FLUIDS AND ELECTROLYTES

For both Search and Rescue personal and the subject, the bodies's management of fluids is central to performance and survival. The constituents and volume of the bodies's water are normally finely tuned to stay within stringent limits. The environmental stresses (heat, cold, high altitude) and physical exercise requirements common to SAR severely stress even the most acclimatized individual. Adequate fluid and electrolyte balance plays a major role in heat, cold, gastrointestinal, shock, and most other medical disorders. Therefore, a through understanding of fluid physiology and the disorders that may result are critical to anyone providing medical care in the wilderness setting.

FLUID PHYSIOLOGY

INPUT VERSUS OUTPUT

Output

Under normal conditions the body losses approximetly 2300 ml of water per day. However temperature, exercise, altitude, relative humidity, and other factors may significantly increase this amount. The routes through which the water is lost can be broken into two catagories: insensible and sensible water loss.

Insensible

Insensible water loss (cannot see the loss) occurs through the skin and through the respiratory tract. Approximately 400 ml of water diffuse directly through the skin each day. After severe burns, 3000ml-5000ml may diffuse through the damaged skin.

An additional 400ml of water escape through the respiratory tract. By the time air reaches the lungs the body has provided enough water to raise the relative humidity to 100%. Therefore, during expiration most of this water is loss. Several factors will influence the precise amount of water loss. Breathing slowly through the nose minimizes the loss since condensation occurs in the upper air passages. however, breathing rapidly through the mouth by passes the nasal passages and increases water loss. Therefore, during prolonged exercise the respiratory water loss may increase to 650ml/day.

This amount will increase even more at cold temperatures and high altitudes. At cold temperatures the air holds little moisture, thus requiring even more waster from the body to be added. At high altitudes due to the lowered vapor pressure and oxygen levels, more air must be inspired and expired. This increased respiratory rate will further the insensible water loss. At elevations above 15,000 feet (4,600m) total body loss often exceeds 4000 ml per day.

Sensible

The source of sensible water loss include the urine, sweat, feces, and may include vomitus. Sensible water loss under normal circumstances usually amounts to 1,600ml of water per day.

In a well hydrated 70 kilogram (K.g.) male, urine is produced at a rate of one ml/minute. This amounts to approximetly 1400ml/day. However, if a decrease on water intake or an increase in water output (sensible or insensible) occurs, the kidneys are able to concentrate the urine in order to conserve water losses. Under these conditions urine production will drop to 300-500 ml/day.

The amount of water loss through sweating is dependent upon temperature and level of exercise. At normal temperatures only 100ml/day of water is lost. During hot weather the rate dramatically increases to 1400ml/day. Finally, during prolonged heavy exercise the rate further increases to 5000ml/day. Depending on the level of exercise, its possible to lose 1500-2000ml/hour of water. In addition, during heavy exercise insensible loss will greatly increase due to rapid, heavy breathing through the mouth. Finally, an additional 75 ml/day is lost for each degree (C) the temperature is elevated.

The amount lost through the feces

stays relatively constant regardless of weather. Approximently 100 ml/day is lost through he gastrointestinal track. however, severe diarrhea can lead to fatal dehydration in some cases. The amount of vomitus must also be included in fluid losses.

Input

In order to maintain the general health of the body it is imperative to match the net fluid loss with adequate intake. Most people receive approximatlye two-thirds of their water from liquid beverages. The other third comes from water found in food. Finally the body produced 200 ml/day as a by-product of biochemical reactions. The typical intake of water amounts to 2300 ml/day, which exactly matches net losses during normal conditions.

FLUID COMPARTMENTS

TOTAL BODY WATER

The body is composed of solid matter and water. The fluid compartment composed of water and dissolved substances account for 60% of the body by weight. This figure represents the percentage for a lean male. Since fat tissue contains a higher percentage of lipids and less water, the amount of fat significantly alters the Total Body Water (TBW) percentage. Thin males may have a TBW of 65%, as opposed to obese males with a TBW of 55%. Since women contain an even greater percentage of fat the TBW of an obese woman may be as low as 45% compared to the normal of 50%. The water is distributed between two major compartments; the intracellular and extracellular.

INTRACELLULAR COMPARTMENT

The intracellular fluid is located inside the approximently 75 trillion cells found in the body. THe Intracellular fluid accounts for two-thirds of the TBW. Since a lean 70 Kg male has a TBW of 60%, he has a total of 42 liters of water. Therefore, 28 liters are located within the cells. The other 14 liters are located outside the cells.

EXTRACELLULAR COMPARTMENT

The remaining 14 liters of extracellular water are further divided into two additional compartments. The interstitial fluid surrounds the cells and the plasma which is found in the circulatory system.

Interstitial

The interstitial fluid surrounds cells and allows nutrients from the circulatory system to reach the cells. Most of the interstitial water becomes incorporated in a gel that holds cells in place. THe cerebrospinal fluid, intraocular fluid (found in the eye), and other miscellaneous fluids are calculated in the 11 liters that make up the interstitial fluid. Therefore, 75% of the extracellular fluid surrounds the cells.

Plasma

The remaining 3 liters of extracellular fluid is found in the plasma of the blood. If all the erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (platlets) are removed from blood, then plasma remains. Plasma represents 55% of bloods volume and also contains proteins, electrolytes, waste material, and gases in solution.

CONSTITUENTS OF EXTRACELLULAR & INTRACELLULAR COMPARTMENTS

Water is not the only essential constitute in the intracellular and extracellular compartments. Electrolytes, glucose, proteins, and fats dissolved in the water play a critical role in maintaining the proper osmotic pressure (water pressure) between the compartments. In order to understand the potential fluid and electrolyte disorders encountered in the field a thorough understanding of the electrolytes is necessary.

ELECTROLYTES

Electrolytes are elements or substances that when dissolved in water or other solvents, dissociated or splits into ions (charged particles) that are able to conduct electricity.

Distilled water conducts electricity poorly. However, most people are familiar with the deadly affect of electricity in a bathtub. When NaCl is added to distilled water it dissociates into a sodium ion (Na^+) and a chloride ion (Cl^-). The chlorinated water or mineral water found in the bathtub, allow the electricity to transmit its deadly affect. If two wires are placed into the solution and ten connected to a battery, the ions will carry the electrical charge. In addition, those ions with a positive charge (cations) will move towards the wire attached to the negative pole of the battery(cathode) while the ions with a negative charge (anions) will move toward the wire with a positive charge (anode). THe major cations and Anions of the Body are listed Below.

CATIONS		ANIONS	
Sodium	Na^+	Chloride	Cl^-
Potassium	K^+	Bicarbonate	
Calcium			
Magnesium			

MILLIEQUIVALENT

The quantity of electrolytes is measured in milliequivalent per liter (mEq/L). the unit is based upon the number of particles present times the amount of electrical charge the ion carries.

$$1 \text{ mEq/L} = \frac{\text{(mg/L) X Valence (charge)}}{\text{molecular weight}}$$

if 58 mg of Sodium Chloride are dissolved into one liter of water the salt will dissociate into 23 mg of Na^+ and 35 mg of Cl^- (an equal number if ions are present, however each chloride ion weighs more). Since the molecular weight of Sodium is 23, Chloride is 35, and each ion carries a single positive or negative charge (monovalent) then 1 mEq/L of both Cl^- and Na^+ is present.

If Ca^{++} and Cl^- are dissolved into water then the situation is different. Since a single Ca^{++} contains two electrical charges it has the same electrical value has two Cl^- ions. Therefore, if 110 mg of Calcium Chloride ($CaCl_2$) is dissolved into one liter of water the salt will dissociate into 40 mg of Ca^{++} and 70 mg of Cl^-. While the molecular weight of Ca^{++} is 40, 2 mEq/L will be present since Ca^{++} contains two charges. Since $Cl\_$ has only one charge and molecular wight of 35, 2 mEq/L will also be present. Twice the number of Cl^- particles are present to react completely with Ca^{++}.

DISTRIBUTION OF ELECTROLYTES

Extracellular

Sodium is the main extracellular Cation (142 mEq/L) in both the interstitial fluid and blood plasma. The extracellular fluid contains almost no Potassium (4 mEq/L). If extracellular Potassium levels increase to greater than 7.5 mEq/L it may prove fatal. The Cations are largely electrically balanced by the anions Chloride (103 mEq/L) and bicarbonate (28 mEq/L). Finally a small amount of protein (5 mEq/L) also serves as an anion.

Intracellular

Potassium (140 mEq/L) is the main intracellular Cation. Sodium only accounts for 10 mEq/L since the cell expends energy to pump sodium out of the cell while pumping Potassium in. Magnesium (58 mEq/L) also make a major contribution, especially when compared to its extracellular level (3 mEq/L). The cations are balanced by intracellular stores of bicarbonate (10 mEq/L), Phosphates (75 mEq/L), and anionic proteins (40 mEq/L).

FUNCTION OF ELECTROLYTES

Cations

SODIUM (Na^+)- Sodium is the major cation of the extracellular fluid. Since it binds so well to water, it causes water to move into or out of the intracellular fluid. The concentration of Sodium in the extracellular compartment controls the kidney's regulation of water and other electrolytes. Changes in Sodium will always be involved in diarrhea, vomiting, burns. dehydration, and other disorders common to the wilderness. This loss of balance may cause swelling or shrinkage of brain cells with potentially lethal results. In addition even minor disturbances may cause changes in the functioning of muscles and nerves.

POTASSIUM (K^+)- potassium is the major cation of the intracellular fluid. It plays a major role in establishing a membrane potential that allows electrical impulses to travel through nerves and muscles. Since 98% of Potassium is stores in the cells, severe and extensive tissue injury that causes the cells to rupture (crush injuries, falls, electrical injuries, burns) and release Potassium can severely upset the heart. A modest increase in blood plasma levels of Potassium may cause ventricular fibrillation.

CALCIUM (Ca^{++})- Calcium is found both intracellular (1 mEq/L) and extracellular (5 mEq/L). Only 1% of the bodies Calcium exists as a free ion, the rest is stored in the bones. Calcium plays a central role in muscle contraction, blood clotting, and bone development. Its role at the neuromuscular junction makes it important for maintenance of a normal heartbeat, nerve junction function, and metabolic activities.

MAGNESIUM (Mg^{++})- Magnesium is mainly found in the intracellular fluid (58 mEq/L) with a small amount in the extracellular fluid (3 mEq/L). Magnesium plays a role similar to Calcium in addition it influenced the metabolism of proteins and carbohydrates.

Anions

CHLORIDE (Cl^-)- Chloride is mainly found in the extracellular fluid in conjunction with Sodium. Since it closely follows Sodium is serve as the major anion in maintaining electrical neutrality and water balance. In addition, it plays a major role in acid-base balance.

BICARBONATE ($-HCO_3^-$)- Bicarbonate is found in nearly equal amounts in both the intracellular fluid and the extracellular fluid. Bicarbonate is the main buffer of the body and therefore maintains the proper pH throughout the body.

MOVEMENT OF WATER AND ELECTROLYTES BETWEEN COMPARTMENTS

DIFFUSION

All water molecules and substances dissolved in water are in constant motion. A single molecule will randomly bounce off other molecules billions of times each second, moving several different directions. The energy for this motion is supplied by heat. At higher temperature molecules will move even faster resulting in even more collisions. However, at absolute zero (0 K) all motion stops and diffusion will not occur. The process of diffusion may be summarized as the movement of molecules in a random fashion as a result of heat.

Although diffusion is a random process nevertheless certain rules apply. molecules will randomly move from areas of high to low concentration. If a bottle of perfume is placed in the corner of a room the perfume molecules will eventually diffuse throughout the room. Another example that relates more directly to processes in the body is the diffusion of dye through a glass of water. The initial drop of dye is highly concentrated. Therefore,it slowly moves throughout the glass until it is evenly dispersed.

Although diffusion requires energy in the form of heat, it is thought of as a passive process since the heat is supplied by the environment. The cell does not have to expend any energy to move substances inside or out if they are diffusing from an area of high to low concentration. However, when moving through a cell membrane the rate of diffusion may be affected by the type and size of the molecule.

SELECTIVE PERMEABILITY

In order to understand how water and electrolytes move in and out of cells its important to understand the function the cell membrane plays. The cell's membrane is composed of two layers of lipids (fats). Since lipids are not soluble in water they are said to be hydrophobic (water hating). This explains why oil (a type of lipid) and vinegar separate. The two layers of lipids or lipid bilayer is semipermeable. This means some molecules are able to diffuse through it while others are trapped on one side. Small molecules such as water, oxygen, and carbon dioxide diffuse through the membrane quite easily. Larger molecules that are similar to lipids are able to dissolve into the lipid bilayer and then diffuse out the other side. However, larger molecules unlike lipids (ex. glucose) are unable to diffuse through the membrane. The movement of glucose requires specialized transport channels. Finally, all electrolytes although small due to their charge are unable to diffuse through the membrane. They also require specialized transportation channels that often require energy.