Objectives:

- Review the physiological mechanism responsible to regulate acid base balance in the body i.e.:
  - Buffers (phosphate, hemoglobin, carbonate)
  - Renal mechanism
  - Respiratory mechanism
- Discuss the classification of acid base imbalance in terms of:
  - Respiratory acidosis
  - Respiratory alkalosis
  - Metabolic alkalosis
- Discuss how to interpret the arterial blood gases (ABGs) to identify four types of acid base imbalance.
- Discuss the causes, Pathophysiology and clinical manifestation of:
  - Respiratory acidosis & alkalosis.
  - Metabolic acidosis & alkalosis.
Acidosis

- Acidosis: process that lowers the ECF pH by a fall in HCO3 or elevation in PCO2
- Alkalosis: process that raises ECF pH by an elevation in ECF HCO3 or fall in PCO2.
- Metabolic Acidosis: low pH and low bicarb
- Metabolic Alkalosis: high pH and high bicarb
- Respiratory Acidosis: low pH and high PCO2
- Respiratory Alkalosis: high pH and low PCO2
Accumulation of acids → Increased concentration of H⁺ → Acidosis

Loss of bases → Increased concentration of H⁺ → pH drops

pH scale

7.4

Alkalosis → pH rises

Decreased concentration of H⁺ → Loss of acids → pH rises

Decreased concentration of H⁺ → Accumulation of bases
First line of defense against pH shift

Chemical buffer system

Bicarbonate buffer system

Phosphate buffer system

Protein buffer system

Second line of defense against pH shift

Physiological buffers

Respiratory mechanism (CO₂ excretion)

Renal mechanism (H⁺ excretion)
Component of the Arterial Blood Gas

The arterial blood gas provides the following values:

**pH**
- Measurement of acidity or alkalinity, based on the hydrogen (H+) ions present.
- The normal range is 7.35 to 7.45.

**PaO2**
- The partial pressure of oxygen that is dissolved in arterial blood
- The normal range is 80 to 100 mm Hg.
**SaO2**
- The arterial oxygen saturation
- The normal range is 95% to 100%.

**PaCO2**
- The amount of carbon dioxide dissolved in arterial blood.
- The normal range is 35 to 45 mm Hg.

**HCO3**
- The calculated value of the amount of bicarbonate in the blood stream.
- The normal range is 22 to 26 mEq/L
Steps to An Arterial Blood Gas Interpretation

- The arterial blood gas is used to evaluate both acid-base balance and oxygenation, each representing separate conditions.

- Acid-base evaluation requires a focus on three of the reported components: pH, PaCO2, and HCO3.

- This process involves three steps.
Step One:

- Assess the pH to determine if the blood is within normal range. (Alkalosis or acidosis).

- If it is above 7.45 the blood is alkalotic. If below 7.35, the blood is acidotic.
**Step Two:**

- If the blood is Alkalotic or acidotic, we now need to determine if it is caused primarily by respiratory or metabolic problem.

- Assess the PaCO2 level. Remember that with a respiratory problem, as the pH decreases below 7.35, the PaCO2 should rise.

- If the pH rises above 7.45, The PaCO2 should fall. Compare the pH and the PaCO2 values.

- If pH and PaCO2 are indeed moving in opposite directions, then the problem is primarily respiratory in nature.
Step 3:

- Finally, assess the HCO3 value. Recall that with a metabolic problem, normally as the pH increases, the HCO3 should also increase.

- Likewise, as the pH decreases, so should the HCO3. Compare the two values. If they are moving in the same direction, then the problem is primarily metabolic in nature.

- The following chart summarizes the relationships between pH, PaCO2 and HCO3
<table>
<thead>
<tr>
<th>Imbalance</th>
<th>pH</th>
<th>PaCO2</th>
<th>HCO3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory acidosis</td>
<td>↓</td>
<td>↑</td>
<td>Normal</td>
</tr>
<tr>
<td>Respiratory alkalosis</td>
<td>↑</td>
<td>↓</td>
<td>Normal</td>
</tr>
<tr>
<td>Metabolic acidosis</td>
<td>↓</td>
<td>Normal</td>
<td>↓</td>
</tr>
<tr>
<td>Metabolic alkalosis</td>
<td>↑</td>
<td>Normal</td>
<td>↑</td>
</tr>
</tbody>
</table>
Example: 1

- Sana is a 45 year old female admitted to the nursing unit with a severe asthma attack. She has been experiencing shortness of breath since admission three hours ago. Her arterial blood gas result is as follow.

Clinical laboratory:
Patient: Sana
Date: 3-3-09

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH</td>
<td>7.22</td>
</tr>
<tr>
<td>PaCO2</td>
<td>55</td>
</tr>
<tr>
<td>HCO3</td>
<td>25</td>
</tr>
</tbody>
</table>
Follow the step:

1. Assess the PH. It is low (normal 7.35-7.45) therefore we have acidosis.

2. Assess the PaCO2. It is high (35-45) and in opposite direction of the pH.

3. Assess the HCO3. It has remain with in normal range.(22-26)

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>PCO2</th>
<th>HCO3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory acidosis</td>
<td>↓</td>
<td>↑</td>
<td>Normal</td>
</tr>
</tbody>
</table>
• Refer to the chart acidosis is present (decrease pH) with the PaCO2 being increased, reflecting primary respiratory problem. For this patient we need to improve ventilation status by providing oxygen therapy, mechanical ventilation, administering bronchodilator.
Example 2

- Najam is a 55 year old male admitted to nursing unit with a recurring bowel obstruction. He has been experiencing intractable vomiting for the last several hours despite the use of anti-emetics. Here is the arterial blood gas result.

Clinical laboratory:

Patient: Najam
Date: 03-02-2015

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH</td>
<td>7.50</td>
</tr>
<tr>
<td>PaCO2</td>
<td>42</td>
</tr>
<tr>
<td>HCO3</td>
<td>33</td>
</tr>
</tbody>
</table>
**Follow the step:**

1. Assess the PH. It is high (normal 7.35-7.45) therefore we have alkalosis.

2. Assess the PaCO2. It is within the normal range (35-45)

3. Assess the HCO3. It is high (22-26) and moving in the same direction as the pH

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>PCO2</th>
<th>HCO3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic alkalosis</td>
<td>↑</td>
<td>normal</td>
<td>↑</td>
</tr>
</tbody>
</table>
• Again look at the chart. Alkalosis is present (increase pH) with the HCO3 increased, reflecting a primary metabolic problem. Treatment of the patient include the administration of IV fluid and measure to reduce the excess base.
Example 3

- Akram is admitted to the hospital. He is a kidney dialysis patient who has missed his last two appointments at the dialysis center. His arterial blood gas value are reported as follow.

Clinical laboratory:
Patient: Akram
Date: 02-01-2015

<table>
<thead>
<tr>
<th>Value</th>
<th>7.32</th>
<th>32</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PaCO2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCO3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Follow the step:**

1. Assess the PH. It is low (normal 7.35-7.45) therefore we have acidosis.

2. Assess the PaCO2. It is low then the normal range (35-45).

- Normally we would expect that the pH and PaCO2 to move in opposite direction, but this is not the case. Because pH and PaCO2 are moving in the same direction, it indicate the acid base disorder is primarily metabolic.
Because there is evidence of compensation (pH and PaCO2 moving in the same direction) and because the pH remain below the normal range we would interpret this ABG result as partially compensated metabolic acidosis.

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>PCO2</th>
<th>HCO3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic acidosis</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
</tr>
</tbody>
</table>
Example 4

- Robert is a patient with chronic COPD being admitted for surgery. Her admission lab work reveals an arterial blood gas with the following values:

Clinical laboratory:
Patient: Robert:
Date: 02-02-2015

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH</td>
<td>7.35</td>
</tr>
<tr>
<td>PaCO2</td>
<td>48</td>
</tr>
<tr>
<td>HCO3</td>
<td>28</td>
</tr>
</tbody>
</table>
Because they are moving in opposite directions, it confirms that the primary acid-base disorder is respiratory and that the kidneys are attempting to compensate by retaining HCO3.

Because the pH has returned into the low normal range, we would interpret this ABG as a fully compensated respiratory acidosis.

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>PCO2</th>
<th>HCO3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory acidosis</td>
<td>Normal but &lt; 7.40</td>
<td>↑</td>
<td>↑</td>
</tr>
</tbody>
</table>
Example 5:

- Aqsa is a 54-year-old female admitted for an ileus. She had been experiencing nausea and vomiting. An NG tube has been in place for the last 24 hours. Here are the last ABG results:

Clinical laboratory:
Patient: Aqsa
Date: 02-02-2015

PH  7.43
PaCO2  48
HCO3  36
Follow the three steps:

1. Assess the pH. It is normal, but on the high side of neutral (>7.40).

2. Assess the PaCO2. It is high (normal 35-45). Normally we would expect the pH and PACO2 to move in opposite directions in this case they are moving in the same direction indicating that the primary acid base disorder is metabolic in nature.

3. Assess the HCO3. It is also high (22-26). Because it is moving in the same direction as we would expect, it conform that the primary acid base disorder is metabolic in nature.
<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>PCO2</th>
<th>HCO3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic alkalosis</td>
<td>Normal but &gt;7.40</td>
<td>↑</td>
<td>↑</td>
</tr>
</tbody>
</table>
Compensation

- If underlying problem is metabolic, hyperventilation or hypoventilation can help respiratory compensation.

- If problem is respiratory, renal mechanisms can bring about metabolic compensation.
Acidosis

- Principal effect of acidosis is depression of the CNS through ↓ in synaptic transmission.
- Generalized weakness
- Deranged CNS function the greatest threat
- Severe acidosis causes
  - Disorientation
  - coma
  - death
**Alkalosis**

- Alkalosis causes over excitability of the central and peripheral nervous systems.

- Numbness

- Lightheadedness

- It can cause:
  - Nervousness
  - muscle spasms or tetany
  - Convulsions
  - Loss of consciousness
  - Death
Respiratory Acidosis

Causes:

- **Carbonic acid excess** caused by blood levels of CO$_2$ above 45 mm Hg.

- **Hypercapnia** – High levels of CO$_2$ in blood

- Chronic conditions:
  - Depression of respiratory center in brain that controls breathing rate – drugs or head trauma
  - Paralysis of respiratory or chest muscles
  - Emphysema
Respiratory Acidosis

- Acute conditions:
  - Adult Respiratory Distress Syndrome
  - Pulmonary edema
  - Pneumothorax
Compensation for Respiratory Acidosis

- Kidneys eliminate hydrogen ion and retain bicarbonate ion.
Clinical manifestation of Respiratory Acidosis

- Breathlessness
- Restlessness
- Lethargy and disorientation
- Tremors, convulsions, coma
- Respiratory rate rapid, then gradually depressed
- Skin warm and flushed due to vasodilatation caused by excess CO₂
Treatment of Respiratory Acidosis

- Restore ventilation.
- IV lactate solution.
- Treat underlying dysfunction or disease.
Respiratory Alkalosis

- Carbonic acid deficit
- \( pCO_2 \) less than 35 mm Hg (hypocapnea)
- Most common acid-base imbalance
- Primary cause is hyperventilation
Respiratory Alkalosis

Causes:

- Oxygen deficiency at high altitudes
- Pulmonary disease and Congestive heart failure – caused by hypoxia
- Acute anxiety
- Fever, anemia
- Early salicylate intoxication
- Cirrhosis
- Gram-negative sepsis
Compensation of Respiratory Alkalosis

- Kidneys conserve hydrogen ion.
- Excrete bicarbonate ion.
Treatment of Respiratory Alkalosis

- Treat underlying cause.
- IV Chloride containing solution – Cl⁻ ions replace lost bicarbonate ions
Metabolic Acidosis

- **Bicarbonate deficit** - blood concentrations of bicarbonate drop below 22mEq/L

- **Causes:**
  - Loss of bicarbonate through diarrhea or renal dysfunction
  - Accumulation of acids (lactic acid or ketones)
  - Failure of kidneys to excrete H+
Clinical manifestation of Metabolic Acidosis

- Headache, lethargy
- Nausea, vomiting, diarrhea
- Coma
- Death
Compensation for Metabolic Acidosis

- Increased ventilation
- Renal excretion of hydrogen ions if possible
- $K^+$ exchanges with excess $H^+$ in ECF
- (H$^+$ into cells, K$^+$ out of cells).

Treatment.

- IV lactate solution.
**Metabolic Alkalosis**

- **Bicarbonate excess** - concentration in blood is greater than 26 mEq/L

**Causes:**
- Excess vomiting = loss of stomach acid
- Excessive use of alkaline drugs
- Certain diuretics
- Endocrine disorders
- Heavy ingestion of antacids
- Severe dehydration
Compensation for Metabolic Alkalosis

- Alkalosis most commonly occurs with renal dysfunction, so can’t count on kidneys.

- Respiratory compensation difficult – hypoventilation limited by hypoxia.
Clinical manifestation of Metabolic Alkalosis

- Respiration slow and shallow
- Hyperactive reflexes; tetany
- Often related to depletion of electrolytes
- Atrial tachycardia
- Dysrhythmias
Treatment of Metabolic Alkalosis

- Electrolytes to replace those lost
- IV chloride containing solution
- Treat underlying disorder
Buffers, Acids and Bases

- Buffers: Resist changes in pH
  - When $H^+$ added, buffer removes
  - When $H^+$ removed, buffer replaces
- Acids
  - Retain $H^+$ into solution
- Bases
  - Remove $H^+$ from solution
- Acids and bases
  - Grouped as strong or weak
How the body defends against fluctuations in pH

Three systems in the body:

1. Buffers in the blood
2. Respiration through the lungs
3. Excretion by the kidneys
Acid-Base Balance

BUFFERS

• Any mechanism that resisting significant charges in pH.

• Accomplished by converting:

• Strong acid ------- Weak acid

• Strong base ------- Weak base
Buffers: Resist changes in pH
- When $H^+$ added, buffer removes
- When $H^+$ removed, buffer replaces

Types of buffer systems
- Carbonic acid / bicarbonate
- Protein
- Phosphate
**Bicarbonate Buffer System**

Carbonic acid (H₂CO₃)
- Weak acid

Bicarbonate ION (HCO₃⁻)
- Weak base
- Work in concert with respiratory and urinary system
- These systems removes CO₂ and HCO₃
- CO₂ + H₂O → H₂CO₃ → H⁺ + HCO₃⁻
- Main extra cellular buffer
- Also affected by lung and kidneys
Phosphate Buffer System

- Stronger than bicarbonate buffering system
- More important in buffering ICF and renal tubules than in ECF.

- \( \text{H}_2\text{PO}_4 \rightarrow \text{H}^+ + \text{HPO}_4 \)
- Dihydrogen Phosphate --- weak acid
- Monohydrogen phosphate weak base.
Protein buffer system

- Proteins are more concentrated than bicarbonate and phosphate buffers
- Accounts for 75% of all chemical buffering of body fluids.
Circulation

H₂O + ↑CO₂ → Carbonic anhydrase → H₂CO₃ → H⁺ + HCO₃⁻

Erythrocyte

Kidney

Lungs

Respiratory center in brain stem

↑Respiration rate and depth

↑CO₂ given off

↓pH

Regulation of Acid-Base Balance

Kidneys
- The decreased number of H⁺ are detected by the distal tubules in the kidneys.
- The distal tubules decrease H⁺ secretion into the urine, which increases urine pH, and decreases HCO₃⁻ reabsorption into the blood.
- Fewer H⁺ are removed from the blood. The decrease in HCO₃⁻ results in increased dissociation of carbonic acid to form H⁺.

Respiratory system
- The decreased number of H⁺ are detected by the medullary respiratory center.
- The respiratory center decreases the rate and depth of respiration, resulting in decreased gas exchange between the blood and air.
- Increased blood CO₂ reacts with water to produce carbonic acid, which dissociates to increase H⁺.

Buffers
- Buffers release H⁺.

Blood pH
- Blood pH increases (H⁺ concentration decreases).
- A decrease in blood pH results from an increase in H⁺ concentration.

Blood pH homeostasis is maintained.
Regulation of Acid-Base Balance

Blood pH (normal range)

Blood pH decreases (H⁺ ion concentration increases).

Buffers
Buffers bind H⁺.

Respiratory system
The increased number of H⁺ are detected by the medullary respiratory center.

The respiratory center increases the rate and depth of respiration, resulting in increased gas exchange between the blood and air.

As blood CO₂ decreases, H⁺ and HCO₃⁻ combine to form carbonic acid, which becomes CO₂ and water.

Kidneys
The increased number of H⁺ are detected by the distal tubules in the kidneys.

The distal tubules increase H⁺ secretion into the urine, which decreases urine pH, and increases HCO₃⁻ reabsorption into the blood.

More H⁺ are removed from the blood. The increased number of HCO₃⁻ in the blood remove H⁺ from the blood by combining with H⁺ to form carbonic acid.
<table>
<thead>
<tr>
<th>Buffer System</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein Buffer System</td>
<td>Intracellular proteins and plasma proteins form a large pool of protein molecules that can act as buffer molecules. Because of their high concentration, they provide approximately three-fourths of the buffer capacity of the body. Hemoglobin in red blood cells is an important intracellular protein. Other intracellular molecules like histone proteins and nucleic acids also act as buffers.</td>
</tr>
<tr>
<td>Bicarbonate Buffer System</td>
<td>Components of the bicarbonate buffer system are not present in high enough concentrations in the extracellular fluid to constitute a powerful buffer system. Because the concentrations of the components of the buffer system are regulated, however, it plays an exceptionally important role in controlling the pH of extracellular fluid.</td>
</tr>
<tr>
<td>Phosphate Buffer System</td>
<td>Concentration of the phosphate buffer components is low in the extracellular fluids compared to the other buffer systems, but it’s an important intracellular buffer system.</td>
</tr>
</tbody>
</table>
Respiratory Regulation of Acid-Base Balance

- Respiratory regulation of pH is achieved through carbonic acid/bicarbonate buffer system
  - As carbon dioxide levels increase, pH decreases
  - As carbon dioxide levels decrease, pH increases
- Carbon dioxide levels and pH affect respiratory centers
  - Hypoventilation increases blood carbon dioxide levels
  - Hyperventilation decreases blood carbon dioxide levels
Respiratory Regulation of Acid-Base Balance

1. Carbonic anhydrase
   - $\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{H}_2\text{CO}_3 \rightarrow \text{H}^+ + \text{HCO}_3^-$

2. Decreased pH
   - Respiratory center in brainstem

3. Increased respiration rate and depth
   - Lungs
   - Increased $\text{CO}_2$ expelled from the lungs
Renal Regulation of Acid-Base Balance

- Secretion of $\text{H}^+$ into filtrate and reabsorption of $\text{HCO}_3^-$ into ECF cause extracellular pH to increase
- $\text{HCO}_3^-$ in filtrate reabsorbed
- Rate of $\text{H}^+$ secretion increases as body fluid pH decreases or as aldosterone levels increase
- Secretion of $\text{H}^+$ inhibited when urine pH falls below 4.5
Renal Regulation of Acid-Base Balance

The image illustrates the renal mechanism for regulating acid-base balance. It shows the conversion of carbon dioxide and water into carbonic acid, which dissociates into hydrogen ions and bicarbonate ions. The bicarbonate ions are then transported into the renal tubule lumen for excretion.

Key steps in the process:
1. **CO₂ + H₂O ⇌ H₂CO₃**
2. **H₂CO₃ ⇌ H⁺ + HCO₃⁻**
3. **H⁺** is transported into the tubule lumen.
4. **HCO₃⁻ + Na⁺** are transported into the tubule lumen.
5. **Na⁺** is transported back into the capillary fluid.

The diagram also highlights transport mechanisms:
- **Countertransport** (green) refers to the movement of sodium ions against their concentration gradient.
- **Cotransport** (yellow) refers to the movement of sodium ions down their concentration gradient.

This process helps maintain the acid-base balance in the body by regulating the concentration of hydrogen ions and bicarbonate ions.
## Acidosis and Alkalosis

### Acidosis

**Respiratory Acidosis**
- Reduced elimination of $\text{CO}_2$ from the body fluids
- Asphyxia
- Hypoventilation (e.g., impaired respiratory center function due to trauma, tumor, shock, or renal failure)
- Advanced asthma
- Severe emphysema

**Metabolic Acidosis**
- Elimination of large amounts of $\text{HCO}_3^-$ resulting from mucous secretion (e.g., severe diarrhea and vomiting of lower intestinal contents)
- Direct reduction of the body fluid pH as acid is absorbed (e.g., ingestion of acidic drugs like aspirin)
- Production of large amounts of fatty acids and other acidic metabolites, such as ketone bodies (e.g., untreated diabetes mellitus)
- Inadequate oxygen delivery to tissue resulting in anaerobic respiration and lactic acid buildup (e.g., exercise, heart failure, or shock)

### Alkalosis

**Respiratory Alkalosis**
- Reduced $\text{CO}_2$ levels in the extracellular fluid (e.g., hyperventilation due to emotions)
- Decreased atmospheric pressure reduces oxygen levels, which stimulates the chemoreceptor reflex, causing hyperventilation (e.g., high altitudes)

**Metabolic Alkalosis**
- Elimination of $\text{H}^+$ and reabsorption of $\text{HCO}_3^-$ in the stomach or kidney (e.g., severe vomiting or formation of acidic urine in response to excess aldosterone)
- Ingestion of alkaline substances (e.g., large amounts of sodium bicarbonate)
THANK YOU