Ch 25- The Urinary System
Introduction to the Urinary System

- **Kidney**: Produces urine
- **Ureter**: Transports urine toward the urinary bladder
- **Urinary bladder**: Temporarily stores urine prior to elimination
- **Urethra**: Conducts urine to exterior; in males, transports semen as well
**Introduction to the Urinary System**

**Kidneys** — organs that produce urine. Located on either side of vertebral column. Position is maintained by:
- Overlying peritoneum – lie below peritoneum (retroperitoneal)
- Contact with adjacent visceral organs supporting connective tissues

**Urinary tract** — organs that eliminate urine
- Ureters (paired tubes)
- Urinary bladder (muscular sac)
- Urethra (exit tube)

**Urination** or **micturition** — process of eliminating urine
- Contraction of muscular urinary bladder forces urine through urethra, and out of body
The Kidneys

Nephrons- microscopic functional unit

- Structures where urine production begins by filtering blood into tubes. Filtrate is adjusted to maintain homeostasis.
Functions of the Urinary System

1. **Excretion**: Removal of organic wastes from body fluids

2. **Elimination**: Discharge of waste products

3. **Homeostatic regulation**: Of blood plasma volume and solute concentration

   *Regulates blood volume and blood pressure:*
   - By adjusting volume of water lost in urine
   - Releasing erythropoietin and renin
Homeostatic Function the Urinary System

*Regulates plasma ion concentrations:*

- Sodium, potassium, and chloride ions (by controlling quantities lost in urine)
- Calcium ion levels (through synthesis of calcitriol)

*Helps stabilize blood pH:*

- By controlling loss of hydrogen ions and bicarbonate ions in urine

*Conserves valuable nutrients:*

- By preventing excretion while excreting organic waste products

*Assists liver in detoxifying poisons*
Normal Urine

- Sterile and pH varies with diet
- No blood, proteins, or bacteria,
- Odor, volume, and color varies with diet and water intake.
- Normal color occurs from breakdown of RBCs
- Results from filtration, absorption, and secretion activities of *nephrons (functional unit of kidney)*
- Compounds like urea, ammonia, and creatinine are actively secreted into tubular fluid and become part of urine.
Normal Urine

- Urine concentration depends on osmotic movement of water across walls of tubules and collecting ducts
- Yellow color (pigment urobilin)
  - Generated in kidneys from urobilinogens
- **Urinalysis**, the analysis of a urine sample, is an important diagnostic tool
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Normal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>4.5–8 (average: 6.0)</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.003–1.030</td>
</tr>
<tr>
<td>Osmotic concentration (osmolarity)</td>
<td>855–1335 mOsm/L</td>
</tr>
<tr>
<td>Water content</td>
<td>93–97%</td>
</tr>
<tr>
<td>Volume</td>
<td>700–2000 mL/day</td>
</tr>
<tr>
<td>Color</td>
<td>Clear yellow</td>
</tr>
<tr>
<td>Odor</td>
<td>Varies with composition</td>
</tr>
</tbody>
</table>

**Typical Values Obtained from Standard Urinalysis**

<table>
<thead>
<tr>
<th>Compound</th>
<th>Primary Source</th>
<th>Daily Elimination*</th>
<th>Concentration</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NITROGENOUS WASTES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>Deamination of amino acids by liver and kidneys</td>
<td>21 g</td>
<td>1.8 g/dL</td>
<td>Rises if negative nitrogen balance exists</td>
</tr>
<tr>
<td>Creatinine</td>
<td>Breakdown of creatine phosphate in skeletal muscle</td>
<td>1.8 g</td>
<td>150 mg/dL</td>
<td>Proportional to muscle mass; decreases during atrophy or muscle disease</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Deamination by liver and kidney, absorption from intestinal tract</td>
<td>0.68 g</td>
<td>60 mg/dL</td>
<td></td>
</tr>
<tr>
<td>Uric acid</td>
<td>Breakdown of purines</td>
<td>0.53 g</td>
<td>40 mg/dL</td>
<td>Increases in gout, liver diseases</td>
</tr>
<tr>
<td>Hippuric acid</td>
<td>Breakdown of dietary toxins</td>
<td>4.2 mg</td>
<td>350 μg/dL</td>
<td></td>
</tr>
<tr>
<td>Urobilin</td>
<td>Urobilinogens absorbed at colon</td>
<td>1.5 mg</td>
<td>125 μg/dL</td>
<td>Gives urine its yellow color</td>
</tr>
<tr>
<td>Bilirubin</td>
<td>Hemoglobin breakdown product</td>
<td>0.3 mg</td>
<td>20 μg/dL</td>
<td>Increase may indicate problem with liver elimination or excess production; causes yellowing of skin</td>
</tr>
</tbody>
</table>
### Table 26-6 Typical Values Obtained from Standard Urinalysis

<table>
<thead>
<tr>
<th>Compound</th>
<th>Primary Source</th>
<th>Daily Elimination*</th>
<th>Concentration</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NUTRIENTS AND METABOLITES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbohydrates</td>
<td></td>
<td>0.11 g</td>
<td>9 μg/dL</td>
<td>Primarily glucose; <em>glycosuria</em> develops if $T_m$ is exceeded</td>
</tr>
<tr>
<td>Ketone bodies</td>
<td></td>
<td>0.21 g</td>
<td>17 μg/dL</td>
<td>Ketonuria may occur during postabsorptive state</td>
</tr>
<tr>
<td>Lipids</td>
<td></td>
<td>0.02 g</td>
<td>1.6 μg/dL</td>
<td>May increase in some kidney diseases</td>
</tr>
<tr>
<td>Amino acids</td>
<td></td>
<td>2.25 g</td>
<td>287.5 μg/dL</td>
<td>Note relatively high loss compared with other metabolites due to low $T_m$; excess <em>aminoaciduria</em> indicates $T_m$ problem</td>
</tr>
<tr>
<td><strong>IONS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td></td>
<td>4.0 g</td>
<td>333 mg/dL</td>
<td>Varies with diet, urine pH, hormones, etc.</td>
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<tr>
<td>Chloride</td>
<td></td>
<td>6.4 g</td>
<td>533 mg/dL</td>
<td></td>
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<tr>
<td>Potassium</td>
<td></td>
<td>2.0 g</td>
<td>166 mg/dL</td>
<td>Varies with diet, urine pH, hormones, etc.</td>
</tr>
<tr>
<td>Calcium</td>
<td></td>
<td>0.2 g</td>
<td>17 mg/dL</td>
<td>Hormonally regulated (PTH/CT)</td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
<td>0.15 g</td>
<td>13 mg/dL</td>
<td></td>
</tr>
<tr>
<td><strong>BLOOD CELLS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RBCs</td>
<td></td>
<td>130,000/day</td>
<td>100/mL</td>
<td>Excess (<em>hematuria</em>) indicates vascular damage in urinary system</td>
</tr>
<tr>
<td>WBCs</td>
<td></td>
<td>650,000/day</td>
<td>500/mL</td>
<td>Excess (<em>pyuria</em>) indicates renal infection or inflammation</td>
</tr>
</tbody>
</table>

*Representative values for a 70-kg (154-lb) male.
†Usually estimated by counting the cells in a sample of sediment after urine centrifugation.
Urine Transport, Storage, and Elimination

Urinary tract

- Ureters
- Urinary bladder
- Urethra

Structures

- Minor and major calyces of kidneys, renal pelvis, ureters, urinary bladder, and proximal portion of urethra
  - Lined by *transitional epithelium*
  - So …undergoes cycles of distention and contraction
Urine Transport, Storage, and Elimination

**Ureters** - pair of muscular tubes
- Extend from kidneys to urinary bladder
- Begin at renal pelvis
- Are retroperitoneal, attached to posterior abdominal wall
- Penetrate posterior wall of the urinary bladder
- Pass through bladder wall at oblique angle
- Ureteral openings are slit-like rather than rounded
- Shape helps prevent backflow of urine when urinary bladder contracts

**Peristaltic Contractions**
- Begin at renal pelvis and sweep along ureter
- Force urine toward urinary bladder - every 30 seconds
Histology of the Ureters

- **Inner mucosa** - Transitional epithelium and lamina propria
- **Middle muscular layer** - Longitudinal and circular bands of smooth muscle
- **Outer connective tissue layer** - Continuous with fibrous renal capsule and peritoneum
Urinary Bladder - hollow, muscular organ

- Functions as temporary reservoir for urine storage
- Full bladder can contain 1 liter of urine
Urinary Bladder

Mucosa

- Lining the urinary bladder has folds (rugae) that disappear as bladder fills

Trigone of the Urinary Bladder-triangular area bounded by openings of ureters and entrance to urethra

- Acts as a funnel -Channels urine from bladder into urethra

Urethral Entrance

- Lies at apex of trigone- most inferior point in urinary bladder
Urinary Bladder

**Neck** of the Urinary Bladder - region surrounding urethral opening

- Contains a muscular **internal urethral sphincter**
- Smooth muscle - involuntary control of urine discharge

**Histology of the Urinary Bladder**

- Contains mucosa, submucosa, and muscularis layers
  - Form powerful detrusor muscle of urinary bladder
  - Contraction compresses urinary bladder and expels urine

**Muscularis Layer** - Consists of the **detrusor muscle**

- Inner and outer layers of longitudinal smooth muscle with a circular layer in between
Urethra

- Extends from neck of urinary bladder to the exterior of the body

**Male Urethra** - Extends from neck of urinary bladder to tip of penis

- **Prostatic urethra** passes through center of prostate gland
- **Membranous urethra** includes short segment that penetrates the urogenital diaphragm
- **Spongy urethra** (penile urethra) extends from urogenital diaphragm to external urethral opening
Urethra

Female Urethra

- very short (3–5 cm; 1-2 in.)
- Extends from bladder to vestibule
- External urethral orifice is near anterior wall of vagina

External Urethral Sphincter

- In both sexes - circular band of skeletal muscle
- urethra passes through urogenital diaphragm
- Acts as a valve and under voluntary control
  - Has resting muscle tone and
  - Voluntarily relaxation permits micturition
Micturition

Infants

- Lack voluntary control over urination

Incontinence - the inability to control urination voluntarily

- May be caused by trauma to internal or external urethral sphincter

Age-Related Problems with micturition reflex

- Sphincter muscles lose tone leading to incontinence
- Control of micturition can be lost due to a stroke, Alzheimer disease, and other CNS problems
- In males, urinary retention may develop if enlarged prostate gland compresses the urethra and restricts urine flow
25-3 The Kidneys

- Lie on bilaterally to vertebrae and retroperitoneal
- Left kidney lies superior to right kidney
- Superior surface capped by suprarenal (adrenal) gland

Typical Adult Kidney - about 10 cm long, 5.5 cm wide, and 3 cm thick (4 in. x 2.2 in. x 1.2 in.) and weighs about 150 g (5.25 oz)
The Kidneys

Each kidney is protected and stabilized by:

- **Fibrous (renal) capsule**
  - A layer of collagen fibers
  - Covers outer surface of entire organ

- **Fat capsule**
  - A thick layer of adipose tissue
  - Surrounds renal capsule

- **Renal fascia**
  - A dense, fibrous outer layer
  - Anchors kidney to surrounding structures
The Kidneys

Hilum
- Point of entry for renal artery and renal nerves
- Point of exit for renal vein and ureter

Renal Cortex
- Superficial portion of kidney in contact with renal capsule –contains nephrons (functional units)

Renal Pyramids
- 6 to 18 distinct conical or triangular structures in renal medulla -tip (renal papilla) projects into renal sinus
The Kidneys

Renal Columns

- Bands of cortical tissue separate adjacent renal pyramids
- Extend into medulla and have distinct granular texture

Renal Lobe

- Consists of
  - Renal pyramid
  - Overlying area of renal cortex and adjacent tissues of renal columns
- Produces urine
The Kidneys

Renal Papilla
- Ducts discharge urine into **minor calyx**, a cup-shaped drain

Major Calyx
- Formed by four or five minor calyces

Renal Pelvis
- Large, funnel-shaped chamber
- Consists of two or three major calyces
- Fills most of renal sinus
- Connected to ureter, which drains kidney
The Kidneys

- Renal cortex
- Renal medulla
- Renal pyramid
- Inner layer of fibrous capsule
- Renal sinus
- Adipose tissue in renal sinus
- Renal pelvis
- Hilum
- Renal papilla
- Connection to minor calyx
- Minor calyx
- Major calyx
- Renal lobe
- Renal columns
- Fibrous capsule
- Ureter
Blood Supply to Kidneys

- Kidneys receive 20–25% of total cardiac output
- 1200 mL of blood flows through kidneys each minute from renal artery

Segmental Arteries

- Receive blood from **renal artery**
- Divide into **interlobar arteries**
  - Which radiate outward through renal columns between renal pyramids
- Supply blood to **arcuate arteries**
  - Which arch along boundary between cortex and medulla of kidney and form **cortical arteries**

**Afferent arterioles** - branch from each **cortical artery** - deliver blood to capillaries supplying individual nephrons
Nervous Innervation

Renal Nerves - Innervate kidneys and ureters

- Enter each kidney at hilum and follows tributaries of renal arteries to individual nephrons

Sympathetic Innervation - adjusts rate of urine formation

- By changing blood flow and blood pressure at nephron
- Stimulates release of renin
  - Which restricts losses of water and salt in urine and stimulates reabsorption at nephron
25-4 Microscopic Histology
The Nephron- Functional Unit

Consists of **renal tubule (filtrate system)** and **renal corpuscle (glomerulus/Bowman’s capsule)**

**Renal tubule** - long tubular passageway – begins with **proximal convoluted tubule (PCT)** through **distal convoluted tubule (DCT)**

- Begins at renal corpuscle -

**Renal corpuscle** - spherical structure consisting of:

- **glomerular capsule (Bowman’s capsule)** - cup-shaped chamber - starts the tubular system of the filtrate - (forms and carries urine).
- **capillary network (glomerulus)**
Cortical and Juxtamedullary Nephrons

(b) Cortical nephron

(c) Juxtamedullary nephron
Glomerulus

Consists of 50 intertwining *fenestrated* capillaries

Blood delivered via **afferent arteriole** and leaves in **efferent arteriole**

- Flows into peritubular capillaries
- Drain into small venules and return blood to venous system
Filtration at Renal Corpuscle

Filtration - Occurs in renal corpuscle

- Blood pressure
  - Forces water and dissolved solutes out of glomerular capillaries into capsular space - hydrostatic pressure
- Produces protein-free solution (filtrate) similar to blood plasma inside capsule
The Glomerulus

*Endothelium-* simple squamous with large-diameter pores (fenestrated capillaries)

Visceral Epithelium - consists of large cells (*podocytes*)

- With complex processes or “feet” (*pedicels*) that wrap around specialized lamina densa of glomerular capillaries

- **Filtration Slits** - narrow gaps between adjacent pedicels

  Materials passing out of blood at glomerulus

  - Must be small enough to pass between filtration slits
Blood Flow Control

- Special supporting cells - (mesangial cells)
  - Between adjacent capillaries
  - Control diameter and rate of capillary blood flow
Bowman’s Capsule

Outer wall is lined by simple squamous **capsular epithelium**

- Continuous with **visceral epithelium** which covers glomerular capillaries
  - separated by **capsular space**
Filtration at Renal Corpuscle

- Is passive

- Blood pressure
  - Forces water and small solutes across membrane into capsular space

Larger solutes, such as plasma proteins, are excluded

- Solute enter capsular space
  - Metabolic wastes (like urea, chemical metabolites), excess water soluble vitamins, and excess ions
  - Glucose, free fatty acids, amino acids, and vitamins
Renal Tubule System of Nephron

Filtrate from Bowman’s capsule empties into the renal tubule system: series of secretory/absorptive tubes that carries tubular fluid away from nephron. capsule ➔ proximal convoluted tubule ➔ nephron loop ➔ distal convoluted tubule ➔ collecting duct

Three Functions of Renal Tubule

1. Reabsorb useful organic nutrients that enter filtrate
2. Reabsorb more than 90% of water in filtrate
3. Secrete waste products that failed to enter renal corpuscle through filtration at glomerulus
Renal Tubule System of Nephron

- Traveling along tubule, filtrate (tubular fluid) gradually changes composition
- Changes vary with activities in each segment of nephron
The Nephron- Renal Tubule System

Segments of Renal Tubule

- Located in cortex- from Bowman’s capsule to
  - Proximal convoluted tubule (PCT)
  - Nephron loop
  - Distal convoluted tubule (DCT)
- PCT and DCT - Separated by **nephron loop (loop of Henle)**
  - U-shaped tube
  - Extends partially into medulla
The Proximal Convoluted Tubule (PCT)

- first segment of renal tubule
- Entrance to PCT lies opposite point of connection of afferent and efferent arterioles with glomerulus

Epithelial Lining of PCT

- simple cuboidal with microvilli (called tubular cells)
- Functions in reabsorption
The PCT

Reabsorption

- Useful materials are recaptured before filtrate leaves kidneys
- Reabsorption occurs in **proximal convoluted tubule**

Epithelial -Tubular Cells

- Absorb organic nutrients, ions, water, and plasma proteins from tubular fluid
- Release them into peritubular fluid (interstitial fluid around renal tubule)
The Nephron Loop

also called **loop of Henle**

- Renal tubule turns toward renal medulla
  - Leads to nephron loop
- Descending limb
  - Fluid flows toward renal pelvis
- Ascending limb
  - Fluid flows toward renal cortex
- Each limb contains
  - **Thick segment**
  - **Thin segment**
The Nephron Loop

Short Thick Descending Limb
- Has functions similar to PCT
  - Pumps sodium and chloride ions out of tubular fluid

Thick Ascending Limb
- Ends at a sharp angle near the renal corpuscle where DCT begins. Sodium and chloride ions pumped out

Thin Segments
- Are freely permeable to water - Not to solutes
- Water movement helps concentrate tubular filtrate
The Distal Convoluted Tubule (DCT)

- The third segment
- Epithelial cells lack microvilli
- Lies near renal corpuscle

Three Processes at the DCT

1. Active secretion of ions, acids, drugs, and toxins
2. Selective reabsorption of sodium and calcium ions from tubular fluid – receptors for aldosterone
3. Selective reabsorption of water: receptors for ADH
   - Concentrates tubular fluid
Specialized Cells Near Renal Corpuscle and DCT

Macula Densa
- Epithelial cells of DCT, near renal corpuscle
- Tall cells with densely clustered nuclei

Juxtaglomerular Cells
- Smooth muscle fibers in wall of afferent arteriole
  - Associated with cells of macula densa
  - Together with macula densa forms juxtaglomerular apparatus/complex (JGA)
    - Endocrine structure – secretes:
      - Hormone *erythropoietin* & Enzyme *renin*
The Collecting System

DCT opens into the collecting system

- Transports tubular fluid from *nephron to renal pelvis*
- Individual nephrons drain into a nearby collecting duct

Several collecting ducts converge into a larger papillary duct

-empties into a minor calyx

Adjusts fluid composition

- determines final osmotic concentration and volume of urine
Collecting System/Ducts

Receive filtrate fluid from many nephrons

- Each collecting duct
  - Begins in cortex
  - Descends into medulla
  - Carries fluid to papillary duct that drains into a minor calyx
Renal Tubule Locations

**Cortical Nephrons**
- 85% of all nephrons
- Located mostly within superficial cortex of kidney
- Nephron loop (Loop of Henle) is relatively short
- Efferent arteriole delivers blood to a network of peritubular capillaries

**Juxtamedullary Nephrons**
- 15% of nephrons
- Nephron loops extend deep into medulla
Urine production maintains homeostasis by regulating:

- volume and composition of blood

includes excretion of metabolic waste products

Three Organic Waste Products

1. Urea
2. Creatinine
3. Uric acid
Renal Physiology

Kidney Functions

- To concentrate filtrate by glomerular filtration
  - Failure leads to fatal dehydration
- Absorbs and retains valuable materials for use by other tissues like sugars and amino acids

Basic Processes in Urine Formation - Nephron

1. Glomerular Filtration
2. Reabsorption
3. Secretion
<table>
<thead>
<tr>
<th>Solute</th>
<th>Urine</th>
<th>Plasma</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IONS (mEq/L)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium (Na&lt;sup&gt;+&lt;/sup&gt;)</td>
<td>90</td>
<td>140</td>
</tr>
<tr>
<td>Potassium (K&lt;sup&gt;+&lt;/sup&gt;)</td>
<td>47.5</td>
<td>4.6</td>
</tr>
<tr>
<td>Chloride (Cl&lt;sup&gt;-&lt;/sup&gt;)</td>
<td>153.3</td>
<td>99</td>
</tr>
<tr>
<td>Bicarbonate (HCO&lt;sub&gt;3&lt;/sub&gt;&lt;sup&gt;-&lt;/sup&gt;)</td>
<td>1.9</td>
<td>24.8</td>
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<tr>
<td><strong>METABOLITES AND NUTRIENTS (mg/dL)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose</td>
<td>0</td>
<td>100</td>
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<td>Lipids</td>
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<td>Proteins</td>
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<tr>
<td><strong>NITROGENOUS WASTES (mg/dL)</strong></td>
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</tr>
<tr>
<td>Urea</td>
<td>900</td>
<td>10–20</td>
</tr>
<tr>
<td>Creatinine</td>
<td>150</td>
<td>1–1.5</td>
</tr>
<tr>
<td>Ammonia</td>
<td>60</td>
<td>&lt;0.1</td>
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<tr>
<td>Uric acid</td>
<td>40</td>
<td>3</td>
</tr>
</tbody>
</table>
Glomerular Filtration

Glomerular Filtration –

*Occurs across glomerulus capillary walls* - water and dissolved materials are pushed into capsular space of Bowman’s capsule.

- Hydrostatic (fluid) pressure forces water and solutes through membrane pores
  - Small solute molecules pass through pores
  - Larger solutes and suspended materials are retained in blood
Glomerular filtration is governed by the balance between

- **Hydrostatic pressure (fluid pressure)**
- **Colloid osmotic pressure (of materials in solution)** on either side of capillary walls

**Glomerular Hydrostatic Pressure (GBHP)** - is blood pressure in glomerular capillaries - tends to push water and solute molecules out of plasma and into the filtrate

**Capsular Hydrostatic Pressure (CHP)** - opposes glomerular hydrostatic pressure - pushes water and solutes out of filtrate and back into plasma

- **Net Hydrostatic Pressure (NHP)** - difference between GBHP and CHP
Glomerular Filtration

Colloid Osmotic Pressure of a Solution - osmotic pressure resulting from the presence of suspended proteins

- Blood colloid osmotic pressure (BCOP)
  - Tends to draw water out of filtrate and into plasma - opposes filtration

Filtration Pressure (NFP)

- average pressure forcing water and dissolved materials
  - Out of glomerular capillaries and into capsular spaces

-The difference between

- Hydrostatic pressure and blood colloid osmotic pressure across glomerular capillaries = 10 mm Hg
Glomerular Filtration

(a) Glomerulus

Pores in endothelium
Capillary lumen
Pedicels of podocytes
Capsular space
Filtration slit
Dense layer

(b) Blood
Plasma protein
Filtration slit
Small solute particles
Filtrate in capsular space
Filtration pressure = 10 mm Hg
Glomerular Filtration Rate (GFR)

- amount of filtrate kidneys produce each minute
  - Averages 125 mL/min (male) 105mL/min (female)
  - About 10% of fluid delivered to kidneys
    - Leaves bloodstream and enters capsular spaces
    - Approximately 1-2 L urine/day

Filtrate

- Glomeruli generate about 180 L (men) of filtrate per day
  - 99% is reabsorbed in renal tubules
Filtration Pressure

- Glomerular filtration rate depends on \textbf{net filtration pressure (NFP)}
- Any factor that alters filtration pressure alters GFR

Control of the GFR

- Autoregulation (local level)
- Hormonal regulation (initiated by kidneys)
- Autonomic regulation (by sympathetic division of ANS)
Reabsorption and Secretion

Involves: Diffusion; Osmosis; Active transport; Carrier-mediated active transport

Reabsorption

- Recovers useful materials from filtrate and returns these materials back to blood via peritubular capillaries that surround nephron to efferent arterioles

Secretion

- Ejects waste products, toxins, and other undesirable solutes – these materials remain in filtrate in renal tubules or enter from interstitial fluids

Both processes occur in every segment of nephron

- Except renal corpuscle
# Tubular Reabsorption and Secretion

<table>
<thead>
<tr>
<th>Reabsorbed</th>
<th>Secreted</th>
<th>No Transport Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ions</td>
<td>Ions</td>
<td>Urea</td>
</tr>
<tr>
<td>$\text{Na}^+$, $\text{Cl}^-$, $\text{K}^+$</td>
<td>$\text{K}^+$, $\text{H}^+$, $\text{Ca}^{2+}$, $\text{PO}_4^{3-}$</td>
<td>Water</td>
</tr>
<tr>
<td>$\text{Ca}^{2+}$, $\text{Mg}^{2+}$, $\text{SO}_4^{2-}$, $\text{HCO}_3^-$</td>
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<td>Urobilinogen</td>
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<td><strong>Wastes</strong></td>
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<tr>
<td>Creatinine</td>
<td></td>
<td>Bilirubin</td>
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<td><strong>Metabolites</strong></td>
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<tr>
<td>Glucose</td>
<td>Ammonia</td>
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<tr>
<td>Amino acids</td>
<td>Organic acids and bases</td>
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<tr>
<td>Proteins</td>
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<tr>
<td>Vitamins</td>
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<tr>
<td><strong>Miscellaneous</strong></td>
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<tr>
<td>Neurotransmitters ($\text{ACh}$, $\text{NE}$, $\text{E}$, $\text{dopamine}$)</td>
<td></td>
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<tr>
<td>Histamine</td>
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<tr>
<td>Drugs (penicillin, atropine, morphine, many others)</td>
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Reabsorption and Secretion at PCT

Functions of the PCT

1. Reabsorption of nearly all organic nutrients and water

2. Active and passive reabsorption of ions

PCT cells normally reabsorb 60–70% of filtrate produced in renal corpuscle

Reabsorbed materials enter peritubular fluid and diffuse into peritubular capillaries
Reabsorption/Secretion Back Into Peritubular Capillaries (vasa recta)

**Sodium**-important in nearly every PCT process

Ions enter peritubular capillaries by

*Active transport*- water follows by

osmosis!

Sodium-linked cotransport -

*symport* of organic solutes to peritubular capillaries:

- glucose, small proteins, a.a’s, vitamins
- ions- Cl, bicarbonate

**Diffusion**- hydrogen ions, ammonium, some drugs
Countercurrent Multiplication

- Exchange that occurs between two parallel segments of loop of Henle
  - The thin, descending limb
  - The thick, ascending limb

* Nephron loop reabsorbs about 1/2 of remaining water and 2/3 of sodium and chloride ions remaining in tubular fluid/filtrate by the process of countercurrent exchange-produces a hypotonic filtrate
Reabsorption and Secretion at Nephron Loop

**Countercurrent** - Refers to exchange between tubular fluids moving in opposite directions

- Fluid in descending limb flows toward renal pelvis
- Fluid in ascending limb flows toward cortex

**Multiplication** - Refers to effect of exchange

- Increases as movement of fluid continues

**Thin Descending Limb:**
- permeable to water - osmosis
- relatively impermeable to solutes

**Thick Ascending Limb:**
- relatively impermeable to water

Contains active transport (pumps) mechanisms
- Pump Na\(^+\) and Cl\(^-\) from tubular fluid into peritubular fluid of medulla
Reabsorption and Secretion at Nephron Loop

**Thin Descending Limb** - permeable to water, impermeable to solutes

- As tubular filtrate flows along thin descending limb-
  - Osmosis moves water into IF, leaving solutes behind
  - Osmotic concentration of tubular filtrate increases

**Sodium and Chloride Pumps** - elevate osmotic concentration in IF around thin descending limb

- Cause osmotic flow of water-out of thin descending tube limb into IF
- Increasing solute concentration in thin descending limb
Reabsorption and Secretion at Nephron Loop

Solute Pumping at *ascending limb*

- Increases solute concentration in descending limb
- Which then accelerates solute pumping in ascending limb – multiplication!

Sodium and Chloride Ions -

- Removed from tubular filtrate in ascending limb
- Elevate osmotic concentration of IF around thin descending limb
Reabsorption and Secretion at Nephron Loop

Thick Ascending Limb - highly effective pumping mechanism

- 2/3 of Na<sup>+</sup> and Cl<sup>-</sup> are pumped out of filtrate before it reaches DCT

- solute concentration in filtrate declines
Benefits of Countercurrent Multiplication

1. Efficiently reabsorbs solutes and water into blood:
   - Before filtrate reaches DCT and collecting system
   - Ensures hypotonic filtrate

2. Establishes concentration gradient:
   - permits passive reabsorption of water from tubular fluid in collecting system:
     - regulated by circulating levels of antidiuretic hormone (ADH)
Reabsorption and Secretion at DCT

Tubular Composition and volume of tubular fluid arriving
- only 15–20% of initial filtrate volume reaches DCT
- concentrations of electrolytes and organic wastes in arriving tubular fluid no longer resemble blood plasma

Selective reabsorption or secretion, primarily along DCT, makes final adjustments in solute composition and volume of tubular fluid - has receptors for ADH and aldosterone
Reabsorption and Secretion-DCT

Tubular Cells at the DCT

- Actively transport Na\(^+\) and Cl\(^-\) out of tubular fluid (secretion)
- Along distal portions: contain ion pumps
  - reabsorb tubular Na\(^+\) in exchange for K\(^+\)
- Adjusts pH- by secreting H\(^+\) and reabsorbing HCO\(_3^-\)

Receptors in both DCT and Collecting Ducts:

- For aldosterone - accelerates sodium reabsorption:
- For antidiuretic hormone (ADH) - stimulates reabsorption of water
Reabsorption and Secretion-DCT

Hydrogen Ion Secretion/Reabsorption - By H\(^+\) removal and bicarbonate production at kidneys - important to homeostasis

- Acidifies tubular fluid and can elevates blood pH

Examples:

**Acidosis** – low blood pH

- Lactic acidosis develops after exhaustive muscle activity
- Ketoacidosis develops in starvation or diabetes mellitus

**Alkalosis** - abnormally high blood pH

- Can be caused by prolonged aldosterone stimulation
Renal Threshold (tubular maximum, $T_m$)- the plasma concentration at which a specific compound or ion begins to appear in urine - Varies with the substance involved  Examples:

**Renal Threshold for Glucose** - approximately 180 mg/dL

- If plasma glucose is greater than 180 mg/dL
  - $T_m$ of tubular cells is exceeded
  - Glucose appears in urine: - Glycosuria

**Renal Threshold for Amino Acids**

- Amino acids commonly appear in urine
  - After a protein-rich meal - Aminoaciduria
25-7 Control of Blood Flow

Autoregulation of the GFR

- Maintains GFR despite changes in local blood pressure and blood flow
- By changing diameters of afferent arterioles, efferent arterioles, and glomerular capillaries

Hormonal Regulation of the GFR

- By hormones of the
  - Renin–angiotensin system
  - Natriuretic peptides (ANP)
Control of Blood Flow

- **Autoregulation of the GFR**
  - Reduced blood flow or glomerular blood pressure triggers
    - Dilation of afferent arteriole
    - Dilation of glomerular capillaries
    - Constriction of efferent arterioles
  - Rise in renal blood pressure
    - Stretches walls of afferent arterioles
    - Causes smooth muscle cells to contract
    - Constricts afferent arterioles
    - Decreases glomerular blood flow
Renin–Angiotensin System

- Three stimuli cause the juxtaglomerular complex (JGA) to release renin

1. Decline in blood pressure at glomerulus due to decrease in blood volume
2. Fall in systemic pressures due to blockage in renal artery or tributaries
3. Stimulation of juxtaglomerular cells by sympathetic innervation due to decline in osmotic concentration of tubular fluid at macula densa
Endocrine Regulation

Renin–Angiotensin System: Angiotensin II Activation

- Constricts efferent arterioles of nephron
  - Elevating glomerular pressures and filtration rates
- Stimulates reabsorption of sodium ions and water at PCT
- Stimulates secretion of *aldosterone* by suprarenal (adrenal) cortex
- Stimulates thirst
- Triggers release of *antidiuretic hormone (ADH)*
  - Stimulates reabsorption of water in distal portion of DCT and collecting system
The Response to a Reduction in the GFR.
Natriuretic Peptides - released by the heart in response to stretching walls due to increased blood volume or pressure

- Atrial natriuretic peptide (ANP) is released by atria
- Trigger dilation of afferent arterioles and constriction of efferent arterioles
- Elevates glomerular pressures and increases GFR
- Oppose secretion of aldosterone and its actions on DCT and collecting system

Parathyroid Hormone and Calcitriol - levels regulate reabsorption at the DCT
Control of Urine Volume and Osmotic Concentration

Through control of water reabsorption at:

- Water is reabsorbed by osmosis early in:
  - PCT and descending loop of nephron
- Water volume and solute concentration is regulated by hormones in DCT and collecting ducts:
  - Aldosterone, ADH, and PTH
Fluid Volume

ADH

- Higher levels of ADH increase reabsorption of water into Blood by:
  - Increasing permeability of DCT and collecting system

Without ADH

- Water is not reabsorbed
- All fluid reaching DCT is lost in urine - producing large amounts of dilute urine
The Effects of ADH on the DCT and Collecting Duct.
Reabsorption/Secretion in DCT and Collecting Duct

In the DCT and Collecting Duct

**Aldosterone**

Sodium, chloride ion reabsorption

Secretion potassium

**PTH**

Calcium reabsorption

Collecting Duct

- *Reabsorbs and secretes most ions, minerals, and urea*
Collecting Duct

Control body fluid pH - hydrogen or bicarbonate ions

Low pH in IF surrounding collection system:
- Carrier proteins - Pump $H^+$ into tubular fluid
- Reabsorb bicarbonate ions

High pH in IF surrounding collection system:
- Collecting system - Secretes bicarbonate ions
  - Pumps $H^+$ into peritubular fluid
Reabsorption and Secretion of Urea

Urea and the Concentration Gradient - diffusion

- Descending limb of nephron loop and collecting ducts are permeable to urea
- As water is reabsorbed, concentration of urea rises

Urine Production

- A healthy adult produces
  - Approximately 1-2 L per day (0.6% of filtrate)
Diuretics and Fluid Volume

Diuresis - is the elimination of urine

- Typically indicates production of large volumes of urine

Diuretics

- Are drugs that promote water loss in urine
- Diuretic therapy reduces
  - Blood volume
  - Blood pressure
  - Extracellular fluid volume
Summary - Renal Function

Step 1: Filtration of Blood - Glomerulus

- Filtrate produced at renal corpuscle has the same composition as blood plasma (minus plasma proteins)

Step 2: Reabsorption – PCT

Active removal of ions and organic substrates from tubes into pericapillary beds (blood)

- Produces osmotic water flow out of tubular fluid
- Reduces volume of filtrate
- All glucose, amino acids, and about 65% of Na and water reabsorbed.
Renal Function – Nephron Loop

Countercurrent Exchange

Step 3: Descending Limb

- Water moves into peritubular capillaries, leaving highly concentrated tubular fluid
- Reduction in volume occurs by obligatory water reabsorption
- No solutes are reabsorbed

Step 4: Thick Ascending Limb

- Tubular cells actively transport Na\(^+\) and Cl\(^-\) out of tubule
- Urea accounts for higher proportion of total osmotic concentration
- No water is reabsorbed
Renal Function – DCT and Collecting Ducts

Step 5: DCT and Collecting Ducts

- Final adjustments in composition of tubular fluid
- Osmotic concentration is adjusted through active transport (reabsorption or secretion)

Step 6: DCT and Collecting Ducts

- Final adjustments in volume and osmotic concentration of tubular fluid
- Exposure to ADH determines final urine concentration
Renal Function

Step 7: Vasa Recta (Pericapillary Bed in Medulla)

- Absorbs solutes and water reabsorbed by nephron loop and the ducts
- Maintains concentration gradient of medulla

Urine Production

- Ends when fluid enters the minor calyx from papillary area of renal pyramid.
The Urinary System and Homeostasis

Kidneys:

**Vitamin D and Calcium**

- Vitamin D activation at kidney - calcidiol from liver is changed to calcitriol, which aids $\text{Ca}^{2+}$ absorption in small intestines
- Calcium reabsorption into blood in PCT and nephron loop
  - hormone PTH

**Erythropoiesis**

- Produce 85% of circulating erythropoietin
Homeostasis

Blood Pressure Regulation

- Water volume and solute concentration is regulated by hormones in DCT and collecting ducts:
  - Aldosterone and ADH
  - Blood pressure low- kidneys synthesize renin.

Osmolarity Regulation

- Similar to BP regulation

Regulation of Electrolytes - sodium, calcium, potassium

Regulation of pH