# Urinary System

## Chapter 24

### → *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 <u>outside</u> and <u>posterior</u> to *peritoneal membrane*

  (_____)
- Right kidney is found in a slightly <u>inferior</u> position due to liver

- Left kidney is positioned <u>between</u> $T_{12}$–$L_3$ using vertebral column as reference
- 11th and 12th ribs provide some protection for <u>both</u> 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

→

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- 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
      - _____ **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***)

    - _____

    - _____

- **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, <u>not</u> 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*

GLOMERULAR FILTRATION

- 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 =

  ]

TUBULAR REABSORPTION

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

  Reabsorption =

TUBULAR SECRETION

- 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 <u>are large pores</u>
  - Water and small dissolved solutes pass through filtration membrane easily
  - Nitrogenous wastes – group of small substances that are readily filtered; include:
    - _____ and ammonium ions ($NH_4^+$) from protein metabolism
    - Creatinine
    - _____ – product of nucleic acid metabolism

**Filtration Membrane**:

1. Fenestrated glomerular _____ cells
2. Basal lamina
3. Podocytes

## GLOMERULAR FILTRATION RATE

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:

  **NFP** = **GHP** – (**GCOP** + **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

## RENAL 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 <u>less</u> 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 <u>reduce</u> *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 <u>decrease</u> GFR in patients with *pre-existing renal disease*; must be monitored
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→ ***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**

## 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 ($NH_4^+$), 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*

## 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**
  - _____; breakdown product of hemoglobin
  - 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

- **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
    - ($H_2O$ in = $H_2O$ 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 →

   _____

## 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)

→ ***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**

**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