Chapters 24: Urinary System

**Urinary System:**

Kidneys ain’t just for pee’in

Major Functions of Urinary System:
1) Removal of organic waste products from fluids (excretion)
2) Discharge of waste products into the environment (elimination)
3) Homeostatic regulation of the volume / solute concentration of blood plasma

• Regulate blood volume / blood pressure (renin)
• Regulate red blood cell formation (erythropoietin)
• Stabilize blood pH
• Metabolize vitamin D to active form (Ca**++** uptake)

**Urinary System – Anatomy:**

1) **Kidneys** (retroperitoneal)
   - Renal capsule (collagen fibers)
   - Adipose capsule (support / protection)
   - Renal fascia (fibrous layer – anchoring)

2) **Ureters**
3) **Urinary bladder**
4) **Urethra**
Renal artery

Renal vein

Kidney:

Hilus

Cortex

Medulla

Renal pyramids

Renal columns

Calyces (calyx)

Blood Supply to Kidneys:

- 1/4 of cardiac output delivered to kidneys
  - 0.25 x 5 L / min = 1.25 L / min (kidneys only 0.5% of total body mass)

Nerve Supply to Kidneys:

- Sympathetic nervous system
  1) Adjust rate of urine formation (change blood flow / pressure)
  2) Adjust overall blood pressure / volume (renin release)
Nephron: Functional unit of the kidney (urine formation)
- ~ 1 million / kidney
- Filter ~ 200 L of blood plasma / day
- Produce ~ 1 - 1.5 L of urine / day

Nephron Anatomy:
1) Glomerulus
   - Network of capillaries
   - Tightly wound coil (↑ surface area)
2) Tubule
   - Location of filtrate / urine

Peritubular Capillaries
(Portal System)
Reabsorb materials from
   tubule of nephron

Urinary System – Anatomy:
Nephron: Functional unit of the kidney (urine formation)
- ~ 1 million / kidney
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Nephron Anatomy:
1) Renal Corpuscle (filtration)
   A) Glomerulus
      - Blood enters via afferent artery and exits via efferent artery
      - Fenestrated endothelium
   B) Glomerular Capsule (Bowman’s Capsule)
      - Expanded proximal end of nephron (surrounds glomerulus)
        - Outer layer = simple squamous epithelium
        - Inner layer = Podocytes (foot cells)
Urinary System – Anatomy:
Nephron Anatomy:
1) Renal Corpuscle

Pedicels: Podocyte processes that embrace capillary, form filtration slits
Urinary System – Anatomy:
Nephron Anatomy:

2) **Proximal Convoluted Tubule** (nutrient reabsorption)
   - Continuous with outer layer of glomerular capsule
   - Simple cuboidal epithelium with brush border (↑ surface area)

3) **Loop of Henle** (water conservation)
   - Thin segments (ascending / descending) = simple squamous epithelium
   - Thick segments (ascending / descending) = simple cuboidal epithelium

4) **Distal Convoluted Tubule** (secretion / selective reabsorption)
   - Simple cuboidal epithelium; no microvilli (brush border)
     - Smaller lumen / ↑ number of cells (compared to PCT)
   - **Juxtaglomerular Apparatus**:
     - **Macula Densa cells**: Line DCT near renal corpuscle
       - tall cells – nuclei clustered together
       - Measures [osmotic] of tubule filtrate
     - **Juxtaglomerular cells**: Modified smooth muscle cells; located in afferent artery
       - Release renin if 1) ↓ glomerular BP, 2) ↓ tubule fluid [osmotic]
       - **Renin-angiotensin Mechanism** (↑ blood pressure)
Urinary System – Anatomy:
Nephron Anatomy:
5) **Collecting Ducts** (secretion / selective reabsorption)
   - Simple cuboidal epithelium → simple columnar epithelium
Urinary System – Anatomy:

Types of Nephrons:

1) **Cortical Nephrons (85%)**:  
   - Located entirely in the cortex

2) **Juxtamedullary Nephrons (15%)**:  
   - Bowman’s capsule in cortex; loop of Henle in medulla
Urinary System – Anatomy:

- Interlobular artery
- Afferent arteriole
- Glomerular capillaries
- Efferent arteriole
- Peritubular capillaries
- Bowman’s capsule
- Tubule

Urinary System – Physiology:

- Single day → kidneys filter 60x normal blood plasma volume present
  - Consume 20 - 25 % of all oxygen at rest

  Filtrate = all blood borne solutes except proteins
  Urine = metabolic waste and unneeded solutes

- Major processes in urine formation:
  1) **Glomerular filtration** (glomeruli)
  2) **Tubular reabsorption** (renal tubules)
  3) **Tubular secretion** (renal tubules)
Urinary System – Physiology:
1) **Glomerular Filtration:**
   A) Blood pressure = driving force
Glomerular Hydrostatic Pressure

Net Filtration Pressure = 55 mm Hg - (15 mm Hg + 30 mm Hg)

Urinary System – Physiology:
1) Glomerular Filtration:
   A) Blood pressure = driving force

Net Filtration Pressure = 10 mm Hg
1) Glomerular Filtration:
   A) Blood pressure = driving force
   B) Molecules Filtered < 3 nm Diameter
      - Water, glucose, amino acids, ions, nitrogenous waste (cells / proteins too large)
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1) **Glomerular Filtration:**
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   **Capillary endothelial cell**
   **Basement Membrane**
   **Podocytes**
   **Filtration slits**
   **Filtration membrane**
   **Water, glucose, amino acids, ions, nitrogenous waste**

   C) **Glomerular filtration rate** (GFR):
      • Volume of fluid filtered into Bowman’s capsule / minute
        • Normal adult = 120-150 ml / min
      • Factors governing filtration rate:
        1) Surface area \( (65 ft^2 / 	ext{kidney}) \) Relatively fixed…
        2) Filtration membrane permeability
        3) Net filtration pressure (\( \downarrow 20\% \text{GHP} = \text{no filtration} \))

   • Control of GFR
      1) Autoregulation: Local changes in afferent / efferent arteriole diameters
         • Reduced blood flow (\( \downarrow \text{GHP} \)) = Dilation of afferent arteriole
           Relaxation of glomerular capillaries
           Constriction of efferent arteriole
         Increased blood flow (\( \uparrow \text{GHP} \))
Urinary System – Physiology:

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  2) Hormonal Regulation: Renin-angiotensin mechanism...

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**Creatinine Clearance Test**
- Metabolite of creatine phosphate
- Eliminated in urine (not reabsorbed…)

\[
\text{Amount cleared in urine (mg / h)} \quad \frac{\text{Amount in blood (mg / dl)}}{\text{Rate (ml / min)}}
\]

**Chapters 24: Urinary System**

**Juxtaglomerular Apparatus:**
- Decline in glomerular blood pressure
- Sympathetic stimulation
- ↓ [osmotic] (macula densa cells…)

\[
\text{Renin release} \quad \text{Angiotensin activation}
\]

- Efferent arteriole constriction
- Thirst sensation
- ADH release from pituitary
- Sympathetic motor tone
B) Molecules Filtered < 3 nm Diameter

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      2) Hormonal Regulation: Renin-angiotensin mechanism…
      3) Autonomic Regulation: Sympathetic innervation
         • Associated with vasoconstriction of afferent arteriole (over-rides local control)

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Chapters 24: Urinary System

Urinary System – Physiology:

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2) Tubular Reabsorption:
   • Return of fluid from renal tubules to blood
   • ~ 80% of water & solutes reabsorbed at proximal convoluted tubule

   A) Active processes:
      • Chemicals moved against gradient
      • Requires ATP (pumps in epithelial cell membranes)

   B) Passive processes:
      • Chemicals move down gradients

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Urinary System – Physiology:

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Urinary System – Physiology:
2) Tubular Reabsorption:
Assisting movement into blood:
- Highly permeable basement membrane
- Low blood pressure and high [protein] in capillary

Transport Maximums ($T_m$)
- Diabetes

Key:
- = Primary active transport
- = Secondary active transport
- = Passive transport (diffusion)
- = Protein carrier
- = Ion channel

Urinary System – Physiology:
2) Tubular Reabsorption:
- Absorptive capabilities of tubules:

<table>
<thead>
<tr>
<th>Proximal Convoluted Tubule</th>
<th>Loop of Henle</th>
<th>Distal Convoluted Tubule &amp; Collecting Duct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose (100%)</td>
<td>Na$^+$ (~25%)</td>
<td>Na$^+$ (hormone dependent)</td>
</tr>
<tr>
<td>Amino acids (100%)</td>
<td>Water (~25%)</td>
<td>Water (hormone dependent)</td>
</tr>
<tr>
<td>Na$^+$ (~70%)</td>
<td>Cl$^-$ (~35%)</td>
<td>Cl$^-$ (hormone dependent)</td>
</tr>
<tr>
<td>Water (~70%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCO$_3^-$ (~90%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl$^-$ (~50%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Urinary System – Physiology:
2) Tubular Reabsorption:
   • Non-reabsorbed substances:
     1) Urea (~ 21 g / day)
        • Result of amino acid breakdown
     2) Creatinine (~ 1.8 g / day)
        • Result of creatine phosphate breakdown
     3) Uric Acid (~ 480 mg / day)
        • Result of nucleotide breakdown
   • Not reabsorbed because:
     A) Lack protein carriers
     B) Not lipid soluble
     C) Too large to pass through membrane pores

Urinary System – Physiology:
3) Tubular Secretion:
   • Movement of material from capillary / tubule cells to filtrate
   • Functions:
     A) Eliminating substances not in filtrate (e.g., antibiotics)
     B) Eliminating substances reabsorbed (e.g., urea)
     C) Eliminating excess K⁺ (exchanged for Na⁺)
     D) Balancing pH
        \( \text{(H}^+ / \text{HCO}_3^- \text{): dependent on pH of peritubular blood} \)
Urinary System – Physiology:
Regulation of Urine Volume / Concentration:

Osmolality: \((\text{Osml})\)

# of solute particles dissolved in 1 L of water

Units:
\[ \text{Osml} = 1 \text{ mole of non-ionizing substance in 1 L of water} \]
- 1 mole glucose dissolved in 1 L water = 1 Osmol
- 1 mole of NaCl dissolved in 1 L water = 2 Osmol

\[ m\text{Osml} = 0.001 \text{ Osml} \]

Hyper-osmotic
\((\uparrow \text{Osml})\)

Hypo-osmotic
\((\downarrow \text{Osml})\)
1) Descending limb of loop of Henle permeable to water but not solutes
2) Ascending limb of loop of Henle actively pumps out NaCl but is impermeable to water.

3) Collecting ducts in medulla are permeable to urea (assists in maintenance of interstitial gradient).
Urinary System – Physiology:
Regulation of Urine Volume / Concentration:

**Formation of Dilute Urine (~ 100 mOsm):**
- 15 – 19 ml fluid / min produced (~ 22.5 L urine / day)
- Collecting ducts impermeable to water
- **Diuretics** = Chemicals that enhance urinary output
  - Used to treat various medical conditions (e.g., hypertension)

**Formation of Concentrated Urine (~ 1200 mOsm):**
- 1.0 ml fluid / min produced (~ 1.5 L urine / day)
- Hormonally controlled (**facultative water reabsorption**)
  1) **Antidiuretic Hormone** (ADH)
Urinary System – Physiology:
Regulation of Urine Volume / Concentration:

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Formation of Concentrated Urine (~ 1200 mOsml):
- 1.0 ml fluid / min produced (~ 1.5 L urine / day)
- Hormonally controlled (facultative water reabsorption)
  1) Antidiuretic Hormone (ADH)
  2) Aldosterone

Water channels open in distal tubule and collecting duct

Activation of osmoreceptors in hypothalamus

↑ osmolality of blood

Alcohol

↑ ADH (posterior pituitary)
Urinary System – Physiology:

Regulation of Urine Volume / Concentration:

- ↑ Aldosterone (adrenal cortex)
- Angiotensinogen converted to Angiotensin II
- Renin released

↑ reabsorption of Na⁺
↑ reabsorption of water
↑ secretion of K⁺

↓ blood volume (↓ BP)
↓ [Na⁺]
↑ [K⁺]

Chapters 24: Urinary System

Urinary System – Physiology:

Summary:
Urinary System – Physiology:
Composition of Urine:
- 95% water
- 5% solutes
  - Nitrogenous wastes (urea > creatinine > uric acid)
  - Ions (Na⁺, K⁺, phosphates, sulfates)

Physical Characteristics of Urine:
1) Color & Transparency
   - Dilute = clear / pale yellow; Conc. = deep yellow (urobilin)
2) Odor
   - Fresh = slight odor; Old = ammonia odor (bacterial metabolism)
3) pH
   - Acidic (pH ~ 6)

Urinary System – Physiology:
Urine Transport, Storage, and Elimination:
1) Ureters: Convey urine from kidney to bladder
   - Movement = Peristalsis
   - Histology:
     - Mucosa (Transitional epithelium)
     - Smooth muscle layer (longitudinal / circular)
     - Adventitia
     ➢ Kidney Stones
Urinary System – Physiology:
Urine Transport, Storage, and Elimination:
2) **Bladder**: Collapsible, muscular sack → urine storage
   - Retroperitoneal (maximum capacity ~ 1 L)
   - Histology:
     - Mucosa (Transitional epithelium)
     - Smooth muscle layer *(Detrusor muscle)*
     - Adventitia / serosa

3) **Urethra**: Opening to external environment
   - Distinct between sexes
   - Histology:
     - Mucosa (Stratified epithelium – transitional / columnar / squamous)
       - Mucin-secreting cells present
     - Lamina propria anchors to surrounding structures
Urinary System – Physiology:
Urine Transport, Storage, and Elimination:

Micturition (urination):

Incontinence:
Inability to control urination voluntarily (e.g., spinal cord injury)

If not acknowledged, relaxation for ~ 1 hr.

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