Fluids & Electrolytes

made Incredibly Easy!

~~Sixth Edition~~

Clinical Editor
~~Laura M. Willis, MSN, APRN, FNP-C~~

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Contributors

Cheryl Brady, MSN, RN, CNE
Nursing Faculty
Kent State University
Salem, OH

Shelba Durston, MSN, RN, CCRN
Nursing Instructor
San Joaquin Delta College
Stockton, CA

Laura Favand, MS, RN, CEN
Chief of Plans, Training Mobilization
U.S. Army Medical Department Activities
Fort Knox, KY

Margaret Gingrich, MSN, RN, CRNP
Professor of Nursing
Harrisburg Area Community College
Harrisburg, PA

Mary Jones, DNP, CNM, ENP-BC, FNP-BC
Family Nurse Practitioner
Doctor of Nursing Practice
MedQuest Health Center, Inc.
Mansfield, OH

Rexann Pickering, PhD, MS, RN, CIM, CIP
Director of Continuing Medical and Nursing Education
Methodist Le Bonheur Healthcare
Memphis, TN

Cherie Rebar, PhD, MBA, RN, FNP, COI
Director, Division of Nursing
Kettering College
Dayton, OH

Donna Scemons, PhD, FNP-BC, CNS
Assistant Professor
California State University
Los Angeles, CA

Allison Terry, PhD, MSN, RN
Assistant Dean of Clinical Practice
Auburn University
Montgomery, AL

Leigh Ann Trujillo, MSN, RN
Patient Care Manager
University of Chicago
Chicago, IL

Prior Contributors

Cheryl L. Brady, MSN, RN

Shelba Durston, MSN, RN, CCRN

Laura R. Favand, MS, RN, CEN

Margaret M. Gingrich, MSN, RN

Karla Jones, MS, RN

Patricia Lemelle-Wright, MS, RN

Linda Ludwig, BS, RN, MED

Rexann G. Pickering, PhD, MS, RN, CIP, CIM

Alexis Puglia, RN

Roseanne Hanlon Rafter, MSN, RN, GCNS-BC

Donna Scemons, PhD, RN, FNP-C, CNS

Vanessa M. Scheidt, RN, TNS, PHRN, FF2

Allison J. Terry, PhD, MSN, RN

Leigh Ann Trujillo, BSN, RN

Foreword

If you are like me, you are too busy to wade through a foreword that uses pretentious terms and umpteen dull paragraphs to get to the point. So let's cut right to the chase! Here is why this book is so terrific:

1. It will teach you all the important things you need to know about fluids and electrolytes. (It will leave out all the fluff that wastes your time.)
2. It will help you remember what you have learned.
3. It will make you smile as it enhances your knowledge and skills. Don't believe me? Try these recurring logos on for size:

Memory jogger!—helps you remember and understand difficult concepts

CAUTION!—lists dangerous signs and symptoms and enables you to quickly recognize trouble

It's not working—helps you find alternative interventions when patient outcomes aren't what you expected

Chart smart—lists critical documentation elements that can keep you out of legal trouble

Teaching points—provides clear patient-teaching tips that you can use to help your patients prevent recurrence of the problem

Ages and stages—identifies issues to watch for in your pediatric and geriatric patients

That's a wrap!—summarizes what you've learned in the chapter

See? I told you! And that's not all. Look for me and my friends in the margins throughout this book. We will be there to explain key concepts, provide important care reminders, and offer reassurance. Oh, and if you don't mind, we'll be spicing up the pages with a bit of humor along the way to teach and entertain in a way that no other resource can.

I hope you find this book helpful. Best of luck throughout your career!

Joy

Part I

Balancing basics

Chapter 1

Balancing fluids

Just the facts

In this chapter, you'll learn:

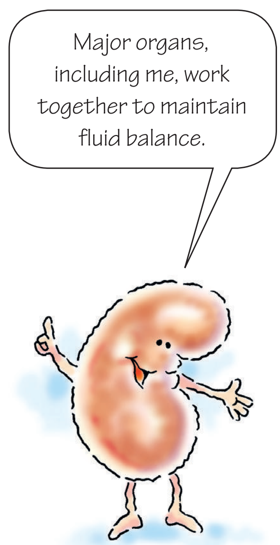
- the process of fluid distribution throughout the body
- the meaning of fluid-related terms
- the different ways fluid moves through the body
- the roles that hormones and kidneys play in fluid balance.

A look at fluids

Where would we be without body fluids? Fluids are vital to all forms of life. They help to maintain body temperature, cell shape, as well as transport nutrients, gases, and wastes. Let's take a closer look at fluids and the way the body balances them.

Making gains equal losses

Just about all major organs work together to maintain the proper balance of fluid. To support that balance, the amount of fluid gained throughout the day must equal the amount lost. Some of those losses can be measured; others can't.



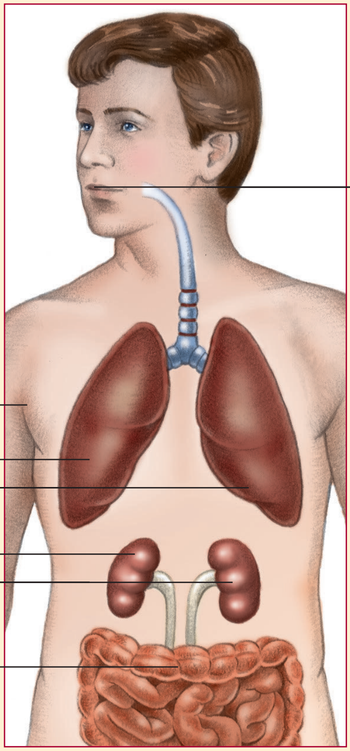
How insensible

Fluid losses from the skin and lungs are referred to as *insensible losses* because they can't be measured or seen. Losses from evaporation of fluid through the skin are constant but depend on a person's total body surface area. For example, the body surface area of an infant is greater than that of an adult relative to the respective weights. Because of this difference in body surface area—a higher metabolic rate, a larger percentage of extracellular body fluid, and immature kidney function—infants typically lose more water than adults do.

Changes in environmental humidity levels also affect the amount of fluid lost through the skin. Likewise, respiratory rate and depth affect the amount of fluid lost through the lungs. Tachypnea, for example, causes more water to be lost; bradypnea, less. Fever increases insensible losses of fluid from both the skin and lungs.

Sites involved in fluid loss

Each day, the body gains and loses fluid through several different processes. This illustration shows the primary sites of fluid losses and gains as well as their average amounts. Gastric, intestinal, pancreatic, and biliary secretions are almost completely reabsorbed and are not usually counted in daily fluid losses and gains.



Now that's sensible

Fluid losses from urination, defecation, wounds, and other means are referred to as *sensible losses* because they can be measured.

A typical adult loses about 150 to 200 ml/day of fluid through defecation. In cases of severe diarrhea, losses may exceed 5,000 ml/day. (See *Sites involved in fluid loss*.)

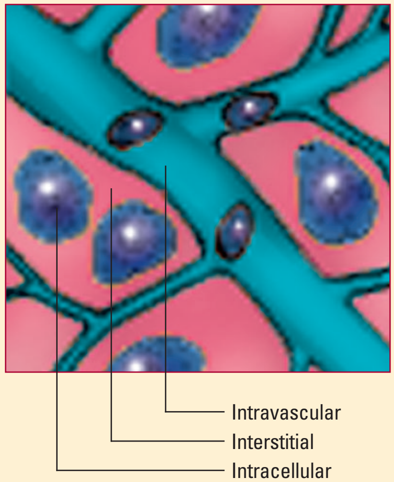
Following the fluid

The body holds fluid in two basic areas, or compartments—inside the cells and outside the cells. Fluid inside the cells is *intracellular fluid (ICF)*; fluid outside the cells is *extracellular fluid (ECF)*. Capillary walls and cell membranes separate the intracellular and extracellular compartments. (See *Fluid compartments*.)

To maintain proper fluid balance, the distribution of fluid between the two compartments must remain relatively constant. In an average adult, the total amount of fluid is 42 L, with the total amount of ICF

Fluid compartments

This illustration shows the primary fluid compartments in the body: intracellular and extracellular. Extracellular is further divided into interstitial and intravascular. Capillary walls and cell membranes separate ICFs from ECFs.



Memory Jogger

*To help you remember which fluid belongs in which compartment, keep in mind that **inter** means between (as in **inter**val—between two events) and **intra** means within or inside (as in **intra**venous—inside a vein).*

averaging 40% of the person's body weight, or about 28 L. The total amount of ECF averages 20% of the person's body weight, or about 14 L.

ECF can be broken down further into interstitial fluid, which surrounds the cells, and intravascular fluid or plasma, which is the liquid portion of blood. In an adult, interstitial fluid accounts for about 75% of the ECF. Plasma accounts for the remaining 25%.

The body contains other fluids, called *transcellular fluids*, in the cerebrospinal column, pleural cavity, lymph system, joints, and eyes. Transcellular fluids generally aren't subject to significant gains and losses throughout the day, so they aren't discussed in detail here.

Water here, water there

The distribution of fluid within the body's compartments varies with age. Compared with adults, infants have a higher percentage of body water stored inside interstitial spaces. About 75% to 80% (40% ECF, 35% ICF) of the body weight of a full-term neonate is water. About 90% (60% ECF and 30% ICF) of the body weight of a premature (23 weeks' gestation) infant is water. The amount of water as a percentage of body weight decreases with age until puberty. In a typical 154-lb (70 kg) lean adult male, about 60% (93 lb [42 kg]) of body weight is water. (See *The evaporation of time*, page 6.)

Skeletal muscle cells hold much of that water; fat cells contain little of it. Women, who normally have a higher ratio of fat to skeletal muscle than men, typically have a somewhat lower relative water content. Likewise, a person with obesity may have a relative water content level as low as 45%. Accumulated body fat in these individuals increases weight without boosting the body's water content.

Ages and stages

The evaporation of time

The risk of suffering a fluid imbalance increases with age. Why? Skeletal muscle mass declines, and the proportion of fat within the body increases. After age 60 years, water content drops to about 45%.

Likewise, the distribution of fluid within the body changes with age. For instance, about 15% of a typical young adult's total body weight is made up of interstitial fluid. That percentage progressively decreases with age.

About 5% of the body's total fluid volume is made up of plasma. Plasma volume remains stable throughout life.

Fluid types

Fluids in the body generally aren't found in pure forms. There are three types of solutions fluids are found in: isotonic, hypotonic, and hypertonic.

Isotonic: Already at match point

An isotonic solution has the same solute (matter dissolved in solution) concentration as another solution. For instance, if two fluids in adjacent compartments are equally concentrated, they are already in balance, so the fluid inside each compartment stays put. No imbalance means no net fluid shift. (See *Understanding isotonic fluids*.)

For example, normal saline solution is considered isotonic because the concentration of sodium in the solution nearly equals the concentration of sodium in the blood.

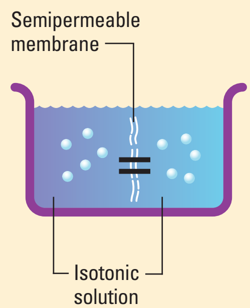
Hypotonic: Get the lowdown

A hypotonic solution has a lower solute concentration than another solution. For instance, say one solution contains only one part sodium and another solution contains two parts; the first solution is hypotonic compared with the second solution. As a result, fluid from the hypotonic solution would shift into the second solution until the two solutions have equal concentrations of sodium. Remember that the body continually strives to maintain a state of balance, or equilibrium (also known as *homeostasis*). (See *Understanding hypotonic fluids*.)

Half-normal saline solution is considered hypotonic because the concentration of sodium in the solution is less than the concentration of sodium in the patient's blood.

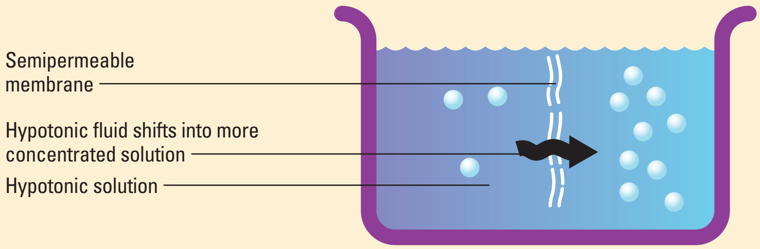
Understanding isotonic fluids

No net fluid shifts occur between isotonic solutions because the solutions are equally concentrated.



Understanding hypotonic fluids

When a less concentrated, or hypotonic, solution is placed next to a more concentrated solution, fluid shifts from the hypotonic solution into the more concentrated compartment to equalize concentrations.

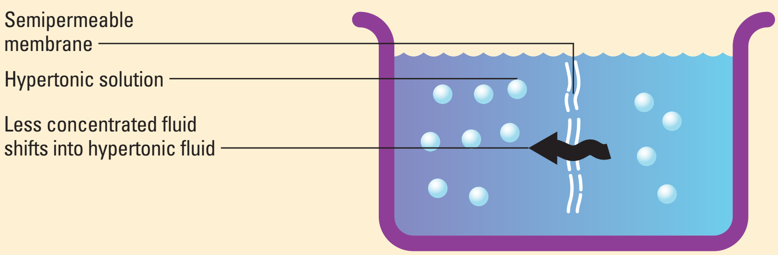


Hypertonic: Just the highlights

A hypertonic solution has a higher solute concentration than another solution. For instance, say one solution contains a large amount of sodium and a second solution hardly any; the first solution is hypertonic compared with the second solution. As a result, fluid from the second solution would shift into the hypertonic solution until the two solutions had equal concentrations. Again, the body continually strives to maintain a state of equilibrium (homeostasis). (See *Understanding hypertonic fluids*.)

Understanding hypertonic fluids

If one solution has more solutes than an adjacent solution, it has less fluid relative to the adjacent solution. Fluid will move out of the less concentrated solution into the more concentrated, or hypertonic, solution until both solutions have the same amount of solutes and fluid.



Fluid tips

Fluids, nutrients, and waste products constantly shift within the body's compartments—from the cells to the interstitial spaces, to the blood vessels, and back again. A change in one compartment can affect all the others.

Keeping track of the shifts

That constant shifting of fluids can have important implications for patient care. For instance, if a hypotonic fluid, such as half-normal saline solution, is given to a patient, it may cause too much fluid to move from the veins into the cells, and the cells can swell. On the other hand, if a hypertonic solution, such as dextrose 5% in normal saline solution, is given to a patient, it may cause too much fluid to be pulled from cells into the bloodstream, and the cells shrink.

For more information about I.V. solutions, see chapter 19, I.V. fluid replacement.

For example, a solution of dextrose 5% in normal saline solution is considered hypertonic because the concentration of solutes in the solution is greater than the concentration of solutes in the patient's blood.

Fluid movement

Just as the heart continually beats, fluids and solutes constantly move within the body. That movement allows the body to maintain homeostasis, a state of balance the body seeks. (See *Fluid tips*.)

Within the cells

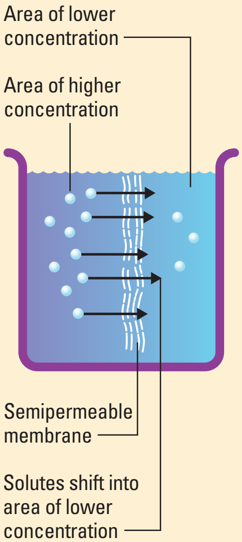
Solutes within the intracellular, interstitial, and intravascular compartments of the body move through the membranes, separating those compartments in different ways. The membranes are semipermeable, meaning that they allow some solutes to pass through but not others. In this section, you'll learn the different ways fluids and solutes move through membranes at the cellular level.

Going with the flow

In diffusion, solutes move from an area of higher concentration to an area of lower concentration, which eventually results in an equal distribution of solutes within the two areas. Diffusion is a form of passive transport because no energy is required to make it happen. Like fish swimming with the current, the solutes go with the flow. (See *Understanding diffusion*.)

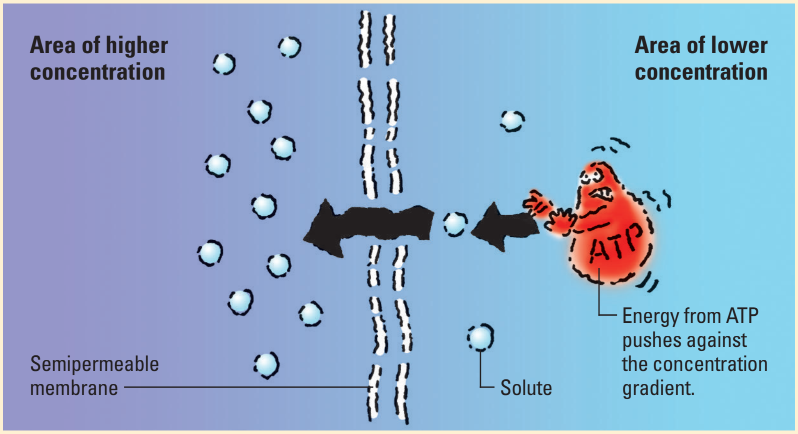
Understanding diffusion

In diffusion, solutes move from areas of higher concentration to areas of lower concentration until the concentration is equal in both areas.



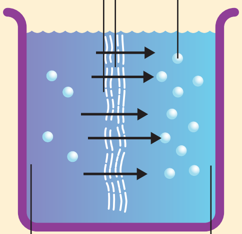
Understanding active transport

During active transport, energy from a molecule called *adenosine triphosphate (ATP)* moves solutes from an area of lower concentration to an area of higher concentration.



Understanding osmosis

In osmosis, fluid moves passively from areas with more fluid (and fewer solutes) to areas with less fluid (and more solutes). Remember that in osmosis, fluid moves, whereas in diffusion, solutes move.



Giving that extra push

In active transport, solutes move from an area of lower concentration to an area of higher concentration. Like swimming against the current, active transport requires energy to make it happen.

The energy required for a solute to move against a concentration gradient comes from a substance called *adenosine triphosphate* or ATP. Stored in all cells, ATP supplies energy for solute movement in and out of cells. (See *Understanding active transport*.)

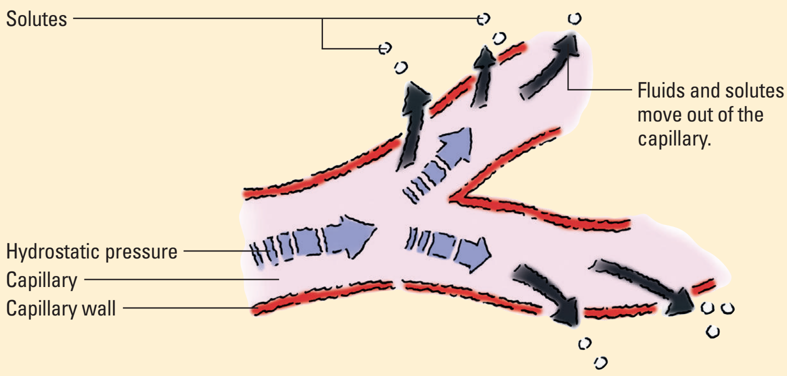
Some solutes, such as sodium and potassium, use ATP to move in and out of cells in a form of active transport called the *sodium-potassium pump*. (For more information on this physiologic pump, see chapter 5, When sodium tips the balance.) Other solutes that require active transport to cross cell membranes include calcium ions, hydrogen ions, amino acids, and certain sugars.

Letting fluids through

Osmosis refers to the passive movement of fluid across a membrane from an area of lower solute concentration and comparatively more fluid into an area of higher solute concentration and relatively less fluid. Osmosis stops when enough fluid has moved through the membrane to equalize the solute concentration on both sides of the membrane. (See *Understanding osmosis*.)

Fluid movement through capillaries

When hydrostatic pressure builds inside a capillary, it forces fluids and solutes out through the capillary walls into the interstitial fluid, as shown below.



Within the vascular system

Within the vascular system, only capillaries have walls thin enough to let solutes pass through. The movement of fluids and solutes through capillary walls plays a critical role in the body's fluid balance.

The pressure is on

The movement of fluids through capillaries—a process called *capillary filtration*—results from blood pushing against the walls of the capillary. That pressure, called *hydrostatic pressure*, forces fluids and solutes through the capillary wall.

When the hydrostatic pressure inside a capillary is greater than the pressure in the surrounding interstitial space, fluids and solutes inside the capillary are forced out into the interstitial space. When the pressure inside the capillary is less than the pressure outside of it, fluids and solutes move back into the capillary. (See *Fluid movement through capillaries*.)

Keeping the fluid in

A process called *reabsorption* prevents too much fluid from leaving the capillaries no matter how much hydrostatic pressure exists within the capillaries. When fluid filters through a capillary, the protein albumin remains behind in the diminishing volume of water. Albumin is a large molecule that generally can't pass through capillary membranes. As the concentration of albumin inside a capillary increase, fluid begins to move back into the capillaries through osmosis.

Think of albumin as a water magnet. The osmotic, or pulling, force of albumin in the intravascular space is called the *plasma colloid osmotic pressure*. The plasma colloid osmotic pressure in capillaries averages about 25 mm Hg. (See *Albumin magnetism*.)

As long as capillary blood pressure (hydrostatic pressure) exceeds plasma colloid osmotic pressure, water and solutes can leave the capillaries and enter the interstitial fluid. When capillary blood pressure falls below plasma colloid osmotic pressure, water and diffusible solutes return to the capillaries.

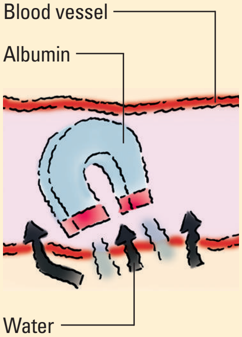
Normally, blood pressure in a capillary exceeds plasma colloid osmotic pressure in the arteriole end and falls below it in the venule end. As a result, capillary filtration occurs along the first half of the vessel; reabsorption, along the second. As long as capillary blood pressure and plasma albumin levels remain normal, the amount of water that moves into the vessel equals the amount that moves out.

Coming around again

Occasionally, extra fluid filters out of the capillary. When that happens, the excess fluid shifts into the lymphatic vessels located just outside the capillaries and eventually returns to the heart for recirculation.

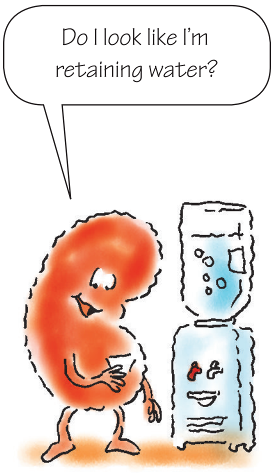
Albumin magnetism

Albumin, a large protein molecule, acts as a magnet to attract water and hold it inside the blood vessel.



Maintaining the balance

Many mechanisms in the body work together to maintain fluid balance. Because one problem can affect the entire fluid-maintenance system, it's important to keep all mechanisms in check. Here's a closer look at what makes this balancing act possible.



The kidneys

The kidneys play a vital role in fluid balance. If the kidneys don't work correctly, the body has a hard time controlling fluid balance. The workhorse of the kidney is the nephron. The body puts the nephrons to work every day.

A nephron consists of a glomerulus and a tubule. The tubule, sometimes convoluted, ends in a collecting duct. The glomerulus is a cluster of capillaries that filter blood. Like a vascular cradle, Bowman's capsule surrounds the glomerulus.

Capillary blood pressure forces fluid through the capillary walls and into Bowman's capsule at the proximal end of the tubule. Along the length of the tubule, water and electrolytes are either excreted or retained depending on the body's needs. For instance, when the body needs more fluid, it retains more. If it requires less, less is reabsorbed, and more fluid gets excreted.

Electrolytes, such as sodium and potassium, are either filtered or reabsorbed throughout the same area. The resulting filtrate flows through the tubule into the collecting ducts and eventually into the bladder as urine.

Superabsorbent

Nephrons filter about 125 ml of blood every minute, or about 180 L/day. That rate, called the *glomerular filtration rate*, usually leads to the production of 1 to 2 L of urine per day. The nephrons reabsorb the remaining 178 L or more of fluid, an amount equivalent to more than 30 oil changes for the family car!

A strict conservationist

If the body loses even 1% to 2% of its fluid, the kidneys take steps to conserve water. Perhaps the most crucial step involves reabsorbing more water from the filtrate, which produces more concentrated urine.

The kidneys must continue to excrete at least 20 ml of urine every hour (about 500 ml/day) to eliminate body wastes. Usually, a urine excretion rate that's less than 20 ml/hour indicates renal disease and impending renal failure. The minimum excretion rate varies with age. (See *The higher the rate, the greater the waste*.)

The kidneys respond to fluid excesses by excreting urine that is more dilute, which rids the body of fluid and conserves electrolytes.

Ages and stages

The higher the rate, the greater the waste

Infants and young children excrete urine at a higher rate than adults as a result of their higher metabolic rates which produce more waste. Also, an infant's kidneys can't concentrate urine until about age 3 months, and they remain less efficient than an adult's kidneys until about age 2 years.

Antidiuretic hormone

Several hormones affect fluid balance, among them, a water retainer called *antidiuretic hormone (ADH)*. (You may also hear this hormone called *vasopressin*.) The hypothalamus produces ADH, but the posterior pituitary gland stores and releases it. (See *How antidiuretic hormone works*.)

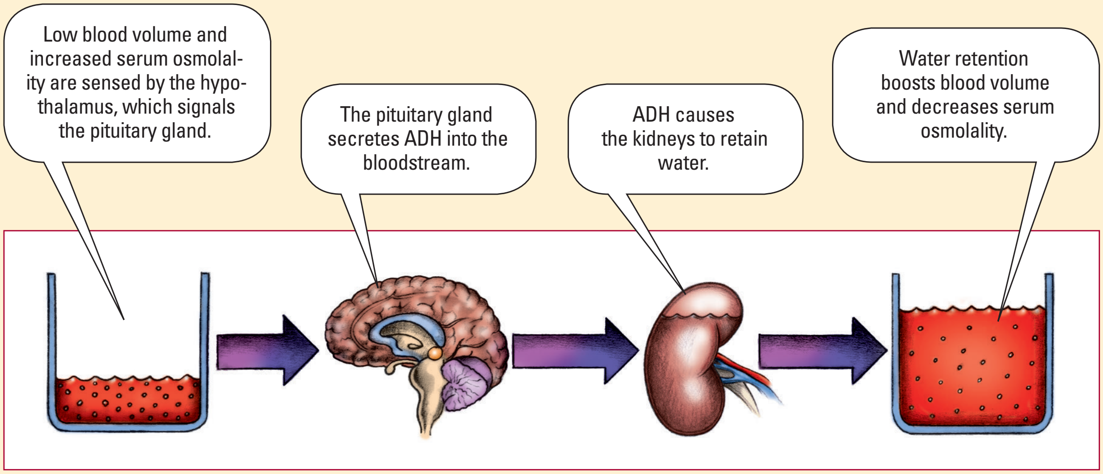
Adaptable absorption

Increased serum osmolality, or decreased blood volume, can stimulate the release of ADH, which in turn increases the kidneys' reabsorption of water. The increased reabsorption of water results in more concentrated urine.

Likewise, decreased serum osmolality, or increased blood volume, inhibits the release of ADH and causes less water to be reabsorbed, making the urine less concentrated. The amount of ADH released varies throughout the day, depending on the body's needs.

How antidiuretic hormone works

ADH regulates fluid balance in four steps.



This up-and-down cycle of ADH release keeps fluid levels in balance all day long. Like a dam in a river, the body holds water when fluid levels drop and releases it when fluid levels rise.

Renin-angiotensin-aldosterone system

To help the body maintain a balance of sodium and water as well as a healthy blood volume and blood pressure, specialized cells (called *juxtaglomerular cells*) near each glomerulus secrete an enzyme called *renin*. Through a complex series of steps, renin leads to the production of angiotensin II, a potent vasoconstrictor.

Angiotensin II causes peripheral vasoconstriction and stimulates the production of aldosterone. Both actions raise blood pressure. (See *Aldosterone production*, page 14.)

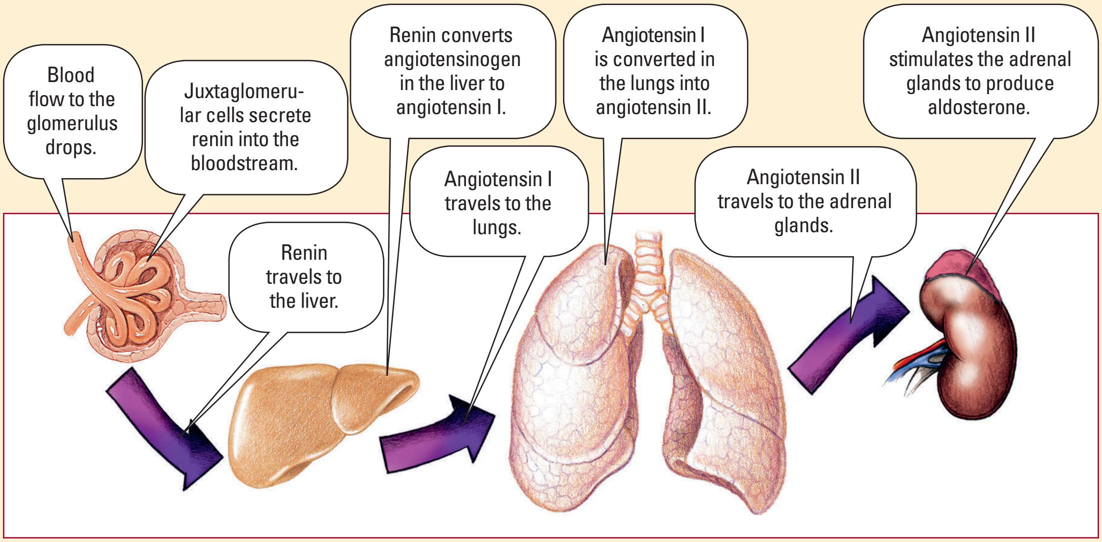
Usually, as soon as the blood pressure reaches a normal level, the body stops releasing renin, and this feedback cycle of renin to angiotensin to aldosterone ends.

Memory Jogger

Remember what ADH stands for—antidiuretic hormone—and you'll remember its job: restoring blood volume by reducing diuresis and increasing water retention.

Aldosterone production

This illustration shows the steps involved in the production of aldosterone (a hormone that helps to regulate fluid balance) through the renin-angiotensin-aldosterone system.



The ups and downs of renin

The amount of renin secreted depends on blood flow and the level of sodium in the bloodstream. If blood flow to the kidneys diminishes, as happens in a patient who is hemorrhaging, or if the amount of sodium reaching the glomerulus drops, the juxtaglomerular cells secrete more renin. The renin causes vasoconstriction and a subsequent increase in blood pressure.

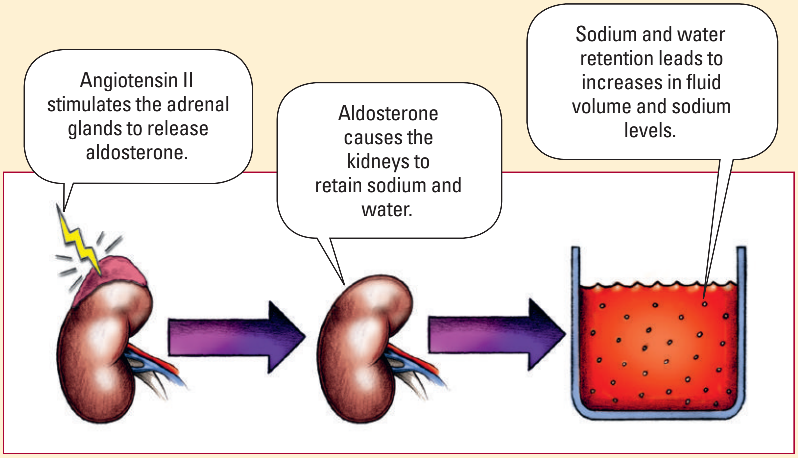
Conversely, if blood flow to the kidneys increases, or if the amount of sodium reaching the glomerulus increases, juxtaglomerular cells secrete less renin. A drop-off in renin secretion reduces vasoconstriction and helps to normalize blood pressure.

Sodium and water regulator

The hormone aldosterone also plays a role in maintaining blood pressure and fluid balance. Secreted by the adrenal cortex, aldosterone regulates the reabsorption of sodium and water within the nephron. (See *How aldosterone works*.)

How aldosterone works

Aldosterone, produced because of the renin-angiotensin mechanism, acts to regulate fluid volume as described below.



Triggering active transport

When blood volume drops, aldosterone initiates the active transport of sodium from the distal tubules and the collecting ducts into the bloodstream. When sodium is forced into the bloodstream, more water is reabsorbed, and blood volume expands.

Atrial natriuretic peptide

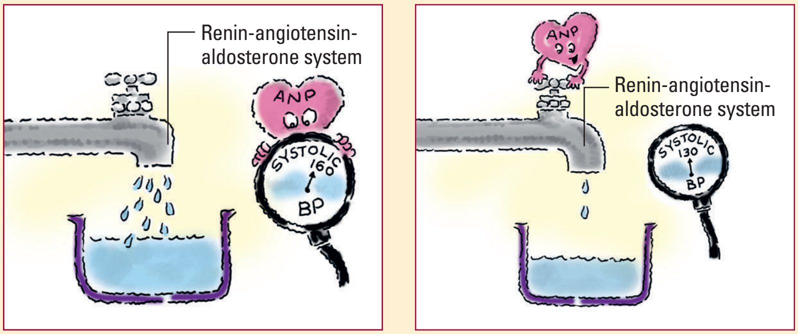
The renin-angiotensin-aldosterone system isn't the only factor at work balancing fluids in the body. A cardiac hormone called *atrial natriuretic peptide (ANP)* also helps keep that balance. Stored in the cells of the atria, ANP is released when atrial pressure increases. The hormone counteracts the effects of the renin-angiotensin-aldosterone system by decreasing blood pressure and reducing intravascular blood volume. (See *How atrial natriuretic peptide works*, page 16.)

This powerful hormone:

- suppresses serum renin levels
- decreases aldosterone release from the adrenal glands
- increases glomerular filtration, which increases urine excretion of sodium and water
- decreases ADH release from the posterior pituitary gland
- reduces vascular resistance by causing vasodilation.

How atrial natriuretic peptide works

When blood volume and blood pressure rise and begin to stretch the atria, the heart's ANP shuts off the renin-angiotensin-aldosterone system, which stabilizes blood volume and blood pressure.



Stretch that atrium

The amount of ANP that the atria release rises in response to some conditions; for example, chronic renal failure and heart failure.

Anything that causes atrial stretching can also lead to increases in the amount of ANP released, including orthostatic changes, atrial tachycardia, high sodium intake, sodium chloride infusions, and use of drugs that cause vasoconstriction.

Thirst

Perhaps the simplest mechanism for maintaining fluid balance is the thirst mechanism. Thirst occurs with even small losses of fluid. Losing body fluids or eating highly salty foods leads to an increase in ECF osmolality. This increase leads to drying of the mucous membranes in the mouth, which in turn stimulates the thirst center in the hypothalamus. In an elderly person, the thirst mechanism is less effective than it is in a younger person, leaving the older person more prone to dehydration. (See *Dehydration in elderly people*.)

Quench that thirst

Usually, when a person is thirsty, he or she drinks fluid. The ingested fluid is absorbed from the intestine into the bloodstream, where it moves freely between fluid compartments. This movement leads to an increase in the amount of fluid in the body and a decrease in the concentration of solutes, thus balancing fluid levels throughout the body.

Ages and stages

Dehydration in elderly people

The signs and symptoms of dehydration may be different in older adults. For example, they might include:

- confusion
- subnormal temperature
- tachycardia
- pinched facial expression.

That's a wrap

Balancing fluids review

Fluid balance basics

- Fluid movement throughout the body helps maintain body temperature and cell shape.
- Fluids help transport nutrients, gases, and wastes.
- Most of the body's major organs work together to maintain fluid balance.
- The amount of fluids gained through intake must equal the amount lost.

Fluid losses

- *Insensible losses*
  - Immeasurable
  - Examples: through the skin (affected by humidity and body surface area) and lungs (affected by respiratory rate and depth)
- *Sensible losses*
  - Measurable
  - Examples: from urination, defecation, and wounds

Understanding body fluids

- Different types of fluids are located in different compartments.
- Fluids move throughout the body by going back and forth across a cell's semipermeable membrane.
- Distribution of fluids varies with age.

Fluid compartments

- *ICF*—fluid inside the cell; must be balanced with ECF
- *ECF*—fluid outside the cell; must be balanced with ICF; made up of 75% interstitial fluid (fluid surrounding the cell) and 25% plasma (liquid portion of blood)
- *Transcellular fluid*—in the cerebrospinal column, pleural cavity, lymph system, joints, and eyes; remains relatively constant

Fluid types

- *Isotonic*—equally concentrated with other solutions
- *Hypotonic*—less concentrated than other solutions
- *Hypertonic*—more concentrated than other solutions

Fluid movement

- *Diffusion*— a form of passive transport (no energy is required) that moves solutes from an area of higher concentration to an area of lower concentration, resulting in an equal distribution of solutes between the two areas
- *Active transport*—uses ATP to move solutes from an area of low concentration to an area of higher concentration; example: sodium-potassium pump
- *Osmosis*—passive movement of fluid across a membrane from an area of lower solute concentration to an area of higher solute concentration; stops when both sides have an equal solute concentration
- *Capillary filtration*—the movement of fluid through capillary walls through hydrostatic pressure; balanced by plasma colloid osmotic pressure from albumin that causes reabsorption of fluid and solutes

(continued)

Balancing fluids review *(continued)*

Maintaining fluid balance

Kidneys

- Nephrons form urine by filtering blood.
- If the body needs more fluid, nephron tubules retain or reabsorb water and electrolytes.
- If the body needs less fluid, tubules absorb less, causing more fluids and electrolytes to be excreted.
- Kidneys also secrete renin, an enzyme that activates the renin-angiotensin-aldosterone system.
- Aldosterone secreted by the adrenal cortex regulates sodium and water reabsorption by the kidneys.

Hormones

- *ADH*—Also known as *vasopressin*, ADH is produced by the hypothalamus to reduce diuresis and increase water retention if serum osmolality increases or blood volume decreases.
- *Renin-angiotensin-aldosterone system*—If blood flow decreases, the juxtaglomerular cells in the kidneys secrete renin, which leads to the production of angiotensin II, a potent vasoconstrictor; angiotensin II stimulates the production of aldosterone; aldosterone regulates the reabsorption of sodium and water in the nephron.
- *ANP*—This hormone, produced and stored in the atria of the heart, stops the action of the renin-angiotensin-aldosterone system; ANP decreases blood pressure by causing vasodilation and reduces fluid volume by increasing excretion of sodium and water.

Thirst

- Regulated by the hypothalamus
- Stimulated by an increase in ECF and drying of the mucous membranes
- Causes a person to drink fluids, which are absorbed by the intestines, moved to the bloodstream, and distributed between the compartments

Quick quiz

1. A nurse is admitting a patient who has been experiencing vomiting and diarrhea for the last 3 days. The nurse knows that based on the patient's symptoms, the amount of ADH secreted would most likely:

   A. increase.
   B. decrease.
   C. stay the same.
   D. not be affected.

Answer: A. The patient is most likely dehydrated. As a result, the body would try and retain as much fluid as possible. To retain fluid, ADH secretion increases.

2. The nurse is planning care for a 50-year-old patient admitted with the flu. Which piece of assessment data is most important to report to the provider?

A. Urine output of 10 ml/hour
•AQ1• B. An oral temperature reading of 101.9
•AQ1• C. Blood pressure of 98/70
D. Patient report of pain 4/10 when coughing

Answer: A. The kidneys must excrete at least 20 ml of urine every hour (about 500 ml/day) to eliminate body wastes. Usually, a urine excretion rate that's less than 20 ml/hour indicates renal disease and impending renal failure.

3. The nurse is assessing an elderly patient and notes the following: •AQ1• T 97.0, HR 110, and increased confusion. The nurse knows that this may indicate what problem?

A. Infection
B. Dementia
C. Dehydration
D. Hypervolemia

Answer: C. The signs and symptoms of dehydration may be different in older adults. For example, they might include confusion, subnormal temperature, tachycardia, or pinched facial expression.

4. A 70-year-old patient arrives in the emergency department after mowing grass in the hot sun and feeling lightheaded. The patient's •AQ1• blood pressure is 90/50, the nurse knows that the kidneys will respond by:

A. secreting renin.
B. producing aldosterone.
C. slowing the release of ADH.
D. secreting ANP.

Answer: A. Juxtaglomerular cells in the kidneys secrete renin in response to low blood flow or a low sodium level. The final effect of renin secretion is an increase in blood pressure.

5. A patient is admitted to the hospital after sustaining burns over 70% of the body. Based on this information, the nurse knows the patient is at risk for developing which of the following?

A. ECF deficit
B. ICF deficit
C. Interstitial fluid deficit
D. ICF overload

Answer: B. Due to the patient's burns, the fluid within the cell is diminished leading to an ICF deficit.

Scoring

☆☆☆ If you answered all five questions correctly, congratulations! You're a fluid whiz.

☆☆ If you answered four correctly, take a swig of water; you're just a little dry.

☆ If you answered fewer than four correctly, pour yourself a glass of sports drink and enjoy an invigorating burst of fluid refreshment!

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QUERY:

AQ1: Please confirm if the following values in Quick quiz should have units of measure; if so, please supply:

- 101.9
- 98/70
- T 97.0
- 90/50, HR 110

Chapter 2

Balancing electrolytes

Just the facts

In this chapter, you'll learn:

- the difference between cations and anions
- the interpretation of normal and abnormal serum electrolyte results
- the role nephrons play in electrolyte balance
- the effect diuretics have on electrolytes in the kidneys
- the electrolyte concentration of selected I.V. fluids.

A look at electrolytes

Electrolytes work with fluids to maintain health and well-being. They're found in various concentrations, depending on whether they're inside or outside the cells. Electrolytes are crucial for nearly all cellular reactions and functions. Let's take a look at what electrolytes are, how they function, and what upsets their balance.

Ions

Electrolytes are substances that, when in solution, separate (or dissociate) into electrically charged particles called *ions*. Some ions are positively charged, and others are negatively charged. Several pairs of oppositely charged ions are so closely linked that a problem with one ion causes a problem with the other. Sodium and chloride are linked that way, as are calcium and phosphorus.

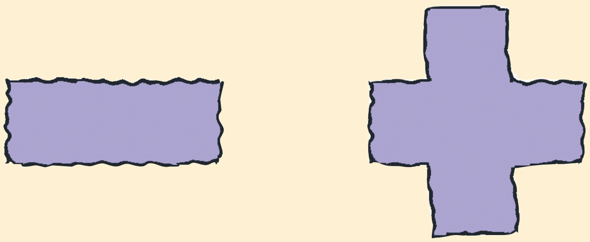
A variety of diseases can disrupt the normal balance of electrolytes in the body. Understanding electrolytes and recognizing imbalances can make your patient assessment more accurate.

Anions and cations

Anions are electrolytes that generate a negative charge; cations are electrolytes that produce a positive charge. An electrical charge makes cells function normally. (See *Looking on the plus and minus sides*, page 22.)

Looking on the plus and minus sides

Electrolytes can be either anions or cations. Here's a list of anions (the negative charges) and cations (the positive charges).



- Bicarbonate
- Chloride
- Phosphorus

- Calcium
- Magnesium
- Potassium
- Sodium

The anion gap is a useful test for distinguishing types and causes of acid-base imbalances because it reflects serum anion-cation balance. (The anion gap is discussed in chapter 3, Balancing acids and bases.)

Balancing the pluses and minuses

Electrolytes operate outside the cell in extracellular fluid (ECF) compartments and inside the cell in intracellular fluid (ICF) compartments. Individual electrolytes differ in concentration, but electrolyte totals balance to achieve a neutral electrical charge (positives and negatives balance each other). This balance is called *electroneutrality*.

Hooking up with hydrogen

Most electrolytes interact with hydrogen ions to maintain acid-base balance. The major electrolytes have specialized functions that contribute to metabolism and fluid and electrolyte balance.

Memory Jogger

To remind yourself about the difference between anions and cations, remember that the *T* in "cation" looks like the positive symbol, "+."

Major electrolytes outside the cell

Sodium and chloride, the major electrolytes in ECF, exert most of their influence outside the cell. Sodium concentration affects serum osmolality (solute concentration in 1 L of water) and ECF volume.

Sodium also helps nerve and muscle cells interact. Chloride helps maintain osmotic pressure (water-pulling pressure). Gastric mucosal cells need chloride to produce hydrochloric acid, which breaks down food into absorbable components.

More outsiders

Calcium and bicarbonate are two other electrolytes found in ECF. Calcium is the major cation involved in the structure and function of bones and teeth. Calcium is needed to:

- stabilize the cell membrane and reduce its permeability to sodium
- transmit nerve impulses
- contract muscles
- coagulate blood
- form bone and teeth.

Bicarbonate plays a vital role in acid-base balance.

Major electrolytes inside the cell

Potassium, phosphorus, and magnesium are among the most abundant electrolytes inside the cell.

Potent potassium

Potassium plays an important role in:

- cell excitability regulation
- nerve impulse conduction
- resting membrane potential
- muscle contraction and myocardial membrane responsiveness
- intracellular osmolality control.

Fundamental phosphorus

The body contains phosphorus in the form of phosphate salts. Sometimes, the words *phosphorus* and *phosphate* are used interchangeably. Phosphate is essential for energy metabolism. Combined with calcium, phosphate plays a key role in bone and tooth mineralization. It also helps maintain acid-base balance.

Magnificent magnesium

Magnesium acts as a catalyst for enzyme reactions. It regulates neuromuscular contraction, promotes normal functioning of the nervous and cardiovascular systems, and aids in protein synthesis and sodium and potassium ion transportation.

Electrolyte movement

When cells die (e.g., from trauma or chemotherapy), their contents spill into the extracellular area and upset the electrolyte balance. In this case, elevated levels of intracellular electrolytes are found in plasma.

Although electrolytes are generally concentrated in a specific compartment, they aren't confined to these areas. Like fluids, they move around trying to maintain balance and electroneutrality.

Electrolyte balance

Fluid intake and output, acid-base balance, hormone secretion, and normal cell function all influence electrolyte balance. Because electrolytes function both collaboratively, with other electrolytes, and individually, imbalances in one electrolyte can affect balance in others. (See *Understanding electrolytes*.)

Electrolyte levels

Even though electrolytes exist inside and outside the cell, only the levels outside the cell in the bloodstream are measured. Although serum levels remain fairly stable throughout a person's life span, understanding which levels are normal and which are abnormal is critical to reacting quickly and appropriately to a patient's electrolyte imbalance.

The patient's condition determines how often electrolyte levels are checked. Results for many laboratory tests are reported in milliequivalents per liter (mEq/L), which is a measure of the ion's chemical activity, or its power. (See *Interpreting serum electrolyte test results*, page 26, for a look at normal and abnormal electrolyte levels in the blood.)

See the whole picture

When you see an abnormal laboratory test result, consider what you know about the patient. For instance, a serum potassium level of 7 mEq/L for a patient with previously normal serum potassium levels and no apparent reason for the increase may be an inaccurate result. Perhaps the patient's blood sample was hemolyzed from trauma to the cells, which can occur when drawing the blood or during transport to the lab.

With that said, look at the whole picture before you act, including what you know about the patient, patient's signs and symptoms, and patient's electrolyte levels. (See *Documenting electrolyte imbalances*, page 27.)

Understanding electrolytes

Electrolytes help regulate water distribution, govern acid-base balance, and transmit nerve impulses. They also contribute to energy generation and blood clotting. This table summarizes the functions of each of the body's major electrolytes. Check the illustration below to see how electrolytes are distributed in and around the cell.

Potassium (K)

- Main ICF cation
- Regulates cell excitability
- Permeates cell membranes, thereby affecting the cell's electrical status
- Helps to control ICF osmolality and, consequently, ICF osmotic pressure

Magnesium (Mg)

- A leading ICF cation
- Contributes to many enzymatic and metabolic processes, particularly protein synthesis
- Modifies nerve impulse transmission and skeletal muscle response (unbalanced Mg concentrations dramatically affect neuromuscular processes)
- Maintains cell membrane stability (Lobo, Lewington, & Allison, 2013)

Phosphorus (P)

- Main ICF anion
- Promotes energy storage and carbohydrate, protein, and fat metabolism
- Acts as a hydrogen buffer

Sodium (Na)

- Main ECF cation
- Helps govern normal ECF osmolality (a shift in Na concentrations triggers a fluid volume change to restore normal solute and water ratios)
- Helps maintain acid-base balance
- Activates nerve and muscle cells
- Influences water distribution (with chloride)

Chloride (Cl)

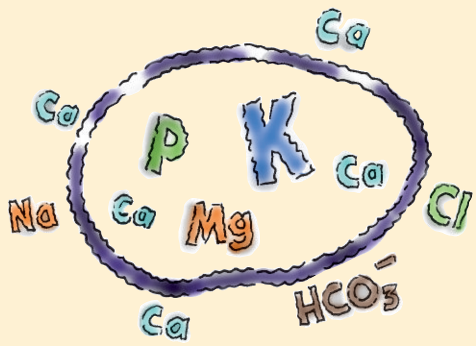
- Main ECF anion
- Helps maintain normal ECF osmolality
- Affects body pH
- Plays a vital role in maintaining acid-base balance; combines with hydrogen ions to produce hydrochloric acid

Calcium (Ca)

- A major cation in teeth and bones; found in fairly equal concentrations in ICF and ECF
- Also found in cell membranes, where it helps cells adhere to one another and maintain their shape
- Acts as an enzyme activator within cells (muscles must have Ca to contract)
- Aids coagulation
- Affects cell membrane permeability and firing level

Bicarbonate (HCO_3^-)

- Present in ECF
- Regulates acid-base balance



Interpreting serum electrolyte test results

Use the quick-reference chart below to interpret serum electrolyte test results in adult patients. This chart also lists disorders that can cause imbalances. Note: Always check your facility's norms, as they may differ slightly.

Electrolyte	Results	Implications	Common causes
Serum sodium	135 to 145 mEq/L	Normal	
	<135 mEq/L	Hyponatremia	Syndrome of inappropriate antidiuretic hormone secretion
	>145 mEq/L	Hypernatremia	Diabetes insipidus, diabetes mellitus, fluid loss, vomiting, and diarrhea
Serum potassium	3.5 to 5 mEq/L	Normal	
	<3.5 mEq/L	Hypokalemia	Diarrhea, vomiting, diuretic therapy, excessive sweating, refeeding syndrome
	>5 mEq/L	Hyperkalemia	Burns, renal failure, and response to injury
Total serum calcium	8.9 to 10.1 mg/dl	Normal	
	>8.9 mg/dl	Hypocalcemia	Acute pancreatitis
	>10.1 mg/dl	Hypercalcemia	Hyperparathyroidism
Ionized calcium	4.4 to 5.3 mg/dl	Normal	
	<4.4 mg/dl	Hypocalcemia	Massive transfusion
	>5.3 mg/dl	Hypercalcemia	Acidosis
Serum phosphates	2.5 to 4.5 mg/dl or 1.8 to 2.6 mEq/L	Normal	
	>2.5 mg/dl or 1.8 mEq/L	Hypophosphatemia	Diabetic ketoacidosis
	<4.5 mg/dl or 2.6 mEq/L	Hyperphosphatemia	Renal insufficiency
Serum magnesium	1.5 to 2.5 mEq/L	Normal	
	<1.5 mEq/L	Hypomagnesemia	Malnutrition, chronic diarrhea
	>2.5 mEq/L	Hypermagnesemia	Renal failure
Serum chloride	98 to 108 mEq/L	Normal	
	<98 mEq/L	Hypochloremia	Prolonged vomiting or gastric aspiration
	>108 mEq/L	Hyperchloremia	Hypernatremia

From Lobo, D. N., Lewington, A. J. P., & Allison, S. P. (2013). Disorders of sodium, potassium, calcium, magnesium, and phosphate. In *Basic concepts of fluid and electrolyte therapy* (pp. 105, 110). Melsungen, Germany: Medizinische Verlagsgesellschaft.

Fluid regulation

Many activities and factors are involved in regulating fluid and electrolyte balance. A quick review of some of the basics will help you understand this regulation better.

Fluid and solute movement

As discussed in chapter 1, active transport moves solutes upstream and requires pumps within the body to move the substances from areas of lower concentration to areas of higher concentration—against a concentration gradient. Adenosine triphosphate is the energy that moves solutes upstream.

Pushing fluids

The sodium-potassium pump, an example of an active transport mechanism, moves sodium ions from ICF (an area of lower concentration) to ECF (an area of higher concentration). With potassium, the reverse happens: A large amount of potassium in ICF causes an electrical potential at the cell membrane. As ions rapidly shift in and out of the cell, electrical impulses are conducted. These impulses are essential for maintaining life.

Organ and gland involvement

Most major organs and glands in the body—the lungs, liver, adrenal glands, kidneys, heart, hypothalamus, pituitary gland, skin, gastrointestinal (GI) tract, and parathyroid and thyroid glands—help to regulate fluid and electrolyte balance.

As part of the renin-angiotensin-aldosterone system, the lungs and liver help regulate sodium and water balance as well as blood pressure. The adrenal glands secrete aldosterone, which influences sodium and potassium balance in the kidneys. These levels are affected because the kidneys excrete potassium, or hydrogen ions, in exchange for retained sodium.

The heart says no

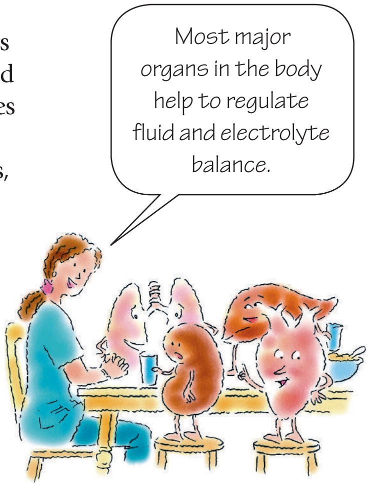
The heart counteracts the renin-angiotensin-aldosterone system when it secretes atrial natriuretic peptide (ANP), causing sodium excretion. The hypothalamus and posterior pituitary gland produce and secrete an antidiuretic hormone that causes the body to retain water which, in turn, affects solute concentration in the blood.

Chart smart

Documenting electrolyte imbalances

Be sure to include the following information in your documentation of a patient's electrolyte imbalance:

- assessment findings
- laboratory results pertaining to the imbalance
- related nursing diagnoses
- notification and response of the health care provider
- interventions and treatment for the electrolyte imbalance, including safety measures
- patient teaching
- patient's response to interventions.



Where electrolytes are lost

Sodium, potassium, chloride, and water are lost in sweat and from the GI tract; however, electrolytes are also absorbed from the GI tract. Discussions of individual electrolytes in upcoming chapters explain how GI absorption of foods and fluids affects their balance.

The glands play on

The parathyroid glands also play a role in electrolyte balance, specifically the balance of calcium and phosphorus. The parathyroid glands (usually two pairs) are located behind and to the side of the thyroid gland. They secrete parathyroid hormone, which draws calcium into the blood from the bones, intestines, and kidneys and helps move phosphorus from the blood to the kidneys, where it's excreted in urine.

The thyroid gland is also involved in electrolyte balance by secreting calcitonin. This hormone lowers an elevated calcium level by preventing calcium release from bone. Calcitonin also decreases intestinal absorption and kidney reabsorption of calcium.

Kidney involvement

Remember filtration? It's the process of removing particles from a solution by allowing the liquid portion to pass through a membrane. Filtration occurs in the nephron (the anatomic and functional unit of the kidneys). As blood circulates through the glomerulus (a tuft of capillaries), fluids and electrolytes are filtered and collected in the nephron's tubule.

Some fluids and electrolytes are reabsorbed through capillaries at various points along the nephron; others are secreted. Age can play an important role in the way kidneys function—or malfunction. (See *Who's at risk?*)

A juggling act

A vital part of the kidneys' job is to regulate electrolyte levels in the body. Normally functioning kidneys maintain the correct fluid level in the body. Sodium and fluid balances are closely related. When too much sodium is released, the body's fluid level drops.

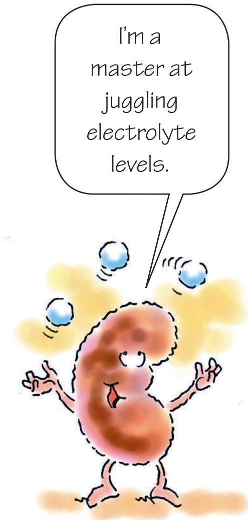
The kidneys also rid the body of excess potassium. When the kidneys fail, potassium builds up in the body. High levels of potassium in the blood can be fatal. (For more information about which areas of the nephron control fluid and electrolyte balance, see *How the nephron regulates fluid and electrolyte balance*.)

Ages and stages

Who's at risk?

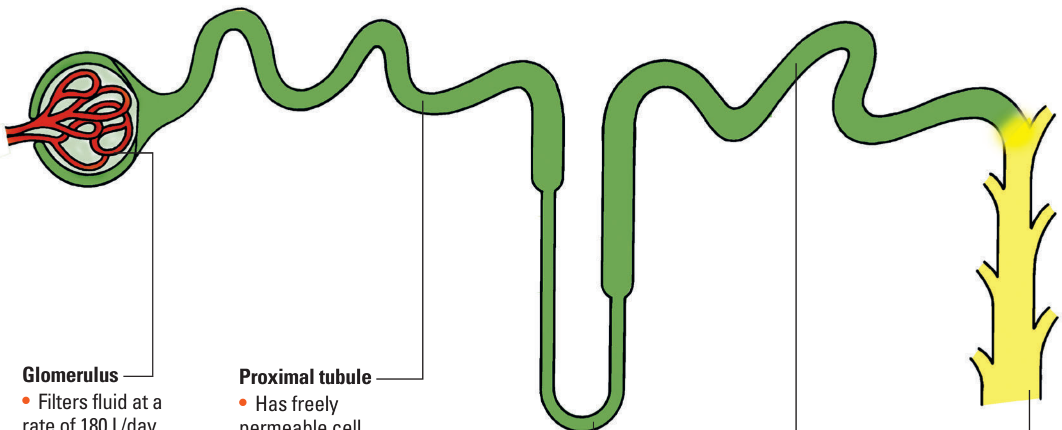
The immature kidneys of an infant can't concentrate urine or reabsorb electrolytes the way the kidneys of an adult can, so infants are at a higher risk for electrolyte imbalances.

Older adults are also at risk for electrolyte imbalances. Their kidneys have fewer functional nephrons, a decreased glomerular filtration rate, and a diminished ability to concentrate urine.



How the nephron regulates fluid and electrolyte balance

In this illustration, the nephron has been stretched to show where and how fluids and electrolytes are regulated.



Glomerulus
- Filters fluid at a rate of 180 L/day
- Acts as a bulk filter to pass along protein-free and red blood cell–free filtrate (liquid that has been filtered)

Proximal tubule
- Has freely permeable cell membranes
- Reabsorbs most electrolytes, glucose, urea, and amino acids
- Carries large amounts of water with electrolytes back to circulation
- Reduces water content of filtrate by 70%

Loop of Henle
- Contains a high concentration of salts, mostly sodium
- Further concentrates filtrate because of water lost by osmosis
- Pulls chloride and sodium out of filtrate without water and reabsorbs them in ascending limb
- Causes filtrate to become more dilute as it moves into distal tubule

Distal tubule
- Reabsorbs water and concentrates urine as a result of antidiuretic hormone (ADH) action
- Reabsorbs sodium and water
- Secretes potassium as a result of aldosterone action

Collecting duct
- Has ADH, which reabsorbs water
- Absorbs or secretes potassium, sodium, urea, hydrogen ions, and ammonia, according to the body's needs

How diuretics affect balance

Many patients—whether in a medical facility or at home—take a diuretic to increase urine production. Diuretics are used to treat many disorders, such as hypertension, heart failure, electrolyte imbalances, and kidney disease.

Keeping a close watch

The health care team monitors the effects of a diuretic, including its effect on electrolyte balance. A diuretic may cause electrolyte loss, whereas an I.V. fluid causes electrolyte gain. Older adults, who are at risk for fluid and electrolyte imbalances, need careful monitoring because a diuretic can worsen an existing imbalance.

When you know how the nephron functions normally, you can predict a diuretic's effects on your patient by knowing where along the nephron the drug acts. This knowledge and understanding can help you provide optimal care for a patient taking a diuretic. (See *How drugs affect nephron activity*.)

I.V. fluids

Like diuretics, I.V. fluids affect electrolyte balance in the body. When providing I.V. fluid, keep in mind the patient's normal electrolyte requirements. For instance, the patient may require:

- 1 to 2 mEq/kg/day of sodium
- 0.5 to 1 mEq/kg/day of potassium
- 1 to 2 mEq/kg/day of chloride.

Improving your I.V. IQ

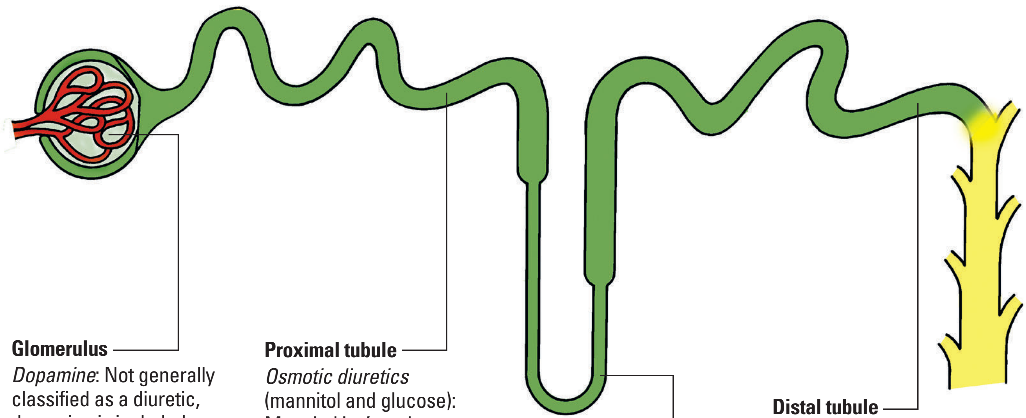
To evaluate I.V. fluid treatment, ask:

- Is the I.V. fluid providing the correct amount of electrolytes?
- How long has the patient been receiving I.V. fluids?
- Is the patient receiving oral supplementation of electrolytes?

For more about I.V. fluids, see chapter 19, I.V. fluid replacement. (For the electrolyte content of some commonly used I.V. fluids, see *I.V. fluid components*, page 32.)

How drugs affect nephron activity

Here's a look at how certain diuretics and other drugs affect the nephron's regulation of fluid and electrolyte balance.



Glomerulus
Dopamine: Not generally classified as a diuretic, dopamine is included here because it may increase urine output. Dopaminergic receptor sites exist along the afferent arterioles (tiny vessels that bring blood to the glomerulus). In low doses (0.5 to 3 mcg/kg/minute), dopamine dilates these vessels in the glomerulus to increase blood flow to it. This, in turn, increases filtration in the nephron.

Proximal tubule
Osmotic diuretics (mannitol and glucose): Mannitol isn't reabsorbed in the tubule; it remains in high concentrations throughout its journey, increasing filtrate osmolality and hindering water, sodium, and chloride reabsorption, thereby increasing their excretion.

High blood glucose levels cause excess glucose to spill over into the tubules. The osmotic effect of glucose also results in increased urine output.

Carbonic anhydrase inhibitors (acetazolamide [Diamox]): These drugs reduce hydrogen ion (acid) concentration in the tubule, which causes increased excretion of bicarbonate, water, sodium, and potassium.

Loop of Henle
Loop diuretics (furosemide [Lasix], bumetanide [Bumex], and ethacrynic acid [Edecrin]): Loop diuretics act on the ascending loop of Henle to prevent water and sodium reabsorption. As a result, volume in the tubules is increased and blood volume is decreased. Potassium and chloride are also excreted here.

Distal tubule
Thiazide diuretics (hydrochlorothiazide [HydroDIURIL] and metolazone [Zaroxolyn]): Thiazide diuretics act high in the distal tubule to prevent sodium reabsorption, which increases the amount of tubular fluid and electrolytes farther down the nephron. Blood volume decreases, aldosterone increases sodium reabsorption, and, in exchange, potassium is lost from the body.

Potassium-sparing diuretics (spironolactone [Aldactone]): These diuretics interfere with sodium and chloride reabsorption in the tubule. Potassium is spared, and sodium, chloride, and water are excreted. Urine output increases, and the body retains potassium.

I.V. fluid components

This table lists the electrolyte content of some commonly used I.V. fluids.

I.V. solution	Electrolyte	Amount
Dextrose	None	—
Sodium chloride		
5%	Sodium chloride	855 mEq/L
3%	Sodium chloride	513 mEq/L
0.9%	Sodium chloride	154 mEq/L
0.45%	Sodium chloride	77 mEq/L
Dextrose and sodium chloride		
5% dextrose and 0.9% sodium chloride	Sodium chloride	154 mEq/L
5% dextrose and 0.45% sodium chloride	Sodium chloride	77 mEq/L
Ringer's solution (plain)		
	Chloride	156 mEq/L
	Sodium	147 mEq/L
	Calcium	4.5 mEq/L
	Potassium	4 mEq/L
Lactated Ringer's solution		
	Sodium	130 mEq/L
	Chloride	109 mEq/L
	Lactate	28 mEq/L
	Potassium	4 mEq/L
	Calcium	3 mEq/L

That's a wrap

Balancing electrolytes review

Electrolyte basics
- Found throughout the body in various concentrations
- Critical to cell function

Ions, anions, cations
- *Ions*—electrically charged particles created when electrolytes separate in a solution; may be positively or negatively charged
- *Anions*—negatively charged electrolytes; include chloride, phosphorus, and bicarbonate
- *Cations*—positively charged electrolytes; include sodium, potassium, calcium, and magnesium
- *Electroneutrality*—positive and negative ions balance each other out, achieving a neutral electrical charge

Major extracellular electrolytes
- *Sodium*—helps nerve cells and muscle cells interact
- *Chloride*—maintains osmotic pressure and helps gastric mucosal cells produce hydrochloric acid
- *Calcium*—stabilizes cell membrane, reducing its permeability; transmits nerve impulses; contracts muscles; coagulates blood; and forms bones and teeth
- *Bicarbonate*—regulates acid-base balance

Major intracellular electrolytes
- *Potassium*—regulates cell excitability, nerve impulse conduction, resting membrane potential, muscle contraction, myocardial membrane responsiveness, and intracellular osmolality
- *Phosphate*—controls energy metabolism
- *Magnesium*—influences enzyme reactions, neuromuscular contractions, normal functioning of nervous and cardiovascular system, protein synthesis, and sodium and potassium ion transportation

Influences on electrolyte balance
- Normal cell function
- Fluid intake and output
- Acid-base balance
- Hormone secretion

Maintaining electrolyte balance
- Most major organs and glands in the body help regulate fluid and electrolyte balance.

The role of organs and glands
- *Kidneys*—regulate sodium and potassium balance (excrete potassium in exchange for sodium retention)
- *Lungs and liver*—regulate sodium and water balance and blood pressure
- *Heart*—secretes ANP, causing sodium excretion
- *Sweat glands*—excrete sodium, potassium, chloride, and water in sweat
- *GI tract*—absorbs and excretes fluids and electrolytes
- *Parathyroid glands*—secrete parathyroid hormone, which draws calcium into the blood and helps move phosphorous to the kidneys for excretion
- *Thyroid gland*—secretes calcitonin, which prevents calcium release from the bone

(continued)

Balancing electrolytes review *(continued)*

- *Hypothalamus and posterior pituitary*—produce and secrete antidiuretic hormone causing water retention, which affects solute concentration
- *Adrenal glands*—secrete aldosterone, which influences sodium and potassium balance in the kidneys

The effect of diuretics

- Treat hypertension, heart failure, electrolyte imbalances, and kidney disease
- Increase urine production
- Cause loss of electrolytes, particularly potassium
- Require careful monitoring of electrolytes

Key issues in I.V. fluid treatment

- Patient's normal electrolyte requirements
- Correct amount of electrolytes prescribed and given
- Length of treatment
- Concomitant oral electrolyte supplementation

Quick quiz

1. A nurse is providing care for a patient who has burns over 18% of the body. Because of tissue destruction, the nurse expects which of the following laboratory values to be elevated?

A. Potassium
B. Chloride
C. Calcium
D. Sodium

Answer: A. Potassium is one of the major electrolytes inside the cell that leaks out into ECF after a major trauma, such as a burn. This puts the patient at risk for hyperkalemia.

2. A nurse is providing care for a patient experiencing congestive heart failure. Treatment includes administration of diuretics which alter the excretion and reabsorption of which of the following?

A. Water only
B. Electrolytes only
C. Water and electrolytes
D. Other drugs

Answer: C. Diuretics generally affect how much water and sodium the body excretes. At the same time, other electrolytes such as potassium can also be excreted in urine.

3. A nurse is providing care to a patient experiencing a multisystem disease process. Because it is the main extracellular cation, the nurse monitors the laboratory values of which of the following electrolytes?

A. Calcium
B. Potassium
C. Bicarbonate
D. Sodium

Answer: D. Sodium is the main extracellular cation. In addition to other functions, it helps regulate fluid balance in the body.

4. A nurse is providing care for a patient in a dialysis clinic. The nurse understands that in the nephron, most electrolytes are reabsorbed in the:

A. proximal tubule.
B. glomerulus.
C. loop of Henle.
D. distal tubule.

Answer: A. The proximal tubule reabsorbs most electrolytes from the filtrate. It also reabsorbs glucose, urea, amino acids, and water.

5. Potassium is essential for conducting electrical impulses because it causes ions to:

A. clump together to generate a current.
B. shift in and out of the cell to conduct a current.
C. trap sodium inside the cell to maintain a current.
D. adhere to each other to create a current.

Answer: B. Potassium in the ICF causes ions to shift in and out of the cell, which allows electrical impulses to be conducted from cell to cell.

6. A nurse at a subacute center understands that older adults are at increased risk for electrolyte imbalances because, with age, the kidneys have:

A. increased glomerular filtration rate.
B. fewer functioning nephrons.
C. increased ability to concentrate urine.
D. increased blood flow.

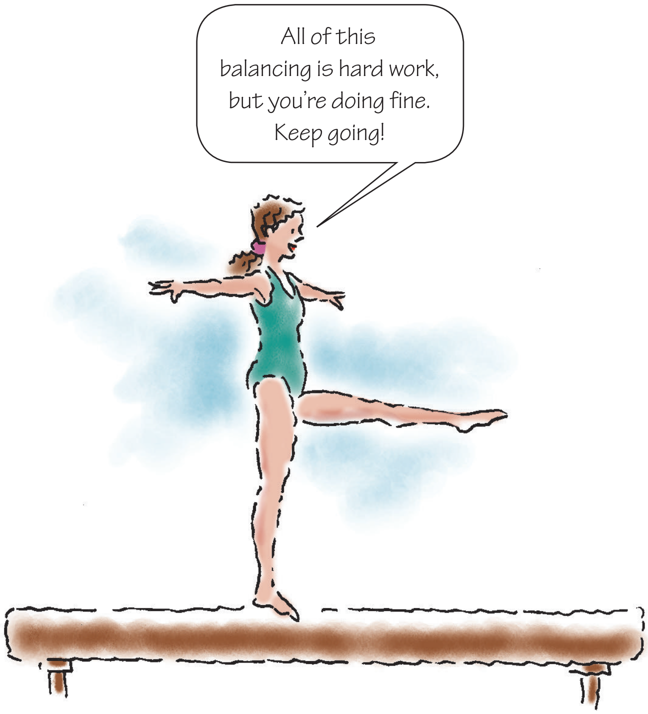
Answer: B. Older adults are at increased risk for electrolyte imbalances because their kidneys have fewer functioning nephrons, a decreased glomerular filtration rate, and a diminished ability to concentrate urine.

Scoring

☆☆☆ If you answered all six questions correctly, congratulations! You understand balance so well, you're ready to walk the high wire.

☆☆ If you answered four or five correctly, great! You still have all the qualities of a well-balanced individual!

☆ If you answered fewer than four correctly, no need to feel too unbalanced! Just review the chapter and you'll be fine.



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Chapter 3

Balancing acids and bases

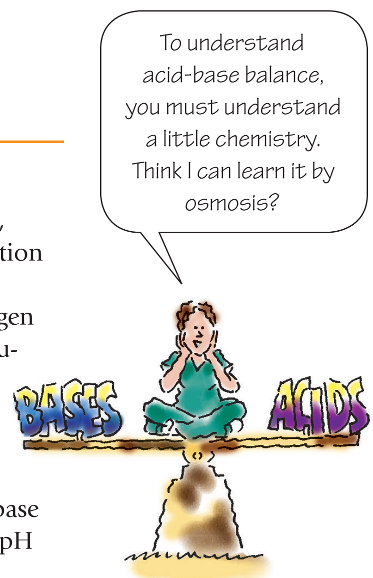
Just the facts

In this chapter, you'll learn:

- the definitions of acids and bases
- the role pH plays in metabolism
- regulation of acid-base balance in the body
- essential diagnostic tests for assessing acid-base balance.

A look at acids and bases

The chemical reactions that sustain life depend on a delicate balance—or homeostasis—between acids and bases in the body. Even a slight imbalance can profoundly affect metabolism and essential body functions. Several conditions, such as infection or trauma, and medications can affect acid-base balance. However, to understand this balance, you need to understand some basic chemistry.



Understanding pH

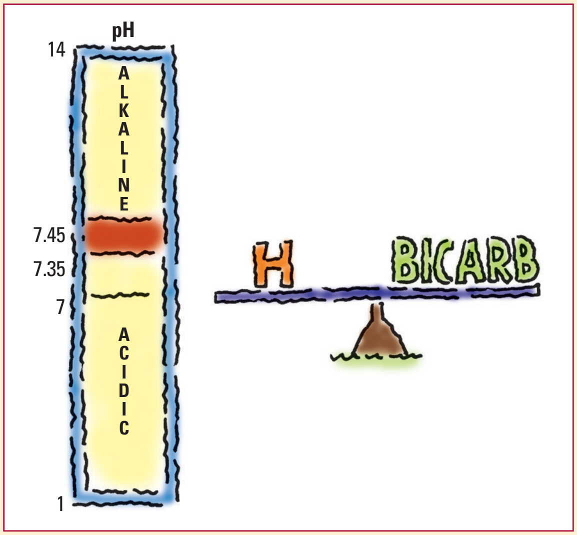
Understanding acids and bases requires an understanding of pH, a calculation based on the percentage of hydrogen ions in a solution as well as the amount of acids and bases.

Acids consist of molecules that can give up, or donate, hydrogen ions to other molecules. Carbonic acid is an acid that occurs naturally in the body. Bases consist of molecules that can accept hydrogen ions; bicarbonate is one example of a base.

A solution that contains more base than acid has fewer hydrogen ions, so it has a higher pH. A solution with a pH above 7 is a base, or alkaline. A solution that contains more acid than base has more hydrogen ions, so it has a lower pH. A solution with a pH below 7 is an acid, or acidotic.

Understanding normal pH

This illustration shows that blood pH normally stays slightly alkaline, between 7.35 and 7.45. At that point, the amount of acid (H+) is balanced with the amount of base (represented here as bicarbonate). A pH below 7.35 is abnormally acidic; a pH above 7.45 is abnormally alkaline.



Getting your PhD in pH

You can assess a patient's acid-base balance if you know the pH of the patient's blood. Because arterial blood is usually used to measure pH, this discussion focuses on arterial samples.

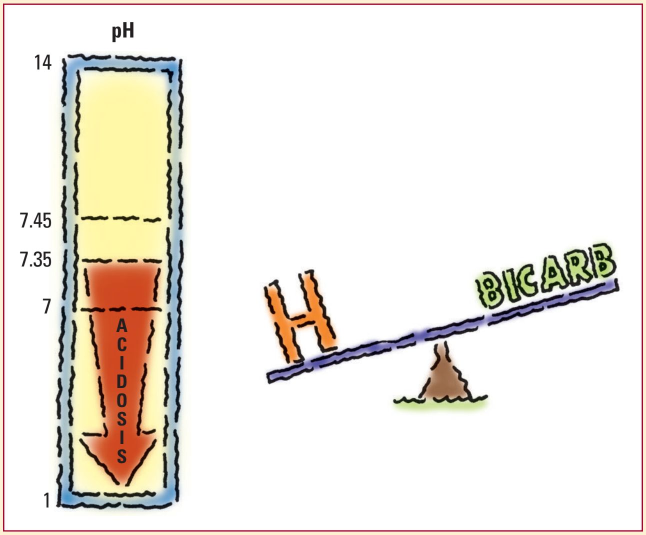
Arterial blood is normally slightly alkaline, ranging from 7.35 to 7.45. A pH level within that range represents a balance between the percentage of hydrogen ions and bicarbonate ions. Generally, pH is maintained in a ratio of 20 parts bicarbonate to 1 part carbonic acid. A pH below 6.8 or above 7.8 is usually fatal. (See *Understanding normal pH*.)

Too low

Under certain conditions, the pH of arterial blood may deviate significantly from its normal narrow range. If the blood's hydrogen ion concentration increases or bicarbonate level decreases, pH may decrease. In either case, a decrease in pH below 7.35 signals acidosis. (See *Understanding acidosis*.)

Understanding acidosis

Acidosis, a condition in which pH is below 7.35, occurs when acids (H+) accumulate or bases, such as bicarbonate, are lost.



Too high

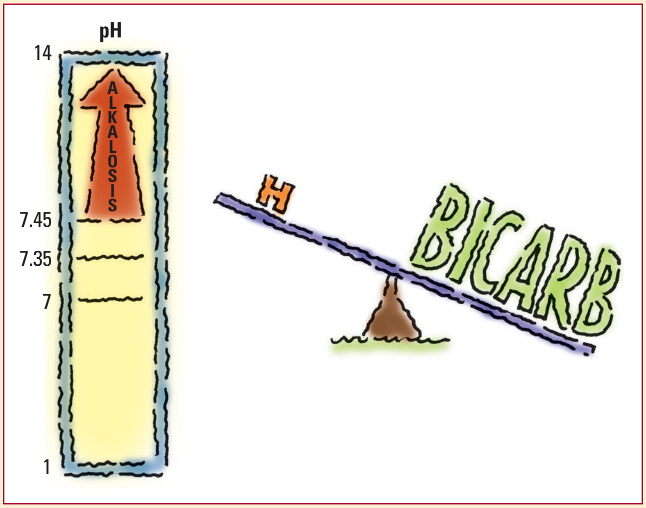
If the blood's bicarbonate level increases or hydrogen ion concentration decreases—the opposite effect of a low pH—pH may increase. In either case, an increase in pH above 7.45 signals alkalosis. (See *Understanding alkalosis*, page 40.)

Regulating acids and bases

A person's well-being depends on the person's ability to maintain a normal pH. A deviation in pH can compromise essential body processes, including electrolyte balance, activity of critical enzymes, muscle contraction, and basic cellular function. The body normally maintains pH within a narrow range by carefully balancing acidic and alkaline elements. When one aspect of that balancing act breaks down, the body can't maintain a healthy pH as easily, and problems arise.

Understanding alkalosis

Alkalosis, a condition in which pH is higher than 7.45, occurs when bases, such as bicarbonate, accumulate or acids (H+) are lost.



The big three

The body regulates acids and bases to avoid potentially serious consequences. Therefore, when pH rises or falls, three regulatory systems come into play:

- *Chemical buffers* act immediately to protect tissues and cells. These buffers instantly combine with the offending acid or base, neutralizing harmful effects until other regulators take over.
- The *respiratory system* uses hypoventilation or hyperventilation as needed to regulate excretion or retention of acids within minutes of a change in pH.
- The *kidneys* kick in by excreting or retaining acids and bases as needed. Renal compensation kicks in after the aforementioned systems fail to restore normal pH levels, typically after approximately 6 hours of alkalosis or acidosis (Appel & Downs, 2008). Renal regulation can take hours or days to restore normal hydrogen ion concentration.

Regulation system 1: Buffers

The body maintains a healthy pH in part through chemical buffers, substances that minimize changes in pH by combining with excess acids or bases. Chemical buffers in the blood, intracellular fluid, and interstitial fluid serve as the body's most efficient pH-balancing weapon. The main chemical buffers are bicarbonate, phosphate, and protein.

Bring on the bicarbonate

The bicarbonate buffer system is the body's primary buffer system. It's mainly responsible for buffering blood and interstitial fluid. This system relies on a series of chemical reactions in which pairs of weak acids and bases (such as carbonic acid and bicarbonate) combine with stronger acids (such as hydrochloric acid) and bases to weaken them.

Decreasing the strength of potentially damaging acids and bases reduces the danger those chemicals pose to pH balance. The kidneys assist the bicarbonate buffer system by regulating production of bicarbonate. The lungs assist by regulating the production of carbonic acid, which results from combining carbon dioxide and water.

Feeling better with phosphate

Like the bicarbonate buffer system, the phosphate buffer system depends on a series of chemical reactions to minimize pH changes. Phosphate buffers react with either acids or bases to form compounds that slightly alter pH, which can provide extremely effective buffering. This system proves especially effective in renal tubules, where phosphates exist in greater concentrations.

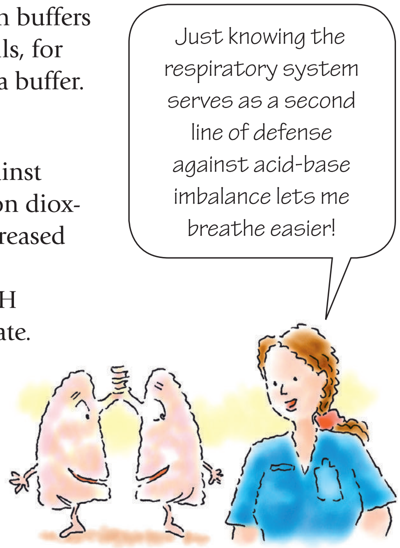
Plenty of protein

Protein buffers, the most plentiful buffers in the body, work inside and outside cells. They're made up of hemoglobin as well as other proteins. Behaving chemically like bicarbonate buffers, protein buffers bind with acids and bases to neutralize them. In red blood cells, for instance, hemoglobin combines with hydrogen ions to act as a buffer.

Regulation system 2: Respiration

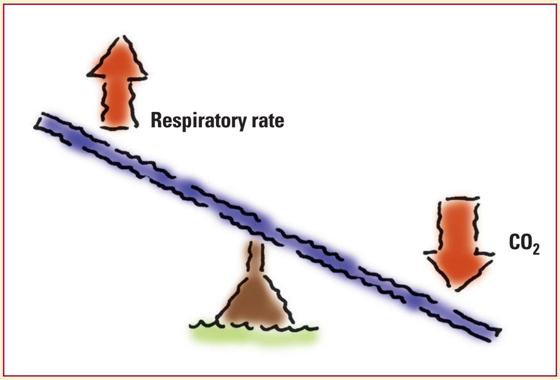
The respiratory system serves as the second line of defense against acid-base imbalances. The lungs regulate blood levels of carbon dioxide, a gas that combines with water to form carbonic acid. Increased levels of carbonic acid lead to a decrease in pH.

Chemoreceptors in the medulla of the brain sense those pH changes and vary the rate and depth of breathing to compensate. Breathing faster or deeper eliminates more carbon dioxide from the lungs. The more carbon dioxide that is lost, the less carbonic acid that is made and, as a result, pH rises. The body detects that pH change and reduces carbon dioxide excretion by breathing slower or less deeply. (See *Carbon dioxide and hyperventilation*, page 42.)



Carbon dioxide and hyperventilation

When a patient's rate of breathing increases, the body blows off carbon dioxide, and carbon dioxide level drops.



Check for success

To assess the effectiveness of ventilation, look at the partial pressure of carbon dioxide in arterial blood ($Paco_2$). A normal $Paco_2$ level in the body is 35 to 45 mm Hg. $Paco_2$ values reflect carbon dioxide levels in the blood. As those levels increase, so does $Paco_2$.

Twice as good

As a buffer, the respiratory system can maintain acid-base balance twice as effectively as chemical buffers because it can handle twice the amount of acids and bases. Although the respiratory system responds to pH changes within minutes, it can restore normal pH only temporarily. The kidneys are responsible for long-term adjustments to pH.

Regulation system 3: Kidneys

The kidneys serve as yet another mechanism for maintaining acid-base balance in the body. They can reabsorb acids and bases or excrete them into urine. They can also produce bicarbonate to replenish lost supplies. Such adjustments to pH can take the kidneys hours or days to complete. As with other acid-base regulatory systems, the effectiveness of the kidneys changes with age. (See *Acid-base balance across the life span*.)

Ages and stages

Acid-base balance across the life span

The effectiveness of the systems that regulate acid-base balance varies with age. For example, an infant's kidneys can't acidify urine as well as an adult's can. Also, the respiratory system of an older adult may be compromised and, therefore, less able to regulate acid-base balance. In addition, because ammonia production decreases with age, the kidneys of an older adult can't handle excess acid as well as the kidneys of a younger adult.

The kidneys also have a part in the regulation of the bicarbonate level, which is a reflection of the metabolic component of acid-base balance. Normally, the bicarbonate level is reported with arterial blood gas (ABG) results. The normal bicarbonate level is 22 to 26 mEq/L.

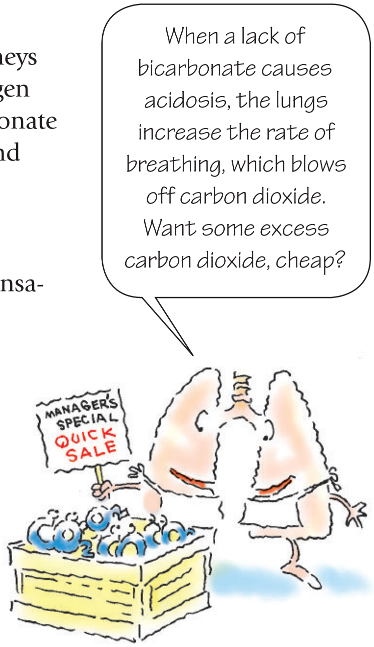
The kidneys keep working

If the blood contains too much acid or not enough base, pH drops and the kidneys reabsorb sodium bicarbonate. The kidneys also excrete hydrogen along with phosphate or ammonia. Although urine tends to be acidic because the body usually produces slightly more acids than bases, in such situations, urine becomes more acidic than normal.

The reabsorption of bicarbonate and the increased excretion of hydrogen causes more bicarbonate to be formed in the renal tubules and eventually retained in the body. The bicarbonate level in the blood then rises to a more normal level, increasing pH.

Ups and downs of acids and bases

If the blood contains more base and less acid, pH rises. The kidneys compensate by excreting bicarbonate and retaining more hydrogen ions. As a result, urine becomes more alkaline and blood bicarbonate level drops. Conversely, if the blood contains less bicarbonate and more acid, pH drops.



Altogether now

The body responds to acid-base imbalances by activating compensatory mechanisms that minimize pH changes. Returning the pH to a normal or near-normal level mainly involves changes in the component—metabolic or respiratory—not primarily affected by the imbalance.

If the body compensates only partially for an imbalance, pH remains outside the normal range. If the body compensates fully or completely, pH returns to normal.

Respiratory helps metabolic . . .

If metabolic disturbance is the primary cause of an acid-base imbalance, the lungs compensate in one of two ways. When a lack of bicarbonate causes acidosis, the lungs increase the rate of breathing, which blows off carbon dioxide and helps raise the pH to normal. When an excess of bicarbonate causes alkalosis, the lungs decrease the rate of breathing, which retains carbon dioxide and helps lower pH.

. . . And vice versa

If the respiratory system disturbs the acid-base balance, the kidneys compensate by altering levels of bicarbonate and hydrogen ions. When $PaCO_2$ is high (a state of acidosis), the kidneys retain bicarbonate and excrete more acid to raise the pH. When $PaCO_2$ is low (a state of alkalosis), the kidneys excrete bicarbonate and hold on to more acid to lower the pH.

Memory jogger

Remember, $PaCO_2$ and pH move in opposite directions. If $PaCO_2$ rises, then pH falls, and vice versa.

Diagnosing imbalances

A number of tests are used to diagnose acid-base disturbances. Here's a look at the most commonly used tests.

Arterial blood gas analysis

An ABG analysis is a diagnostic test in which a sample of blood obtained from an arterial puncture can be used to assess the effectiveness of breathing and overall acid-base balance. In addition to helping you identify problems with oxygenation and acid-base imbalances, the test can help you monitor a patient's response to treatment. (See *Taking an ABG sample*.)

Keep in mind that ABG analysis should be used only in conjunction with a full patient assessment. Only by assessing all information can you gain a clear picture of what's happening.

An ABG analysis involves several separate test results, only three of which relate to acid-base balance: pH, $PaCO_2$, and bicarbonate level. The normal ranges for adults are:

- pH—7.35 to 7.45
- $PaCO_2$—35 to 45 mm Hg
- bicarbonate—22 to 26 mEq/L.

Taking an ABG sample

When a needle puncture is needed to obtain an ABG sample, the radial, brachial, or femoral arteries may be used. However, the angle of penetration varies.

For the radial artery (the artery most commonly used), the needle should enter bevel up at a 45-degree angle, as shown below. For the brachial artery, the angle should be 60 degrees; for the femoral artery, 90 degrees.

Whatever site you use, always apply pressure after performing a needle puncture of an artery until all signs of bleeding have resolved.

The ABCs of ABGs

Recall that pH is a measure of the hydrogen ion concentration of blood; $PaCO_2$ is a measure of the partial pressure of carbon dioxide in arterial blood, which indicates the effectiveness of breathing. $PaCO_2$ levels move in the opposite direction of pH levels. Bicarbonate, which moves in the same direction of pH, represents the metabolic component of the body's acid-base balance.

Other information routinely reported with ABG results includes partial pressure of oxygen dissolved in arterial blood (PaO_2) and arterial oxygen saturation (SaO_2). The normal PaO_2 range is 80 to 100 mm Hg; however, PaO_2 varies with age. After age 60 years, the PaO_2 may drop below 80 mm Hg without signs and symptoms of hypoxia. The normal SaO_2 range is 95% to 100%.

Interpreting ABG results

When interpreting results from an ABG analysis, follow a consistent sequence to analyze the information. Here's one step-by-step process you can use. (See *Quick look at ABG results*.)

Step 1: Check the pH

First, check the pH level. This figure forms the basis for understanding most other figures.

If pH is abnormal, determine whether it reflects acidosis (below 7.35) or alkalosis (above 7.45). Then figure out whether the cause is respiratory or metabolic.

Step 2: Determine the $Pa{CO_2}$

Remember that the $Pa{CO_2}$ level provides information about the respiratory component of acid-base balance.

If $Pa{CO_2}$ is abnormal, determine whether it's low (less than 35 mm Hg) or high (greater than 45 mm Hg). Then determine whether the abnormal result corresponds with a change in pH. For example, if the pH is high, you would expect the $Pa{CO_2}$ to be low (hypocapnia), indicating that the problem is respiratory alkalosis. Respiratory alkalosis is caused by hyperventilation, mechanical overventilation, pregnancy, stroke, high altitudes, and septicemia (Appel & Downs, 2008; Rogers & McCutcheon, 2013). Conversely, if the pH is low, you would expect the $Pa{CO_2}$ to be high (hypercapnia), indicating that the problem is respiratory acidosis caused by hypoventilation. Causes of respiratory acidosis may be acute or chronic and are linked to chronic diseases such as chronic bronchitis, asthma, pneumonia, and airway obstruction (Rogers & McCutcheon, 2013).

Step 3: Watch the bicarbonate

Next, examine the bicarbonate level. This value provides information about the metabolic aspect of acid-base balance.

If the bicarbonate level is abnormal, determine whether it's low (less than 22 mEq/L) or high (greater than 26 mEq/L). Then determine whether the abnormal result corresponds with the change in pH. For example, if pH is high, you would expect the bicarbonate level to be high, indicating that the problem is metabolic alkalosis. Causes of metabolic alkalosis include the use of diuretics, vomiting, hyperaldosteronism, excessive use of alkaline medications such as antacids, and Cushing's syndrome (Appel & Downs, 2008; Rogers & McCutcheon, 2013). Conversely, if pH is low, you would expect the bicarbonate level to be low, indicating that the problem is metabolic acidosis. Causes of metabolic acidosis include diabetic ketoacidosis, lactic acidosis, and severe

Quick look at ABG results

Here's a quick look at how to interpret ABG results:

- Check the pH. Is it normal (7.35 to 7.45), acidotic (below 7.35), or alkalotic (above 7.45)?
- Check $Pa{CO_2}$. Is it normal (35 to 45 mm Hg), low, or high?
- Check the bicarbonate level. Is it normal (22 to 26 mEq/L), low, or high?
- Check for signs of compensation. Which value ($Pa{CO_2}$ or bicarbonate) more closely corresponds to the change in pH?
- Check $Pa{O_2}$ and $Sa{O_2}$. Is the $Pa{O_2}$ normal (80 to 100 mm Hg), low, or high? Is the $Sa{O_2}$ normal (95% to 100%), low, or high?

Memory Jogger

Remember, bicarbonate and pH increase or decrease together. When one rises or falls, so does the other.

diarrhea that lead to a loss of bicarbonate (Appel & Downs, 2008; Rogers & McCutcheon, 2013).

Step 4: Look for compensation

Sometimes you'll see a change in both the $PaCO_2$ and the bicarbonate level. One value indicates the primary source of the pH change; the other, the body's effort to compensate for the disturbance.

Complete compensation occurs when the body's ability to compensate is so effective that pH falls within the normal range. Partial compensation, on the other hand, occurs when pH remains outside the normal range.

Compensation involves opposites. For instance, if results indicate primary metabolic acidosis, compensation will come in the form of respiratory alkalosis. For example, the following ABG results indicate metabolic acidosis with compensatory respiratory alkalosis:

- pH—7.29
- $PaCO_2$—17 mm Hg
- bicarbonate—19 mEq/L.

The low pH indicates acidosis. However, the $PaCO_2$ is low, which normally leads to alkalosis, and the bicarbonate level is low, which normally leads to acidosis. The bicarbonate level, then, more closely corresponds with the pH, making the primary cause of the problem metabolic. The resultant decrease in $PaCO_2$ reflects partial respiratory compensation.

Normal values for pH, $PaCO_2$, and bicarbonate would indicate that the patient's acid-base balance is normal.

Step 5: Determine PaO_2 and SaO_2

Last, check PaO_2 and SaO_2, which yield information about the patient's oxygenation status. If the values are abnormal, determine whether they're high (PaO_2 greater than 100 mm Hg) or low (PaO_2 less than 80 mm Hg and SaO_2 less than 95%).

Remember that PaO_2 reflects the body's ability to pick up oxygen from the lungs. A low PaO_2 represents hypoxemia and can cause hyperventilation. The PaO_2 value also indicates when to make adjustments in the concentration of oxygen being administered to a patient. (See *Inaccurate ABG results*.)

Inaccurate ABG results

To avoid altering ABG results, be sure to use proper technique when drawing a sample of arterial blood. Remember:

- A delay in getting the sample to the laboratory or drawing blood for ABG analysis within 15 to 20 minutes of a procedure, such as suctioning or administering a respiratory treatment, could alter results.
- Air bubbles in the syringe could affect the oxygen level.
- Venous blood in the syringe could alter carbon dioxide and oxygen levels and pH.

Anion gap

You may also come across a test result called the *anion gap*. (See *Crossing the great anion gap*.) Earlier chapters discuss how the strength of cations (positively charged ions) and anions (negatively charged ions) must be equal in the blood to maintain a proper balance of electrical charges. The anion gap result helps you differentiate among various acidotic conditions.