

Body Fluids and Fluid Compartments

Blood composition depends on three major factors: diet, cellular metabolism, and urine output. In general, the kidneys have four major roles to play, which help keep the blood composition relatively constant. These are:

1. Excretion of nitrogen-containing wastes.
2. Maintaining water.
3. Maintaining electrolyte balance of the blood.
4. Ensuring proper blood pH.

In healthy young adult, water probably is half or more of body weight—50 percent in females and about 60 percent in males. These differences reflect the fact that females have relatively less muscle and a larger amount of body fat (fat contains the least water). Water is the universal body solvent within which all solutes (including the very important electrolytes) are Dissolved.

Water occupies three main locations within the body, referred to as **fluid compartments**. About two-thirds of body fluid, the so-called **intracellular fluid (ICF)**, is contained within the living cells. The remainder, called **extracellular fluid (ECF)**, includes all body fluids located outside the cells. Although ECF most importantly includes **blood plasma** and **interstitial (or tissue) fluid**, it also accounts for cerebrospinal and serous fluids, the humors of the eye, lymph, and others.

Electrolyte Balance

Electrolytes such as sodium, potassium, and calcium ions, are also vitally important to overall body homeostasis, and water and electrolyte balance are tightly linked as the kidneys continuously process the blood. Very small changes in **electrolyte balance**, the solute concentrations in the various fluid compartments, cause water to move from one compartment to another. Not only does this alter blood volume and blood pressure, but it can also severely impair the activity of irritable cells like nerve and muscle cells. For example, a deficit of sodium ions (Na^+) in the ECF results in water loss from the bloodstream into the tissue spaces (edema) and muscular weakness.

Most water intake is a result of fluids and foods ingested in diet. However, a small amount (about 10 percent) is produced during cellular metabolism.

There are several routes for water to leave the body:

1. Some water vaporizes out of the lungs
2. Some water is lost in perspiration,
3. Some water leaves the body in the stool.

If large amounts of water are lost in other ways, the kidneys is putting out less urine to conserve body water. On the other hand, when water intake is excessive, the kidneys excrete generous amounts of urine.

Most electrolytes enter the body in foods and mineral-rich water. Although very small amounts are lost in perspiration and in feces, the major factor regulating the electrolyte composition of body fluids is the kidneys.

Reabsorption of water and electrolytes by the kidneys is regulated primarily by **hormones**:

1. Highly sensitive cells in the hypothalamus called **osmo-receptors** react to the change in blood composition by becoming more active. The result is that nerve impulses are sent to the posterior pituitary which then releases **antidi-uretic hormone (ADH)**, this hormone prevents excessive water loss in the urine. As more water is returned to the bloodstream, blood volume and blood pressure increase to normal levels, and only a small amount of very concentrated urine is formed. ADH is released more or less continuously unless the solute concentration of the blood drops too low. When this happens, the osmoreceptors become "quiet," and excess water is allowed to leave the body in the urine.
2. **Aldosterone** is the major factor regulating Na^+ content of the ECF and in the process helps regulate the concentration of other ions (Cl^- , K^+ , and Mg^{2+} as well. Na^+ is the electrolyte most responsible for osmotic water flows. Consequently, water leaves

the bloodstream and flows out into the tissue spaces, causing edema and possibly a shutdown of the circulatory system. When aldosterone concentrations are high, most of the remaining Na^+ are reabsorbed. Generally each Na^+ reabsorbed, Cl^- follows and K^+ is secreted into the nitrate. Thus, as the sodium content of the blood increases, potassium concentration decreases, bringing these two ions back to their normal balance in the blood. Still another effect of aldosterone is to increase water reabsorption.

Aldosterone is produced by the adrenal cortex. Although rising potassium levels or falling sodium levels in the ECF directly stimulate the adrenal cells to release aldosterone, the most important trigger for aldosterone release is the **renin-angiotensin mechanism**. Renin catalyzes the series of reactions that produce angiotensin II, which in turn acts directly on the blood vessels to cause vasoconstriction and on the adrenal cortical cells to promote aldosterone release. As a result, blood volume and blood pressure increase. The renin-angiotensin mechanism is extremely important for regulating blood pressure.

Maintaining Acid-Base Balance of Blood

Blood pH must be maintained between 7.35 and 7.45, a very narrow range. Whenever the pH of arterial blood rises above 7.45, a person is said to have **alkalosis**. A drop in arterial pH to below 7.35 results in **acidosis**.

Although small amounts of acidic substances enter the body in ingested foods, most hydrogen ions originate as by-products of cellular metabolism, which continuously adds substances to the blood that tend to disturb its **acid-base balance**.

Many different acids are produced (for example, phosphoric acid, lactic acid, and many types of fatty acids). In addition, carbon dioxide, which is released during energy production, forms carbonic acid. Ammonia and other basic substances are also released to the blood as cells go about their usual function.

Blood Buffers

Chemical buffers are systems of one or two molecules that act to prevent dramatic changes in hydrogen ion (H^+) concentration when acids or bases are added. They do this by binding to hydrogen ions whenever the pH drops and by releasing hydrogen ions when the pH rises.

-*Strong acids* dissociate completely and liberate all their H^+ in water. Consequently they can cause large changes in pH.

-*Weak acids* like carbonic acid dissociate only partially and so have a much slighter effect on a solution's pH.

However, weak acids are very effective at preventing pH changes since they are forced to dissociate and release more H^+ when the pH rises over the desirable pH range. This feature allows them to play a very important role in the chemical buffer systems.

-*Strong bases* like hydroxides dissociate easily in water and quickly tie up H^+ .

-*Weak bases* like bicarbonate ion (HCO_3^-) and ammonia (NH_3) are slower to accept H^+ . However, as pH drops, the weak bases become "stronger" and begin to tie up more hydrogen ions. Thus, like weak acids, they are valuable members of the chemical buffer systems.

The three major chemical buffer systems of the body are the *bicarbonate*, *phosphate*, and *protein buffer systems*.

The bicarbonate buffer system is a mixture of *carbonic acid* (H_2CO_3) and its salt, *sodium bicarbonate* ($NaHCO_3$). Since carbonic acid is a weak acid, it does not dissociate much in neutral or acidic solutions. Thus, when a strong acid, such as hydrochloric acid (HCl) is added, most of the carbonic acid remains intact. However, the *bicarbonate ions* (HCO_3^-) of the salt act as bases to tie up the H^+ released by the stronger acid, forming more carbonic acid.

Similarly, if a strong base like sodium hydroxide ($NaOH$) is added to a solution containing the bicarbonate buffer system, $NaHCO_3$ will not dissociate further under such alkaline conditions. However, carbonic acid will be forced to dissociate further by the presence of the strong base—liberating more H^+ to bind with the OH^- released by $NaOH$.

The net result is replacement of a strong base by a weak one, so that the pH of the solution rises very little.

Respiratory System Controls

the respiratory system eliminates carbon dioxide from the blood while it "loads" oxygen into the blood. When carbon dioxide (CO_2) enters the blood from the tissue cells, most of it enters the red blood cells where it is converted to bicarbonate ion (HCO_3^-) for transport in the plasma.

Under normal conditions, the hydrogen ions produced by carbon dioxide transport have essentially no effect on blood pH. However, when CO₂ accumulates in the blood or more H⁺ is released to the blood by metabolic processes, the chemoreceptors in the respiratory control centers of the brain (or in peripheral blood vessels) are activated. As a result, breathing rate and depth increase, and the excess H⁺ is "blown off" as more CO₂ is removed from the blood.

On the other hand, when blood pH begins to rise (alkalosis), the respiratory center is depressed. Consequently, the respiratory rate and depth fall, allowing carbon dioxide (hence, H⁺) to accumulate in the blood.