Chapter 15: The urinary system

I. Functions of the urinary system
   A. Elimination of waste products
      1. Nitrogenous wastes
      2. Toxins
      3. Drugs
   B. Regulate aspects of homeostasis
      1. Water balance
      2. Electrolytes
      3. Acid-base balance in the blood
      4. Blood pressure
      5. Red blood cell production
      6. Activation of vitamin D

II. Organs of the urinary system
   A. Kidneys
      1. Location of the kidneys
         a. Against the dorsal body wall
         b. At the level of the T12 to L3 vertebrae
         c. The right kidney is slightly lower than the left (due to position of liver)
      2. Kidney features
         a. Renal hilum
            1) A medial indentation where several structures enter or exit the kidney (ureters, renal blood vessels, and nerves)
         b. An adrenal gland sits atop each kidney
      3. Coverings of the kidneys
         a. Fibrous capsule- surrounds each kidney
         b. Perirenal fat capsule- surrounds the kidney and cushions against blows
         c. Renal fascia- outermost capsule that helps hold the kidney in place against the muscles of the trunk wall
      4. Regions of the kidney
         a. Renal cortex- outer region
         b. Renal medulla- inside the cortex
         c. Renal pelvis- inner collecting tube
      5. Kidney structures
         a. Renal or medullary pyramids- triangular regions of tissue in the medulla
         b. Renal columns- extensions of cortex-like material inward that separates the pyramids
         c. Calyces-cup shaped structures that funnel urine towards the renal pelvis
      6. Blood supply
         a. One-quarter of the total blood supply of the body passes through the kidneys each minute

b. Renal artery provides each kidney with arterial blood supply
    1) Renal artery divides into segmental arteries, interlobar arteries, arcuate arteries, cortical radiate arteries
c. Venous blood flow
    1) Cortical radiate veins, arcuate veins, interlobar veins, renal veins
    2) There are no segmental veins

7. Nephron anatomy and physiology
    a. The structural and functional units of the kidneys
    b. Responsible for forming urine
    c. Main structures of the nephrons
        1) Glomerulus
        2) Renal tubule
8. Nephrons
    a. Nephron anatomy
        1) Glomerulus
            a) Knot of capillaries
            b) Capillaries are covered with podocytes from the renal tubule
            c) Glomerulus sits within a glomerular (Bowman's) capsule and ends at the collecting duct
        2) Renal tubule extends from glomerular (Bowman's) capsule (the first part of the renal tubule)
            a) Glomerular (Bowmans's) capsule
            b) Proximal convoluted tubule (PCT)
            c) Loop of henle
            d) Distal convoluted tubule (DCT)
        3) Nephrons are associated with two capillary beds
            a) Glomerulus
            b) Peritubular capillary bed
        4) Glomerulus
            a) Fed and drained by arterioles
                i. Afferent arteriole- arises from a cortical radiate artery and feeds the glomerulus
                ii. Efferent arteriole- receives blood that has passed through the glomerulus
            b) Specialized for filtration
            c) High pressure forces fluid and solutes out of blood and into the glomerular capsule
        5) Peritubular capillary beds
            a) Arise from efferent arteriole of the glomerulus
            b) Normal, low pressure capillaries
            c) Adapted for absorption instead of filtration

d) Cling close to the renal tubule to reabsorb (reclaim) some substances from collecting tubes

b. Types of nephrons
    1) Cortical nephrons
        a) Located entirely in the cortex
        b) Includes most nephrons
    2) Juxtamedullary nephrons
        a) Found at the boundary of the cortex and medulla

9. Collecting duct
    a. Receives urine from many nephrons
    b. Run through the medullary pyramids
    c. Deliver urine into the calcyes and renal pelvis

B. Ureters
1. Ureters
    a. Slender tubes attaching the kidney to the bladder
        1) Continuous with the renal pelvis
        2) Enter the posterior aspect of the bladder
    b. Runs behind the peritoneum
    c. Peristalsis aids gravity in urine transport

C. Urinary bladder
1. Urinary bladder
    a. Smooth, collapsible, muscular sac
    b. Temporarily stores urine
    c. Trigone- triangular region of the bladder base
        1) Three openings
            a) Two from the ureters
            b) One to the urethra
    d. In males, the prostate gland surrounds the neck of the bladder
    e. Urinary bladder wall
        1) Three layers of smooth muscle collectively called the detrusor muscle
        2) Mucosa made of transitional epithelium
        3) Walls are thick and folded in an empty bladder
        4) Bladder can expand significantly without increasing internal pressure
    f. Urinary bladder capacity
        1) A moderately full bladder is about 5 inches long and holds about 500 mL of urine
        2) Capable of holding twice that amount of urine

D. Urethra
1. Urethra

a. Thin-walled tube that carries urine from the bladder to the outside of the body by peristalsis
b. Release of urine is controlled by two sphincters
    1) Internal urethral sphincter- involuntary and made of smooth muscle
    2) External urethral sphincter- voluntary and made of skeletal muscle
c. Urethra gender differences
    1) Length
        a) Femaldes is 3-4 cm (1in)
        b) Males is 20 cm (8in)
    2) Location
        a) Females- along wall of the vagina
        b) Males0 through the prostate and penis
    3) Function
        a) Females- only carries urine
        b) Males- carries urine and is a passageway for sperm cells
d. Micturition (Voiding)
    1) Both sphincter muscles must open to allow voiding
    2) The internal urethral sphincter is relaxed after stretching of the bladder
    3) Pelvic splanchnic nerves initiate bladder to go into reflex contractions
    4) Urine is forced past the internal urethra sphincter and the person feels the urge to void
    5) The external urethral sphincter must be voluntarily relaxed to void

III. Urine formation
    A. Glomerular filtration
    B. Tubular reabsorption
        1. Tubular reabsorption
            a. The peritubular capillaries reabsorb useful substances
                1) Water
                2) Glucose
                3) Amino acids
                4) Ions
            b. Some reabsorption is passive, most is active
            c. Most reabsorption occurs in the proximal convoluted tubule
            d. Materials not reabsorbed
                1) Nitrogenous waste products
                    a) Urea- protein breakdown
                    b) Uric acid- nucleic acid breakdown

c) Creatinine- associated with creatine metabolism in muscles

C. Tubular secretion
    1. Some materials move from the peritubular capillaries into the renal tubules
        a. Hydrogen and potassium ions
        b. Creatinine
    2. Process is important for getting rid of substances not already in the filtrate
    3. Materials left in the renal tubule more toward the ureter

D. Characteristics of urine
    1. In 24 hours, about 1.0- 1.8 liters of urine are produced
    2. Urine and filtrate are different
        a. Filtrate contains everything that blood plasma does (except proteins)
        b. Urine is what remaines after the filtrate has lost most of its water, nutrients, and necessary ions
        c. Urine contains nitrogenous wastes and substances that are not needed
    3. Yellow color is due to the pigment urochrome (from the digestion of hemoglobin) and solutes
    4. Sterile
    5. Slightly aromatic
    6. Normal pH of around 6
    7. Specific gravity of 1.001 to 1.035
    8. Solutes normally found in urine
        a. Sodium and potassium ions
        b. Urea, uric acid, creatinine
        c. Ammonia
        d. Bicarbonate ions
    9. Solutes NOT normally found in urine
        a. Glucose
        b. Blood proteins
        c. Red blood cells
        d. Hemoglobin
        e. White blood cells (pus)
        f. Bile

IV. Fluid, electrolyte, and acid-base balance

A. Blood composition depends on three factors
    1. Diet
    2. Cellular metabolism
    3. Urine output

B. Kidneys have four roles in maintaining blood composition
    1. Excretion of nitrogen-containing wastes (previously discussed)
    2. Maintaining water balance of the blood
    3. Maintaining electrolyte balance of the blood

4. Ensuring proper blood pH

C. Maintaining water balance
    1. Normal amount of water in the human body
        a. Young adult females = 50%
        b. Young adult males = 60%
        c. Babies = 75%
        d. The elderly = 45%
    2. Water is necessary for many body functions, and levels must be maintained

D. Distribution of body fluid
    1. Intracellular fluid (ICF)
        a. Fluid inside cells
        b. About two-thirds of body fluid
    2. Extracellular fluid (ECF)
        a. Fluids outside cells that includes
            1) Interstitial fluid
            2) Blood plasma

E. The link between water and salt
    1. Solutes in the body include electrolytes like sodium, potassium, and calcium ions
    2. Changes in electrolyte balance causes water to move from one compartment to another
        a. Alters blood volume and blood pressure
        b. Can impair the activity of cells

F. Maintaining water balance
    1. Water intake must equal water output
    2. Sources for water intake
        a. Ingested foods and fluids
        b. Water produced from metabolic processes
    3. Thirst mechanism is the driving force for water intake
    4. Sources for water output
        a. Vaporization out the lungs
        b. Lost in perspiration
        c. Leaves the body in the feces
        d. Urine production
    5. Dilute urine is produced if water intake is excessive
    6. Less urine (concentrated) is produced if large amounts of water are lost
    7. Proper concentrations of various electrolytes must be present

G. Regulation of water and electrolyte reabsorption
    1. Osmoreceptors
        a. Cells in the hypothalamus
        b. React to changes in blood composition by becoming more active
    2. Regulation occurs primarily by hormones

a. Antidiuretic hormone (ADH)
    1) Prevents excessive water loss in urine
    2) Causes kidney's collecting ducts to reabsorb more water
    3) Diabetes insipidus
        a) Occurs when ADH is not released
        b) Leads to huge outputs of dilute urine
b. Aldosterone
    1) Regulates sodium ion content to ECF
    2) Sodium is the electrolyte most responsible for osmotic water flows
    3) Aldosterone promotes reabsorption of sodium ions
    4) Remember, water follows salt!
c. Renin-angiotension mechanism
    1) Mediated by the juxtaglomerular (JG) apparatus of the renal tubules
    2) When cells of the JG apparatus are stimulated by low blood pressure, the enzyme renin is released into blood
    3) Renin produces angiotension II
    4) Angiotension causes vasconstriction and aldosterone release
    5) Result is increase in blood volume and blood pressure

H. Maintaining acid-base balance in blood
1. Blood pH must remain between 7.35 and 7.45 to maintain homeostasis
    a. Alkalosis- pH above 7.45
    b. Acidosis- pH below 7.35
2. Physiological acidosis- pH between 7.35-7.0
    a. Most ions originate as by-products of cellular metabolism
3. Acids produced by the body
    a. Phosphoric acid, lactic acid, fatty acids
    b. Carbon dioxide forms carbonic acid
    c. Ammonia
4. Most acid-base balance is maintained by the kidneys
5. Other acid-base controlling systems
    a. Blood buffers
    b. Respiration
6. Blood buffers
    a. Acids are proton (H+) donors
        1) Strong acids dissociate completely and liberate all of their H+ in water
        2) Weak acids, such as carbonic acid, dissociate only partially
    b. Bases are proton (H+) acceptors
        1) Strong bases dissociate easily in water and tie up H+

2) Weak bases, such as bicarbonate ion and ammonia, are slower to accept H+

c. Dissociation of strong and weak acids

d. Molecules react to prevent dramatic changes in hydrogen ion (H+) concentrations

1) Bind to H+ when pH drops

2) Release H+ when pH rises

e. Three major chemical buffer systems

1) Bicarbonate buffer system

a) Mixture of carbonic acid (H_2CO_3) and sodium bicarbonate ($NaHCO_3$)

i. Carbonic acid is a weak acid that does not dissociate much in neutral or acid solutions

ii. Bicarbonate ions (HCO_3-) react with strong acids to change them to weak acids

b) Carbonic acid dissociates in the presence of a strong base to form a weak base and water

2) Phosphate buffer system

3) Protein buffer system

I. Respiratory system controls of acid-base balance

1. Carbon dioxide in the blood is converted to bicarbonate ion and transported in the plasma
2. Increases in hydrogen ion concentration produces more carbonic acid
3. Excess hydrogen ion can be blown off with the release of carbon dioxide from the lungs
4. Respiratory rate can rise and fall depending on the changing blood pH

J. Renal mechanisms of acid-base balance

1. Excrete bicarbonate ions if needed
2. Conserve (reabsorb) or generate new bicarbonate ions if needed
3. When blood pH rises
    a. Bicarbonate ions are excreted
    b. Hydrogen ions are retained by kidney tubules
4. When blood pH falls
    a. Bicarbonate ions are reabsorbed
    b. Hydrogen ions are secreted
5. Urine pH varies from 4.5 to 8.0

V. Developmental aspects of the urinary system

A. Functional kidneys are developed by the third month

B. Urinary system of a newborn

1. Bladder is small
2. Urine cannot be concentrated for first 2 months
3. Void 5 to 40 times per day

4. Control of the voluntary urethral sphincter does not start until 18 months of age
5. Complete nighttime control may not occur until the child is 4 years old
6. Urinary infections are the only common problems before old age
    a. Escherichia coli (E. coli) a type of bacteria, accounts for 80% of all UTIs (Urinary tract infection)

C. Aging and the urinary system
1. There is a progressive decline in urinary function
2. The bladder shrinks and loses bladder tone with aging
3. Associated problems with aging
    a. Urgency- feeling that it is necessary to void
    b. Frequency- frequent voiding of small amounts of urine
    c. Nocturia- need to get up during the night to urinate
    d. Incontinence- loss of control
    e. Urinary retention- common in males, often the result of hypertrophy of the prostate gland