ACID-BASE BALANCE AND ACID-BASE DISORDERS

I. Concept of Balance
   A. Determination of Acid-Base status
      1. Specimens used - what they represent

II. Electrolyte Composition of Body Fluids
   A. Extracellular Compartment
      1. Vascular - Plasma, RBC
      2. Interstitial fluid, CSF & bone
   B. Intracellular Compartment
   C. Mechanism for maintaining body water levels
   D. Mechanisms for the movement of substances between compartments
      1. Gibbs-Donnan Equilibrium
      2. Active & Passive Transport

III. Estimation of Vascular Compartment pH
   A. Henderson-Hasselbalch Equation

\[
pH = pK' + \log \left( \frac{cHCO_3^-}{cdCO_2} \right)
\]

Average ratio of log term is about 20/1
pH imbalances of metabolic origin are classified as primary disturbances of \([HCO_3^-]\), while those of respiratory origin are considered primary disturbances of \([dCO_2]\)

IV. Acid-Base Parameters - Definitions and Abbreviations
   Bicarbonate - plasma bicarbonate, carbonate and \(CO_2\) bound in plasma carbamino compounds
   Dissolved \(CO_2\) \((dCO_2)\) - free \(CO_2 + H_2CO_3\)
   Partial Pressure of \(CO_2\) \((pCO_2)\) - \(\alpha pCO_2 = [dCO_2]\)
Total CO₂ (tCO₂) = [HCO₃⁻] + [dCO₂]

Standard [HCO₃⁻] of blood

Base Excess of the Extracellular fluid or Standard Base Excess: Concentration of titratable base when titrating a model of extracellular fluid to a pH of 7.4 at a pCO₂ of 40 mm Hg.

pH: - log aH⁺. [H⁺] = K(pCO₂/cHCO₃⁻)

V. Buffer Systems and Their Role in Regulating the pH of Body Fluids

A. Bicarbonate/Carbonic Acid Buffer System

\[ \beta_{HCO_3^-} = \frac{\Delta[HCO_3^-]}{\Delta pH} \]

\[ \beta_{HCO_3^-}, \text{ closed} = 2.303 \left[ tHCO_3^- \right] \left\{ K' aH^+/(K' + aH)^2 \right\} = 2.7 \text{ mM} \]

\[ \beta_{HCO_3^-}, \text{ open} = 2.303[HCO_3^-] = 56.6 \text{ mM} \]

B. Phosphate Buffer System

C. Plasma Protein Buffer System: imidazole side chains

D. Hemoglobin Buffer System

VI. Isohydric & Chloride Shift

VII. Respiratory Mechanism in the Regulation of Acid-Base Balance

VIII. Renal Excretion of Acid, Ammonia Formation and Reabsorption of Bicarbonate - Renal Compensatory Mechanism

A. Excretion of Acids

B. Na⁺-H⁺ Exchange

C. Renal Production of Ammonia & Excretion of NH₄⁺

D. Excretion of H⁺ as H₂PO₄⁻

E. Reclamation of Filtered Bicarbonate
1. Conditions Associated with Abnormal Acid-Base Status and Abnormal Anion-Cation Composition of the Blood

- Assumes that extracellular composition is same as intracellular composition
- Anion & cation shifts accompany alterations in $H^+$
  - Anion to balance $H^+$, cation to balance organic acid anions
- Separated into respiratory (acidosis and alkalosis) and metabolic (acidosis and alkalosis)
- Compensatory mechanisms may fully, partially or not restore acid-base balance

A. Metabolic Acidosis

1. Production of organic acids > excretion of these acids
2. Decreased urinary excretion of acids
3. Excessive loss of $HCO_3^-$ due to loss of duodenal fluid

$$pH = pK' + \log([HCO_3^-]/[dCO_2])$$

Symptoms: hyperventilation, acidic urine

4. Normal Anion Gap Acidoses
   a. Hypokalemic
      1. Diarrhea
      2. Renal tubular acidosis
      3. Carbonic anhydrase inhibitors
      4. Ureterosigmoidostomy
b. Normokalemic
   1. Early renal failure
   2. Hydronephrosis
   3. Treatment with NH₄⁺, Arg-HCl
   4. Hypoaldosteronism or aldosterone-antagonizing drugs

   c. Hyperkalemic
   1. Severe inhibition of renal NH₄⁺ formation
   2. Severe reaction to aldosterone antagonists, renin synthesis failure, advanced Addison’s disease, renal resistance to aldosterone

5. Increased Anion Gap Acidosis
   a. Renal Failure
   b. Ketoacidosis
   c. Salicylate intoxication
   d. Lactic Acidosis
      Type A - severe hypoxia
      Type B - drugs & toxins, defects in gluconeogenesis enzymes, severe acidoses

\[
\text{Lactate} + \text{NAD}^+ <=====> \text{Pyruvate} + \text{NADH} + \text{H}^+ \\
\]

6. Compensatory Mechanisms
   a. Respiratory (decreased dCO₂)
   b. Renal

7. Lab Findings:

   \[
   [\text{HCO}_3^-] + 15 = 25 \quad \text{pH} = 7.25 \\
   \text{pCO}_2 \pm 2 = 1.5[\text{HCO}_3^-] + 8
   \]
Diabetic Ketoacidosis

B. Metabolic Alkalosis

1. Administration of excess alkali
2. Excessive loss of HCl from stomach
3. K⁺ depletion
4. Renal bicarbonate retention
5. Prolonged administration of thiazide diuretics

Symptoms - hypoventilation

6. Compensatory Mechanisms - hypoventilation
7. Lab Findings. Use formulas

C. Respiratory Acidosis

1. Respiratory Center Depression
2. Obstruction - both blockage & scarring of alveoli
3. Abdominal Distention, extreme obesity, extreme scoliosis, sleep apnea
4. Compensatory Mechanisms
   a. Increased depth & volume of breathing
   b. Renal
5. Lab Findings: pH > 7.20, usually uncomplicated
   \[ \Delta cH^+ = 0.8(\Delta pCO_2) \]

D. Respiratory Alkalosis

1. Nonpulmonary Stimulation of Respiratory Center
2. Pulmonary Stimulation of Respiratory Center
3. Ventilation-Induced
4. Compensatory
   a. Renal
5. Lab Findings

E. Anion Gap

F. Osmolal Gap Calculation - useful at identifying presence of osmotically active unknown substance

Osmolal Gap = Observed - Calculated

Calculated: $1.86[\text{Na}^+] + [\text{Glu}] + [\text{Urea}] + 9$

G. Use of acid-base nomograms