Principles of Fluid Balance

I. The Cellular Environment: Fluids and Electrolytes

A. Water
   1. Total body water (TBW) = 60% of total body weight
   2. Fluid Compartments in the Body
      a. Intracellular Compartment – Intracellular Fluid (ICF)
         (1) Fluid within body cells
         (2) 75% of total body water
         (3) 40% of total body weight (2/3 of all fluid weight)
      b. Extracellular Compartment – Extracellular Fluid (ECF)
         (1) All fluid outside the body cells
         (2) 25% of total body water
         (3) Two divisions of extracellular fluid
            (a) Intravascular fluid (17.5% of TBW)
               i) Fluid outside the cells but inside the circulatory system
               ii) Essentially blood plasma
            (b) Interstitial fluid
               i) Fluid outside the cells and not in the circulatory system
               ii) Examples include synovial fluid, aqueous humor, saliva, gastric juices, etc. (7.5% of TBW)
   3. Hydration
      a. Water is the universal solvent (most substances dissolve in water).
      b. Intake (water coming in) and output (water excreted) need to balance.
      c. Dehydration = abnormal decrease in total body water. Can be caused by:
         (1) Gastrointestinal – Vomiting, Diarrhea
         (2) Perspiration
         (3) Internal losses (“third space” losses) – Peritonitis, Malnutrition, etc.
         (4) Plasma losses – Burns, Open wounds
      d. Overhydration = the presence or retention of an abnormally high amount of body fluid.

B. Electrolytes
   1. Basic Concepts
      a. Atom
         (1) The smallest particle of an element.
         (2) Examples of elements and their symbols include:
            (a) Hydrogen H
            (b) Oxygen O
            (c) Calcium Ca
            (d) Potassium K
            (e) Sodium Na
         (3) Atoms are made up of 3 smaller particles:
            (a) Electrons – have a negative charge
            (b) Protons – have a positive charge
            (c) Neutrons – have a neutral charge
         (4) In a normal atom, the electrons and protons are equal so that the atom has a neutral charge.
b. Molecule
(1) A combination of atoms.
(2) Examples of molecules and their symbols include:
   (a) Sodium Chloride  NaCl
   (b) Water     H₂O
   (c) Sodium Bicarbonate NaHCO₃

c. Ions
(1) An atom or group of atoms that has become either positively or negatively charged.
(2) This can happen in one of two ways:
   (a) An atom can lose one or more electrons and become positively charged (a cation). Examples include:
      i) Sodium   Na⁺
      ii) Potassium   K⁺
      iii) Calcium   Ca²⁺
   (b) An atom can gain one or more electrons and become negatively charged (an anion). Examples include:
      i)   Chloride  Cl⁻
      ii) Bicarbonate HCO₃⁻

2. Electrolytes
   a. Substances that dissociate (break down) into electrically charged particles (ions) when placed into water.
   b. Major Cation (positively charged) Electrolytes:
      (1) Sodium (Na⁺)
         (a) Most prevalent cation in extracellular fluid.
         (b) Plays a major role in regulating the distribution of water and the transmission of nervous impulses.
         (c) Hyponatremia/Hyponatremia
      (2) Potassium (K⁺⁺)
         (a) Most prevalent cation in intracellular fluid.
         (b) Important in the transmission of electrical impulses.
         (c) Hypokalemia/Hyperkalemia
      (3) Calcium (Ca⁺⁺)
         (a) Plays a major role in muscle contraction and transmission of nervous impulses.
         (b) Hypocalcemia/Hypercalcemia
      (4) Magnesium (Mg⁺⁺)
         (a) Closely associated with phosphate in renal function.
         (b) Hypomagnesemia/Hypomagnesemia
   c. Major Anion (negatively charged) Electrolytes:
      (1) Chloride (Cl⁻)
         (a) Primarily regulates the pH of the stomach
         (b) Closely associated with sodium (regulates extracellular fluid)
      (2) Bicarbonate (HCO₃⁻)
         (a) Principle buffer of the body.
         (b) It neutralizes the highly acidic hydrogen (H⁺) ion.
      (3) Phosphate (HPO₄²⁻)
         (a) Important component is the formation of adenosine triphosphate (ATP)
         (b) Closely associated with magnesium in renal function.
         (c) Also acts as a buffer.
C. Osmosis and Diffusion

1. Basic concepts
   a. Solutions
      (1) Isotonic = when solutions on opposite sides of a semipermeable membrane are equal in concentration.
      (2) Hypertonic = when the concentration of a solution on one side of the membrane is greater than on the other side.
      (3) Hypotonic = when the concentration of a solution on one side of the membrane is less than on the other side.
      (4) This difference in concentration is known as the osmotic gradient.
   b. Diffusion = movement of molecules through a membrane from an area of greater concentration to one of lesser concentration.
      (1) Does not require energy.
      (2) This is referred to as movement “with the osmotic gradient.”
   c. Osmosis = passage of a solvent (usually water) through a membrane from an area of lower concentration to an area of higher concentration in order to dilute it.
   d. Active transport = movement of a substance through a cell wall from an area of lesser concentration to one of greater concentration.
      (1) Faster than diffusion, but requires energy.
      (2) This is referred to as movement “against the osmotic gradient.”
   e. Facilitated diffusion = movement of a substance through a cell membrane with the assistance of a “helper” (carrier) protein.

2. Water Movement between Intracellular and Extracellular Compartments
   a. Osmolality/Osmolarity
      (1) Osmolality = the concentration of solute per kilogram of water.
      (2) Osmolarity = the concentration of solute per liter of water.
      (3) These two terms are used interchangeably.
   b. When there is a change in the concentration of extracellular fluid, water will move from the intracellular to the extracellular compartment (or vice versa) until osmotic equilibrium is regained.

3. Water Movement between Intravascular and Interstitial Compartments
   a. Osmotic pressure = the pressure exerted by a high concentration of solutes on one side of membrane that pulls water from the other side of the membrane.
   b. Oncotic force
      (1) A form of osmotic pressure exerted by the large protein particles (colloids) found in blood plasma.
      (2) This pulls water from the interstitial space across the capillary membrane into the capillaries.
      (3) Oncotic force is also called colloid osmotic pressure.
   c. Hydrostatic pressure = blood pressure or force against vessel walls created by the contractions of the heart.
   d. Filtration = When water is forced out of the plasma and across the capillary wall into the interstitial space by hydrostatic pressure.
e. Net filtration = the total loss of water from the blood plasma across the capillary membrane into the interstitial space.
   (1) Starling's hypothesis:
   Net filtration = (Forces favoring filtration) - (Forces opposing filtration)
   (2) Normally, filtration and oncotic force work against each other so that the total loss of water from blood plasma across the capillary membrane into the interstitial space is zero.

4. Edema
   a. Accumulation of water in the interstitial space.
   b. This occurs when there is an imbalance between the forces favoring filtration and the forces opposing filtration.
   c. Edema affecting organs such as the brain, lung, heart, or larynx may be life threatening.

D. Intravenous Fluids
   1. Colloids
      a. Substances (such as proteins or starches) consisting of large molecules or molecule aggregates that disperse evenly within a liquid without forming a true solution.
      b. Colloids tend to remain in the intravascular space and exert oncotic force (colloid osmotic pressure) that pulls water out of the interstitial space and into the intravascular space.
      c. Examples of colloids include:
         (1) Plasma protein fraction (Plasmanate) – contains albumin
         (2) Salt poor albumin – contains only human albumin
         (3) Dextran – a large sugar molecule
         (4) Hetastarch (Hespan) – also a large sugar molecule

   2. Crystalloids
      a. Solutions created by dissolving crystals such as salts and sugars in water. Unlike colloids, these substances can diffuse through a membrane.
      b. These are the primary IV fluids used in the prehospital setting.

   3. Fluids can be classified according to their tonicity (the solute concentration or osmotic pressure in relation to the blood plasma or body cells).
      a. Isotonic solutions
         (1) Have electrolyte composition similar to blood plasma.
         (2) Will not cause a significant fluid or electrolyte shift.
         (3) Examples: Normal saline (0.9% NaCl), Lactated Ringers (LR)
      b. Hypertonic solutions
         (1) Have a higher solute concentration than the cells.
         (2) Because of this, these solutions will pull fluid out of the interstitial space and intracellular compartment into the intravascular space.
         (3) Examples: Plasmanate, Dextran
      c. Hypotonic solutions
         (1) Have a lower solute concentration than the cells.
         (2) Because of this, these solutions will cause fluid to move from the intravascular space into the interstitial space and intracellular compartment.
         (3) Example: 5% Dextrose in Water (D₅W)
Acid-Base Balance

A. General Information
1. Hydrogen ions (H\(^+\)) are very acidic and their concentration in the body must be maintained within fairly strict limits.
2. Hydrogen ion concentration is constantly changing.

B. The pH Scale
1. pH = an abbreviation for “potential of hydrogen”.
2. It is a measurement of hydrogen ion concentration.
3. The pH scale is inversely related to the hydrogen ion concentration.
   a. The higher the H\(^+\) concentration, the lower the pH (more acidic).
   b. The lower the H\(^+\) concentration, the higher the pH (more alkaline / basic).
4. The pH scale is a common logarithm, meaning each number is ten times that of its neighbor. (For example: a pH of 8 is 10 times greater than a pH of 7
5. The pH scale ranges from 1 to 14.
6. The normal pH of the body is 7.35-7.45
   a. Acidosis = pH less than 7.35 (higher concentration of hydrogen ions)
   b. Alkalosis = pH above 7.45 (lower concentration of hydrogen ions)
7. A variation in pH of only 0.4 in either direction (6.95 or 7.85) can be fatal.

C. Bodily Regulation of Acid-Base Balance
1. General Information
   a. The body is constantly producing H\(^+\) through metabolism and other processes.
   b. To maintain acid-base balance, H\(^+\) must be constantly eliminated from the body.
   c. There are three major mechanisms to remove H\(^+\) from the body:
      (1) The Buffer System (also called the Bicarbonate Buffer System)
      (2) Respiration
      (3) Kidney Function
2. The Buffer (or Bicarbonate Buffer) System
   a. The two components of the bicarbonate buffer system are:
      (1) Bicarbonate Ion (HCO\(_3^−\))
      (2) Carbonic Acid (H\(_2\)CO\(_3\)) formed when H\(^+\) combines with HCO\(_3^−\)
   b. The formula that shows how this part of the buffer system works is:
      \[ \text{H}^+ + \text{HCO}_3^- \leftrightarrow \text{H}_2\text{CO}_3 \]
   c. This formula can move back and forth in both directions.
      (1) When there is an increase in H\(^+\) (acidosis), the excess H\(^+\) will combine with HCO\(_3^−\) to form more carbonic acid (H\(_2\)CO\(_3\)).
      (2) When there is a decrease in H\(^+\) (alkalosis), carbonic acid will dissociate to produce more bicarbonate and hydrogen ions.
   d. Carbonic acid is a weaker acid than pure H\(^+\) and is better tolerated by the body, but it still has to be eliminated from the body.
      (1) Carbonic acid (H\(_2\)CO\(_3\)) is eliminated by dissociating into carbon dioxide (CO\(_2\)) and water (H\(_2\)O).
      (2) The speed of this process is increased by an enzyme called carbonic anhydrase that is contained in the blood’s erythrocytes.
   e. The complete formula showing the entire buffer system is:
      \[ \text{H}^+ + \text{HCO}_3^- \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}_2\text{O} + \text{CO}_2 \]
   f. Because this formula moves in both directions, an increase in carbon dioxide will lead to an increase in H\(^+\) (acidosis).
3. Respiration (as an acid-base balance mechanism)
   a. Increased respiration eliminates more CO$_2$. Reducing CO$_2$ in the body causes a reduction in H$^+$.
   b. Decreased respiration causes CO$_2$ to build up in the body which causes an increase in H$^+$.

4. Kidney Function
   a. The kidneys regulate pH by adjusting the amount of bicarbonate ion in the blood.
   b. Increased elimination of HCO$_3^-$ causes the concentration of H$^+$ to increase because there is less bicarbonate ion in the body to combine with the hydrogen ions and eliminate them.
   c. Increased retention of HCO$_3^-$ causes the concentration of H$^+$ to decrease because there is more bicarbonate ion in the body to combine with the hydrogen ions and eliminate them.

D. Acid-Base Derangements

1. Acidosis
   a. When the blood pH falls below 7.35.
      (1) Causes a depression of synaptic transmission in the central nervous system (the brain and spinal cord).
      (2) When the pH falls below 7.0, the depression is so severe that the person becomes disoriented, lapses into a coma, and death soon follows.
   b. Respiratory Acidosis
      (1) Caused by retention of CO$_2$
         (a) Normal CO$_2$ in arterial blood (called pCO$_2$) = 35 – 45 mm Hg
         (b) When pCO$_2$ is above 45 mm Hg, this indicates that too much CO$_2$ is being retained in the blood.
      (2) Any condition that hinders the movement of CO$_2$ from the blood to the alveoli to the atmosphere can cause respiratory acidosis.
         (a) Airway obstruction
         (b) Emphysema
         (c) Pulmonary edema, etc.
      (3) This condition is corrected by improving ventilation.
   c. Metabolic Acidosis
      (1) Caused by an increase in the production of metabolic acids or a loss of bicarbonate ions.
         (a) Normal bicarbonate ion concentration is = 22 – 26 mEq/liter.
         (b) When HCO$_3^-$ concentration drops below 22 mEq/liter, this indicates that there are not enough bicarbonate ions to bind with and eliminate H$^+$.
      (2) This can be due to:
         (a) Loss of HCO$_3^-$ from dehydration (diarrhea, etc.)
         (b) Loss of HCO$_3^-$ from kidney dysfunction
         (c) Increased metabolic acids (such as increased lactic acid from anaerobic metabolism, or increased acidic ketone bodies formed due to diabetes, or certain drug overdoses)
      (3) Treatment includes treating the underlying cause, increasing ventilation.
2. Alkalosis
   a. When the blood pH rises above 7.45.
      (1) Causes hyperexcitability in both the central nervous system (the brain
          and spinal cord) and the peripheral nerves.
      (2) This leads to extreme nervousness and muscle spasms and, if
          untreated, may lead to convulsions and death.
   b. Respiratory Alkalosis
      (1) Caused by increased respiration and excessive elimination of CO\(_2\)
          (a) Normal pCO\(_2\) = 35 – 45 mm Hg
          (b) When pCO\(_2\) is less than 35 mm Hg, this indicates that too much
              CO\(_2\) is being eliminated from the body.
      (2) Any condition that overly stimulates the respiratory center in the
          medulla oblongata region of the brain stem can cause respiratory
          alkalosis.
          (a) Severe anxiety (hyperventilation)
          (b) Oxygen deficiency (due to high altitude)
          (c) Early stages of aspirin overdose
      (3) Treatment is focused on increasing CO\(_2\) by helping to calm the patient
          and coaching them to slow down their respiratory rate.
   c. Metabolic Alkalosis
      (1) Caused by an increase in bicarbonate ions in the blood or a loss of too
          much acid.
          (a) Normal bicarbonate ion concentration is = 22 – 26 mEq/liter.
          (b) When HCO\(_3^-\) concentration rises above 26 mEq/liter, this indicates
              that there are too many bicarbonate ions in the blood, causing too
              much H\(^+\) to be eliminated.
      (2) This can be due to:
          (a) Increased HCO\(_3^-\) concentration due to overadministration of
              sodium bicarbonate or excessive ingestion of antacids.
          (b) Loss of acid due to diuretics.
          (c) Loss of acid due to vomiting (loss of hydrochloric acid from the
              stomach).
      (3) Treatment consists of correcting the underlying problem.