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- _______________ \(\rightarrow\)

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 \(\rightarrow\)

7- _______________ \(\rightarrow\)

8- efferent arteriole \(\rightarrow\)

9- _______________ capillaries
- Venous blood exits kidney parallel to arterial pathway

10- interlobular veins \(\rightarrow\)

11- arcuate veins \(\rightarrow\)

12- interlobar vein \(\rightarrow\)

13- _______________

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

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**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

- **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

- **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

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**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

Filtration =

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

Reabsorption =

Substances are added into filtrate from peritubular capillaries

- Helps maintain electrolyte and acid-base homeostasis; removes toxins from blood that did not enter tubular fluid by filtration

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

**RENNAL 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**

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<tr>
<th>PRINCIPLES OF TUBULAR REABSORPTION AND SECRETION</th>
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- 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**

**REABSORPTION AND SECRETION IN THE PROXIMAL TUBULE**

• 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 (NH₄⁺), 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

**REABSORPTION IN THE NEPHRON LOOP**

• 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

**COUNTERCURRENT MECHANISM & PRODUCTION OF CONCENTRATED URINE**
• 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 ________________ filtrate into interstitial fluid
    - Hypertonic fluid then pulls water out of filtrate in ________________ into interstitial fluid

→ 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**
  - Darker urine is more concentrated; has less water
  - 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
    
    • (H₂O in  =  H₂O 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

WATER LOSSES AND GAINS

• 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 →
   _______________________________

   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

   HORMONAL REGULATION OF FLUID BALANCE

   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)

→ *Module 25.4: Acid-Base Homeostasis*

- 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

**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