THE URINARY SYSTEM

KIDNEYS

A. Location:
    a. under the back muscles
    b. behind the parietal peritoneum
    c. just above the waistline
    d. right kidney a little lower than the left
B. internal structure
    a. cortex: outer layer of kidney substance
    b. medulla: inner portion of kidney
    c. pyramids: triangular divisions of medulla
    d. papilla: narrow, innermost end of pyramid
    e. pelvis: expansion of upper end of ureters
        i. lies inside kidney
    f. calyces: (singular-calyx) divisions of the renal pelvis
C. microscopic structure
    a. nephrons are microscopic units of kidnes
        i. consist of:
            1. renal corpuscle: Bowman's capsule with its glomerulus
                a. Bowman's capsule-cup shaped top
                b. glomerulus-network of blood capillaries surrounded by bowman's capsule
            2. renal tubule:
                a. proximal convoluted tubule-first segment
                b. Loop of Henle-extension of proximal tubule
                    i. Consists of descending limb
                    ii. Loop
                    iii. Ascending limb
                c. Distal convoluted tubule-extension of ascending limb of loop of Henle
                d. Collecting tubule-straight extension of distal tubule
D. Functions
    a. Excretes toxins and nitrogenous wastes
    b. Regulated levels of many chemical in the blood
    c. Maintains water balance
    d. Helps regulate blood pressure via secretion of rennin

FORMATION OF URINE

A. Occurs by a series of three processes that take place in successive parts of the nephron
    a. Filtration
        i. Goes on continually in renal corpuscles
        ii. Glomerular blood pressure causes water and dissolved substances to filter out of glomeruli into Bowman's capsule

iii. Normal glomerular filtration rate is 125 ml per minute

b. Reabsorption

i. Movement of substances out of renal tubules into blood in peritubular capillaries

1. Water
2. Nutrients
3. Ions
4. All are reabsorbed
5. Water is reabsorbed by osmosis from proximal tubules

c. Secretion

i. Movement of substances into urine in the distal and collecting tubules from blood in the peritubular capillaries

ii. Hydrogen ions, potassium ions and certain drugs are secreted by active transport

iii. Ammonia is secreted by diffusion

B. Control of urine volume

a. Mainly by posterior pituitary hormone ADH, which decreases it

C. Urinalysis

a. Examination of the physical, chemical and microscopic characteristics of urine

b. May help determine the presence and nature of a pathological condition

URETERS

A. Structure: narrow long tubes with expanded upper end (the renal pelvis) located inside the kidney and lined with mucous membrane

B. Function: drain urine from renal pelvis to the urinary bladder

URINARY BLADDER

A. Structure:

a. Elastic muscular organ

b. Capable of great expansion

c. Lined with mucous membrane arranged in rugae like stomach mucosa

B. Functions:

a. Storage of urine before voiding

b. Voiding (synonyms: micturition, urination, emptying bladder)

URETHRA

A. Structure

a. Narrow tube from urinary bladder to exterior

b. Lined with mucous membrane

c. Opening of urethra to exterior called urinary meatus

B. Functions:

a. Passage of urine from bladder to exterior of the body

b. Passage of male reproductive fluid (semen) from the body

MICTURITION:

A. Passage of urine from body, also called urination or voiding
B. Regulatory sphincters
    a. Internal urethral sphincter (involuntary)
    b. External urethral sphincter (voluntary)
C. Bladder wall permits storage of urine with little increase in pressure
D. Emptying reflex
    a. Initiated by stretch reflex in bladder wall
    b. Bladder wall contracts
    c. Internal sphincter relaxes
    d. External sphincter relaxes and urination occurs
E. Urinary retention: urine produced but not voided
F. Urinary suppression: no urine produce by bladder is normal
G. Incontinence: urine is voided involuntarily
    a. May be caused by spinal injury or stroke
    b. Retention of urine may cause cystitis

RENAL AND URINARY DISEASE

A. Obstructive disorders
    a. Interfere with normal flow of urine
    b. Possibly causing urine to back up and cause hydronephrosis or other kidney damage
        i. Renal calculi (kidney stones) may block ureters, causing intense pain called renal colic
        ii. Neurogenic bladder: paralysis or abnormal function of the bladder
            1. Prevents normal flow of urine out of the body
        iii. Tumors: renal cell carcinoma (kidney cancer) and bladder cancer are often characterized by hematocrit (blood in the urine)
B. Urinary tract infections (UTIs) are often caused by gram-negative bacteria
    a. Urethritis – inflammation of the urethra
    b. Cystitis-inflammation or infection of the bladder
    c. Pyelonephritis—inflammation of the renal pelvis and connective tissue of the kidney
        i. May be acute (infectious) or chronic (autoimmune)
C. Glomerular disorders result from damage to the glomerular capsular membrane of the renal corpuscles
    a. Nephritic syndrome accompanies many glomerular disorders
        i. Proteinuria-protein in the urine
        ii. Hypoalbuminemia-low plasma protein (albumin) level
            1. Caused by loss of proteins to urine
        iii. Edema-tissue swelling caused by loss of water from plasma as a result of hypoalbuminemia
    b. Acute glomerulonephritis is caused by delayed immune response to a streptococcal infection
    c. Chronic glomerulonephritis is a slow inflammatory condition caused by immune mechanisms and often leads to renal failure
D. Kidney failure or renal failure occurs when the kidney fails to function
    a. Acute renal failure-abrupt reduction in kidney function that is usually reversible

b. Chronic renal failure-slow, progressive loss of nephrons caused by a variety of underlying diseases
   i. Early in this disorder, healthy nephrons often compensate for the loss of damaged nephrons
   ii. Loss of kidney function ultimately results in uremia (high BUN (blood urea nitrogen) levels and its life threatening consequences
   iii. Complete kidney failure results in death unless a new kidney is transplanted or an artificial kidney substitute is used

VOCABULARY

atrial natriuretic hormone (ANH)	calyx	micturition	trigone
	catheterization	papilla	urination
Bowman's capsule	glormerulus	pyramid	voiding

DISEASES AND OTHER CLINICAL TERMS

Anuria	hematuria	nephritic syndrome	Pyelonephritis
Catheterization	hypoalbuminemia	Neurogenic bladder	renal colic
Cystitis	incontinence	oliguria	renal filure
Glomerulonephritis	lithotripter	polyuria	uremia
Glycosuria	nephritis	Proteinuria	Urethritis

THE URINARY SYSTEM

1) ORGANS of the urinary system:

a) **Kidney** – the main organ of the urinary system. Located behind the peritoneum (retroperitoneal space) in the lower thoracic and upper lumbar region, against the posterior wall of the abdominal cavity; responsible for filtering the blood and producing urine;
   i) specific functions include:
      (1) Filtration of blood to remove wastes, excess salts, and toxins
      (2) Production of urine to excrete unwanted materials
      (3) Maintenance of water balance for the body
      (4) Regulation of acid-base balance
      (5) Production of hormones (i.e. erythropoietin, renin)
      (6) The kidneys and the pancreas are retroperitoneal, meaning they are located behind the parietal peritoneum. This protects the body from any harmful wastes or enzymes that could be released when one of these organs is damaged.
   ii) **Hilus** – the concave area on the medial aspect of the kidney; where the renal artery and ureter come into or out of the kidney
   iii) **Renal capsule** – the outer layer of tissue surrounding the kidney; functions as a protective membrane to encapsulate the kidney
   iv) **Renal cortex** – the outer zone of the kidney
   v) **Renal medulla** – the inner zone of the kidney, contains the renal pyramids

(1) **Renal pyramids** – triangular areas in the kidney that contain the nephrons; the apex on each renal pyramid contains many little openings (papillae) where the urine can drain out of the nephron.

vi) **Calyces (major and minor)** – inlets on the renal pelvis that collect the urine from the renal pyramids

vii) **Renal pelvis** – an expansion of the ureter inside the kidney; collects the urine from the calyces and direct it down the ureter

viii) **Nephron** – the functional unit of the kidney; approximately 1 million per kidney

ix) **Glomerulus** – a network of capillaries where filtration of the blood takes place

(a) The afferent arteriole (blood vessel that brings blood into the glomerulus) is larger in diameter than the efferent arteriole (blood vessel that takes blood out of the glomerulus). This difference in size creates a mechanical pressure in the glomerulus that forces fluid and small particles through the pores of the glomerulus (these pores are called fenestrae – [L] = windows) and into the glomerular capsule. Because blood cells are too large, they do not pass through the fenestrae; therefore; blood cells are not normally found in the urine.

x) **Glomerular (Bowman's) capsule** – surrounds and encapsulates the glomerulus; receives the filtrate forced out of the glomerulus that will eventually become urine.

(1) **Proximal convoluted tubule** – the first segment of the nephron tubule; reabsorbs about 65% of the water, reabsorbs many nutrients (i.e., glucose, amino acids, proteins, citric acid, ascorbic acid, calcium, potassium, sodium, phosphates, and sulfates) and secretes substances such as histamines and some drugs into the urine.

(2) **Nephron loop (Loop of Henle)** – includes the descending and ascending limbs

(a) **Descending limb** – permeable to water only; absorbs about 15% of the reabsorbed water from the filtrate

(b) **Ascending limb** – permeable to salts (i.e. sodium and chloride) only; absorbs sodium and chloride from the filtrate.

(3) **Distal convolute tubule** – the last segment of the nephron before the collecting duct; reabsorbs sodium, potassium, and about 10% of the water when activated by antidiuretic hormone.

(a) Remember that antidiuretic hormone is put out by the posterior pituitary gland in response to the body's need for water. It goes to the distal convoluted tubule and the collecting duct and stimulates them to reabsorb more water.

(4) **Collecting duct** – the tubule that takes the filtrate from the distal convoluted tubule out through the papillae and into the minor calyces where it becomes urine, reabsorbs about 10% of the water when activated by antidiuretic hormone.

xi) **Ureters** – long tubes that conduct urine from each kidney to the urinary bladder.

xii) **Urinary bladder** – a holding pouch for urine located at the bottom of the pelvic cavity behind the **symphysis pubis**; lined with transition epithelial tissue to allow for distension (stretching); has an average capacity of 7—to 800 ml. (3.0 to 3.5 cups of liquid); contains a layer of smooth muscle to help expel urine during **micturition** (urination, voiding.)

(1) With a shorter urethra than that of men, females are more likely to develop urinary tract infections. It is much easier for the bacteria to move up the shorter female urethra to infect the bladder. This results in the appearance of bacteria in the urine, which is normally sterile.

xiii) **Urethra** – a tube that transports urine out of the bladder; varies in length for males and females (male urethra = 20 cm or 8 inches; female urethra 4 cm or 1.5 inches); also used in the male reproductive system to transport semen.

(1) Because the urethra passes through the prostate gland in the male, Prostatitis (inflammation of the prostate gland) can block the urethra and cause urinary retention 9the inability to void urine.) Prostate

cancer can lead to a prostatectomy (removal of the prostate gland); which can disrupt the function of the internal and external urethral sphincters, resulting in incontinence (inability to control the flow of urine, micturition, voiding, urination.)

(2) **Internal urethral sphincter** – involuntary smooth muscle; located around the neck of the bladder where the urethra emerges

(3) **External urethral sphincter** – voluntary skeletal muscle; located below the internal urethral sphincter

URINE

a) **Normal constituents of urine**
   i) **Water** – makes up nearly 95% of urine
   ii) **Nitrogenous wastes** – include urea, uric acid, creatine
   iii) **Electrolytes** – include sodium, chloride, calcium, magnesium, potassium, sulfates, bicarbonate
   iv) **Yellow pigment – bilirubin**; produced when red blood cells break down; comes from the blood; converted into a yellow pigment called urobilinogen, which dissolves into the urine and gives it is characteristic color.
      (1) Less than 1% of the volume of water that enters the nephron actually passes into the urine. This makes the urine about 65% more concentrated than the filtrate as it comes out of the glomerulus.

b) **Abnormal constituents of urine**
   i) Glucose
   ii) Red blood cells
   iii) Albumin
   iv) White blood cells
   v) Ketones

The Urinary System -- SYNOPSIS

This chapter discusses the urinary system, which is primarily concerned with the removal of nitrogenous waste products from the body. The kidneys function in several capacities: as an excretory organ, maintaining electrolyte continuity, stabilizing the acid-base balance, and maintaining an adequate fluid balance. The urinary system consists of two kidneys, two ureters, a bladder, and a urethra. As the kidneys filter toxins from the blood, these toxins are deposited out of the body in urine; at the same time the kidneys are retaining those substances that help maintain a state of homeostasis within the body. The formation of urine by the kidneys involves several steps: filtration, reabsorption, and secretion. The malfunction of the kidneys can alter one's state of wellness drastically, and if untreated can cause irreversible damage to the kidneys and even death.

LEARNING OBJECTIVES WITH RATIONALE

the student will be able to:

1. Identify the major organs of the urinary system and give the generalized function of each.

The major components of the urinary system include the following:

a. Kidneys—Their function is to form urine.
b. Ureters—They drain from the renal pelvis to the urinary bladder.
c. Urinary bladder—It stores urine and voids urine.

d. Urethra—It serves as a passageway through which urine leaves the bladder and goes to the exterior.

2. Name the parts of a nephron and describe the role each component plays in the formation of urine.

The parts of a nephron include the following:

a. **Bowman's capsule**—the cup-shaped top of a nephron. Bowman's capsule surrounds the glomerulus, it receives water and dissolved substances from blood.

b. **Glomerulus**—a network of blood capillaries located inside of Bowman's capsule. It passes water and dissolved substances into Bowman's capsule.

c. **Proximal convoluted tubule**—the first segment of the renal tubule. Resorption begins here.

d. **Loop of Henle**—an extension of the proximal tubule. It consists of a straight descending limb, a loop, and a straight ascending limb; resorption takes place here.

e. **Distal convoluted tubule**—the part of the tubule that is distal to the ascending limb; resorption and secretion take place here.

f. **Collecting tubule**—the last part of the renal tubule. It is a straight tube; resorption and secretion take place here.

3. Explain the importance of filtration, tubular reabsorption, and tubular secretion in urine formation.

Urine formation begins with the process of filtration. Blood flowing through the glomeruli exerts pressure, and this pressure is sufficiently high to push water and dissolved substances out of the glomeruli into Bowman's capsule. Tubular reabsorption is the movement of substances out of the renal tubules into the blood capillaries located around the tubules. Substances reabsorbed are water, glucose, and other nutrients, as well as sodium and other ions. Large amounts of water are also reabsorbed. This process of reabsorption prevents substances needed by the body from being lost in urine.

Secretion is reabsorption in reverse; it moves substances out of the blood into the urine. Substances secreted include hydrogen ions, potassium ions, ammonia, and certain drugs. Secretion plays a crucial role in maintaining the body's acid-base balance.

4. Discuss the mechanisms that control urine volume.

A hormone from the posterior pituitary gland called antidiuretic hormone tends to decrease the amount of urine excreted by making the distal and collecting tubules permeable to water. If no ADH is present, both distal and collecting tubules are practically impermeable to water, so little or no water is reabsorbed from them. As a result, more water is retained by the body.

The hormone aldosterone, secreted by the adrenal cortex, plays an important part in controlling the kidney tubules' reabsorption of salt. It stimulates the tubules to reabsorb sodium salts at a faster rate. It also increases the rate of tubular water reabsorption.

5. Explain how the kidneys act as vital organs in maintaining homeostasis.

The kidneys' major function is to filter the blood of waste products, passing them out of the body in urine. To maintain a balance, the kidneys perform the processes of filtration, reabsorption, and secretion, and in so doing, they adjust the output of the body to its intake.

LECTURE OUTLINE

I. KIDNEYS

A. Location—under back muscles, behind parietal peritoneum, just above waistline; right kidney usually a little lower than left

B. Internal structure

1. Cortex—outer layer of kidney substance
2. Medulla—inner portion of kidney
3. Pyramids—triangular divisions of medulla
4. Papilla—narrow, innermost end of pyramid
5. Pelvis—expansion of upper end of ureter; lies inside kidney
6. Calyces—divisions of renal pelvis

C. Microscopic structure—nephrons are microscopic units of kidneys; consist of (Figure 17-3):
1. Renal corpuscle—Bowman's capsule with its glomerulus
   a. Bowman's capsule—the cup-shaped top
   b. Glomerulus—network of blood capillaries surrounded by Bowman's capsule
2. Renal tubule
   a. Proximal convoluted tubule—first segment
   b. Loop of Henle—extension of proximal tubule; consists of descending limb, loop, and ascending limb
   c. Distal convoluted tubule—extension of ascending limb of loop of Henle
   d. Collecting tubule—straight extension of distal tubule

D. Functions
1. Excretes toxins and nitrogenous wastes
2. Regulates levels of many chemicals in blood
3. Maintains water balance
4. Helps regulate blood pressure via secretion of renin

II. FORMATION OF URINE

A. Occurs by a series of three processes that take place in successive parts of nephron
1. Filtration—goes on continually in renal corpuscles; glomerular blood pressure causes water and dissolved substances to filter out of glomeruli into Bowman's capsule; normal glomerular filtration rate 125 ml per minute
2. Reabsorption—movement of substances out of renal tubules into blood in peritubular capillaries; water, nutrients, and ions are reabsorbed; water is reabsorbed by osmosis from proximal tubules
3. Secretion—movement of substances into urine in the distal and collecting tubules from blood in peritubular capillaries; hydrogen ions, potassium ions, and certain drugs are secreted by active transport; ammonia is secreted by diffusion

B. Control of urine volume—mainly by posterior pituitary hormone ADH, which decreases it

III. URETERS

A. Structure—narrow long tubes with expanded upper end (renal pelvis) located inside kidney and lined with mucous membrane

B. Function—drain urine from renal pelvis to urinary bladder

IV. URINARY BLADDER

A. Structure (Figure 17-8)
1. Elastic muscular organ, capable of great expansion
2. Lined with mucous membrane arranged in rugae, like stomach mucosa

B. Functions
1. Storage of urine before voiding
2. Voiding

V. URETHRA

A. Structure
1. Narrow tube from urinary bladder to exterior
2. Lined with mucous membrane
3. Opening of urethra to the exterior called urinary meatus

B. Functions
1. Passage of urine from bladder to exterior of the body
2. Passage of male reproductive fluid (semen) from the body

VI. MICTURITION

A. Passage of urine from body (also called urination or voiding)

B. Regulatory sphincters
1. Internal urethral sphincter (involuntary)
2. External urethral sphincter (voluntary)

C. Bladder wall permits storage of urine with little increase in pressure

D. Emptying reflex
1. Initiated by stretch reflex in bladder wall
2. Bladder wall contracts
3. Internal sphincter relaxes
4. External sphincter relaxes, and urination occurs

E. Urinary retention—urine produced but not voided

F. Urinary suppression—no urine produced but bladder is normal

G. Incontinence—urine is voided involuntarily
1. May be caused by spinal injury or stroke
2. Retention of urine may cause cystitis

H. Cystitis—bladder infection

I. Overactive bladder—need for frequent urination
1. Called interstitial cystitis
2. Amounts voided are small
3. Extreme urgency and pain are common

ANSWERS TO QUESTIONS

Review Questions

1. Describe the location of the kidneys.

Answer: There are two kidneys located under the muscles of the back, behind the parietal peritoneum. A cushion of fat normally encases each kidney, which helps maintain their position.

2. Name and describe the internal structures of the kidneys.

Answer: The internal structures of the kidney are composed of the following: (a) cortex—the outer layer of each kidney; (b) medulla—the inner portion of the kidney; (c) pyramids—the triangular divisions of the medulla of the kidney; (d) papilla—the narrow innermost end of a pyramid; (e) pelvis—an expansion of the upper end of a ureter, which lies inside the kidney; and (f) calyx—a division of the renal pelvis.

3. Define filtration, reabsorption, and secretion as they apply to the kidney function.

Answer: Filtration is an ongoing process in the renal corpuscles. Glomerular blood pressure causes water and dissolved substances to filter out of the glomeruli into the Bowman's capsule, at a filtration rate of 125 ml per minute. Reabsorption is the movement of substances out of the renal tubules into blood in the peritubular capillaries, where water, nutrients, and ions are reabsorbed. Water is reabsorbed by osmosis from the proximal tubules. Secretion is a process by which substances move into urine in the distal and collecting tubules, from blood in the capillaries around these tubules.

Secretion moves substances out of the blood into the urine.

4. Briefly explain the formation of urine.

Answer: The following processes occur in the nephron, which result in the formation of urine.
Water, solutes, sodium, glucose, ions, and other nutrients are filtered out of the glomeruli into the Bowman's capsule. The proximal tubule reabsorbs water and solutes. Approximately 178 liters per day of water are reabsorbed by osmosis. It is estimated that nearly 99% of the water that leaves the blood each day by glomerular filtration returns to the blood by proximal reabsorption. Reabsorption continues in the loop of Henle, distal convoluted tubules, and collecting tubules. Reabsorption moves substances out of urine into the blood, and secretion moves substances out of blood into urine. Substances secreted are hydrogen ions, potassium, ammonia, and certain drugs. The result of this process is the formation of urine.

5. Name several substances eliminated or regulated by the kidney.

Answer: Water, sodium, glucose, hydrogen ions, potassium, ammonia, hormones, and certain drugs are some of the substances regulated by the kidney.

6. Explain the function of the juxtaglomerular apparatus.

Answer: The juxtaglomerular apparatus functions by controlling and regulating blood pressure.
When blood pressure is low, these cells secrete a hormone that constricts blood vessels, which then elevates blood pressure.

7. Describe the structure of the ureters.

Answer: The ureters are long narrow tubes that carry urine from each kidney to the bladder. They originate in the pelvis of the kidney and terminate in the bladder. Mucous membranes line both ureters with a muscular coat that produces peristaltic movements that aid in the transport of urine into the bladder.

8. Describe the structure of the bladder. What is the trigone?

Answer: The structure of the bladder is an elastic muscular organ capable of great expansion. It is lined with a mucous membrane, is very wrinkled, and lies in folds called rugae. The triangular area on the back or posterior surface of the bladder, called trigone, is free of rugae and is always smooth.
The trigone extends between the openings of the two ureters.

9. Describe the structure of the urethra.

Answer: The urethra is a narrow tube about 1/2-inch long in a woman and about 8 inches long in a man. The urethra is lined with mucous membrane. It extends from the urinary bladder to the urinary meatus.

10. Briefly describe the process of micturition.

Answer: Micturition is the passing of urine from the body, or the emptying of the bladder. As the bladder wall stretches, nerve impulses are transmitted to the second, third, and fourth sacral segments of the spinal cord, and the emptying reflex is initiated. The bladder and the internal sphincter relax and urine enters the urethra. If the external sphincter, which is normally under voluntary control, is relaxed, micturition occurs.

11. Differentiate between retention and suppression of urine.

Answer: Urinary retention is a condition in which urine is not voided. The bladder is unable to empty even though the kidneys have produced urine. Suppression is a condition in which the kidneys do not produce urine.

12. What is incontinence? What can cause incontinence?

Answer: Incontinence is a condition in which a person involuntarily voids urine. This condition may be caused by a stroke, a spinal cord injury, damage or destruction of spinal innervation, and other conditions.

Critical Thinking Questions

13. Explain the salt and water balance maintained by aldosterone and ADH.

Answer: Aldosterone is a hormone secreted by the adrenal cortex. It plays an important role in reabsorption of salt by the kidney tubules. Aldosterone also increases tubular water reabsorption; it is described as the water-retaining hormone. ADH is present in blood and is called the antidiuretic hormone. It decreases the amount of urine by making the collecting tubules permeable to water.

14. Why is proper blood pressure necessary for proper kidney function?

Answer: Glomerular blood pressure causes filtration through the glomerular capsular membrane. If the glomerular blood pressure drops below a certain level, filtration and urine formation stop. In addition, the kidneys produce an enzyme called renin that helps regulate blood pressure.

15. If a person were doing strenuous work on a hot day and perspiring heavily, would there be a great deal of ADH in the blood or very little? Explain your answer.

Answer: The loss of fluid from the internal environment of the body by sweating would trigger the hypothalamus to rapidly release ADH from the posterior pituitary gland. ADH would then increase water reabsorption by the kidney by increasing the water permeability of the distal tubules and collecting ducts.

CLASSROOM APPLICATION

The following questions can be used as individual assignments or for small-group discussion. Note: to copy the questions, cover the answers with a blank sheet of paper and print, thus leaving space for answers or note-taking.

1. The kidneys function as important homeostatic mechanisms for many conditions in the body. Predict what changes in urine production would occur in a patient who suffered a surgical injury to the hypothalamus.

Answer: Damage to the hypothalamus may cause diabetes insipidus, in which large amounts of urine (sometimes 5–10 L per day) are produced. Remember that the hypothalamus actually produces the posterior pituitary hormones, which are then secreted from the ends of the axons in the posterior pituitary. Damage to the hypothalamus neurons that produce ADH could result in this disorder. If little or no ADH is produced, much less water is reabsorbed in the collecting duct of the nephron, and large amounts of dilute urine are excreted.

2. Predict the changes that would occur in urine production if a patient developed an adrenal cortex tumor, resulting in excessive adrenal cortex secretions.

Answer: Secretion of large amounts of aldosterone might be one consequence of an adrenal cortex tumor. Aldosterone increases the reabsorption of salt and water. Therefore, the patient would produce a smaller-than-normal amount of urine, and the urine would have a decreased salt content.

3. Predict the changes that would occur in the urine of a runner who had just completed a marathon.

Answer: After a marathon, it would be logical to predict that proteinuria would occur. In addition, it would not be surprising if the runner were dehydrated, and the amount of urine produced was less than normal.

4. Predict the changes that would occur in urine production of a person who just ate a jumbo bag of popcorn with extra salt.

Answer: With greatly increased salt intake, the person would have decreased salt reabsorption, and therefore a larger amount of salt excreted in the urine. Their urine would be saltier than normal.

5. What effect on urine volume would occur if a drug decreased sodium transport in the proximal and distal convoluted tubules?

Answer: Urine volume would increase because less sodium would be removed from the filtrate, the osmotic concentration of the filtrate would be increased, and less water would move from the filtrate back into the blood. As a result, urine volume would increase (a diuretic effect).

PRACTICAL/CREATIVE LEARNING ACTIVITIES

1. Make a chart of all the normal and abnormal components of urine.
2. Assign student partners and have the pairs present to the class information concerning one of the following topics:
    - Information concerning the kidneys—their location, internal structure, microscopic structure, and function
    - What are the physical properties of urine?
    - Make a diagram showing the steps in urine formation.
    - Explain the term proteinuria. What influence does exercise have on proteinuria?

STUDENT ASSIGNMENT: THE URINARY SYSTEM

Select the most correct answer from column B for each item in column A. (Only one answer is correct.)

Column A	Column B
_____ 1. Retention	A. Involuntary voiding
_____ 2. Anuria	B. Movement of substance out of renal tubules into blood
_____ 3. Cystitis	C. Absence of urine
_____ 4. Micturition	D. Urination
_____ 5. Oliguria	E. Bladder does not empty
_____ 6. Polyuria	F. Inflammation of the urinary bladder
_____ 7. Incontinence	G. Large amount of protein in urine
_____ 8. Proteinuria	H. Large amount of urine
_____ 9. Suppression	I. Kidneys not producing urine
_____ 10. Reabsorption	J. Scanty amount of urine

Multiple Choice

11. Which of the following is true of urinary catheterization?

A. It can be used to treat retention.
B. It requires aseptic technique.
C. It can lead to cystitis.
D. All of the above are true.

12. Which of the following processes are used by the artificial kidney to remove waste materials from blood?

A. Pinocytosis
B. Dialysis
C. Catheterization
D. Active transport

13. Failure of the kidneys to remove waste from the blood will result in which of the following?

A. Retention
B. Anuria
C. Incontinence
D. Uremia

14. Hydrogen ions are transferred from blood back into nephron during which of the following processes?

A. Secretion
B. Filtration
C. Reabsorption
D. All of the above

15. Which of the following conditions would be considered abnormal in a child under 5 years of age?

A. Urine retention
B. Cystitis
C. Incontinence
D. All of the above

16. Which of the following steps involved in urine formation allows the blood to retain most body nutrients?

A. Secretion
B. Filtration
C. Reabsorption
D. All of the above

17. Voluntary control of micturition is achieved by the action of which of the following?

A. Internal urethral sphincter
B. External urethral sphincter
C. Trigone
D. Bladder muscles

18. What is the structure that carries urine from the kidney to the bladder called?

A. Urethra
B. Bowman’s capsule

C. Ureter
D. Renal pelvis

19. What are the capillary loops contained within Bowman's capsule called?
A. Convoluted tubules
B. Glomeruli
C. Limbs of Henle
D. Conducting ducts

Complete the following statements using the terms listed below.

A. Polyuria	G. Glomerulus
B. ANH	H. Pyramids
C. Urinary meatus	I. Distal convoluted tubule
D. Antidiuretic hormone	J. Reabsorption
E. Kidney stones	K. Aldosterone
F. Uremia	L. Cystitis

20. The medulla of the kidney can be subdivided into triangular areas called _____.
21. The hormone _____ is a salt- and water-losing hormone.
22. The network of blood capillaries located inside of the Bowman's capsule is called _____.
23. The last twisted segment of the renal tubule is called _____.
24. The movement of substances out of the renal tubules into the blood capillaries during the process of urine formation is called _____.
25. The water-retaining hormone is _____.
26. The lithotripter is used to treat _____.
27. Urine passes from the bladder through the urethra to the exterior through an external opening called the _____.
28. Bladder infection is referred to as _____.
29. If the kidney excretes an abnormally large amount of urine, the condition is referred to as _____.

Multiple Choice

Albert is suffering from low levels of ADH.

30. What symptoms will be most obvious?
A. Urinary output will be decreased.
B. The amount of urine will increase drastically.
C. Urine will be dilute with large amounts of sugar present.
D. Micturition will be painful and excessive.

31. Albert asks you where ADH comes from. What do you tell him?
A. It is a substance found in most foods.
B. It is produced in the kidney.
C. It is secreted by the posterior pituitary gland.
D. It is secreted by the anterior pituitary gland.

Vicki is a 17-year-old high school senior. She is currently studying the urinary system and asks you to

explain the function of aldosterone. What do you tell her?

32. Aldosterone is a hormone secreted by the _____.
    - A. Adrenal cortex
    - B. Glomerulus
    - C. Papilla
    - D. Bowman's capsule

33. Aldosterone plays an important part in controlling the reabsorption of salt by the _____.
    - A. Calyx
    - B. Tubules
    - C. Ureters
    - D. Glomerulus

34. Aldosterone _____ water reabsorption.
    - A. Increases
    - B. Decreases

ANSWERS TO CHAPTER 17 STUDENT ASSIGNMENT
Matching
1. E
2. C
3. F
4. D
5. J
6. H
7. A
8. G
9. I
10. B
Multiple Choice
11. D
12. B
13. D
14. A
15. D
16. C
17. B
18. C
19. B
Completion
20. H
21. B
22. G
23. I
24. J
25. D
26. E

27. C
28. L
29. A
Multiple Choice
30. B
31. C
32. A
33. C
34. A

Fluid and Electrolyte Balance SYNOPSIS

This chapter describes the fluid and electrolyte compartments of the body. Special attention is given to water as a major body fluid, describing ways in which water enters and leaves the body and the mechanisms that maintain fluid balance. The importance of electrolytes and an explanation of aldosterone are covered in this chapter, as well as the interaction between capillary blood pressure and blood proteins. Finally, examples of common fluid imbalances are listed.

LEARNING OBJECTIVES WITH RATIONALE

the student will be able to:

1. List, describe, and compare the body fluid compartments and their subdivisions.

Water, the body's most abundant compound, occupies three main locations known as fluid compartments. The largest volume of water lies inside cells and is called intracellular fluid (ICF). Water that lies outside of cells, extracellular fluid (ECF), is located in two compartments: in the microscopic spaces between cells, where it is called interstitial fluid (IF), and in the blood vessels, where it is called plasma.

2. Discuss avenues by which water enters and leaves the body and the mechanisms that maintain fluid balance.

Humans have three sources of fluid intake: the liquids they drink, the water in the foods they eat, and the water they form by the catabolism of foods. Fluid output from the body occurs by way of four organs: the kidneys, lungs, skin, and intestines. Fluid balance is maintained by several mechanisms, the three main ones being (1) concentration of electrolytes in extracellular fluid, (2) capillary blood pressure, and (3) concentration of proteins in blood.

3. Discuss the nature and importance of electrolytes in body fluid and explain the aldosterone mechanism of extracellular fluid volume control.

Compounds that have molecular bonds that permit them to break up in solution are known as electrolytes. The dissociated particles are called ions and they carry an electrical charge. To remember how extracellular fluid electrolyte concentration affects fluid volumes, remember one short sentence: where sodium goes, water soon follows. For example, if the concentration of sodium in blood increases, the volume of blood increases. Conversely, if blood sodium concentration decreases, blood volume soon decreases.

The aldosterone mechanism tends to restore normal ECF volume when it decreases below normal. When there is a decrease in ECF volume, there is a decrease in blood volume and a corresponding decrease in arterial blood pressure. This stimulates baroreceptors located in the hypothalamus to stimulate the adrenal cortex. The adrenal cortex increases its secretion of aldosterone. This causes increased kidney tubule reabsorption of Na^+ and, in turn, increases kidney tubule reabsorption of water (i.e., urine volume decreases). Therefore, as a result of this process, ECF volume increases. In time, some factor (e.g., nothing by mouth for 24 hours) will cause ECF volume to decrease and the cycle will begin again.

4. Explain the interaction between capillary blood pressure and blood proteins.

Water will move in both directions through the membranous walls of capillaries. How much water moves out of capillary blood into interstitial fluid depends largely on capillary blood pressure, a water-pushing force. How much water moves into blood from interstitial fluid depends largely on the concentration of proteins present in blood plasma. Plasma proteins act as a water-pulling or water-holding force. They tend to hold water in the blood and to pull it into the blood from interstitial fluid. If, for example, the concentration of proteins in the blood decreases, less water moves into blood from interstitial fluid. As a result, blood volume decreases and interstitial fluid volume increases.

5. Give examples of common fluid imbalances.

Fluid imbalances are common ailments. Dehydration is the imbalance seen most often. Here, interstitial fluid volume decreases first, but eventually, if treatment has not been given, intracellular fluid and plasma volumes also decrease below normal levels. Either too small a fluid intake or too large a fluid output causes dehydration.

When total volume of body fluids is larger than normal, overhydration results. If volume expands first and treatment is not given, ICF volume increases, and finally, plasma volume increases above normal. This excess fluid volume will put too heavy a burden on the heart. It will also deprive the body of essential electrolytes.

LECTURE OUTLINE

I. BODY FLUIDS

A. Water most abundant body compound
- 1. References to “average” body water volume based on healthy, nonobese, 70 kg male
- 2. Water is 60% of body weight in males; 50% in females (Table 18-1)
- 3. Volume averages 40 liters in 70 kg male (Figure 18-1)

B. Variation in total body water related to:
- 1. Total body weight of individual
- 2. Fat content of body—the more fat the less water (adipose tissue is low in water content)
- 3. Sex—female body about 10% less than male body (Figure 18-2)
- 4. Age—in newborn infant water may account for 80% of total body weight. In elderly, water per pound of weight decreases (muscle tissue [high in water] replaced by fat which is lower in water)

II. BODY FLUID COMPARTMENTS

A. Two major fluid compartments (Table 18-1)
- 1. Extracellular fluid (ECF)
  - a. Types
    - (1) Plasma
    - (2) Interstitial fluid (IF)
    - (3) Miscellaneous—lymph; joint fluids; cerebrospinal fluid; eye humors
  - b. Called internal environment of body
  - c. Surrounds cells and transports substances to and from them
- 2. Intracellular fluid (ICF)

a. Largest fluid compartment
b. Located inside cells
c. Serves as solvent to facilitate intracellular chemical reactions

III. MECHANISMS THAT MAINTAIN FLUID BALANCE

A. Fluid output, mainly urine volume, adjusts to fluid intake; ADH from posterior pituitary gland acts to increase kidney tubule reabsorption of sodium and water from tubular urine into blood, thereby tending to increase ECF (and total body fluid) by decreasing urine volume (Figure 18-5)

B. ECF electrolyte concentration (mainly Na^+ concentration) influences ECF volume; an increase in ECF Na^+ tends to increase ECF volume by increasing movement of water out of ICF and increasing ADH secretion, which decreases urine volume, and this increases ECF volume

C. Capillary blood pressure pushes water out of blood into IF; blood protein concentration pulls water into blood from IF; hence these two forces regulate plasma and IF volume under usual conditions

D. Importance of electrolytes in body fluids

1. Nonelectrolytes—organic substances that do not break up or dissociate when placed in water solution (for example, glucose)
2. Electrolytes—compounds that break up or dissociate in water solution into separate particles called ions (e.g., ordinary table salt or sodium chloride)
3. Ions—the dissociated particles of an electrolyte that carry an electrical charge (for example, ordinary table salt or sodium chloride)
4. Positively charged ions (for example, potassium [K^+] and sodium [Na^+])
5. Negatively charged particles (ions) (for example, chloride [Cl^-] and bicarbonate [HCO_3^-])
6. Electrolyte composition of blood plasma—Table 18-3
7. Sodium—most abundant and important positively charged ion of plasma
   a. Normal plasma level—142 mEq/L
   b. Average daily intake (diet)—100 mEq
   c. Chief method of regulation—kidney
   d. Aldosterone increases Na^+ reabsorption in kidney tubules (Figure 18-5)
   e. Sodium-containing internal secretions—Figure 18-6

E. Capillary blood pressure and blood proteins

IV. FLUID IMBALANCES

A. Dehydration—total volume of body fluids smaller than normal; IF volume shrinks first, and then if treatment is not given, ICF volume and plasma volume decrease; dehydration occurs when fluid output exceeds intake for an extended period

B. Overhydration—total volume of body fluids larger than normal; overhydration occurs when fluid intake exceeds output; various factors may cause this (for example, giving excessive amounts of intravenous fluids or giving them too rapidly may increase intake above output)

ANSWERS TO QUESTIONS
Review Questions

1. Name and give the location of the three main fluid compartments of the body. Which of these make up extracellular fluid?

Answer: The three fluid compartments of the body are
(1) intracellular fluid (ICF)—water inside the cells;
(2) extracellular fluid (ECF)—water outside the cells; and

(3) interstitial fluid (IF)—water between cells. Extracellular fluid is located in two compartments, the interstitial fluid and plasma.

2. What factors influence the percent of water in the body? Explain the effect of each factor.

Answer: The following factors influence the **percent of water** in the body:

(1) Total body weight—the more a person weighs, the more water the body contains.

(2) Fat content of the body—the more fat, the less water.

(3) Sex—the proportion of body weight represented by water is about 10% less in women that in men.

(4) Age—in newborns water may account for 80% of total body weight.

3. List the three sources of water for the body.

Answer: The three **sources** of water in the human body are liquids we drink, water in foods we eat, and water formed by the body's catabolism of foods.

4. List the four organs from which fluid output occurs.

Answer: Fluid output occurs through the kidneys, lungs, skin, and intestines.

5. Differentiate between an electrolyte and a nonelectrolyte.

Answer: Electrolytes are compounds that break up or dissociate in a water solution into separate particles called ions. **Nonelectrolytes** are organic substances that do not break up or dissociate when placed in a water solution.

6. Name three important negative ions.

Answer: Negative ions—chloride (Cl^-), bicarbonate (HCO_3^-), and phosphate (HPO_4).

7. Name three important positive ions.

Answer: Positive ions—Sodium (Na^+), calcium (Ca^{++}), and potassium (K^+).

8. Explain why the body is unable to reduce its fluid output to zero no matter how dehydrated it is.

Answer: Even as the body makes every effort to compensate for a zero intake, some **output of fluid** occurs as long as life continues. Water is continually lost through expired air and diffusion through the skin.

9. Explain how aldosterone influences water movement between the kidney tubules and the blood.

Answer: The adrenal cortex secretes **aldosterone**, which increases kidney tubule reabsorption of sodium. Sodium then moves out of blood and into ECF. This increases sodium content in the body. The kidneys then increase tubule reabsorption of water, "where sodium goes, water soon follows." This then decreases urine volume, which increases water volume in ECF; that is, excess blood volume and excess interstitial volume.

10. Explain the role of capillary blood pressure in water movement between the plasma and interstitial fluid.

Answer: Capillary blood pressure pushes fluid out of the blood in capillaries into IF. The more pressure, the more fluid is pushed and filtered out of blood and then transferred to IF. If, however, the capillary blood pressure decreases, less fluid filters out of blood into IF.

11. Explain the role of plasma proteins in water movement between the plasma and interstitial fluid.

Answer: The amount of water that moves into blood from IF depends on the concentration of **proteins** in blood plasma. Plasma proteins hold water in the blood and pull it into the blood from IF.

12. Define dehydration and give a possible cause.

Answer: Dehydration is a total volume of body fluids less than normal. It occurs when fluid output exceeds intake for an extended period of time. Possible causes of dehydration are too large a fluid output, too small a fluid input, prolonged diarrhea, and vomiting.

13. Define overhydration and give a possible cause.

Answer: Overhydration is a total volume of body fluids greater than normal. It can occur when fluids, especially intravenous fluids, are given too rapidly or in too large a quantity.

Critical Thinking Questions

14. Name the three hormones that regulate the urine volume. State where each is made and the specific effect on urine volume.

Answer: The three **hormones** that regulate urine volume are
(1) **ADH**, **antidiuretic hormone** from the posterior pituitary gland—decreases the amount of urine (called the water-retaining hormone or the urine-decreasing hormone), thus ADH reduces water loss by the body;
(2) **aldosterone**, secreted by the adrenal cortex—stimulates the tubules to reabsorb sodium and increases tubular water reabsorption;
(3) **ANH**, **atrial natriuretic hormone**, secreted from the atrial wall of the heart—stimulates the kidney tubules to secrete sodium and lose water (called the salt- and water-losing hormone).

15. Atrial natriuretic hormone has the opposite effect of aldosterone. Explain its effect on water movement between the kidney tubules and the blood.

Answer: The **atrial natriuretic hormone** (ANH) has the opposite effect of aldosterone. ANH promotes the secretion of sodium into the kidney tubules rather than sodium reabsorption. Thus ANH reduces the plasma and interstitial fluid sodium concentration, which in turn reduces the reabsorption of water by having the opposite effect of aldosterone. ANH inhibits the ADH mechanism, which in turn inhibits water conservation and increases urine volume.

CLASSROOM APPLICATION

The following questions can be used as individual assignments or for small-group discussion. Note: to copy the questions, cover the answers with a blank sheet of paper and print, thus leaving space for answers or note-taking.

1. Changes in electrolytes or amount of fluid in the ICF or ECF affect every system in the body. Sometimes chemicals or infectious organisms can result in extreme irritation of the cells lining the large intestine. In response to this irritation, these cells may secrete sodium into the large intestine. Suggest the changes that would occur in the IF if sodium were excreted from the intestinal lining into the large intestine.

Answer: Remember the statement "where sodium goes, water soon follows." If large amounts of sodium were present in the large intestine, water from the ICF of the intestinal cells would follow the sodium into the large intestine, producing diarrhea. If the ICF of intestinal cells had decreased sodium and water, then sodium would diffuse from the IF into the ICF of the intestinal cells, and water would soon follow. Thus the IF would have decreased amounts of sodium and water.

2. How would decreased sodium and water in the IF affect blood plasma? How would this change affect arterial blood pressure?

Answer: A decrease in sodium and water in the IF would result in sodium diffusion from the blood into the IF; water would soon follow. This movement of sodium and water would decrease the volume of plasma, and result in decreased arterial blood pressure.

3. How would decreased arterial blood pressure affect aldosterone secretion? What would be the results of this change in aldosterone secretion?

Answer: Decreased arterial blood pressure results in increased aldosterone secretion. An increase in aldosterone secretion increases the amount of sodium reabsorbed into the blood from the kidney tubules; once again, water soon follows. As a result, blood sodium levels are restored, and blood volume is restored.

4. What hormone besides aldosterone would be involved in maintaining water homeostasis?

Answer: ADH is secreted in response to decreased plasma volume; ADH increases the amount of water reabsorbed in the collecting ducts of kidney tubules, helping to restore plasma volume.

5. How does the action of aldosterone and ADH affect urine volume and content?

Answer: Urine volume would decrease as a consequence of the action of aldosterone and ADH, the sodium content of the urine would decrease, and the potassium content of the urine would increase, because aldosterone also causes increased secretion of potassium into the kidney tubules.

6. How is the ICF in the cells lining the large intestine restored to its original state after it is lost due to diarrhea?

Answer: Increased sodium in the blood diffuses into the IF, and from the IF, sodium diffuses into the ICF of the cells lining the large intestine; water soon follows. This movement of sodium and water restores the cell contents to their original level.

PRACTICAL/CREATIVE LEARNING ACTIVITIES

1. Have the students write a paper explaining how too large a fluid volume output and too small a fluid volume intake can be the causes of the same condition. Identify the term and explain what is taking place.
2. Explain how a protein-deficient diet can influence capillary blood pressure.
3. Discuss how the environment might influence the amount of fluid needed.
4. Have students determine the effect that salt tablets versus diuretics would have on urine output.
5. Design a poster showing the source of fluid intake and output. Include a chart showing the average amount of fluid an adult takes in and the amount expelled from the body in a 24-hour period.
6. Have students write a report on the cause and effect of edema, listing the diseases and conditions that often result in edema. Form small discussion groups and have the “group” select a spokesperson to report to class their conclusions.

STUDENT ASSIGNMENT: FLUID AND ELECTROLYTE BALANCE
Multiple Choice

1. Avenues of fluid output include which of the following?
    A. Skin
    B. Lungs
    C. Kidneys
    D. All of the above

2. Excessive water loss and fluid imbalance can result from which of the following?
    A. Diarrhea
    B. Vomiting
    C. Severe burns
    D. All of the above

3. What factor is primarily responsible for moving water from interstitial fluid into blood?
    A. Aldosterone
    B. Pressure in blood capillaries
    C. Protein concentration of blood plasma

D. Antidiuretic hormone secretion

4. What is the chief regulator of sodium level in body fluids?
   A. Kidney
   B. Intestine
   C. Blood
   D. Lung

5. If blood sodium concentration decreases, what does blood volume do?
   A. Increases
   B. Decreases
   C. Remains the same
   D. None of the above

6. Which of the following is true of body water?
   A. It is obtained from the liquids we drink.
   B. It is obtained from the foods we eat.
   C. It is formed by the catabolism of food.
   D. All of the above are true.

7. Edema may result from which of the following?
   A. Retention of electrolytes
   B. Decreased blood pressure
   C. Increased concentration of blood plasma proteins
   D. All of the above

8. The most abundant and most important ion is which of the following?
   A. Sodium
   B. Chloride
   C. Calcium
   D. Oxygen

9. Which of the following is true when extracellular fluid volume decreases?
   A. Aldosterone secretion increases.
   B. Kidney tubule reabsorption of sodium increases.
   C. Urine volume decreases.
   D. All of the above are true.

10. Which of the following statements, if any, is false?
   A. The more fat present in the body, the more total water content per unit of weight.
   B. Infants have more water in comparison with body weight than adults.
   C. As age increases, the amount of water per pound of body weight decreases.
   D. All of the above statements are true.

Complete the following statements using the terms listed below.

A. Aldosterone	H. Antidiuretic hormone
B. Edema	I. Dehydration
C. Proteins	J. Extracellular fluid

D. Decreases	K. Plasma
E. Diuretic	L. Urine
F. Electrolytes	M. Interstitial fluid
G. Positive	N. Negative

11. Any drug that promotes or stimulates the production of urine is called a _____.
12. The presence of abnormally large amounts of fluid in the intercellular tissues spaces of the body is called _____.
13. Water located outside of cells is called _____. It can be divided into two categories. If located in the spaces between the cells, it is called _____; if located in blood vessels, it is called _____.
14. Compounds like sodium chloride that form ions when placed in solution are called _____.
15. When the adrenal cortex increases its secretion of aldosterone, urine volume _____.
16. Most fluids leave the body in the form of _____.
17. When fluid output is greater than fluid intake, _____ occurs.
18. How much water moves into blood from interstitial fluid depends largely on the concentration of _____ present in blood plasma. These substances act as a water-pulling or water-holding force.
19. Urine volume is regulated primarily by a hormone called _____ secreted by the posterior lobe of the pituitary gland and by a hormone called _____ secreted by the adrenal gland.

Multiple Choice

Mrs. Tanton, 64 years old, has been put on a low-salt diet by her doctor. She complains about the swelling in her feet and hands and sees no connection between the swelling and the low-salt diet the doctor has prescribed.

20. What do you tell her?
   - A. Where sodium goes, so does water.
   - B. There is no significant connection between swelling and sodium.
   - C. The swelling is only temporary and should subside in a couple of days.
   - D. Sodium does not contribute to the edema in her extremities, but because of her age, the doctor felt it best to limit her intake of salt (especially salty meats, which are difficult to digest)

21. The doctor prescribed a diuretic for Mrs. Tanton. She asks you the purpose and function of diuretics. What do you tell her?
   - A. They influence water and electrolyte balance in the body.
   - B. They are among the most commonly used drugs in medicine.
   - C. They promote, or stimulate, the production of urine.
   - D. All of the above explain the function of diuretics.

Reviewing your knowledge concerning fluid balance of the body, answer the following questions:

22. Overall fluid balance requires that fluid output equal fluid intake.
   - A. True
   - B. False

23. The type of fluid output that changes most is which of the following?
   - A. Urine volume

B. Intestines (feces)

24. Renal tubule regulation of salt and water is the most important factor in determining which of the following?
A. Plasma volume
B. Urine volume

25. Aldosterone controls sodium reabsorption in which of the following?
A. Intestines
B. Kidneys

26. The presence of sodium forces water to move (where sodium goes, water soon follows).
A. True
B. False

Definitions

Define the following terms.

27. Intracellular fluid (ICF)____

28. Extracellular fluid (ECF)____

29. Interstitial fluid____

30. Plasma____

31. Draw a chart or diagram in the box below that explains intracellular fluid.

32. Draw a chart or diagram in the box below that explains extracellular fluid.

ANSWERS TO CHAPTER 18 STUDENT ASSIGNMENT
Multiple Choice
1. D
2. D
3. C
4. A
5. B
6. D
7. A
8. A
9. D
10. A
Completion
11. E
12. B

13. J, M, K
14. F
15. D
16. L
17. I
18. C
19. H, A

Multiple Choice

20. A
21. D
22. A
23. A
24. B
25. B
26. A

Definitions

27. Intracellular fluid (ICF)—fluid inside cells
28. Extracellular fluid (ECF)—fluid outside cells
29. Interstitial fluid (IF)—fluid between cells
30. Plasma—the liquid part of blood

31–32. Note: The drawings, charts, or diagrams will be individualized to express the student's understanding and concept of intracellular and extracellular fluid

Acid-Base Balance SYNOPSIS

This chapter discusses the concept of pH, which has a direct relationship to the hydrogen-ion concentration of fluid. A contrast is made concerning the respiratory and urinary mechanisms of control as they relate to the homeostasis of the body. The three primary influences controlling pH of fluid are the buffer, respiratory, and urinary systems. Acidosis and alkalosis are presented as examples of acid-base imbalances.

These imbalances are further identified as metabolic or respiratory. The compensatory mechanisms that help return blood pH to normal levels involve the ratio between carbonic acid and sodium bicarbonate present in the blood.

LEARNING OBJECTIVES WITH RATIONALE

the student will be able to:

1. Discuss the concept of pH and define the phrase acid-base balance.

Water and all water solutions contain both hydrogen ions (H+) and hydroxyl ions (OH–). The term pH followed by a number indicates a fluid's hydrogen ion concentration. More specifically, pH 7.0 means an equal concentration of H+ and OH–. A pH higher than 7.0 indicates an alkaline solution; that is, one with a lower concentration of hydrogen ions than hydroxide ions. A pH lower than 7.0 indicates an acid solution; that is, one with a higher hydrogen ion concentration than hydroxide ion concentration. Maintaining acid-base balance means keeping the concentration of hydrogen ions in the body relatively constant.

2. Define the terms buffer and buffer pair and contrast strong and weak acids and bases.

Buffers are substances that prevent a sharp change in the pH of a fluid when an acid or base is added to it. Because buffers consist of two kinds of substances, they are often called buffer pairs. An example of a buffer system is the sodium bicarbonate/carbonic acid system. Addition of a strong acid, such as hydrochloric acid, to this buffer system causes sodium bicarbonate to combine with the hydrochloric acid. This reaction forms salt and carbonic acid, which is a weak acid. Hydrogen ion concentration of blood is lowered.

On the other hand, if a strong base, such as sodium hydroxide, is present, carbonic acid responds.

It combines with the strong base to form water and sodium bicarbonate, which is a weak base.

3. Contrast the respiratory and urinary mechanisms of pH control.

Respiration plays a vital part in controlling pH. With every expiration, carbon dioxide and water leave the body in the expired air. The carbon dioxide has diffused out of the venous blood as it moves through the lung capillaries. Less carbon dioxide therefore remains in the arterial blood leaving the lung capillaries, so less carbon dioxide is available for combining with water to form carbonic acid.

Hence, arterial blood contains less carbonic acid and fewer hydrogen ions and has a higher pH than does venous blood.

Any change in respiration can change blood pH. If you held your breath, no carbon dioxide would leave your body by way of expired air so the blood's carbon dioxide would increase. This would increase the amount of carbonic acid and the hydrogen-ion concentration of blood, which in turn would decrease blood pH.

Anything that causes an appreciable decrease in respiration will in time produce acidosis. Conversely, anything that causes an excessive increase in respirations will in time produce alkalosis.

The kidneys are also effective regulators of pH. Because more acids than bases usually enter blood, more acids than bases are usually excreted by the kidneys. Kidneys usually give urine an acid pH. The distal tubules of the kidneys rid the blood of excess acid and at the same time conserve the base present in it. Carbon dioxide leaves the blood and enters into cells that form the wall of a distal kidney tubule. In these cells, carbon dioxide combines with water to form carbonic acid. This occurs rapidly because the cells contain carbonic anhydrase, an enzyme that accelerates the reaction. As soon as carbonic acid forms, some of it dissociates to yield hydrogen ions and bicarbonate ions. Hydrogen ions diffuse out of the tubule cells into the urine. Here they replace sodium ions in a salt (Na_2HPO_4) to form another salt (NaH_2PO_4), which leaves the body in urine. The Na^+ displaced from Na_2HPO_4 by the hydrogen ion moves out of the tubular urine into a tubular cell. Here it combines with a bicarbonate (HCO_3^-) ion to form sodium bicarbonate, which is then reabsorbed into the blood. Urine, therefore, has been acidified and sodium bicarbonate has been conserved.

4. Discuss compensatory mechanisms that may help return blood pH to near-normal levels in cases of pH imbalances.

In acidosis the blood pH falls as hydrogen ion concentration increases. In alkalosis the blood pH is higher than normal. Disturbances in acid-base balance can be considered dependent upon the ratio of carbonic acid and sodium bicarbonate present in the blood. Components of this important "buffer pair" must be maintained at a proper ratio (20 times more sodium bicarbonate than carbonic acid) if acid-base balance is to remain normal. Blood levels of sodium bicarbonate are regulated by the kidneys and carbonic acid levels are regulated by the respiratory system.

5. Compare and contrast metabolic and respiratory types of pH imbalances.

Metabolic types of pH imbalance affect the bicarbonate element of the buffer pair, and respiratory disturbances affect the carbonic acid element as follows:

Metabolic disturbances:

Metabolic acidosis (bicarbonate deficit)

Metabolic alkalosis (bicarbonate excess)

Respiratory disturbances:

Respiratory acidosis (carbonic acid excess)

Respiratory alkalosis (carbonic acid deficit)

LECTURE OUTLINE

I. pH OF BODY FLUIDS

A. Definition of pH—a number that indicates the hydrogen ion (H^+) concentration of a fluid; pH 7.0 indicates neutrality, pH higher than 7.0 indicates alkalinity, and pH less than 7.0 indicates acidity

B. Normal arterial blood pH—about 7.45

C. Normal venous blood pH—about 7.35

II. MECHANISMS THAT CONTROL pH OF BODY FLUIDS

A. Buffers

1. Definition—substances that prevent a sharp change in the pH of a fluid when an acid or base is added to it (See Figures 19-2 and 19-3.)
2. "Fixed" acids are buffered mainly by sodium bicarbonate ($NaHCO_3$)
3. Changes in blood produced by buffering of "fixed" acids in the tissue capillaries
    - a. Amount of carbonic acid (H_2CO_3) in blood increases slightly
    - b. Amount of $NaHCO_3$ in blood decreases; ratio of amount of $NaHCO_3$ to the amount of H_2CO_3 does not normally change; normal ratio is 20:1
    - c. H^+ concentration of blood increases slightly
    - d. Blood pH decreases slightly below arterial level

B. Respiratory mechanism of pH control—respirations remove some CO_2 from blood as blood flows through lung capillaries; the amount of H_2CO_3 in blood is decreased and thereby its H^+ concentration is decreased, and this in turn increases blood pH from its venous to its arterial level

C. Urinary mechanism of pH control—the body's most effective regulator of blood pH; kidneys usually acidify urine by the distal tubules secreting hydrogen ions and ammonia (NH_3) into the urine from blood in exchange for $NaHCO_3$ being reabsorbed into the blood

III. pH IMBALANCES

A. Acidosis and alkalosis are the two kinds of pH or acid-base imbalances

B. Disturbances in acid-base balance depend on relative quantities of $NaHCO_3$ and H_2CO_3 in the blood

C. Body can regulate both of the components of the $NaHCO_3$/H_2CO_3 buffer system

1. Blood levels of $NaHCO_3$ regulated by kidneys
2. H_2CO_3 levels regulated by lungs

D. Two basic types of pH disturbances, metabolic and respiratory, can alter the normal 20:1 ratio of $NaHCO_3$ to H_2CO_3 in blood

1. Metabolic disturbances affect the $NaHCO_3$ levels in blood
2. Respiratory disturbances affect the H_2CO_3 levels in blood

E. Types of pH or acid-base imbalances

1. Metabolic disturbances
    - a. Metabolic acidosis—bicarbonate ($NaHCO_3$) deficit
    - b. Metabolic alkalosis—bicarbonate ($NaHCO_3$) excess; complication of severe vomiting
2. Respiratory disturbances
    - a. Respiratory acidosis—H_2CO_3 excess
    - b. Respiratory alkalosis—H_2CO_3 deficit

F. In uncompensated metabolic acidosis, the normal ratio of $NaHCO_3$ to H_2CO_3 is changed; in compensated metabolic acidosis, the ratio remains at 20:1, but the total amount of $NaHCO_3$ and H_2CO_3 changes

ANSWERS TO QUESTIONS

Review Questions

1. Explain the relationship between pH and the relative concentration of hydrogen and hydroxide ions in a solution.

Answer: The pH of a solution refers to the hydrogen ion concentration. A pH of 7.0 means that a solution contains an equal concentration of hydrogen and hydroxide ions. As the concentration of hydrogen (H+) ions increases, the solution becomes more acid and the pH value decreases. As OH2 concentration increases, the pH value also increases, and the solution becomes more basic or alkaline.

As an example, a pH of 7 is neutral, a pH of 1 is very acidic, and a pH of 13 is very basic.

2. Write out the chemical reaction that converts carbon dioxide and water to carbonic acid. What enzyme catalyzes this reaction?

Answer: The chemical reaction that converts carbon dioxide and water into carbonic acid results when carbon dioxide (CO2) enters venous blood as a waste product of cellular metabolism—some of it combines with water (H2O) and is converted into carbonic acid by carbonic anhydrase, an enzyme. CO2 + H2O H2CO3

3. What are buffers?

Answer: Buffers are chemical substances that when combined with an acid or base, prevent a drastic change in the pH of a solution. A buffer, when added to acid, would make the acid weaker, and in the same manner, if a buffer were added to a base, the base would become weaker. Sodium bicarbonate (NaHCO3) and carbonic acid (H2CO3) are chemicals that act as buffer pairs to stabilize pH balance.

4. Explain how a buffer pair would react if more hydrogen ions were added to the blood.

Answer: When hydrogen ions such as those in hydrochloric acid are added to blood, a buffer pair, such as sodium bicarbonate and carbonic acid, would cause sodium bicarbonate to combine with the hydrochloric acid. This reaction forms salt and carbonic acid, which is a weak acid. The hydrogen ion concentration of blood is then lowered.

5. Explain how a buffer pair would react if hydroxide ions were added to the blood.

Answer: If hydroxide ions, present in a strong base such as sodium hydroxide, were added to blood, carbonic acid would combine with a strong base to form water and sodium bicarbonate, which is a weak base.

6. Explain the four changes that occur in the blood as the result of buffering fixed acids.

Answer: The changes that occur in blood as a result of buffering fixed acids are
(1) the amount of H2CO3 in blood increases slightly because an acid, such as lactic acid, is converted to H2CO3;
(2) the amount of bicarbonate in blood, mainly NaHCO3, decreases because bicarbonate ions become part of the newly formed H2CO3;
(3) the hydroxide ion concentration of blood increases slightly; and
(4) blood pH decreases slightly below arterial levels.

7. Explain the respiratory mechanism of pH control.

Answer: The respiratory system plays a major role in controlling pH balance. During respiration, CO2 and H2O leave the body in expired air. As CO2 is diffused out of venous blood, it moves through the lung capillaries and out of the lungs. The amount of H2CO3 in the blood is decreased and thereby its H+ concentration is decreased, which then increases blood pH from venous to arterial levels.

8. Explain how changes in the respiration rate affect blood pH.

Answer: Respiratory rate has a direct effect on blood pH. If breathing is impaired for any length of time, CO_2 would not be expired and blood CO_2 would increase. This would then increase the amount of H_2CO_3 and hydrogen ion concentration in blood and decrease blood pH. Thus arterial blood contains less H_2CO_3 and fewer hydrogen ions and has a higher pH (7.45) than does venous blood pH (7.35).

9. Explain how the chemical reaction that occurs in the distal tubule of the kidney using NaH_2PO_4 removes hydrogen ions from the blood.

Answer: The distal tubules of the kidneys rid the blood of excess acid and at the same time conserve the base present in it. Carbon dioxide leaves the blood and enters into cells that form the wall of the distal kidney tubule. Carbon dioxide then combines with water to form carbonic acid with the aid of carbonic anhydrase, an enzyme. As soon as carbonic acid forms, some of it dissociates to yield hydrogen ions and bicarbonate ions. Hydrogen ions diffuse out of the tubule cells into urine. Here they replace sodium ions in a salt (Na_2HPO_4) to form another salt (NaH_2PO_4), which leaves the body in urine.

10. Define acidosis and alkalosis.

Answer: In acidosis the blood pH falls as hydrogen ion concentration increases or because of a loss of bases. It is usually fatal if blood pH falls as low as 7.0 or even becomes slightly acid. In alkalosis the blood pH is higher than normal because of a loss of acids or an accumulation of bases.

11. Explain metabolic disturbances of the buffer pair.

Answer: Two types of disturbances, metabolic and respiratory, can alter the proper ratio of these components. Metabolic disturbances affect the bicarbonate ($NaHCO_3$) element of the buffer pair, and respiratory disturbances affect the H_2CO_3 element, as follows:

a. Metabolic acidosis (bicarbonate deficit). Patients in metabolic acidosis with a bicarbonate deficit often suffer from renal disease, uncontrolled diabetes, prolonged diarrhea, or have ingested toxic chemicals such as antifreeze (ethylene glycol) or wood alcohol (methanol).

b. Metabolic alkalosis (bicarbonate excess). The bicarbonate excess in metabolic alkalosis can result from diuretic therapy, loss of acid-containing gastric fluid caused by vomiting or suction, or from certain diseases such as Cushing's syndrome.

12. Explain respiratory disturbances of the buffer pair.

Answer:

a. Respiratory acidosis (H_2CO_3 excess). The increase in H_2CO_3 characteristic of respiratory acidosis is caused most frequently by slow breathing, which results in excess CO_2 in arterial blood. Causes include depression of the respiratory center by drugs or anesthesia or by pulmonary diseases such as emphysema and pneumonia.

b. Respiratory alkalosis (H_2CO_3 deficit). Hyperventilation leads to a H_2CO_3 deficit caused by excessive loss of CO_2 in expired air. The result is respiratory alkalosis. Anxiety (hyperventilation syndrome), overventilation of patients on ventilators, or hepatic coma can all reduce H_2CO_3 and CO_2 to dangerously low levels.

Critical Thinking Questions

13. Explain how excessive vomiting causes metabolic alkalosis and explain why normal saline can be used to correct it.

Answer: One of the most serious complications of vomiting is metabolic alkalosis. The bicarbonate excess of metabolic alkalosis results because of the massive loss of chloride from the stomach as HCl. The loss of chloride causes a compensatory increase of bicarbonate in the extracellular fluid. The result is metabolic alkalosis. The treatment most effective is the administration of chloride-containing solutions such as normal saline. The chloride ions of the solution replace bicarbonate ions and help relieve the bicarbonate excess responsible for the imbalance.

14. What is the proper ratio of NaHCO3 and H2CO3 in a buffer pair? Explain how the body can use this ratio to correct uncompensated metabolic acidosis.

Answer: The ration of NaHCO3 to H2CO3 levels in the blood is the key to acid-base balance—normal ratio 20:1 (NaHCO3/H2CO3). The body may attempt to compensate for acidosis by rapid breathing or hyperventilation. This action of the respiratory system results in the blowing off of CO2, which decreases the level of blood CO2, and the lowering of H2CO3—a new compensated ratio of NaHCO3 to H2CO3 (perhaps 10:0.5). In this situation, blood pH returns to normal or near-normal levels. This condition is called compensated metabolic acidosis.

CLASSROOM APPLICATION

The following questions can be used as individual assignments or for small-group discussion. Note: to copy the questions, cover the answers with a blank sheet of paper and print, thus leaving space for answers or note-taking.

1. A mountain climber, Justin Peaks, spent several days camped at a very high altitude on a mountain. He noticed that he was breathing faster than normal and that he began to feel nervous and excitable and his muscles were hyperactive. Suggest a reason for his symptoms.

Answer: Because of the very high altitude, the amount of oxygen the mountain climber was breathing was greatly decreased; the decreased oxygen in his blood continually stimulated his breathing, resulting in hyperventilation. Continued hyperventilation produces metabolic alkalosis because when excessive amounts of carbon dioxide are removed from the blood, the number of hydrogen ions in the blood are also decreased. Symptoms of alkalosis include hyperactivity of the nervous system, which can cause extra muscle contractions.

2. Justin felt ill and vomited several times. How would this affect his alkalosis?

Answer: Vomiting produces metabolic alkalosis because of the loss of chloride ions from the stomach. Therefore, the alkalosis would increase, and his symptoms would probably become more severe.

3. Because Justin didn't feel well, he took several antacid tablets, which contained sodium bicarbonate. Was this a good idea? How would this affect his alkalosis?

Answer: This was definitely not a good idea, because the increased sodium bicarbonate in his system would only serve to increase his alkalosis. His condition would probably worsen.

4. How would his body work to control his alkalosis and maintain homeostasis of the pH of his body fluids?

Answer: Because of the high altitude, respiratory control measures may not be effective because the low amount of oxygen diffusing into the blood could still result in hyperventilation. The kidneys would be the most important control mechanism; the kidney tubules would secrete fewer hydrogen ions into the urine and reabsorb fewer bicarbonate ions from the urine, thereby helping to decrease the pH of the blood to the normal range.

PRACTICAL/CREATIVE LEARNING ACTIVITIES

1. On a posterboard draw a scale that represents the relationship of electrolytes in intracellular fluid and extracellular fluid.
2. Present and explain to the class a poster representing a balance scale that shows the relationship of acid-base balance.
3. Have the students draw a diagram of the respiratory and urinary mechanisms of control involved in maintaining normal pH of body fluids.
4. In small groups, discuss the following topics and present the information gathered to the class for discussion:

    a. Explain how the rate and depth of respirations can influence the pH of blood. b. What mechanisms are taking place in an individual who suffers from diabetes? c. If there is a sodium deficit in the interstitial fluid compartments, how might that contribute to water intoxication and eventual shock?

STUDENT ASSIGNMENT ACID-BASE BALANCE

Matching

Select the most correct answer from column B for each item in column A. (Only one answer is correct.)

Column A	Column B
_____ 1. pH lower than 7.0	A. Bicarbonate deficit
_____ 2. pH higher than 7.0	B. Bicarbonate excess
_____ 3. Buffers	C. Alkaline solution
_____ 4. Decrease in respirations	D. “Fixed” acid
_____ 5. Increase in respirations	E. Respiratory acidosis
_____ 6. Metabolic acidosis	F. Respiratory alkalosis
_____ 7. Metabolic alkalosis	G. Acidic solution
_____ 8. Lactic acid	H. Lower-than-normal ratio of sodium bicarbonate to carbonic acid
_____ 9. Kidney	I. Prevent sharp pH changes
_____ 10. Uncompensated	J. Most effective regulators of body pH metabolic acidosis

Multiple Choice

11. What happens as blood flows through lung capillaries?

A. Carbonic acid in blood decreases.
B. Hydrogen ions in blood decreases.
C. Blood pH increases from venous to arterial blood.
D. All of the above are true.

12. Which of the following organs is considered to be the most effective regulator of blood carbonic acid levels?

A. Kidneys
B. Intestines
C. Lungs
D. Stomach

13. Which of the following organs is considered to be the most effective regulator of blood pH?

A. Kidneys
B. Intestines
C. Lungs
D. Stomach

14. What is the pH of the blood?
    A. 7.00 to 8.00
    B. 6.25 to 7.45
    C. 7.65 to 7.85
    D. 7.35 to 7.45

15. If the ratio of sodium bicarbonate to carbonate ions is lowered (perhaps 10:1) and blood pH is also lowered, what is the condition called?
    A. Uncompensated metabolic acidosis
    B. Uncompensated metabolic alkalosis
    C. Compensated metabolic acidosis
    D. Compensated metabolic alkalosis

16. If a person hyperventilates for a given time period, which of the following will probably develop?
    A. Metabolic acidosis
    B. Metabolic alkalosis
    C. Respiratory acidosis
    D. Respiratory alkalosis

17. What happens when lactic acid dissociates in the blood?
    A. H+ is added to blood.
    B. pH is lowered.
    C. Acidosis results.
    D. All of the above happen.

18. Which of the following is true of metabolic acidosis?
    A. It occurs in the case of prolonged vomiting.
    B. It results when the bicarbonate ion is present in excess.
    C. It causes the pH of blood to drop below 7.0.
    D. All of the above are true.

19. Which of the following is a characteristic of a buffer system in the body?
    A. Prevents drastic changes from occurring in body pH
    B. Picks up both hydrogen and hydroxide ions
    C. Is exemplified by the bicarbonate-carbonic acid system
    D. All of the above

20. In the presence of a strong acid, which of the following is true?
    A. Sodium bicarbonate will react to produce carbonic acid.
    B. Sodium bicarbonate will react to produce more sodium bicarbonate.
    C. Carbonic acid will react to produce sodium bicarbonate.
    D. Carbonic acid will react to form more carbonic acid.

Multiple Choice

Teresa is home from school today with a stomach virus. She has been vomiting since early last evening and is unable to keep anything down. Her mother asks you what she can give Teresa to stop her vomiting.

21. You suggest which of the following?
    A. Hot meal with vegetables but no meat
    B. An antiemetic
    C. Soft foods with a low concentration of fat
    D. Fruit juices with salty snacks several times a day

22. From your study of physiology you know that vomiting can do which of the following?

A. Create a state of respiratory distress
B. Produce a blood pH of 6.8
C. Result in metabolic alkalosis
D. Produce a deficit in bicarbonate

Match the following according to cause and effect:

Effect

A. Acid or acidosis B. Alkaline or alkalosis

Cause

23. Anything that causes an appreciable decrease in respirations will in time produce _____.
24. Repeated excessive vomiting results in _____.
25. Untreated diabetes causes _____.
26. A pH higher than 7.0 is _____.
27. A pH lower than 7.0 is _____.
28. With a bicarbonate deficit, the pH is _____.
29. With a pH of 7.7, bicarbonate is _____.
30. With rapid excessive increase in respirations, the pH will be _____.
31. With a pH of gastric juice at 1.6 it is _____.
32. Blood pH is said to be _____.

ANSWERS TO CHAPTER 18 STUDENT ASSIGNMENT

Matching	Multiple Choice
1. G	11. A
2. C	12. C
3. I	13. A
4. E	14. D
5. F	15. A
6. A	16. D
7. B	17. D
8. D	18. D
9. J	19. D
10. H	20. A

Multiple Choice

21. A 22. B

Matching

23. A
24. B
25. A
26. B
27. A
28. B
29. B
30. B
31. A
32. B