

# 18

## Urinary System and Fluid Balance

**FOCUS:** The urinary system consists of the kidneys, ureters, urinary bladder and urethra. The kidneys remove waste products, many of which are toxic, from the blood and play a major role in controlling the volume, red blood cell concentration, ion concentration, and pH of the blood. The nephron, which is the functional unit of the kidney, utilizes filtration, reabsorption, and secretion in the formation of

urine. Of the filtrate formed in the nephron, 99% is reabsorbed. Regulation of fluid and electrolyte balance is necessary to maintain homeostasis. Hormones, autoregulation, and sympathetic stimulation regulate urine production. Most body fluids are inside cells, but water and electrolytes move between intracellular and extracellular compartments. Mechanisms that regulate body pH are critical to survival.

### CONTENT LEARNING ACTIVITY

#### Kidneys

“The kidneys are bean-shaped organs, each about the size of a tightly-clenched fist.”

A. Match these terms with the correct statement or definition:

Hilum  
Renal capsule  
Renal fat pad

Renal sinus  
Retroperitoneal

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

1. Structures, such as the kidney, found behind the peritoneum.
2. Connective tissue that surrounds each kidney.
3. Thick layer of fat; protects the kidney from mechanical shock.
4. Cavity filled with fat and connective tissue into which the hilum opens.

B. Match these terms with the correct statement or definition:

Cortex  
Medulla  
Renal calyces

Renal pelvis  
Renal pyramids  
Ureter

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

1. Outer portion of the kidney.
2. Cone-shaped structures found in the medulla of the kidney.
3. Inner portion of the kidney, containing the renal pyramids.
4. Funnel-shaped structures that surround the tip of each pyramid.
5. Larger funnel formed from all the calyces; located in the renal sinus.
6. Small tube through which urine exits the kidney; connects to the urinary bladder.

C. Match these terms with the correct parts labeled in figure 18.1:

Renal calyx  
Renal capsule  
Renal cortex  
Renal medulla  
Renal pelvis  
Renal pyramid  
Ureter

1. \_\_\_\_\_
2. \_\_\_\_\_
3. \_\_\_\_\_
4. \_\_\_\_\_
5. \_\_\_\_\_
6. \_\_\_\_\_
7. \_\_\_\_\_

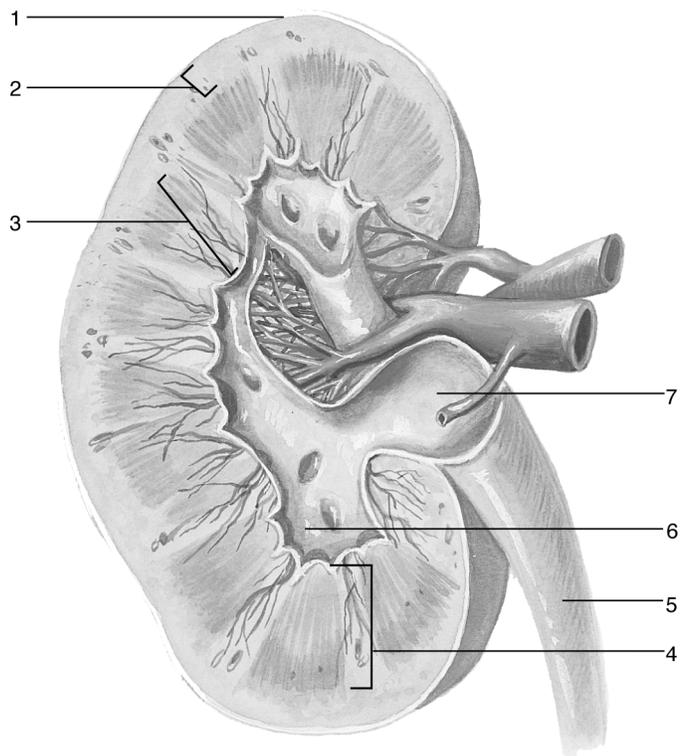


Figure 18.1

D. Match these terms with the correct parts labeled in figure 18.2:

- Collecting duct
- Distal tubule
- Loop of Henle
- Proximal tubule
- Renal corpuscle

1. \_\_\_\_\_
2. \_\_\_\_\_
3. \_\_\_\_\_
4. \_\_\_\_\_
5. \_\_\_\_\_

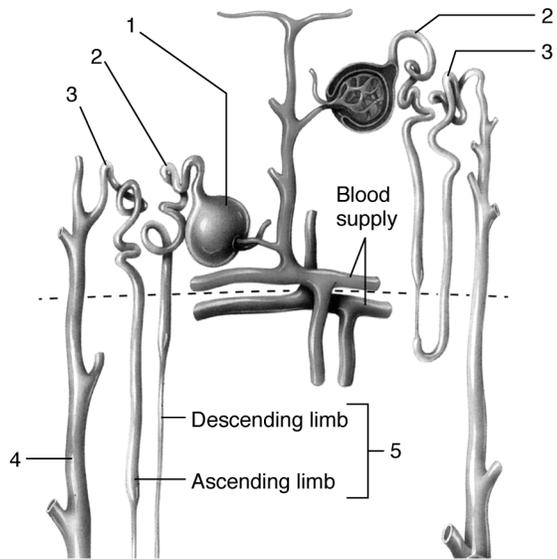


Figure 18.2

E. Match these terms with the correct statement or definition:

- |                     |                 |
|---------------------|-----------------|
| Ascending limb      | Glomerulus      |
| Bowman's capsule    | Nephron         |
| Collecting duct     | Podocytes       |
| Descending limb     | Renal corpuscle |
| Filtration membrane |                 |

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

1. Functional unit of the kidney.
2. Duct into which the distal tubule empties.
3. Enlarged end of nephron; Bowman's capsule and glomerulus.
4. Tuft of capillaries surrounded by Bowman's capsule.
5. Specialized cells that surround the glomerulus and form the inner layer of Bowman's capsule.
6. Composed of glomerular capillary walls, podocytes, and the basement membrane between them.
7. Part of Henle's loop; very permeable to water and solutes.

F. Place these vessels in the correct sequence that blood would pass through them, from abdominal aorta to renal veins.

- |                        |                         |
|------------------------|-------------------------|
| Arcuate artery         | Interlobar artery       |
| Afferent arteriole     | Interlobular artery     |
| Efferent arteriole     | Peritubular capillaries |
| Glomerular capillaries | Renal artery            |

- |                           |          |                        |
|---------------------------|----------|------------------------|
| 1. <u>Abdominal aorta</u> | 5. _____ | 9. _____               |
| 2. _____                  | 6. _____ | 10. <u>Renal veins</u> |
| 3. _____                  | 7. _____ |                        |
| 4. _____                  | 8. _____ |                        |



The juxtaglomerular apparatus is a structure formed where the specialized walls of the afferent arteriole and distal tubule come into contact.

## Ureters, Urinary Bladder, and Urethra

“The ureters and urethra are small tubes that carry urine, and the bladder is a hollow muscular structure that stores urine.”

Match these terms with the correct statement or definition:

External urinary sphincter  
 Internal urinary sphincter  
 Smooth muscle  
 Transitional epithelium  
 Trigone  
 Ureters  
 Urethra

- |       |  |
|-------|--|
| _____ | 1. Small tubes that carry urine from the renal pelvis to the urinary bladder.  |
| _____ | 2. Triangle-shaped portion of the urinary bladder located between the opening of the ureters and the opening of the urethra. |
| _____ | 3. Tube that carries urine from the urinary bladder to the outside of the body.  |
| _____ | 4. Cells that line the ureters and urinary bladder.  |
| _____ | 5. Cells that form the walls of the ureters and urinary bladder.   |
| _____ | 6. Smooth muscle at the junction of the urinary bladder and urethra that regulates urine flow through the urethra.           |
| _____ | 7. Skeletal muscle that surrounds the urethra as the urethra extends through the pelvic floor.                               |

## Urine Production

“The three processes critical to the formation of urine are filtration, reabsorption, and secretion.”

A. Match these terms with the correct statement or definition:

Filtration  
 Tubular reabsorption  
 Tubular secretion

- |       |   |
|-------|---|
| _____ | 1. Movement of plasma through the filtration membrane of the renal corpuscle.                   |
| _____ | 2. Movement of substances from the filtrate back into the blood of the peritubular capillaries. |
| _____ | 3. Transport of substances, usually waste products, into the filtrate.                          |



Urine produced by the nephrons consists of the substances that are filtered and secreted into the nephron minus those substances that are reabsorbed.

B. Using the terms provided, complete these statements:

Blood cells and proteins  
Bowman's capsule  
Decreases  
Filtration membrane

Filtration pressure  
Increases  
Water

1. \_\_\_\_\_
2. \_\_\_\_\_
3. \_\_\_\_\_
4. \_\_\_\_\_
5. \_\_\_\_\_
6. \_\_\_\_\_
7. \_\_\_\_\_
8. \_\_\_\_\_
9. \_\_\_\_\_
10. \_\_\_\_\_

The filtration membrane allows some substances, but not others, to pass from the blood into (1). (2) and small solutes readily pass through the filtration membrane, but (3) do not enter Bowman's capsule. The formation of filtrate depends on a pressure difference called (4), which forces fluid from the glomerular capillaries, through the (5) into Bowman's capsule. When filtration pressure increases, the volume of the filtrate (6), and the urine volume (7). The filtration pressure is influenced by several factors. If the blood pressure in the glomerular capillaries increases, then filtration pressure (8). Filtration pressure (9) when strong sympathetic stimulation produces constriction of renal blood vessels during excitement, vigorous physical activity, or emergencies. Also, decreases in the concentration of plasma protein (10) the filtration pressure.

C. Match these parts of the nephron with the correct function or description:

Ascending limb  
Collecting duct  
Descending limb

Distal tubule  
Proximal tubule

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

1. Sixty-five percent of filtrate is reabsorbed here; proteins, sugars, and ions are transported out of the tubule to the peritubular capillaries, and water follows by osmosis.
2. Functions to concentrate the filtrate by removing water and adding solutes; 15 percent of filtrate volume is removed.
3. Functions to dilute the filtrate by removing sodium and chloride ions; not permeable to water.
4. Sodium ions and chloride ions are removed from the filtrate, and water follows by osmosis; 19 percent of the filtrate volume is removed, leaving only 1 percent of original volume.

D. Match these terms with the correct statement or definition:

Hydrogen ions  
Potassium ions

- \_\_\_\_\_
- \_\_\_\_\_

1. Actively secreted in the proximal tubule of the nephron.
2. Secreted in the distal tubule and collecting duct of the nephron.

## Regulation of Urine Concentration and Volume

“The volume and composition of urine changes, depending on conditions in the body.”

A. Using the terms provided, complete these statements:

Concentrated	Increases
Dilute	Large
Decreases	Small

If body fluid concentration increases above normal levels, the kidneys produce a (1) amount of (2) urine, which eliminates solutes and conserves water. This helps to return the body fluid concentration to normal. If body fluid concentration decreases, the kidneys produce a (3) amount of (4) urine. As a result, water is lost and solutes conserved, and body fluid concentration increases. Urine production also maintains blood volume and therefore blood pressure. When blood volume increases above normal, the kidneys produce a (5) amount of (6) urine. The loss of water (7) blood volume and also (8) blood pressure.

1. \_\_\_\_\_
2. \_\_\_\_\_
3. \_\_\_\_\_
4. \_\_\_\_\_
5. \_\_\_\_\_
6. \_\_\_\_\_
7. \_\_\_\_\_
8. \_\_\_\_\_

B. Match these terms with the correct statement:

Increase(s)  
Decrease(s)

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

1. ADH \_\_\_\_\_ the amount of water reabsorbed from the distal tubules and collecting ducts.
2. ADH \_\_\_\_\_ the volume of urine produced.
3. If concentration of the blood increases, ADH secretion \_\_\_\_\_.
4. Increased blood pressure causes a(n) \_\_\_\_\_ in ADH secretion.

C. Match these terms with the correct statement:

Decrease(s)  
Increase(s)

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

1. Aldosterone \_\_\_\_\_ active transport of sodium ions from the nephron.
2. Increased aldosterone secretion \_\_\_\_\_ urine volume.
3. Increased aldosterone secretion \_\_\_\_\_ blood volume.
4. Increased blood volume \_\_\_\_\_ blood pressure.
5. Decreased blood pressure or decreased sodium ion concentration cause renin production by the juxtaglomerular apparatus in the kidney to \_\_\_\_\_.
6. Renin, an enzyme, \_\_\_\_\_ production of angiotensin I.
7. Angiotensin converting enzyme \_\_\_\_\_ angiotensin II production.
8. Angiotensin II \_\_\_\_\_ aldosterone secretion by adrenal cortex.

D. Match these terms with the correct statement :

Decrease(s)  
Increase(s)

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

1. Increased blood pressure in the right atrium \_\_\_\_ secretion of atrial natriuretic hormone.
2. Atrial natriuretic hormone \_\_\_\_ sodium ion reabsorption.
3. Atrial natriuretic hormone \_\_\_\_ urine volume.
4. Atrial natriuretic hormone \_\_\_\_ blood volume and pressure.
5. Sympathetic stimulation causes constriction of kidney blood vessels, which \_\_\_\_ filtrate formation.

## Urine Movement

“The micturition reflex is initiated by stretching of the bladder wall.”

Using the terms provided, complete these statements:

Contract  
Higher brain centers  
Irritation  
Parasympathetic

Relax  
Spinal cord  
Stretch receptors  
Sympathetic

As the bladder fills with urine, (1) in the wall of the bladder are stimulated. Action potentials travel to the (2) through the pelvic nerves, where integration of the reflex occurs. Action potentials then travel through (3) fibers back to the urinary bladder. Parasympathetic action potentials cause the urinary bladder to (4) and the internal urinary sphincter to (5). Also because of the micturition reflex, action potentials to the external urinary sphincter decrease, which causes the sphincter to (6). (7) can prevent or facilitate the micturition reflex by sending action potentials through the spinal cord to influence the intensity of the autonomic reflex and stimulate or inhibit the external urinary sphincter. Stretch of the urinary bladder also sends action potentials through afferent fibers to the brain, causing awareness of the need to urinate. (8) of the urinary bladder or urethra can also initiate the urge to urinate.

1. \_\_\_\_\_
2. \_\_\_\_\_
3. \_\_\_\_\_
4. \_\_\_\_\_
5. \_\_\_\_\_
6. \_\_\_\_\_
7. \_\_\_\_\_
8. \_\_\_\_\_

## Body Fluid Compartments

“Water and electrolytes move between two major compartments, but their movement is regulated.”

Match these terms with the correct statement or definition:

Extracellular fluid compartment  
Intracellular fluid compartment

\_\_\_\_\_

1. All the water and electrolytes inside the cells of the body; about two thirds of total body water.

\_\_\_\_\_

2. All the fluid outside the cells (about one third of total body water); includes interstitial fluid, plasma in blood vessels, and lymph in lymphatic vessels.

\_\_\_\_\_

3. Protein and potassium, calcium, phosphate, magnesium, and sulfate ions are present in greater concentration.

\_\_\_\_\_

4. Sodium, chloride, and bicarbonate ions are present in greater concentration.



The major influence controlling the movement of water between the intracellular and extracellular spaces is osmotic pressure. Thus, changes in electrolyte concentration result in the movement of water by osmosis.

## Regulation of Extracellular Fluid Composition

“Homeostasis requires that the intake of water and electrolytes equal their elimination.”

A. Match these terms with the correct statement:

Decrease(s)  
Increase(s)

\_\_\_\_\_

1. When the concentration of blood increases, thirst \_\_\_\_.

\_\_\_\_\_

2. If blood pressure decreases, such as during shock, thirst \_\_\_\_.

\_\_\_\_\_

3. Consumption of water \_\_\_\_ blood volume and blood pressure.

\_\_\_\_\_

4. Dry mucosa in the mouth \_\_\_\_ thirst.



Water intake is controlled by neurons in the hypothalamus, collectively called the thirst center.



E. Match these terms with the correct statement or definition:

Calcitonin  
Parathyroid hormone

\_\_\_\_\_

\_\_\_\_\_

1. Causes an increase in blood calcium level by increasing active vitamin D production, calcium reabsorption, and osteoclast activity.
2. Causes a decrease in blood calcium.



If the concentration of phosphate and sulfate ions is low, nearly all of them are reabsorbed by active transport.

## Regulation of Acid-Base Balance

“The mechanisms that regulate body pH are critical for survival.”

A. Match these terms with the correct statement or definition:

Bicarbonate buffer system      Protein buffer system  
Phosphate buffer system

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

1. Two that combine with the largest numbers of hydrogen ions.
2. Amino acid side chains function as weak acids or weak bases.
3. Can be regulated by the respiratory and urinary systems.

B. Using the terms provided, complete these statements:

Bicarbonate  
Carbonic anhydrase  
Decrease(s)

Hydrogen ions  
Increase(s)

1. \_\_\_\_\_
2. \_\_\_\_\_
3. \_\_\_\_\_
4. \_\_\_\_\_
5. \_\_\_\_\_
6. \_\_\_\_\_
7. \_\_\_\_\_
8. \_\_\_\_\_
9. \_\_\_\_\_
10. \_\_\_\_\_
11. \_\_\_\_\_

The ability of the respiratory system to regulate acid-base balance depends on the (1) buffer system. The reaction between carbon dioxide and water is catalyzed by (2), found in erythrocytes and on the surface of capillary endothelial cells. As carbon dioxide levels increase, the pH of the body fluids (3), neurons in the respiratory center of the brain are stimulated, and the rate and depth of respiration (4). Carbon dioxide elimination (5) and the concentration of carbon dioxide in the body (6). This causes hydrogen ions to combine with bicarbonate ions to form carbonic acid, which then dissociates to form carbon dioxide and water, and pH (7) to its normal range. The kidneys can secrete (8) into the urine from cells in the distal tubule of the nephron, and therefore can regulate pH directly. If the pH of the body fluids decreases below normal, the rate at which the kidneys secrete hydrogen ions (9), while the reabsorption of bicarbonate ions (10). Therefore, the pH of the blood (11) toward its normal value.



The kidney is a powerful regulator of pH, but it responds more slowly than does the respiratory system.

## Acidosis and Alkalosis

“Failure to maintain normal pH levels can result in acidosis or alkalosis.”

Using the terms provided, complete these statements:

Acidosis  
Alkalosis  
Central nervous system  
Hyperexcitability

Metabolic  
Respiratory

1. \_\_\_\_\_
2. \_\_\_\_\_
3. \_\_\_\_\_
4. \_\_\_\_\_
5. \_\_\_\_\_
6. \_\_\_\_\_
7. \_\_\_\_\_
8. \_\_\_\_\_

When the pH value of the body fluids is below 7.35, the condition is referred to as (1). When this occurs, the (2) malfunctions, and the individual becomes disoriented and possibly comatose. Acidosis is separated into two categories. (3) acidosis results when the respiratory system is unable to eliminate adequate carbon dioxide, whereas (4) acidosis results from excessive production of acidic substances because of increased metabolism, or decreased ability to eliminate hydrogen ions in the urine. When the pH of the body fluids is above 7.45, the condition is called (5). A major effect of alkalosis is (6) of the nervous system, which can lead to spasms, convulsions, or even tetany of the respiratory muscles and death. (7) alkalosis results from hyperventilation, such as in response to stress. (8) alkalosis usually results from rapid elimination of hydrogen ions during severe vomiting, or from excess aldosterone secretion.

### QUICK RECALL

1. Name six functions of the urinary system.
  
2. List the five major parts of a nephron.
  
3. List the three steps in urine formation.

4. Name four hormones that affect urine production, and give the major effect of each on urine production.
  
5. Following stretch of the bladder, list the events that result in micturition.
  
6. List three ways the sensation of thirst is increased.
  
7. State the effect of ADH, aldosterone, and renin on urine production, blood volume, and blood pressure.
  
8. Name three important buffer systems in the body.
  
9. State the effect on blood pH when respiration rate increases above normal and decreases below normal.

## WORD PARTS

Give an example of a new vocabulary word that contains each word part.

WORD PART	MEANING	EXAMPLE
ren-	a kidney	1. _____
neph-	kidney	2. _____
proxim-	nearest	3. _____
dist-	stand apart; distant	4. _____
glomer-	a ball of yarn	5. _____
corpusc-	little body	6. _____

## MASTERY LEARNING ACTIVITY

Place the letter corresponding to the correct answer in the space provided.

- \_\_\_\_\_ 1. The renal corpuscles are found in the  
a. renal cortex.  
b. renal medulla.  
c. renal pelvis.  
d. hilum.  
e. both a and b
- \_\_\_\_\_ 2. Which of these structures contain blood?  
a. glomerulus  
b. Bowman's capsule  
c. collecting duct  
d. loop of Henle  
e. a and b
- \_\_\_\_\_ 3. The functional unit of the kidney is the  
a. renal pelvis.  
b. renal sinus.  
c. nephron.  
d. calyx.
- \_\_\_\_\_ 4. Podocytes are found in  
a. the glomerulus.  
b. the renal pelvis.  
c. Bowman's capsule.  
d. the loop of Henle.
- \_\_\_\_\_ 5. Given these structures:  
1. Bowman's capsule  
2. collecting duct  
3. distal tubule  
4. loop of Henle  
5. proximal tubule
- Choose the arrangement that lists the structures in order as filtrate leaves the glomerulus and travels to the renal calyx.  
a. 1,5,4,3,2  
b. 4,1,2,3,5  
c. 1,3,4,5,2  
d. 2,5,3,4,1
- \_\_\_\_\_ 6. Kidney function is accomplished by which of these mechanisms?  
a. secretion  
b. filtration  
c. reabsorption  
d. all of the above
- \_\_\_\_\_ 7. Given these vessels:  
1. arcuate artery  
2. interlobar artery  
3. interlobular artery
- Choose the path an erythrocyte takes as it passes from the renal artery to the afferent arteriole.  
a. 1,2,3  
b. 2,1,3  
c. 2,3,1  
d. 3,2,1
- \_\_\_\_\_ 8. The urinary bladder  
a. has walls composed of skeletal muscle.  
b. is lined with simple columnar epithelium.  
c. is connected to the outside of the body by ureters.  
d. is located in the pelvic cavity.
- \_\_\_\_\_ 9. Which of these reduces filtration pressure in the glomerulus?  
a. elevated blood pressure  
b. constriction of afferent arterioles  
c. cardiovascular shock  
d. b and c  
e. all of the above
- \_\_\_\_\_ 10. The greatest volume of water is reabsorbed by the  
a. proximal tubule.  
b. loop of Henle.  
c. distal tubule.  
d. collecting duct.

- \_\_\_\_\_ 11. Water leaves the nephron by  
 a. active transport.  
 b. filtration into the capillary network.  
 c. osmosis.  
 d. facilitated diffusion.
- \_\_\_\_\_ 12. Potassium ions enter the \_\_\_\_\_ by \_\_\_\_\_.  
 a. a. proximal tubule, diffusion  
 b. proximal tubule, active transport  
 c. distal tubule, diffusion  
 d. distal tubule, active transport
- \_\_\_\_\_ 13. At which of these sites is the osmotic pressure lowest? (least concentrated filtrate)  
 a. glomerular capillary  
 b. proximal tubule  
 c. bottom of the loop of Henle  
 d. first part of the distal tubule  
 e. collecting duct
- \_\_\_\_\_ 14. Increased aldosterone causes  
 a. decreased reabsorption of sodium.  
 b. decreased secretion of potassium.  
 c. decreased reabsorption of chloride.  
 d. increased permeability of the distal tubule to water.  
 e. decreased volume of urine.
- \_\_\_\_\_ 15. Juxtaglomerular cells are involved in the secretion of  
 a. ADH.  
 b. oxytocin.  
 c. renin.  
 d. aldosterone.  
 e. atrial natriuretic factor.
- \_\_\_\_\_ 16. A decrease in blood concentration results in which of these?  
 a. increased ADH secretion  
 b. increased permeability of the collecting ducts  
 c. less concentrated urine  
 d. increased volume of urine  
 e. both c and d
- \_\_\_\_\_ 17. Extracellular fluid  
 a. tends to be higher in sodium and chloride than intracellular fluid.  
 b. includes interstitial fluid and plasma.  
 c. has a fairly consistent composition throughout the body.  
 d. all of the above
- \_\_\_\_\_ 18. Which of these causes increased blood sodium levels?  
 a. decrease in aldosterone secretion  
 b. increase in atrial natriuretic factor secretion  
 c. decrease in renin secretion  
 d. decrease in ADH secretion
- \_\_\_\_\_ 19. The sensation of thirst increases when  
 a. the oral mucosa is dry.  
 b. the osmolality of the blood increases.  
 c. blood pressure decreases.  
 d. all of the above
- \_\_\_\_\_ 20. An increase in blood carbon dioxide levels is followed by a (an) \_\_\_\_\_ in hydrogen ions, and a (an) \_\_\_\_\_ in blood pH.  
 a. decrease, decrease  
 b. decrease, increase  
 c. increase, decrease  
 d. increase, increase



## FINAL CHALLENGES



Use a separate sheet of paper to complete this section.

1. What effect does a condition that obstructs blood flow to the kidneys have on renin, ADH, and aldosterone levels? Explain.
2. Given this information: alcohol inhibits ADH secretion and caffeine causes dilation of the afferent arterioles. Explain the effects on urine production if Mr. I. P. Daily drinks several alcoholic beverages and then tries to sober up by drinking several cups of coffee.
3. Which of these symptoms are consistent with a diagnosis of hypersecretion of aldosterone (primary aldosteronism): polydipsia (excessive drinking), polyuria (excessive urine production), blood pressure 15% higher than normal, and diarrhea? Explain.
4. To be effective, a diuretic (drug that increases water loss through the kidneys) should not only increase water loss, but also increase sodium loss. Why?
5. John Uptight has a gastric ulcer. One day he consumes 10 packages of antacid tablets (mainly sodium bicarbonate). What effect does their consumption have on blood pH, urine pH, and respiration rate?