

Total body water volume = 40 L, 60% body weight		
Extracellular fluid (ECF) volume = 15 L, 20% body weight		
Intracellular fluid volume = 25 L, 40% body weight	Interstitial fluid volume = 12 L, 80% of ECF	Plasma volume = 3 L, 20% of ECF

FIGURE 15.8 The major fluid compartments of the body. Approximate values are noted for a 70-kg (154-pound) male.

Micturition

Micturition (mik'tu-rish'un), or **voiding**, is the act of emptying the bladder. Two sphincters, or valves, the internal urethral sphincter (more superiorly located) and the external urethral sphincter (more inferiorly located) control the flow of urine from the bladder (see Figure 15.6). Ordinarily, the bladder continues to collect urine until about 200 ml have accumulated. At about this point, stretching of the bladder wall activates stretch receptors. Impulses transmitted to the sacral region of the spinal cord and then back to the bladder via the *pelvic splanchnic nerves* cause the bladder to go into reflex contractions. As the contractions become stronger, stored urine is forced past the internal urethral sphincter (the smooth muscle, involuntary sphincter) into the upper part of the urethra. It is then that a person feels the urge to void. Because the lower external sphincter is skeletal muscle and is voluntarily controlled, we can choose to keep it closed and postpone bladder emptying temporarily. On the other hand, if it is convenient, the external sphincter can be relaxed so that urine is flushed from the body. When one chooses not to void, the reflex contractions of the bladder will stop within a minute or so, and urine will continue to accumulate in the bladder. After 200 to 300 ml more have been

collected, the micturition reflex occurs again. Eventually, micturition occurs whether one wills it or not.

Homeostatic Imbalance

Incontinence (in-kon'ti-nens) occurs when we are unable to voluntarily control the external sphincter. Incontinence is normal in children 2 years old or younger, because they have not yet gained control over their voluntary sphincter. It may also occur in older children who sleep so soundly that they are not awakened by the stimulus. However, after the toddler years, incontinence is usually a result of emotional problems, pressure (as in pregnancy), or nervous system problems (stroke or spinal cord injury).

Urinary retention is essentially the opposite of incontinence. It is a condition in which the bladder is unable to expel its contained urine. There are various causes for urinary retention. It often occurs after surgery in which general anesthesia has been given because it takes a little time for the smooth muscles to regain their activity. Another cause of urinary retention, occurring primarily in elderly men, is enlargement, or *hyperplasia*, of the prostate gland, which surrounds the neck of the bladder. As it enlarges, it narrows the urethra, making it very difficult to void. When urinary retention is prolonged, a slender flexible drainage tube called a *catheter* (kath'i-ter) must be inserted through the urethra to drain the urine and prevent bladder trauma from excessive stretching. ▲

Fluid, Electrolyte, and Acid-Base Balance

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, maintaining (2) water and (3) electrolyte balance of the blood, and (4) ensuring proper blood pH. Excretion of nitrogenous wastes has already been considered; roles 2 through 4 are discussed briefly next.

Maintaining Water and Electrolyte Balance of Blood

Body Fluids and Fluid Compartments

If you are a healthy young adult, water probably accounts for half or more of your 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 (and of all body tissues, fat contains the least water). Babies, with little fat and low bone mass, are about 75 percent water, but total body water content declines through life and accounts for only about 45 percent of body weight in old age. The importance of water to the functioning of the body and its cells is described in Chapter 2. That information will not be repeated here except to say that 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* (Figure 15.8). 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.

The Link between Water and Salt

Water certainly accounts for nearly the entire volume of body fluids, regardless of type, and all body fluids are similar, but there is more to *fluid balance* than just water. The types and amounts of solutes in body fluids, especially 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. (Recall from Chapter 2 that electrolytes are charged particles [ions] that conduct an electrical current in an aqueous solution.) 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.

If the body is to remain properly hydrated, we cannot lose more water than we take in. Most water intake is a result of fluids and foods we in-

Q How would the values shown here be affected by (1) drinking a six-pack of beer? (2) fasting (only water is ingested)?

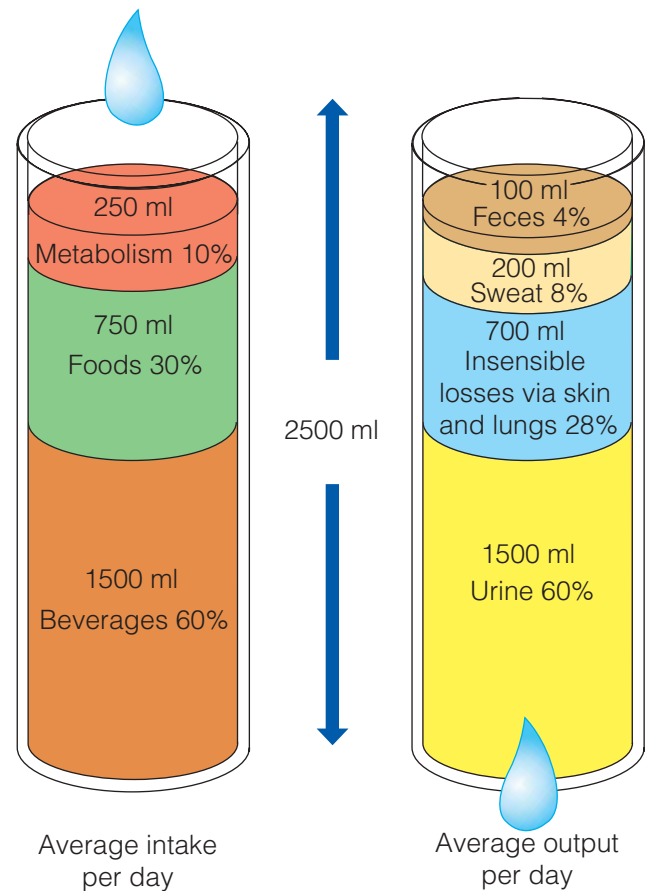


FIGURE 15.9 Water intake and output. Major sources of body water and routes of water loss from the body are shown. When intake and output are in balance, the body is adequately hydrated.

gest in our diet. However, a small amount (about 10 percent) is produced during cellular metabolism, as explained in Chapter 14 and indicated in Figure 15.9. There are several routes for water to leave the body. Some water vaporizes out of the lungs, some is lost in perspiration, and some leaves

A In case #1, the fluid ingested would greatly increase as would the amount of urinary output. In case #2, there would be no fluid intake from ingested foods and less fluid resulting from metabolism. Fluid output would be severely curtailed—no output in feces and less in urine to conserve body water. Insensible losses would not change. Loss of water in perspiration would depend on body and ambient temperatures.

the body in the stool. The job of the kidneys is like that of a juggler. If large amounts of water are lost in other ways, they compensate by putting out less urine to conserve body water. On the other hand, when water intake is excessive, the kidneys excrete generous amounts of urine, and the anguish of a too-full bladder becomes very real.

Likewise, the proper concentrations of the various electrolytes must be present in both intracellular and extracellular fluids. Most electrolytes enter the body in foods and “hard” (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. Just how the kidneys accomplish their balancing act is explained in more detail next.

Reabsorption of water and electrolytes by the kidneys is regulated primarily by hormones. When blood volume drops for any reason (for example, due to hemorrhage or excessive water loss through sweating or diarrhea), arterial blood pressure drops, which in turn decreases the amount of filtrate formed by the kidneys. In addition, highly sensitive cells in the hypothalamus called **osmoreceptors** (oz"mo-re-sep'torz) react to the change in blood composition (that is, less water and more solutes) by becoming more active. The result is that nerve impulses are sent to the posterior pituitary (Figure 15.10), which then releases **antidiuretic hormone (ADH)**. (The term *antidiuretic* is derived from *diuresis* [di"u-re'sis], which means “flow of urine from the kidney,” and *anti*, which means “against.”) As one might guess, this hormone prevents excessive water loss in the urine. ADH travels in the blood to its main target, the kidney's collecting ducts, where it causes the duct cells to reabsorb more water. 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.

Homeostatic Imbalance

When ADH is *not* released (perhaps because of injury or destruction of the hypothalamus or posterior

pituitary gland), huge amounts of very dilute urine (up to 25 liters/day) flush from the body day after day. This condition, *diabetes insipidus* (in-sip'ī-dus), can lead to severe dehydration and electrolyte imbalances. Affected individuals are always thirsty and have to drink fluids almost continuously to maintain normal fluid balance. ▲

A second hormone that helps to regulate blood composition and blood volume by acting on the kidney is **aldosterone** (al"dos'ter-on). Aldosterone is the major factor regulating sodium ion content of the ECF and in the process helps regulate the concentration of other ions (Cl^- , K^+ , and Mg^{2+} [magnesium]) as well. Sodium ion (Na^+) is the electrolyte most responsible for osmotic water flows. When too little sodium is in the blood, the blood becomes too dilute. Consequently, water leaves the bloodstream and flows out into the tissue spaces, causing edema and possibly a shutdown of the circulatory system. Whether aldosterone is present or not, about 80 percent of the sodium in the filtrate is reabsorbed in the proximal convoluted tubules of the kidneys. When aldosterone concentrations are high, most of the remaining sodium ions are actively reabsorbed in the distal convoluted tubules and the collecting ducts. Generally speaking, for each sodium ion reabsorbed, a chloride ion follows and a potassium ion is secreted into the filtrate. 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 by the tubule cells, because as sodium is reclaimed, water follows it passively back into the blood. A little rule to keep in mind here is: *water follows salt*.

Recall that 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** (see Figure 15.10) mediated by the *juxtaglomerular (JG) apparatus* of the renal tubules. The juxtaglomerular apparatus (see Figure 15.3b) consists of a complex of modified smooth muscle cells (JG cells) in the afferent arteriole plus some modified epithelial cells forming part of the distal convoluted tubule. The naming of this cell cluster reflects its location close by

Q

Which pathway would also stimulate thirst?

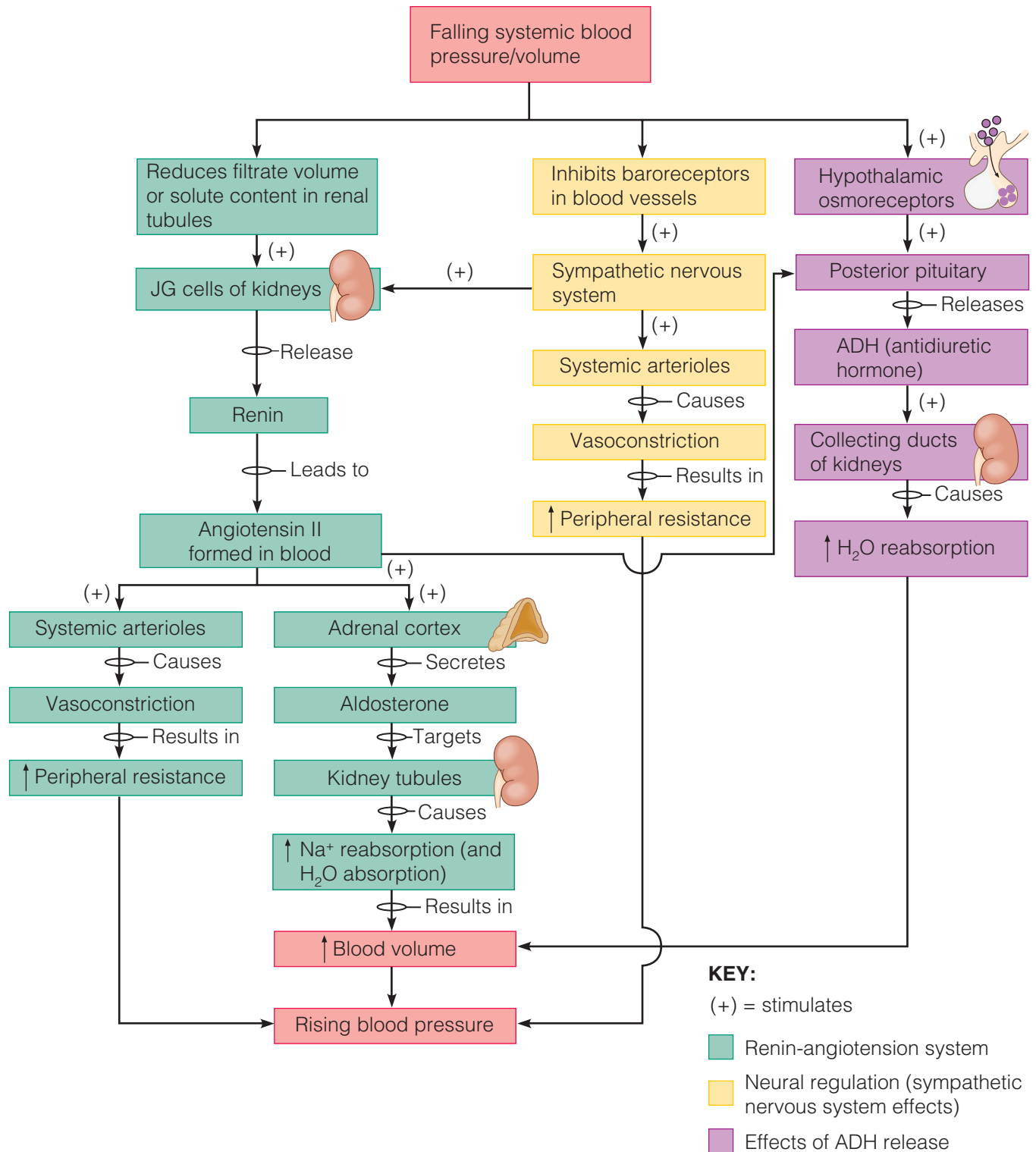


FIGURE 15.10 Flow chart of mechanisms regulating sodium and water balance to help maintain blood pressure homeostasis.

A

The pathway through the hypothalamus, which not only causes water retention, via the effect of ADH on the kidneys, but also stimulates thirst to increase water ingestion.

(*juxta*) the glomerulus. When the cells of the JG apparatus are stimulated by low blood pressure in the afferent arteriole or changes in solute content of the filtrate, they respond by releasing the enzyme **renin** into the blood. (Notice the different spelling of this enzyme from *rennin*, an enzyme secreted by stomach glands.) Renin catalyzes the series of reactions that produce angiotensin II, which in turn acts directly on the blood vessels to cause vasoconstriction (and an increase in peripheral resistance) and on the adrenal cortical cells to promote aldosterone release. As a result, blood volume and blood pressure increase (see Figure 15.10). The renin-angiotensin mechanism is extremely important for regulating blood pressure.

The pressure drop also excites baroreceptors in the larger blood vessels. These baroreceptors alert sympathetic nervous system centers of the brain to cause vasoconstriction (via release of epinephrine and norepinephrine), which increases the peripheral resistance (see Figure 15.10). However, this neural mechanism's major focus is blood pressure regulation, not water and electrolyte balance.

Homeostatic Imbalance

People with Addison's disease (hypoadosteronism) have *polyuria* (excrete large volumes of urine) and lose tremendous amounts of salt and water to urine. As long as adequate amounts of salt and fluids are ingested, people with this condition can avoid problems, but they are constantly teetering on the brink of dehydration. ▲

Maintaining Acid-Base Balance of Blood

For the cells of the body to function properly, 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** (al'kah-lo'sis). A drop in arterial pH to below 7.35 results in **acidosis** (as'i-do'sis). Because a pH of 7.0 is neutral, 7.35 is not acidic, chemically speaking; however, it represents a higher-than-optimal hydrogen ion concentration for the functioning of most body cells. Therefore, any arterial pH between 7.35 and 7.0 is called **physiological 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 "business." Although the chemical buffers in the blood can temporarily "tie up" excess acids and bases, and the lungs have the chief responsibility for eliminating carbon dioxide from the body, the kidneys assume most of the load for maintaining acid-base balance of the blood. Before describing how the kidneys function in acid-base balance, let's take a look at how each of our other two pH-controlling systems, blood buffers and the respiratory system, works.

Prove It Yourself

Demonstrate the Water-Retaining Power of Salt

The amount of water your body retains depends more on the amount of salt you consume than on how much water you drink. Here's how to demonstrate this.

On a normal day between meals, empty your bladder. Wait half an hour, and then urinate again. Measure the volume of urine you produced the second time. This is your baseline rate of urine production. Now quickly drink a quart of water and measure your urine output for four more consecutive half-hour periods. Subtract the baseline amount of urine from each time period to find out how much water you excreted in two hours.

Repeat the experiment on another day. This time dissolve 5 grams (approximately $\frac{3}{4}$ teaspoon) of salt in the water first. You should find that you excrete much less water during the next two hours than you did the first time.

People with certain health conditions, such as hypertension or congestive heart failure, may need to retain less water. Generally, they are advised to restrict their intake of salt, not water. Can you see why?