Chapter 11
Lecture Outline

See separate PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.
Urinary System
Points to ponder

• What are the parts and functions of the urinary system?
• What is the macroscopic and microscopic structure of the kidney?
• What are the three processes in urine formation?
• How is the kidney involved with regulating water-salt and acid-base balance of blood?
• What are the common disorders of the kidney?
• How can kidney failure be treated?
• How is the kidney involved with maintaining homeostasis along with other body systems?
What are the organs of the urinary system?

- **Kidneys** (2) – bean-shaped, fist-sized organ where urine is formed

- **Ureters** (2) – small, muscular tubes that carry urine from the kidneys to the bladder

- **Bladder** (1) – expandable organ that stores urine until it is expelled from the body

- **Urethra** (1) – tube (longer in men than women) that carries urine from the bladder to the outside of the body
11.1 Urinary system

Overview of the urinary system

1. Kidneys produce urine.
2. Ureters transport urine.
3. Urinary bladder stores urine.
4. Urethra passes urine to outside.

Adrenal glands produce aldosterone.

Figure 11.1 The urinary system.
What are the functions of the urinary system?

1. Excretion of metabolic wastes
2. Maintenance of water-salt balance
3. Maintenance of acid-base balance
4. Hormone secretion: renin and erythropoietin (EPO)
5. Reabsorb filtered nutrients and synthesize vitamin D
1. Excretion

- Mostly of nitrogenous wastes
  - **Urea** is made by the breakdown of amino acids in the liver.
  - **Uric acid** is made by the breakdown of nucleotides.
  - **Creatinine** is made by muscle cells from the breakdown of creatine phosphate.
2 and 3. Maintenance of water-salt and acid-base balance

- These are homeostatic mechanisms.

- Water-salt balance helps to maintain blood pressure.

- The kidneys excrete hydrogen ions and reabsorb bicarbonate ions; this acid-base balance helps maintain a blood pH of 7.4.
4. Hormone secretion

- Renin – secreted by the kidneys to allow the adrenal glands to secrete aldosterone to help regulate water-salt balance

- **Erythropoietin** – secreted by the kidneys to stimulate red blood cell production when blood oxygen is low
5. Reabsorb filtered nutrients and synthesize vitamin D

- The urinary system is responsible for reabsorbing filtered nutrients.

- Vitamin D is a molecule that promotes calcium absorption from the digestive tract.
How does the urinary bladder work?

- It stores urine, sphincters keep it closed.
- Expandable wall contains a middle layer of circular fibers of smooth muscle and 2 layers of longitudinal smooth muscle.
- Lining of transitional epithelium allows expansion of mucosa.
- Filling activates stretch receptors which signal to spinal cord.
11.1 The Urinary System

Control of the urinary bladder

Figure 11.2 Sensory impulses trigger a desire to urinate.
What are the 3 regions of the kidney?

- **Renal cortex** – an outer granulated layer
- **Renal medulla** – cone-shaped tissue masses called renal pyramids
- **Renal pelvis** – central cavity that is continuous with the ureter
11.2 Kidney Structure

Anatomy of the kidney

Figure 11.3 The anatomy of a human kidney.

11.3b: © James Cavallini/Science Source; 11.3c: © Ralph Hutchings/Visuals Unlimited/Corbis
What are nephrons?

- Microscopic functional unit of the kidney that produces urine
- > 1 million per kidney
What are nephrons?

Figure 11.4 The structure of a nephron.
Anatomy of a nephron

- **Glomerulus** – a knot of capillaries inside the glomerular capsule where pores produce a blood filtrate

- **Proximal convoluted tubule** – epithelial layer with a brush border of microvilli to allow reabsorption of filtrate components

- **Loop of nephron** – U-shaped structure that has a descending limb to allow water to leave and an ascending limb that pushes out salt
Anatomy of a nephron

- **Distal convoluted tubule** – made of epithelial cells rich in mitochondria and thus is important for movement of molecules from the blood to the tubule (tubular secretion)

- **Collecting ducts** – several nephrons share a collecting duct which serve to carry urine to the renal pelvis
How does the nephron form urine?

11.3 Urine Formation

Glomerular Filtration
Water, salts, nutrient molecules, and waste molecules move from the glomerulus to the inside of the glomerular capsule. These small molecules are called the glomerular filtrate.

Tubular Reabsorption
Nutrient and salt molecules are actively reabsorbed from the convoluted tubules into the peritubular capillary network, and water flows passively.

Tubular Secretion
Certain ions and molecules (e.g., H⁺ and penicillin) are actively secreted from the peritubular capillary network into the convoluted tubules.

Figure 11.6 An overview of urine production.
What are the three processes in the formation of urine?

- Glomerular filtration
- Tubular reabsorption
- Tubular secretion
Glomerular filtration

- Water and small molecules move from the glomerulus to the glomerular capsule, while large molecules and formed elements remain in the glomerular blood.

<table>
<thead>
<tr>
<th>Filterable Blood Components</th>
<th>Nonfilterable Blood Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Formed elements (blood cells and platelets)</td>
</tr>
<tr>
<td>Nitrogenous wastes</td>
<td>Plasma proteins</td>
</tr>
<tr>
<td>Nutrients</td>
<td></td>
</tr>
<tr>
<td>Salts(ions)</td>
<td></td>
</tr>
</tbody>
</table>
Tubular reabsorption and secretion

• Many molecules and ions are reabsorbed from the nephron into the blood.

• Tubular secretion is a second way to remove substances such as drugs, $\text{H}^+$ and creatinine from the blood.

<table>
<thead>
<tr>
<th>Reabsorbed Filtrate Components</th>
<th>Nonreabsorbed Filtrate Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most water</td>
<td>Some water</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Much nitrogenous waste</td>
</tr>
<tr>
<td>Required salts (ions)</td>
<td>Excess salts (ions)</td>
</tr>
</tbody>
</table>
The urinary system and homeostasis

All systems of the body work with the urinary system to maintain homeostasis. These systems are especially noteworthy.

- **Urinary System**: As an aid to all the systems, the kidneys excrete nitrogenous wastes and maintain the water–salt balance and the acid–base balance of the blood. The urinary system also specifically helps the other systems.
  - Production of renin by the kidneys helps maintain blood pressure. Blood vessels transport nitrogenous wastes to the kidneys and carbon dioxide to the lungs. The buffering system of the blood helps the kidneys maintain the acid–base balance.
  - The liver produces urea excreted by the kidneys. The yellow pigment found in urine, called urochrome (breakdown product of hemoglobin), is produced by the liver. The digestive system absorbs nutrients, ions, and water. These help the kidneys maintain the proper level of ions and water in the blood.
  - The kidneys regulate the amount of ions in the blood. These ions are necessary to the contract ion of muscles, including those that propel fluids in the ureters and urethra.

- **Nervous System**: The kidneys regulate the amount of ions (e.g. K⁺, Na⁺, Ca²⁺) in the blood. These ions are necessary for nerve impulse conduction. The nervous system controls urination.

- **Respiratory System**: The kidneys and the lungs work together to maintain the acid–base balance of the blood.

- **Endocrine System**: The kidneys produce renin, leading to the production of aldosterone, a hormone that helps the kidneys maintain the water–salt balance. The kidneys produce the hormone erythropoietin, and they change vitamin D to a hormone. The posterior pituitary secretes ADH, which regulates water retention by the kidneys.

- **Integumentary System**: Sweat glands excrete perspiration, a solution of water, salt, and some urea.

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**Figure 11.7** The urinary system and homeostasis.
How do the kidneys maintain homeostasis?

- Excrete wastes
  - Urea, creatinine, and uric acid
- Water-salt balance of blood
  - Helps regulate blood volume and pressure
- Acid-base balance of blood
  - Helps regulate pH
- Assistance to other systems
  - Endocrine, cardiovascular, skeletal, muscular, nervous, and digestive
What is the juxtaglomerular apparatus?

- Where the afferent arteriole and the distal convoluted tubule touch

- Secretes renin, which causes the release of aldosterone by the adrenal cortex
Figure 11.8  The juxtaglomerular apparatus of the nephron.
How is blood volume and pressure maintained by the kidneys?

- Reabsorption of salt – increases the blood volume
  - **Aldosterone** promotes the excretion of $K^+$ and the reabsorption of $Na^+$.
  - **Atrial natriuretic hormone (ANH)** is secreted by the heart when blood volume increases and inhibits the secretion of aldosterone which promotes the excretion of $Na^+$. 

11.4 Kidneys and homeostasis
How is blood volume and pressure maintained by the kidneys?

- Establishment of solute gradient – a greater concentration is towards the inner medulla

- Reabsorption of water – due to the solute gradient, water leaves the descending limb of the loop of the nephron; then antidiuretic hormone (ADH) from the pituitary plays a role in water reabsorption at the collecting duct
Water reabsorption in nephrons

Figure 11.9 Movement of salt and water within a nephron.

10.4 Kidneys and Homeostasis
What role does alcohol play in this process?

- Alcohol inhibits ADH secretion and thus increases the amount of urine and dehydration.
How is the acid-base balance maintained?

- **Buffers** are a chemical or a combination of chemicals that can take up excess $H^+$ or excess $OH^-$. 

When $H^+$ are added to blood:

$$H^+ + HCO_3^- \rightarrow H_2CO_3$$

When $OH^-$ are added to blood:

$$OH^- + H_2CO_3 \rightarrow HCO_3^- + H_2O$$
How is the acid-base balance maintained?

- The respiratory center in the brain can increase breathing rate if the buffers cannot maintain the pH.

- Ultimately, the kidneys are responsible for maintaining blood pH.
The kidneys and blood pH

Figure 11.10 Blood pH is maintained by the kidneys.
Kidney function disorders

- Diabetes, hypertension, and inherited conditions are the most common cause of renal disease and failure such as:
  - **Urethritis** – localized infection of the urethra
  - **Cystitis** – infection in the bladder
  - **Pyelonephritis** – infection of the kidneys
Kidney function disorders

- Kidney stones – hard granules formed in the renal pelvis due to UTIs, enlarged prostate, pH imbalances, or intake of too much calcium

- Uremia – high levels of urea and other waste substances in the blood that cause a serious condition when water and salts are retained due to extensive nephron damage
How can kidney failure be treated?

• **Hemodialysis** – uses an artificial kidney machine to subtract and add substances to the blood as needed

• Continuous ambulatory peritoneal dialysis (CAPD) – uses the peritoneal membrane to filter the blood and allows a person to go about their normal life without interruption

• Kidney replacement – single kidney transplant with a high success rate
Hemodialysis using an artificial kidney machine

Figure 11.11
Hemodialysis using an artificial kidney machine.