

Definition: Failure of the respiratory system to maintain oxygenation or ventilation.

Types:

- **Type 1: Hypoxic**
  - PaO2 < 60 mmHg on room air
  - SpO2 ≤ 90% on room air (SpO2 of 91% correlates with PO2 of 60 mmHg
  - A-a gradient > 20 mmHg

- **Type 2: Hypercapnic**
  - PaCO2 > 45 mmHg with a pH < 7.35 acutely

Acute vs. Chronic vs. Acute-on-Chronic.

Definition and Classification of Respiratory Failure

Chronic:

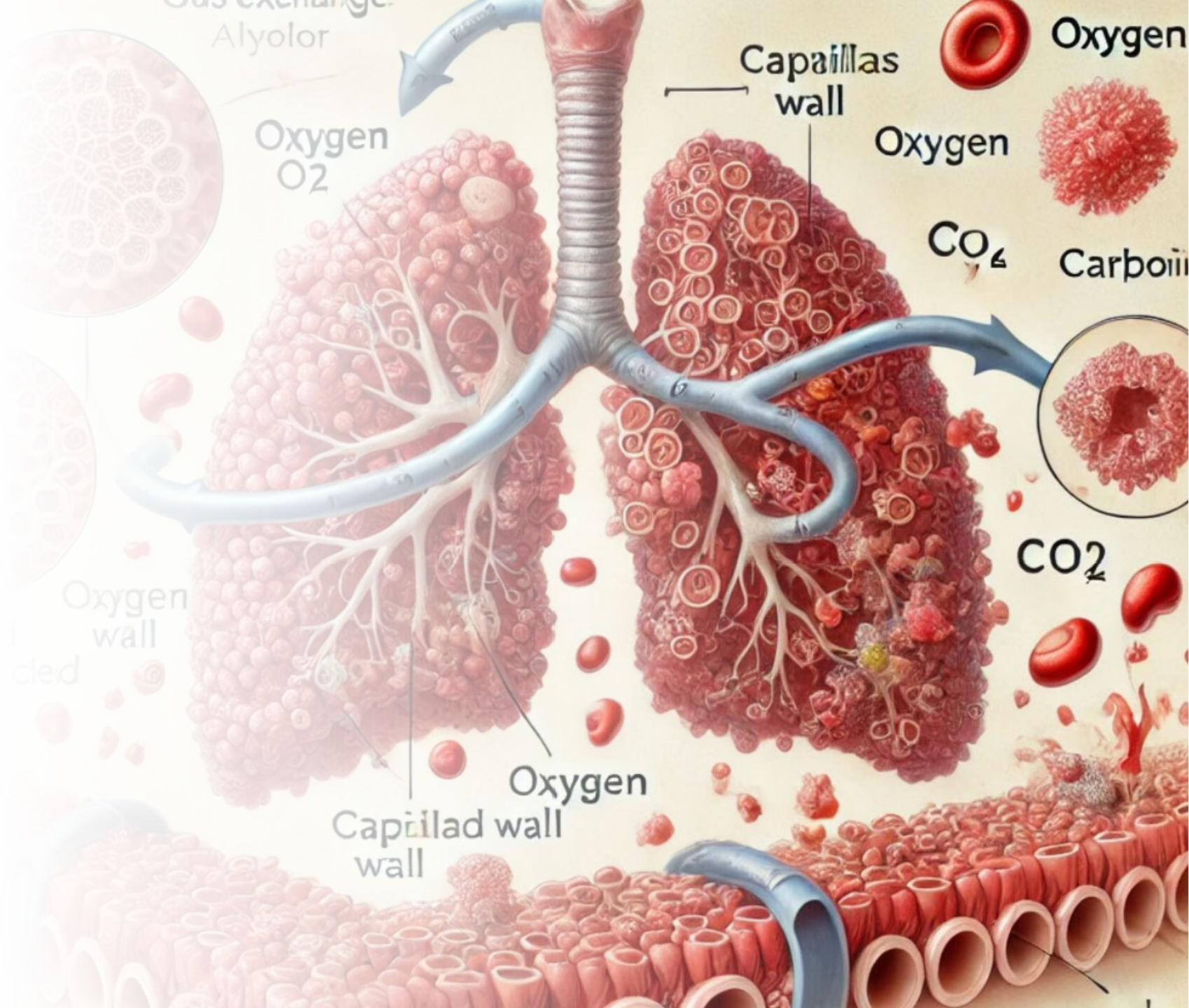
- **Hypoxic:**
  - Dependence on continuous home O2
- **Hypercapnic:**
  - Dependence on home non-invasive mechanical ventilation (BiPAP, AVAPS, etc.)

Acute on Chronic:

- **Hypoxic**
  - Drop in PaO_2 > 10 mmHg from baseline
  - Increased O2 requirements from baseline to maintain SpO_2 > 88%
- **Hypercapnic**
  - $PaCO_2$ > 10 mmHg above baseline and pH < 7.35

Pathophysiology of Hypoxia

- Ventilation/perfusion (V/Q) mismatch.
- Right-to-Left Shunt (mechanical or physiologic).
- Dead Space Ventilation.
- Diffusion Limitation.
- Reduced inspired oxygen tension (high altitude sickness).

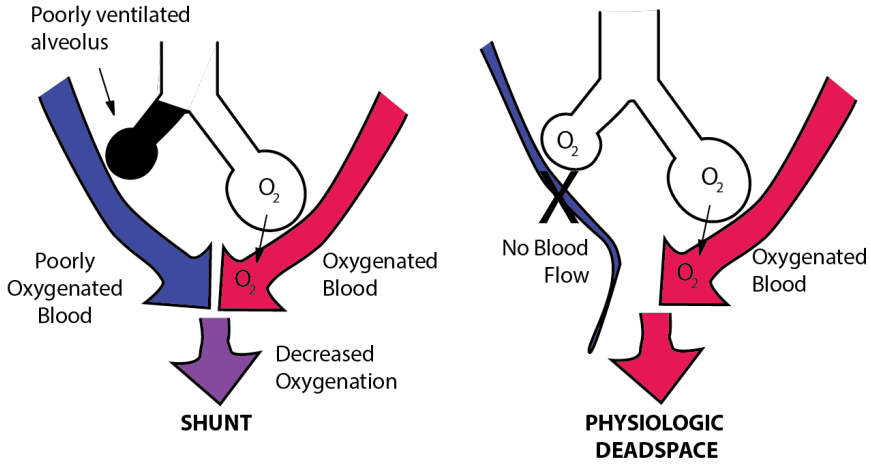


Ventilation/perfusion (V/Q) mismatch

- The balance between **ventilation (V)** (air reaching the alveoli) and **perfusion (Q)** (blood flow to the alveoli) is disrupted.

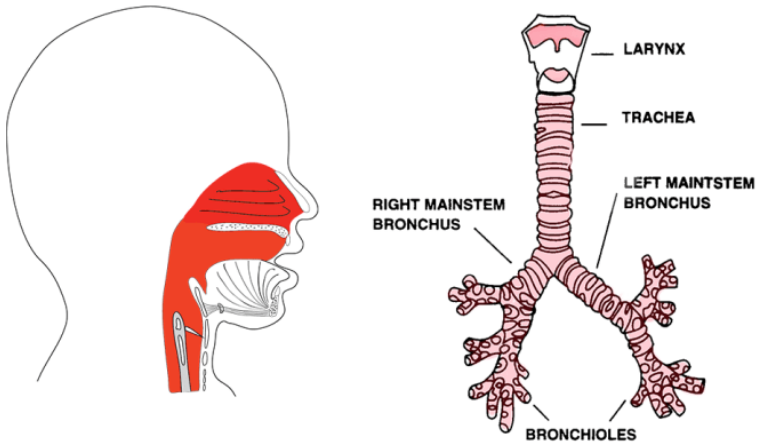
- **Low V/Q (Shunt-like Physiology)**
  - **Poor Ventilation, Normal Perfusion**
  - Shunt is perfusion of poorly ventilated alveoli
  - **Pathophysiology:** Alveoli are poorly ventilated but still perfused → Blood remains deoxygenated, leading to hypoxemia.

- **High V/Q (Dead Space-like Effect)**
  - **Poor Perfusion, Normal Ventilation**
  - Physiologic dead space is ventilation of poor perfused alveoli.
  - **Pathophysiology:** Alveoli are ventilated but receive little or no perfusion → Wasted ventilation.



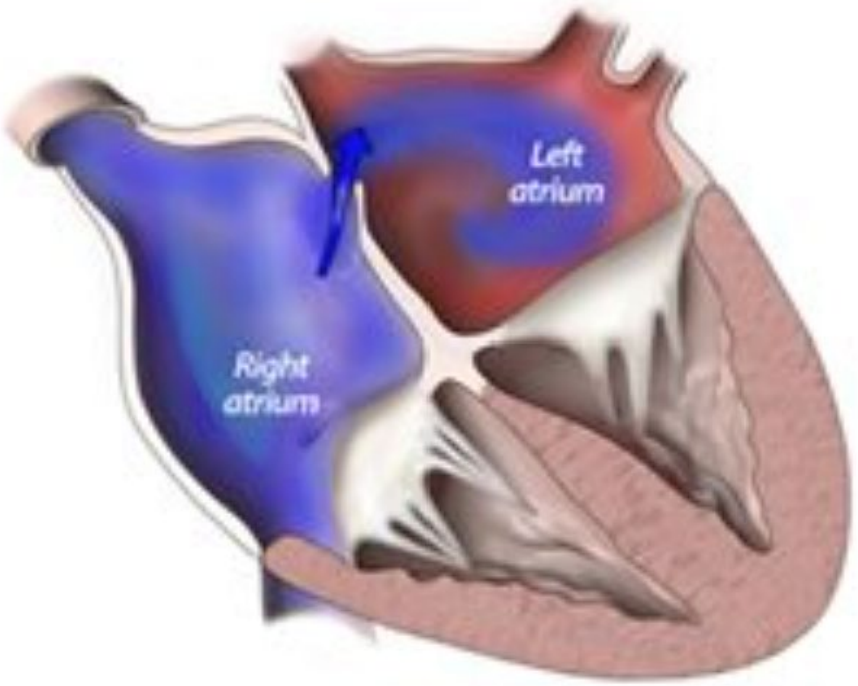
Dead Space

- **Tidal volume:** the amount of air that move in and out of the lungs with each respiratory cycle.
- **Dead Space:** the parts of the respiratory system that do not participate in gas exchange.
    - **Anatomic**: the fixed parts of the respiratory system that are ventilated but not perfused. Anatomic dead space is about 1/3 of normal tidal volume in an adult.
    - **Physiologic**: alveoli that are ventilated, but not perfused. Physiologic dead space can change as blood flow increases.
    - **Equipment**: the volume inside the ventilation mask or endotracheal tube, the connecting elbow, and the breathing circuit. This volume becomes significant in small patients or small tidal volumes.



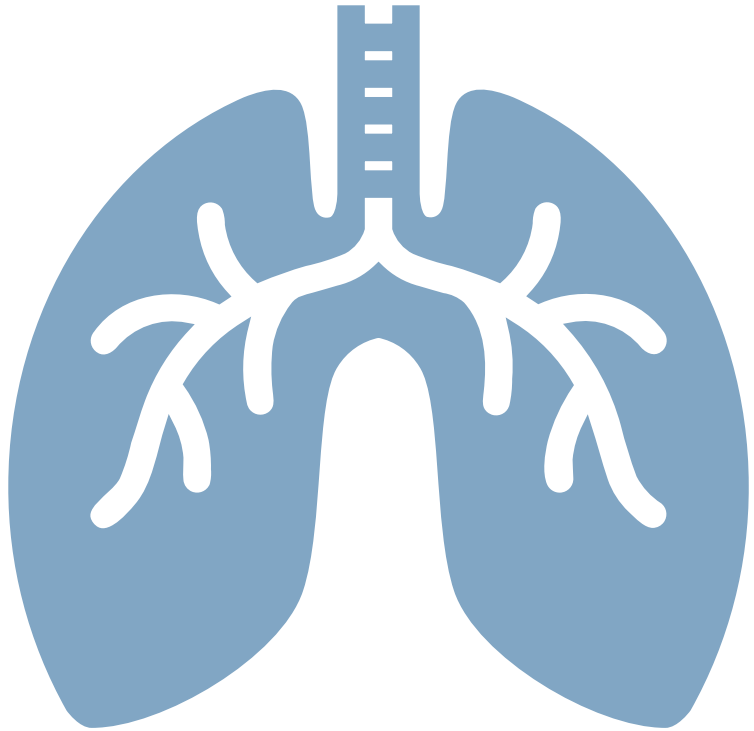
Intracardiac Shunt

- Allows deoxygenated blood from the right side of the heart to mix with oxygenated blood on the left side, bypassing the lungs and resulting in a lower overall oxygen level in the bloodstream → Right-to-left shunt.
- Causes of right to left shunt: patent foramen ovale, atrial septal defect, ventricular septal defect, congenital heart disease.



Diffusion Limitation

- Oxygen transport across the alveolar-capillary membrane is impaired.
- Typically results from thickening or destruction of the alveolar-capillary interface → slower diffusion of oxygen from alveoli into the blood.
- Common causes:
  - Interstitial lung disease (ILD)/Pulmonary fibrosis
  - Sarcoidosis
  - Asbestosis
  - Scleroderma



Reduced inspired oxygen tension

- High altitude sickness

Case presentation

Which mechanism is the main cause of hypoxia?

Additional diagnoses?

Immediate Testing

- ABG/VBG
- CXR
- CBC, BMP
- Lactate
- ECG

ABG Basics

- pH: 7.35-7.45
- $PaCO_2$: 35-45 mmHg
- PaO_2: 80-100 mmHg
- HCO_3: 22-26 mEq/L
- Base Excess: ±2

Case Presentation - ABG

Parameter	Value	Interpretation
pH	7.25	
PaCO2	72 mmHg	
PaO2	50 mmHg	
HCO3-	30 mEq/L	
FiO2	21% (room air)	

ABG Interpretation

Assess Oxygenation	PaO2 A-a gradient P/F ratio
Evaluate pH	< 7.35: Acidosis > 7.45: Alkalosis
Identify primary disorder	Respiratory: PaCO2 Metabolic: HCO3
Check compensation	Winter's formula Expected HCO3 change
Calculate A-a gradient	Bohr equation

Bohr Equation

- Physiologic dead space:

$$\mathrm{VD/VT} = \frac{P_aCO_2 - P_ECO_2}{P_aCO_2}$$

VD: Dead space volume.

VT: Tidal volume.

PaCO2: Partial pressure of carbon dioxide in arterial blood.

PeCO2: Partial pressure of carbon dioxide in exhaled air.

Compensation Principles

Metabolic compensation: The kidneys adjust bicarbonate (HCO_3^-) levels in response to respiratory disorders. This is a slower process, taking hours to days.

Respiratory compensation: The lungs adjust carbon dioxide ($PaCO_2$) levels in response to metabolic disorders. This is a faster process, occurring within minutes to hours.

Respiratory Disorders

Primary Disorder	Compensation Mechanism	Expected Compensation
Respiratory Acidosis (↑ $PaCO_2$)	**Kidneys retain HCO_3^-** (↑ HCO_3^-)	- **Acute:** ↑ HCO_3^- by **1 mEq/L per 10 mmHg** ↑ $PaCO_2$ - **Chronic:** ↑ HCO_3^- by **3.5 mEq/L per 10 mmHg** ↑ $PaCO_2$
Respiratory Alkalosis (↓ $PaCO_2$)	**Kidneys excrete HCO_3^-** (↓ HCO_3^-)	- **Acute:** ↓ HCO_3^- by **2 mEq/L per 10 mmHg** ↓ $PaCO_2$ - **Chronic:** ↓ HCO_3^- by **4-5 mEq/L per 10 mmHg** ↓ $PaCO_2$

Metabolic Disorders

Primary Disorder	Compensation Mechanism	Expected Compensation (Winter's Formula)
Metabolic Acidosis (↓ HCO_3^-)	**Hyperventilation** (↓ $PaCO_2$)	$PaCO_2 = (1.5 \times HCO_3^-) + 8 \pm 2$
Metabolic Alkalosis (↑ HCO_3^-)	**Hypoventilation** (↑ $PaCO_2$)	$PaCO_2$ increases by ~0.6 mmHg per 1 mEq/L HCO_3^-

Simplified Rules for Expected Compensation

Primary Disorder	Compensation Mechanism	Expected Change
Metabolic Acidosis	Decrease in P_aCO_2	$P_aCO_2 = (HCO_3^- + 15) \pm 5$
Metabolic Alkalosis	Increase in P_aCO_2	$P_aCO_2 = (HCO_3^- + 15)$
Respiratory Acidosis (Acute)	Increase in HCO_3^-	$\Delta HCO_3^- = 1$ per 10 mmHg P_aCO_2
Respiratory Acidosis (Chronic)	Increase in HCO_3^-	$\Delta HCO_3^- = 4$ per 10 mmHg P_aCO_2
Respiratory Alkalosis (Acute)	Decrease in HCO_3^-	$\Delta HCO_3^- = 2$ per 10 mmHg P_aCO_2
Respiratory Alkalosis (Chronic)	Decrease in HCO_3^-	$\Delta HCO_3^- = 5$ per 10 mmHg P_aCO_2

Additional diagnoses?

Test Results

☑ **CXR:** hyperinflation, no acute cardiopulmonary process
☑ **ECG:** sinus tachycardia, no ST-T changes
☑ **CBC:** WBC 12.5K
☑ **BMP:** significant electrolyte imbalances, normal renal function
☑ **Lactic acid:** 1.2 mmol/L

Further Diagnostics

- CT chest
- D-dimer
- BNP
- Procalcitonin
- Blood cultures

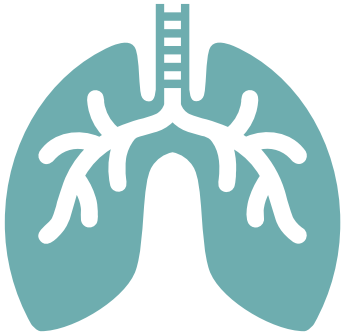
Management Protocol – Hypoxemia

Initiate Oxygen Therapy

Monitor Parameters

Indications for intubation

Risk Stratification



Need for immediate intubation?

Trial of non-invasive support?

Oxygen therapy

Nasal Cannula (1-6 L/min)

High-Flow NC (30-60 L/min)

Non-invasive ventilation

- Initial IPAP: 10 cmH2O
- Initial EPAP: 5 cmH2O
- FiO2: Titrate to SpO2 88-92%
- Rate: 12-15/min

Mechanical ventilation

Monitor Parameters

SpO2

Work of breathing

Mental status

Hemodynamics

Serial ABGs

Case Presentation - ABG

Parameter	Value	Interpretation
pH	7.20	
PaCO2	80 mmHg	
PaO2	65 mmHg	
HCO3-	30 mEq/L	
O2	5 L/min NC	

Management Protocol – Hypercapnia

1. NIV Strategy

- IPAP: Start 10, increase to effect
- EPAP: Start 5, titrate for OSA/COPD
- Monitor tolerance and air leak

2. Medical Management

- Bronchodilators
- Steroids if indicated
- Treat underlying cause

3. Monitoring

- Serial ABGs
- Continuous capnography if available
- Mental status
- Work of breathing

Indications for Intubation

- Persistent hypoxemia despite maximal non-invasive support
- Severe work of breathing
- Altered mental status
- Hemodynamic instability

Case Studies

Case Presentation

- **Scenario:** 55-year-old female admitted with COVID-19 pneumonia now with increased work of breathing.
- **Clinical Findings:**
  - ABG: pH 7.48, $PaCO_2$ 32 mmHg, PaO_2 58 mmHg on 60L/min HFNC.
  - Chest X-ray: Bilateral patchy opacities.
- **Management**

Case Presentation

- **Scenario:** 74-year-old female with CHF and COPD presenting with admitted with acute decompensation
- **Clinical Findings:**
  - ABG: pH 7.37, $PaCO_2$ 54 mmHg, PaO_2 55 mmHg on 2L/min NC.
  - Chest X-ray: Bilateral pulmonary vascular congestion.
- **Management**

References

- Roca O, Riera J, Torres F, Masclans JR. High-flow oxygen therapy in acute respiratory failure. Respir Care 2010; 55:408.
- Fujishima, S. Guideline-based management of acute respiratory failure and acute respiratory distress syndrome. j intensive care 11, 10 (2023). https://doi.org/10.1186/s40560-023-00658-3
- Griffiths MJD, McAuley DF, Perkins GD, Barrett N, Blackwood B, Boyle A, et al. Guidelines on the management of acute respiratory distress syndrome. BMJ Open Respir Res. 2019;6:e000420.
- O'Driscoll BR, Howard LS, Earis J, et al. BTS guideline for oxygen use in adults in healthcare and emergency settings. Thorax 2017; 72:ii1.
- Su L, Zhao Q, Liu T, et al. Efficacy of High-Flow Nasal Cannula Oxygen Therapy in Patients with Mild Hypercapnia. Lung 2021; 199:447.
- Global Initiative for Chronic Obstructive Lung Disease (GOLD). Global Strategy for the Diagnosis, Management and Prevention of Chronic Obstructive Pulmonary Disease: 2024 Report. www.goldcopd.org (Accessed on November 16, 2023).
- Illustrations:
    - https://airwayjedi.com/2017/01/06/ventilation-perfusion-mismatch/
    - https://airwayjedi.com/2024/07/08/understanding-anatomic-dead-space-impact-on-ventilation/
    - https://www.nationaljewish.org/conditions/intracardiac-shunts