Acid-Base Balance

A. Acid-Base Essentials

Regulation of H+ concentration of body fluids (pH homeostasis)

\[ \text{pH} = - \log [\text{H}^+] \quad \uparrow[H^+] = \downarrow\text{pH} \]

normal pH of blood is 7.4 (range 7.35-7.45)

- pH affects many biochemical reactions and physiological processes
- protein structure and function (e.g. enzymes) are very sensitive to pH

The \textit{CO}_2-bicarbonate reaction is the primary acid-base system of the body:

\[
\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \\
\text{carbonic anhydrase} \text{ catalyzes the reversible reaction in both directions}
\]

\(\text{CO}_2\) acts as an acid: \(\uparrow [\text{CO}_2] \rightarrow \uparrow [\text{H}^+] = \downarrow \text{pH}\)
\(\text{HCO}_3^-\) acts as a base: \(\uparrow [\text{HCO}_3^-] \rightarrow \downarrow [\text{H}^+] = \uparrow \text{pH}\)

Buffers – compounds that prevent minimize changes in pH when H+ is added or removed
1. bicarbonate (\textit{CO}_2-bicarbonate reaction) - ECF and ICF
2. proteins (e.g., hemoglobin) - blood and ICF
3. phosphate compounds - ICF

B. Acid-Base Regulation

Acid-base homeostasis requires balancing H+ inputs and outputs to maintain normal blood pH.

Inputs: - \text{CO}_2 produced by aerobic respiration is the largest source of H+ in the body
- non-\text{CO}_2 sources of H+ include \textit{metabolic acids} such as lactic acid and ketone bodies
- diet can be a source of acids or bases

Outputs: - \text{CO}_2 output via ventilation, proportional to \textit{alveolar ventilation} rate (\(V_A\))
- kidneys excrete excess \text{H}^+ in urine and reabsorb \text{HCO}_3^- back into the blood

1. Respiratory System
   - ventilation is regulated to maintain normal blood \(P_{\text{CO}_2}\)
   - \(P_{\text{CO}_2}\) is inversely related to alveolar ventilation rate (\(V_A\))
     \(\downarrow V_A \rightarrow \uparrow P_{\text{CO}_2} \) (hypoventilation) \(\rightarrow \uparrow[H^+] = \downarrow \text{pH}\)
     \(\uparrow V_A \rightarrow \downarrow P_{\text{CO}_2} \) (hyperventilation) \(\rightarrow \downarrow[H^+] = \uparrow \text{pH}\)

2. Kidneys
   - excrete acids/bases in the urine
   - maintain [\text{HCO}_3^-] of blood via \textit{H}^+ \textit{excretion} and \textit{HCO}_3^- \textit{reabsorption}
   - non \text{CO}_2 acids/bases affect [\text{HCO}_3^-]:
     e.g., lactic acid \(\rightarrow \uparrow[H^+] \rightarrow \text{combines with HCO}_3^- \rightarrow \downarrow[\text{HCO}_3^-]\)
     base \(\rightarrow \downarrow[H^+] \rightarrow \text{more HCO}_3^- \text{ formed} \rightarrow \downarrow[\text{HCO}_3^-]\)

Bottom line: pH homeostasis involves regulation of \(P_{\text{CO}_2}\) and [\text{HCO}_3^-] in the blood.
The respiratory system regulates \(P_{\text{CO}_2}\), the kidneys regulate \text{HCO}_3^-.

Normal acid-base values in arterial blood:

\[
\text{pH} = 7.4 \\
P_{\text{CO}_2} = 40 \text{ mm Hg} \\
[\text{HCO}_3^-] = 24 \text{ mM}
\]
3. Acid-Base Disturbances

- **Acidosis** - condition where pH decreases below normal (< 7.35)
- **Alkalosis** - condition where pH increases above normal (> 7.45)

- *Respiratory acidosis/alkalosis* - deviations from normal pH due to a change in $P_{CO_2}$

- *Metabolic acidosis/alkalosis* - deviations from normal pH due to non-$CO_2$ acids/bases
  which cause a change in $[HCO_3^-]$

  - Respiratory acidosis: pH < 7.35, $P_{CO_2}$ > 40 mm Hg
  - Respiratory alkalosis: pH > 7.45, $P_{CO_2}$ < 40 mm Hg
  - Metabolic acidosis: pH < 7.35, $[HCO_3^-]$ < 24 mM
  - Metabolic alkalosis: pH > 7.45, $[HCO_3^-]$ > 24 mM

*Respiratory compensation* can partially offset metabolic acid base disturbances
  e.g., metabolic acidosis with respiratory compensation
  - Metabolic acidosis: pH < 7.35, $[HCO_3^-]$ < 24 mM,
  - Compensation: hyperventilation $\rightarrow$ $\downarrow$ $P_{CO_2}$ $\rightarrow$ $\uparrow$ pH

*Renal compensation* can partially offset respiratory acid base disturbances
  e.g., respiratory acidosis with renal compensation
  - Respiratory acidosis: pH < 7.35, $P_{CO_2}$ > 40 mm Hg
  - Compensation: $\uparrow$ $H^+$ excretion and $HCO_3^-$ reabsorption by kidneys
  $\rightarrow$ $[\uparrow HCO_3^-]$ $\rightarrow$ $\uparrow$ pH