Urinary System

- Urinary System
  - Functions
    - Regulate blood volume and composition
      - Electrolytes
      - pH
      - Nutrients
      - Volume – blood pressure
      - Erythropoiesis
      - Remove nitrogenous waste products
      - Excretion of wastes and metabolites
      - Gluconeogenesis via glutamine acid
    - Vitamin D synthesis
Urinary System

- Organs of the Urinary System

- Renal pelvis
- Esophagus (cut)
- Hepatic veins (cut)
- Inferior vena cava
- Adrenal gland
- Renal artery
- Renal hilus
- Renal vein
- Aorta
- Kidney
- Ureter
- Iliac crest
- Rectum (cut)
- Uterus (part of female reproductive system)
- Urinary bladder
- Urethra
Urinary System

(a) Diagram showing the anatomy of the urinary system, including the inferior vena cava, peritoneum, renal vein, renal artery, adipose capsule, renal capsule, and body wall.

(b) Illustration of the body from the back, highlighting the 12th rib and the body of vertebra L2.
Urinary System

- Gross Anatomy of the Kidney

- [Diagram of the urinary system with labeled parts]

  - Renal column
  - Major calyx
  - Papilla of pyramid
  - Cortex
  - Renal pelvis
  - Minor calyx
  - Renal pyramid of medulla
  - Renal capsule

- Blood flow through the kidneys:
  - Aorta → Renal artery → Segmental artery → Lobar artery → Interlobar artery → Arcuate artery → Interlobular artery → Afferent arteriole → Glomerulus (capillaries)

- Venous return:
  - Inferior vena cava → Renal vein → Interlobar vein → Arcuate vein → Interlobular vein → Peritubular capillaries and vasa recta → Efferent arteriole
Urinary System

• Structure of a Typical Nephron
Urinary System

- Detailed Structure of Nephrons
Urinary System

- Juxtaglomerular Apparatus
Urinary System

- Filtration Membrane
Urinary System

- Mechanisms of Urine Formation
- Glomerular Filtration -
  
  - Glomerular Filtration Rate = 125 ml/min
  
  - Glomerular filtrate – plasma minus blood cells and most blood proteins (about 99% is reabsorbed)
Urinary System

- Regulation of Glomerular Filtration

**Low Blood Pressure in the Renal Blood Vessels**

**Intrinsic Mechanism**
- Myogenic mechanism of autoregulation
  - Renal vascular smooth muscle
  - Vasodilation of afferent arterioles

**Extrinsic Mechanism**
- Tubuloglomerular mechanism of autoregulation
  - Reduced filtrate flow or osmolality in distal tubes
  - Macula densa cells of juxtaglomerular apparatus of kidney
  - Prompted release of vasoactive chemical
  - Vasodilation of afferent arterioles

**Hormonal (renin-angiotensin) mechanism**
- JG cells of juxtaglomerular apparatus of kidney
  - Catalyzes cascade resulting in conversion
  - Angiotensinogen
  - Angiotensin II
  - Systemic arterioles
  - Vasoconstriction; increases peripheral resistance
  - Increased systemic blood pressure

**Neural controls**
- Baroreceptors in blood vessels of systemic circulation
  - Sympathetic nervous system
  - (+) Stimulation

**Key:**
(+)= Stimulation
(-)= Inhibition

**Increased GFR**
Urinary System

- Tubular Reabsorption – movement of filtrate back into the blood

  - Water
  - Glucose
  - Amino Acids
  - Ions
    - Sodium
    - Potassium
    - Calcium
    - Chloride
    - bicarbonate
    - Phosphate
Urinary System

• Reabsorption Routes
  – Paracellular Reabsorption – movement through tight junctions joining cells
  – Transcellular Reabsorption – pass through the cells making up the tubule

• Active Transport
  – Primary Active Transport
  – Secondary Active Transport
  – Transport Maximum $T_m$

• Water Reabsorption
  – Obligatory – follows the movement of solutes
  – Facultative – dependent upon the presence or absence of ADH
Urinary System

- Reabsorption in the PCT

Key:
- Red arrow = Primary active transport
- Red triangle = Secondary active transport
- Blue arrow = Passive transport (diffusion)
- Purple circle = Protein carrier

Filtrate in tubule lumen

Nucleus

Tubule cell

Interstitial fluid

Peritubular capillary

Na⁺

Glucose
Amino acids
Some ions
Vitamins

Urea
Fat-soluble substances

H₂O

Cl⁻
(and other anions), K⁺

3Na⁺

2K⁺

K⁺

Paracellular route
### Urinary System

#### TABLE 25.1  Reabsorption Capabilities of Different Segments of the Renal Tubules and Collecting Ducts

<table>
<thead>
<tr>
<th>Tubule Segment</th>
<th>Substance Reabsorbed</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal convoluted tubule</td>
<td>Sodium ions (Na⁺)</td>
<td>Primary active transport via ATP-dependent Na⁺-K⁺ carrier; sets up electrochemical gradient for passive solute diffusion, osmosis, and secondary active transport (cotransport) with Na⁺</td>
</tr>
<tr>
<td></td>
<td>Virtually all nutrients (glucose, amino acids, vitamins)</td>
<td>Active transport; cotransport with Na⁺</td>
</tr>
<tr>
<td></td>
<td>Cations (K⁺, Mg²⁺, Ca²⁺, and others)</td>
<td>Passive transport driven by electrochemical gradient for most; K⁺ mainly by the paracellular route</td>
</tr>
<tr>
<td></td>
<td>Anions (Cl⁻, HCO₃⁻)</td>
<td>Passive transport; paracellular diffusion driven by electrochemical gradient for Cl⁻; active transport (cotransport with Na⁺ for HCO₃⁻)</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>Osmosis; driven by solute reabsorption (obligatory)</td>
</tr>
<tr>
<td></td>
<td>Urea and lipid-soluble solutes</td>
<td>Passive diffusion driven by the electrochemical gradient created by osmotic movement of water</td>
</tr>
<tr>
<td></td>
<td>Small proteins</td>
<td>Endocytosed by tubule cells and digested to amino acids within tubule cells</td>
</tr>
</tbody>
</table>
Urinary System

- Reabsorption in the Loop of Henle

<table>
<thead>
<tr>
<th>Loop of Henle</th>
<th>Descending limb</th>
<th>Water</th>
<th>Na(^+), Cl(^-), K(^+)</th>
<th>Osmosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ascending limb</td>
<td>Na(^+), Cl(^-), K(^+)</td>
<td>Ca(^{2+}), Mg(^{2+})</td>
<td>Active transport of Cl(^-), Na(^+), and K(^+) via a Na(^+)-K(^+)-2Cl(^-) cotransporter in thick portion; also paracellular transport; Na(^+)-H(^+) antitransport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ca(^{2+}), Mg(^{2+})</td>
<td></td>
<td>Passive transport driven by electrochemical gradient; paracellular route</td>
</tr>
</tbody>
</table>
# Urinary System

- Reabsorption in the DCT

<table>
<thead>
<tr>
<th>Distal convoluted tubule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na&lt;sup&gt;+&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ca&lt;sup&gt;2+&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cl&lt;sup&gt;-&lt;/sup&gt;</td>
</tr>
<tr>
<td>Water</td>
</tr>
</tbody>
</table>
Urinary System

- Reabsorption in the Collecting Duct

<table>
<thead>
<tr>
<th>Collecting duct</th>
<th>Na⁺, H⁺, K⁺, HCO₃⁻, and Cl⁻</th>
<th>Aldosterone-mediated primary active transport of Na⁺ and the medullary gradient create the conditions for passive transport of some HCO₃⁻ and Cl⁻ and cotransport of H⁺, K⁺, Cl⁻, and HCO₃⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Osmosis; facultative water reabsorption; depends on ADH to increase porosity of tubule epithelium</td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>Facilitated diffusion in response to concentration gradient in the deep medulla region; most remains in medullary interstitial space</td>
<td></td>
</tr>
</tbody>
</table>
Urinary System

- Secretion of H+ and Absorption of HCO3- by Intercalated Cells

Key:
- Proton pump (H+ ATPase)
- HCO3-/Cl- antiporter
- Diffusion
Urinary System

• Tubular Secretion
  
  – The last way to alter the composition of the urine by taking materials in the blood and giving them to the fluid
  
  – Takes place for the most part in the PCT
Urinary System

- Regulation of Urine Concentration and Volume
  - Counter Current Multiplier/Counter Current Exchanger

Key:
- Red = Active transport
- Blue = Passive transport
Urinary System

- Formation of Dilute and Concentrated Urine

(a) Key:
- Red = Active transport
- Blue = Passive transport
Urinary System

- Evaluation of Kidney Function
  - urinalysis
  - Blood Tests
    - Blood Urea Nitrogen (BUN) – amount of nitrogen in the blood that is part of urea
    - Plasma Creatinine – metabolism of creatine phosphate in muscle tissue
  - Renal Plasma Clearance – an indication as to how effectively the kidneys remove (clear) a substance from blood plasma
    - Inulin – frequently used as a standard to determine clearance – it is filtered into the nephron but is not reabsorbed
Urinary System

• Clearance

- \( C \) = clearance
- \( P \) = concentration of substance in plasma (mg/ml)
- \( U \) = concentration of substance in urine (mg/ml)
- \( V \) = flow rate of urine production (ml/min)

\[ RC = UV/P \]

For inulin this is typically 125 ml/min, which then tells us the amount of plasma that is filtered per minute
Urinary System

• Urine Movement
  
  – Urine Flow Through the Nephron and Ureters
    
    • Hydrostatic pressure forces urine through the nephron
    
    • Peristalsis moves urine through the ureters
  
  – Micturition Reflex
    
    • Stretch of urinary bladder stimulates a reflex causing bladder to contract and sphincters to relax
    
    • Higher brain centers can inhibit this reflex
Urinary System

- Pons
- Pontine storage center
- Lower thoracic or upper lumbar spinal cord
- Sympathetic fibers
- Inferior hypogastric ganglion
- Bladder
- Internal urethral sphincter
- External urethral sphincter
- Visceral afferent fibers of pelvic nerves
- Sympathetic fibers in hypogastric nerve
- Sacral spinal cord
- Somatic motor fibers of pudendal nerve

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