Module 24.1: Overview of the Urinary System

OVERVIEW OF THE URINARY SYSTEM STRUCTURES

- **Urinary system** (organs of excretion) – composed of a pair of kidneys and urinary tract
  - filter blood to remove metabolic waste products; modify resulting fluid for following purposes:
    - Fluid and electrolyte homeostasis
    - Acid-base and blood pressure homeostasis

- **Urinary tract** – composed of a pair of **ureters**, **urinary bladder**, and a single **urethra**
  - Urine exits kidneys through ________ found on posterior body wall
  - Each ureter empties into **urinary bladder** on floor of pelvic cavity where urine is stored
  - Urine exits from urinary bladder through ________: allows urine to exit body

OVERVIEW OF KIDNEY FUNCTION

- Kidneys are site where urinary system regulates homeostatic processes:
  - Filter blood to remove metabolic wastes
  - Regulate fluid and electrolyte balance
  - Influence blood pressure
  - Releasing hormone **erythropoietin (EPO)**
Kidneys look like beans in both shape and color
Both kidneys are found outside and posterior to peritoneal membrane

(____________________)
Right kidney is found in a slightly inferior position due to liver

Left kidney is positioned between T12–L3 using vertebral column as reference
11th and 12th ribs provide some protection for both kidneys
_________________________ – component of endocrine system; found on superior pole of each kidney

Module 24.2: Anatomy of the Kidneys

EXTERNAL ANATOMY OF THE KIDNEYS

• Three external layers of CT from deep to superficial:

1. _____________________ – thin layer of dense irregular connective tissue; covers exterior of each kidney

2. _____________________ – protects from physical trauma

3. _____________________ – dense irregular CT; anchors each kidney to peritoneum and musculature of posterior abdominal wall

• Hilum – opening on medial surface of kidney where renal artery, vein, nerves, and ureters enter and exit
INTERNAL ANATOMY OF THE KIDNEYS

- Renal cortex and the renal medulla make up *urine-forming* portion of kidney
  - 90–95% of all kidney’s blood vessels are found in renal cortex
- Renal columns – *extensions of renal cortex*; pass through renal medulla toward renal cortex
- Over one million **nephrons** are found within cortex and medulla of each kidney
  - **Renal corpuscle** found in *renal cortex*
  - **Renal tubule** found mostly in cortex with some tubules dipping into medulla
- Cone-shaped ________________ are found within **renal medulla** separated by renal columns on either side
- Each renal pyramid tapers into a slender papilla
  - →
  - →
  - →
  - →
- Smooth muscle tissue contraction within walls of the calyces and renal pelvis propel urine towards ureter

BLOOD SUPPLY OF THE KIDNEYS

- Left and right **renal arteries** are branches of **abdominal aorta**
  1- renal artery →
  2- segmental artery →
  3- interlobar artery →
4- _______________ →

5- interlobular (cortical radiate artery)

- Kidney contains unusual capillary bed system where arterioles both feed and drain capillaries; normally function of a venule

6- afferent arteriole →

7- _______________ →

8- efferent arteriole →

9- _______________ capillaries

- Venous blood exits kidney parallel to arterial pathway

10- interlobular veins →

11- arcuate veins →

12- interlobar vein →

13- _______________

- Renal vein exits kidney from hilum to drain into inferior vena cava

**NEPHRON AND THE COLLECTING SYSTEM**

- **Nephron** – renal corpuscle and renal tubule
  - **Renal corpuscle** – filters blood
    - 1. ________ – group of looping fenestrated capillaries
      - 2. **Glomerular capsule (Bowman’s capsule)** – consists of outer parietal & inner visceral layer
        o ________________ space – hollow region between parietal and visceral layers
• Filtrate from Bowman’s capsule enters renal tubule:
  ________________ (pct)
  -
  ________________ (descending limb, ascending limb)
  -
  ________________ (dct)
  -

• Juxtaglomerular apparatus (JGA)
  - composed of both macula densa and juxtaglomerular (JG) cells;
  ▪ Macula densa is a group of cells in contact with modified smooth muscle cells (juxtaglomerular (JG) cells)
  ▪ JGA regulates blood pressure (BP) and glomerular filtration rate (GFR)
    o ________________
    o ________________

• Collecting system – both medullary collecting duct (cd) and papillary duct that further modify filtrate before it exits kidney
  ▪ cortical cd ➔ medullary cd ➔ ________________
  • Once filtrate enters papillary duct it is known as urine, not filtrate
  • Urine exits papillary duct at papilla of renal pyramid into a ________________

**TYPES OF NEPHRONS**

• ________________ nephrons make up about 80% of nephrons in kidneys
Renal corpuscles are found in outer renal cortex; have short nephron loops that barely enter renal medulla

- ________________ nephrons – much less common than cortical nephrons
  - Renal corpuscles are found near boundary between renal cortex and medulla; have long nephron loops that travel deep within renal medulla

- **Cortical nephrons** make up about 80% of nephrons in kidneys
  - Renal corpuscles are found in outer renal cortex; have short nephron loops that barely enter renal medulla

- **Juxtamedullary nephrons** – much less common than cortical nephrons
  - Renal corpuscles are found near boundary between renal cortex and medulla; have long nephron loops that travel deep within renal medulla

### Nephrolithiasis

- Formation of renal calculi (______________); crystalline structures composed most commonly of calcium oxalate salts
- Form when concentrations of ions (also sodium ions, hydrogen ions, and uric acid) are present in filtrate in higher than normal amounts; known as supersaturation

### Module 24.3: Overview of Renal Physiology

- Selectively based on size so ________and________________are not filtered and remain in the circulating blood
Smaller substances exit blood to enter capsular space as filtrate

\[
\text{Filtration} =
\]

**TUBULAR REABSORPTION**

- Reclaiming or reabsorbing substances such as water, glucose, amino acids, and electrolytes from tubular fluid to return them into circulating blood

\[
\text{Reabsorption} =
\]

**TUBULAR SECRETION**

- Substances are added into filtrate from peritubular capillaries

\[
\text{Secretion} =
\]

**Module 24.4: Renal Physiology I: Glomerular Filtration**

- Fenestrated glomerular capillary
  - Fenestrations are large pores
  - Water and small dissolved solutes pass through filtration membrane easily
  - Nitrogenous wastes – group of small substances that are readily filtered; include:
    - _________ and ammonium ions (NH₄⁺) from protein metabolism
    - Creatinine
    - ______________ – product of nucleic acid metabolism
Filtration Membrane:
1. Fenestrated glomerular______________________cells
2. Basal lamina
3. Podocytes

Amount of filtrate formed by both kidneys in one minute is known as glomerular filtration rate (GFR); 125 ml/min

• Net filtration pressure at glomerulus is determined by three driving forces:
  1. Glomerular hydrostatic pressure ( ) – blood pressure; higher than average capillary bed hydrostatic pressure
  2. Glomerular colloid osmotic pressure ( ) – created mostly by albumin; pulls water back into glomerular capillaries
  3. Capsular hydrostatic pressure ( ) – generated as capsular space rapidly fills with new filtrate (10 mm Hg) as fluid can only move so quickly into renal tubule which opposes filtration

• Net filtration pressure (NFP) is combination of these three forces:
  \[ \text{NFP} = \text{GHP} - (\text{GCOP} + \text{CHP}) \]

• NFP favors filtration as GHP is greater than sum of forces that oppose filtration (GCOP + CHP)

Glomerulonephritis
• Common condition that involves damage to and destruction of glomeruli; inflammation of glomerular capillaries and basement membrane results
• Inflammation increases **blood flow and capillary permeability**; increases GHP; causes filtration membrane to become excessively leaky; leads to **loss of blood cells and proteins** to urine

**FACTORS THAT AFFECT THE GLOMERULAR FilTRATION RATE**

**Autoregulation** – internal kidney mechanisms that work to maintain GFR

• ______________ mechanism – constriction of smooth muscle in blood vessel walls in response to increases in BP

• **Tubuloglomerular feedback** – uses **macula densa** of distal renal tubule to control pressure in glomerulus in response to NaCl concentration of filtrate

• Hormonal effects on GFR are part of a larger system that involves regulation of **systemic BP** and includes angiotensin-II and natriuretic peptides
  
  • **Renin-angiotensin-aldosterone system (RAAS)** – complex system that maintains systemic BP
  
  • **Atrial natriuretic peptide (ANP)** – hormone released by heart cells in **atria** in response to increasing fluid volume; lowers blood volume and BP to reduce workload of the heart
  
  • ANP increases **GFR** by dilating **afferent arterioles** and constricting **efferent arterioles**; increases glomerular hydrostatic pressure

• Neural regulation of GFR primarily involves__________________________of ANS

**RENAAL FAILURE**

• If GFR__________, kidneys may be unable to carry out their vital functions; called **renal failure**
  
  • Renal failure may be a short-term condition known as **acute renal failure** or **acute kidney injury**; **resolves** with treatment
Renal failure may become **chronic** after three or more months of decreased GFR; commonly seen with long-standing *diabetes mellitus* and *hypertension*

- _______________ – condition that can develop when GFR is **less** than 50% of normal; leads to buildup of *waste products*, *fluid*, *electrolytes*, as well as *acid-base imbalances*, all of which can lead to coma, seizures, and death if untreated

- _______________ can be used to treat the signs and symptoms of uremia

**The RAAS and Hypertension**

- Three classes of drugs have been developed that act on RAAS to **reduce blood pressure**:

  - **ACE inhibitors** – developed from snake venom; block ACE; therefore *inhibit conversion of angiotensin I to II*

  - **Angiotensin-receptor blockers** – block receptors on blood vessels and proximal tubule cells; *prevents* vasoconstriction and *reabsorption of water and sodium*

  - **Aldosterone antagonists** – block effects of aldosterone on distal tubule; decrease reabsorption of sodium and water; leads to *diuretic effect*

  - Drugs may **decrease** GFR in patients with *pre-existing renal disease*; must be monitored

**Module 24.5: Renal Physiology II: Tubular Reabsorption and Secretion**

**PRINCIPLES OF TUBULAR REABSORPTION AND SECRETION**

- In ________________, substances pass from filtrate into interstitial fluid then into peritubular capillaries to re-enter blood

- In **tubular secretion**, substances move in *opposite direction*
• ______________ – substances move from blood into interstitial fluid then into tubule with filtrate
  - Secretion is an **active process**

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<th>REABSORPTION AND SECRETION IN THE PROXIMAL TUBULE</th>
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• Reabsorption is the main function of ________
  - Large quantity of ions, sodium, potassium, chloride, sulfate, and phosphate; vital to electrolyte homeostasis
  - Almost 100% of nutrients including glucose, amino acids, water-soluble vitamins, and lactic acid

**Glycosuria**

• **Transport maximum** – especially important with substances such as **glucose**
  • If too much glucose is present in filtrate, TM will be reached **before** all glucose is reabsorbed; excess will appear in urine (**glycosuria**)  

  • Commonly seen in **diabetes mellitus** – due to defects in production of or response to **insulin**; causes inability of cells to take up glucose; leads to high circulating blood glucose (**hyperglycemia**), high filtrate glucose content, and therefore glucose remaining in urine

**Secretion in Proximal tubule**

• Ammonium ions (NH$_4^+$), creatinine, and small amounts of urea are also secreted

• Drugs such as penicillin and morphine have significant renal secretion; must be taken often (typically 3–5 times per day), because amount lost through renal secretion must be replaced in order to maintain **relatively consistent blood levels**

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<th>REABSORPTION IN THE NEPHRON LOOP</th>
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• Once filtrate reaches nephron loop, 60–70% of water and electrolytes and most organic solutes have been reabsorbed (returned to blood)
• About 20% of water and 25% of sodium and chloride ions are reabsorbed from loop

REABSORPTION AND SECRETION—DISTAL TUBULE & COLLECTING SYSTEM

Facultative water reabsorption – water is reabsorbed based on body’s needs

• ______________________—from adrenal cortex; increases reabsorption of sodium ions from filtrate and secretion of potassium ions into filtrate

• ______________________ (ADH) – from hypothalamus and secreted by posterior pituitary; causes water reabsorption; reduces urine output

• Atrial natriuretic peptide (ANP) – stimulates urinary excretion of sodium ions while it also inhibits release of both aldosterone and ADH

Medullary collecting system – last chance for regulation of fluid, electrolyte, and acid-base balance before filtrate becomes urine

• Impermeable to water in absence of ___________

• Permeable to urea; allows urea to be reabsorbed passively into interstitial fluid

• Cells of proximal tubule secrete hydrogen ions to maintain blood pH

Module 24.6: Renal Physiology III: Regulation of Urine Concentration and Volume

PRODUCTION OF DILUTE URINE

• Kidneys produce dilute urine when solute concentration of extracellular fluid is too low
  -  ▪ Distal tubule and collecting duct become impermeable to water
Kidneys effectively conserve water by producing very concentrated urine (reaching nearly 1200 mOsm) using two mechanisms:

- Countercurrent mechanism creates and maintains osmotic gradient by exchanging materials in opposite directions between filtrate and interstitial fluids

- **Countercurrent multiplier** proceeds in following steps
  - NaCl is actively transported from filtrate into interstitial fluid
  - Hypertonic fluid then pulls water out of filtrate into interstitial fluid

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**Module 24.8: Urine and Renal Clearance**

- URINE COMPOSITION & URINALYSIS

  - Potassium
  - Chloride
  - Phosphates
  - Sulfates
  - Metabolic wastes such as urea, creatinine, ammonia, and uric acid
  - Small amounts of bicarbonate, calcium, and magnesium may be present
▪ Urine color
  o _________________; breakdown product of hemoglobin
  o Darker urine is more concentrated; has less water
  o Lighter urine is less concentrated; has more water
▪ Urine should be _________________
▪ Mild odor; strong odor may be caused by diseases, infections, or by ingesting certain foods
▪ Normal pH (6.0); ranges from _________________
▪ **Specific gravity** 1.001 (very dilute) to 1.035 (very concentrated)

▪ Renal clearance:
  ▪ Measurement of rate at which kidneys remove a substance from blood
  ▪ For a substance to provide an accurate measure of renal clearance and GFR, substance should be completely filtered and neither reabsorbed nor secreted
  ▪ **Creatinine** – not totally accurate (5–50% in urine arrived via secretion, not filtration)
  ▪ More accurate assessment of GFR can be obtained using **inulin**; neither secreted or absorbed; must be injected

*Module 24.9: Urine Transport, Storage, and Elimination*

**ANATOMY OF THE URINARY TRACT**

Urinary tract consists of two ureters, urinary bladder, and urethra

▪ **Ureter** is 25–30 cm long and empties into bladder
1. _______________ – most superficial layer; made of fibrous connective tissue

2. _______________ – middle layer; made of smooth muscle cells that contract rhythmically (peristalsis) to propel urine toward urinary bladder

3. _______________ – deepest layer; mucous membrane composed of transitional epithelium

• **Urinary bladder** – hollow, distensible organ found on pelvic cavity floor
  • _______________ – **triangular region** on bladder floor; openings of two ureters are found at each posterior corner

• Bladder wall:
  1. **Adventitia** – most superficial layer; made of areolar connective tissue
  2. **Detrusor muscle** – middle layer; squeeze bladder; (**internal urethral sphincter**) is found at opening of urethra
  3. _______________ – innermost layer; made of transitional epithelium

• _______________ – drains urine from urinary bladder to outside of body; walls are similar to ureters
  • A second **external urethral sphincter** is formed by **levator ani muscle** – *skeletal muscle* of pelvic floor; allows for voluntary control of urination

• Male and female urethra differ structurally and functionally
  • **Female** – about four cm in length; opens at **external urethral orifice** between vagina and clitoris
  • **Male** – about 20 cm, consists of following three regions:
    1. _______________ urethra
    2. _______________ urethra
    3. _______________ (penile) urethra
• **Micturition** – ___________; discharge of urine from urinary bladder to outside of body

• **Micturition reflex** – reflex arc mediated by **parasympathetic nervous system** when urine fills bladder and stretches walls:
  - **Stretch receptors** send a signal to sacral region of the spinal cord via sensory afferent fibers
  - _______________ efferent fibers stimulate detrusor muscle to contract and internal urethral sphincter to relax; allows for micturition

• **Micturition center** – found in **pons** (CNS); given time and training makes micturition a **voluntary process**
Fluid, Electrolyte, and Acid-Base Homeostasis

Chapter 25

Module 25.1: Overview of Fluid, Electrolyte, and Acid-Base Balance

INTRODUCTION TO BODY FLUIDS

Body fluids – blood plasma, interstitial fluid, cytosol, CSF, lymph and exocrine secretions

- Mostly water

• Fluid balance – maintaining volume and concentration of body’s intracellular (___) and extracellular fluid (___)

• Water that is gained must equal water that is lost
  
  • (H\textsubscript{2}O in = H\textsubscript{2}O out)

• Multiple factors impact fluid balance including:
  
  • Amount ingested
  
  •
  
  •
  
  • Medications
  
  • Digestive activities

ELECTROLYTES

• **Electrolytes** – substances that dissociate into ions, or charged particles
  
  • Electrolytes obtained from diet equals those lost
  
  • Controlled mostly by ____________________
Ion concentration is dependent not only on number of ions in a body fluid, but also on amount of water in body fluid.

Fluid balance is a critical factor that determines electrolyte balance.

**ACIDS, BASES, and pH**

- An acid is a chemical that dissociates in water to release a ________________
  - H⁺ ion plays a role in: digestion of food, inactivation of microbes and pathogens, and intracellular digestion in lysosomes
- A ____________ or alkali, is a chemical that accepts a H⁺ or releases a hydroxide ion (__________)
  - Bicarbonate and other bases are components of buffer systems

**pH scale** – used to measure [H⁺] of a solution

- An increase in hydrogen ion concentration results in a solution with a lower pH
- Solutions with a lower hydrogen ion concentration have a higher pH

  pH less than 7 are ____________
  pH greater than 7 are ____________
  pH of 7 are ____________

**Module 25.2: Fluid Homeostasis**

**FLUID COMPARTMENTS**

- **Intracellular fluid (ICF)**; accounts for about 60% of body’s fluids
- **Extracellular fluid (ECF)** composed of a variety of body fluids
  - ________________ – about 8% of total body water
  - ________________ – about 32% of total body water
- Solute composition of ECF and ICF varies
  - ________________, chloride, calcium, and bicarbonate ions are higher in ECF
  - ________________, magnesium, sulfate, and monohydrogen phosphate ions higher in cytosol
Factors that influence water loss – majority of water lost daily is in urine via kidneys

1. **Obligatory water loss** – (500 ml) urine produced daily irrespective of fluid intake
   - Required to prevent toxic buildup of molecules and electrolyte imbalances

2. **Sensible water loss** – usually about 100 ml in feces (noticeable amount of water lost)

3. **Insensible water loss** – usually 600 ml from skin in form of sweat and evaporation
   - 300 ml lost in expired humidified air (an unnoticed amount of daily water loss)
   - Most people lose about _____________ of water daily

Fluctuates with water intake, physical activity, and food intake

Water Gains:

1. Water ingested from foods ( )
2. Metabolic water ( )
3. Drinking liquid ( )

Water intake driven by **thirst mechanism**:

1. Osmoreceptors in hypothalamus
2. Decreased plasma volume that results in a BP drop detected by baroreceptors →
   Stimulates juxtaglomerular cells →
   renin-angiotensin-aldosterone system → angiotensin-II →

HORMONAL REGULATION OF FLUID BALANCE

- **ADH (antidiuretic hormone)** plays most important role in balancing water intake with water loss, or fluid balance
  - Produced in hypothalamus and released from posterior pituitary
  - __________ and __________ reabsorb water
  - **Increased** ADH leads to more water reabsorption that decreases urine volume
  - **Decreased** ADH leads to more water elimination that increases urine volume

IMBALANCES OF FLUID HOMEOSTASIS

- __________ – decreased volume and increased concentration of ECF
  - Common causes include: profuse sweating, diarrhea and/or vomiting, some endocrine conditions, and diuretic overuse
  - Water loss decreases plasma volume and increases solute concentration; increases osmotic pressure
- **Overhydration (hypotonic hydration)** – when ECF volume increases; decreases its osmotic pressure
ADH secretion is abnormal or an extreme amount of water is consumed in a brief time period

Electrolyte imbalances, especially sodium ion decreases (hyponatremia) result from diluted ECF

Module 25.3: Electrolyte Homeostasis

### Sodium
- Sodium ions are most abundant in ECF
- Regulation of sodium ion concentration:
  - Angiotensin-II and aldosterone are two main hormones that increase Na\(^+\) retention
  - ANP decreases Na\(^+\) and water reabsorption
- **Hypernatremia** – elevated Na\(^+\) concentration; greater than 145 mEq/l; commonly caused by dehydration
- **Hyponatremia** – decreased Na\(^+\) concentration; less than 135 mEq/l; commonly caused by overhydration

### Potassium
- Potassium ions are most abundant in ICF
- Regulation of potassium ion concentration:
  - Insulin, aldosterone, and epinephrine are hormones that stimulate uptake of K\(^+\) by cells (endocrine control)
  - Excess K\(^+\) is secreted into urine and excreted from body
- **Hyperkalemia** – high K\(^+\) in plasma
Potentially fatal; resting membrane potential more positive (cells incapable of functioning)

- **Hypokalemia** – low K\(^+\) in plasma
  - Commonly caused by diuretics that lead to excess K\(^+\) loss in urine
  - RMP more negative (less responsive to stimuli)

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**Module 25.4: Acid-Base Homeostasis**

### HYDROGEN IONS AND BUFFERING SYSTEMS

- Normal H\(^+\) level in body fluids equals a pH range of about 7.35–7.45
- pH is maintained by:
  - Respiratory and urinary system using two types of buffer systems
    1. Chemical buffer systems
    2. Physiological buffer systems

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**Acid-Base Imbalances**

- **Acidosis** - body fluid pH of less than 7.35,
  - More H\(^+\) are added
  - Acidosis causes neurons to become less excitable; leads to signs and symptoms of nervous system depression

- **Alkalosis** - body fluid pH greater than 7.45
  - more base ions are added
  - Increases excitability of neurons causing them to fire APs inappropriately