Acid / Base Balance
Objectives

- Define an acid, a base, and the measure of pH.
- Discuss acid/base balance, the effects of acidosis or alkalosis on the body, and the mechanisms in place to maintain balance and homeostasis.
- Describe the role and actions of the bicarbonate buffer system.
- Explain the actions of the respiratory and renal systems in maintenance of acid/base balance.
- Identify the type of imbalance based on lab values.
Acids, Bases, and Salts

- Chemical compounds in the body can be proton donors or acceptors
  - Proton donors are acids
  - Proton acceptors are bases
- Acids and bases react to neutralize each other forming salts
Acid / Base Balance

- pH is the scientific method of expressing the acidity or alkalinity of a solution.
- Normal pH of human blood is 7.35 – 7.45.
- 7 is considered neutral. A change in pH of 1 is a 10X increase or decrease in hydrogen ion concentration. A pH of 6 is 10X more acidic than a pH of 7.
Acidosis

- In the body, a pH < 7.35 represents acidosis. Acidosis causes:
  - Hyperventilation (compensatory response).
  - Right shift of the oxygen-hemoglobin dissociation curve.
  - Depression of myocardial contractility.
  - Sympathetic stimulation.
  - Hyperkalemia (K⁺ shift out of cells).
Alkalosis

- A pH of > 7.45 is considered to be alkalosis.

**Alkalosis causes:**
- A shift of the oxygen-hemoglobin dissociation curve to the left.
- Inhibits the respiratory drive.
- Arrhythmias.
- Cerebral vasoconstriction with decreased cerebral blood flow.
- Increased neuromuscular excitability including carpopedal spasm.
- Causes H⁺ shift into cells leading to hypokalemia.
Mechanisms to maintain normal pH and homeostasis include:

- The buffer systems
- The respiratory system
- The renal system
The Buffer Systems

- pH balance is maintained by buffers in the blood. The buffer systems are the:
  - Bicarbonate buffer system
  - Phosphate buffer system
  - Sulfate buffer system
Buffer Systems

- Function to change strong acids or strong bases into weak ones.
- Most buffers are a weak acid and a salt of that acid which functions as a weak base.
- If strong acids are present, $\text{HCO}_3^-$ (bicarbonate) will react with acid.
- If strong bases are present, $\text{H}_2\text{CO}_3$ (carbonic acid) will react with base.
The Buffer Systems

CO₂ + H₂O → H₂CO₃ → H⁺ + HCO₃⁻

- Removal of H⁺
- Addition of H⁺

Lungs: Increase respiratory rate
Decrease respiratory rate

Other buffer systems

Bicarbonate reserve HCO₃⁻

Kidneys

Bicarbonate Buffer System

- Important ECF and ICF buffer
- Acts continually and immediately
- Maintains 1 carbonic acid molecule for every 20 bicarbonate molecules.

\[
H_2O + CO_2 \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-
\]

Henderson-Hasselbalch Equation

- Typically found as sodium bicarbonate (NaHCO_3^-).

\[
HCl + NaHCO_3 \rightarrow H_2CO_3 + NaCl
\]
20:1 ratio is maintained
Bicarbonate Buffer System

- Bicarbonate buffer system is continually working with its action within seconds. In an acidic environment, it acts on a strong acid to create carbonic acid. The carbonic acid is then broken down into carbon dioxide and water. In an alkaline environment, free hydrogen is created and bicarbonate is placed in reserve or eliminated by the kidneys.

- The bicarbonate buffer system will react depending on what is needed for homeostasis.
Other Buffer Systems

Phosphate Buffer System

- Important intracellular buffer.

\[ \text{H}_2\text{PO}_4^- \leftrightarrow \text{HPO}_4^{2-} + \text{H}^+ \]

Sulfate Buffer System

- Intracellular and systemic buffer

\[ \text{SO}_4^{2-} \]
Buffering

\[ \text{H}_2\text{O} + \text{CO}_2 \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^- \]

- In both the bicarbonate and the phosphate buffering systems, the addition of more acid will shift the equilibrium to the left, consuming the excess H\(^+\).
- On the other hand, an increase in pH in alkaline conditions with lower H\(^+\) will cause the equilibrium to shift to the right restoring the pH to more acid conditions.
Respiratory System

- Respiratory system takes minutes to correct an imbalance. It eliminates or retains carbon dioxide which quickly converts to carbonic acid.
Respiratory System

- Is a back up to the buffer system.
- Takes 1 to 3 minutes to be effective.
- The main contribution is the removal of CO$_2$. 
Renal system

- Renal system takes hours to correct an imbalance by retaining or excreting bicarbonate and/or hydrogen ions. Slow, but very precise.

**Mechanisms of Renal Control**

- CO$_2$ + H$_2$O $\rightarrow$ H$_2$CO$_3$ $\rightarrow$ HCO$_3^-$ + H$^+$

How the kidneys combat acidosis:
1. Conserving (Reabsorbing) of HCO$_3^-$
2. Generating HCO$_3^-$
Renal System

- Requires hours to days to be effective.
- Main contribution is the long-term maintenance of acid-base balance by the removal or reabsorption of $H^+$ and $HCO_3^-$. 
Urinary Control of pH

- The kidneys can excrete varying amounts of hydrogen ions or bicarbonate into the urine.
- Excess $\text{H}^+$ can be excreted resulting in a net increase in $\text{HCO}_3^-$, raising the blood pH.
- $\text{HCO}_3^-$ can be eliminated, lowering blood pH.
Metabolic Acidosis
\((HCO_3^- < 22\text{mEq/L}, \text{pH} < 7.4)\)

- Caused from either an accumulation of acid in the blood or the loss of a base.
- Common causes include uncontrolled diabetes mellitus, diarrhea, ASA overdose, renal failure, liver failure, starvation, alcoholism, ethylene glycol ingestion, or after heavy exercise.
- Hyperventilation and respiratory alkalosis can be a response to metabolic acidosis.
Metabolic Alkalosis
(HCO$_3^-$ > 28 mEq/L, pH > 7.4)

- Abnormal loss of acid or an accumulation of a blood base. Most often caused by either the renal H$^+$ excretion or loss of HCl from the stomach, accompanied by concurrent production of HCO$_3^-$.

- Common causes include vomiting, constipation with excessive reabsorption of HCO$_3^-$, ingestion of alkalis or licorice, nasogastric suctioning, diuretics, steroid use, or blood transfusions.
Respiratory Acidosis
(\(\text{PCO}_2 > 45 \text{ mmHg}, \text{pH} < 7.4\))

- Occurs with a decrease of alveolar ventilation with an increase in \(\text{CO}_2\) levels (\(\text{H}_2\text{CO}_3 \uparrow, \text{pH} \downarrow\)).

- Caused by any condition that impairs gas exchange or lung ventilation.
  - Chronic bronchitis, emphysema, cystic fibrosis.
  - Rapid, shallow breathing with reduced tidal volume.
  - Trauma with injury to the brain stem or chest wall.
  - Narcotic, barbiturate, sedative overdose.
  - Myasthenia gravis, Guillain-Barre syndrome.
  - Exhaustion.
Respiratory Alkalosis
(PCO₂ < 35 mmHg, pH > 7.4)

- Occurs with alveolar hyperventilation and the depletion of CO₂ and H₂CO₃.
- Caused by hyperventilation or overzealous mechanical ventilation.
- Anxiety, fever, pain.
- Pneumonia, ARDS, PE, CHF.
- Trauma, hypoxemia, pregnancy, shock.
# Acid / Base Disturbance

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>HCO₃⁻</th>
<th>PCO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.35-7.45</td>
<td>22-28 mEq/L</td>
<td>35-45 mmHg</td>
</tr>
</tbody>
</table>

- **Respiratory acidosis**
  - pH: ↓
  - HCO₃⁻: ↑ if compensating
  - PCO₂: ↑

- **Respiratory alkalosis**
  - pH: ↑
  - HCO₃⁻: ↓ if compensating
  - PCO₂: ↓

- **Metabolic acidosis**
  - pH: ↓
  - HCO₃⁻: ↓
  - PCO₂: ↓ if compensating

- **Metabolic alkalosis**
  - pH: ↑
  - HCO₃⁻: ↑
  - PCO₂: ↑ if compensating
Determining Imbalance

- Think of the pH as the last name when trying to name the imbalance.
  - If the number is below 7.35, the last name is acidosis.
  - If the number is above 7.45, the last name is alkalosis.
  - 7.4 is the midline or median.
Let’s give the imbalance a first name by looking at the partial pressure of carbon dioxide (pCO$_2$).

- If the arrow indicating the amount of CO$_2$ is pointing in the opposite direction of the pH arrow, the first name is “respiratory.”
- If the arrow indicating the amount of CO$_2$ is pointing in the same direction of the pH arrow, the first name is “metabolic.”
Bicarbonate or base excess will tell you if the body is trying to correct the imbalance or not.

Remember bicarbonate always tries to maintain a 20:1 relationship with carbonic acid.

When it is metabolic, all the arrows will point the same direction and the amount of CO₂ provides clues to determine if the body is compensating or not.
Determining Imbalance

- For example, if your patient is not breathing well and their pH is 7.3, they are acidotic. If they are not able to blow off the carbon dioxide, the pCO$_2$ will be elevated telling you that the patient is in respiratory acidosis.
Determining Imbalance

- If the bicarbonate $\text{HCO}_3^-$ is elevated, the body is trying to correct the accumulation of $\text{CO}_2$ or is “compensating.”
Determining Imbalance

- It is not completely “compensated” until the pH returns to within normal range.
- In this case, we look at the arrows and use the median number of 7.4 to determine if it is a compensated acidosis or alkalosis, even though the pH may be between 7.35 - 7.45.
- So if the pH returns to 7.35 with pCO2 at 48 mmHg with a BE of 30 mEq/L, the patient would be in a “compensated respiratory acidosis.”
Example 1

A 70 y.o. male is admitted to the ICU with acute pancreatitis. He is hypotensive, hypoxic, and in acute renal failure with a respiratory rate of 48 breaths/minute. Blood gases show a pH of 7.1, PCO$_2$ of 22 mmHg and a BE of 21mEq/L. What is this patient’s condition?

Severe metabolic acidosis

Explain the cause of this condition. Describe your treatment.
A 6 week old male infant is admitted with a history of projectile vomiting over 2 days. Blood gas analysis reveals a pH of 7.45, PCO$_2$ of 48 mmHg and a BE of +11 mEq/L

Compensated metabolic alkalosis

If you responded to this call, describe your assessment, possible cause, and treatment.
Example 3

A 40 y.o. male patient is transported by EMS to the ED. Patient is unresponsive with history of a recent back injury. Patient had been found by his wife when she returned home from work. pH is 7.27, PCO$_2$ is 58 mmHg, and BE is 28 mEq/L.

Respiratory acidosis

What may be the cause of the respiratory acidosis?
What are the signs to look for?
How might you treat it?
Questions?

"Whoa! Watch where that thing lands—we'll probably need it."