CHAPTER 11

The Urinary System: To Pee Or Not To Pee

LEARNING OBJECTIVES

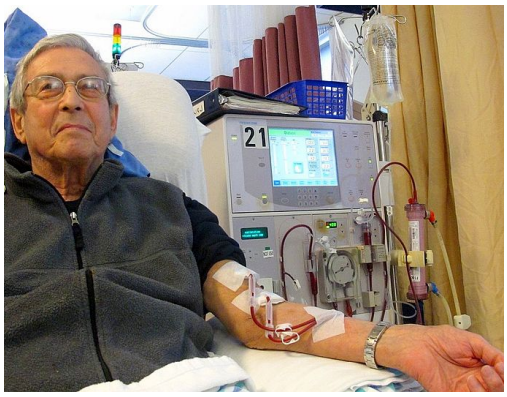
By the end of this class you should be able to:

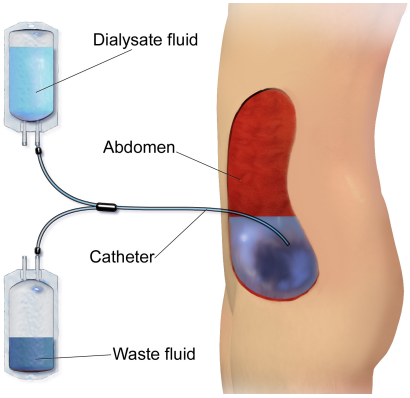
- Describe the urinary system and functions of its different parts.
- Discuss consequences of kidney failure.
- Understand the purpose and principle of dialysis.
- List similarities and differences between male and female urinary systems
- Describe the structure and functions of the kidneys.
- Describe and explain the steps leading to urine formation.
- Perform a urinalysis and discuss the results in relation to kidney function and health

Introduction

Dialysis is a medical process of removing wastes and excess water from the blood by diffusion and ultrafiltration. When kidney function fails, dialysis must be done to artificially rid the body of wastes. This is a vital process to keep patients alive. In some cases, the patients undergo artificial dialysis until they are eligible for a kidney transplant. In others who are not candidates for kidney transplants, dialysis is a life-long necessity. There are two main types of dialysis. Both types filter the blood to rid the body of harmful wastes, extra salt, and water. Dialysis will help patients feel better and live longer, but it is not a cure for kidney failure.

- **Hemodialysis** uses a machine. It is sometimes called an artificial kidney. Patients go to a special clinic for treatments several times a week. During hemodialysis, the blood goes through a filter, called a dialyzer, outside the body. A dialyzer is sometimes called an "artificial kidney." At the start of a hemodialysis treatment, a dialysis nurse or technician places two needles into the patient's arm. Each needle is attached to a soft tube connected to the dialysis machine. The dialysis machine pumps blood through the filter and returns the blood to the patient's body. During the process, the dialysis machine checks for blood pressure and controls how quickly blood flows through the filter and fluid is removed from the body.
- **Peritoneal dialysis** uses the lining of the patient's abdomen, called the peritoneal membrane, to filter the blood. At the start of treatment, dialysis solution—water with salt and other additives—flows from a bag through the catheter into the abdominal cavity. When the bag is empty, it is disconnected and a cap is placed on the catheter so the patient can move around and resume his/her normal activities. While the dialysis solution is inside the patient's abdomen, it absorbs wastes and extra fluid from the body. After a few hours, the solution and the wastes are drained out back into the empty bag and the process is repeated over with a fresh bag of dialysis solution. When the solution is fresh, it absorbs wastes quickly. As time passes, filtering slows. For this reason, refilling the abdomen with a fresh solution is done four to six times every day.





Dialysis. A patient undergoing hemodialysis (left: Anna Frodesiak, Public Domain) and peritoneal dialysis illustration (right; BruceBlaus, CC BY 3.0).

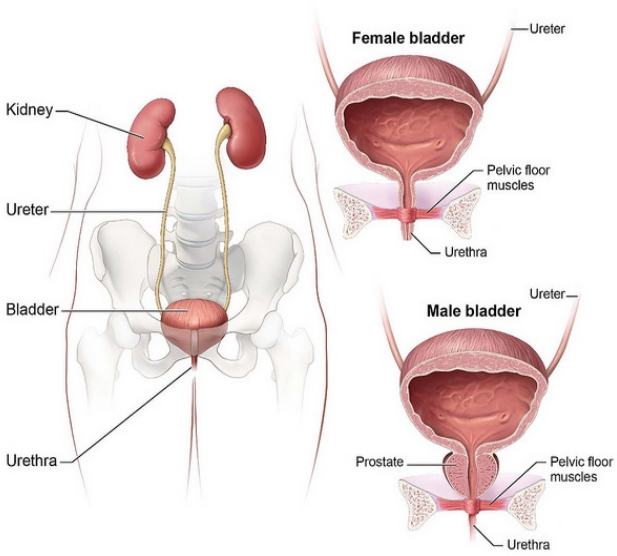
Anatomy of the Urinary System

The human **excretory system** functions to remove waste from the body through the skin as sweat, the lungs in the form of exhaled carbon dioxide, and through the urinary system in the form of urine. All three of these systems participate in osmoregulation and waste removal.

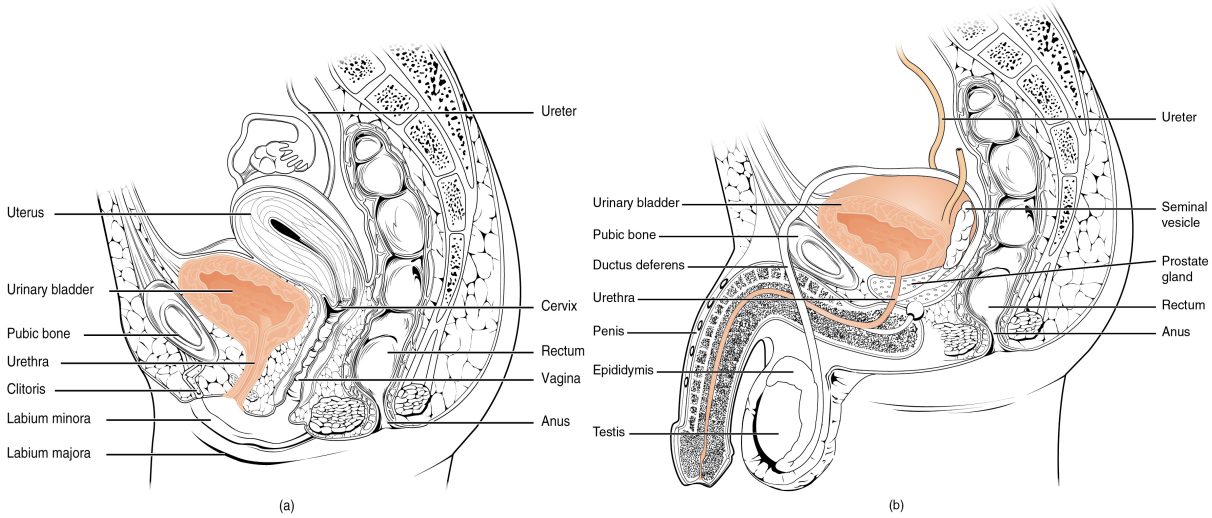
Since kidneys are the major osmoregulatory organ, the urinary system is often times called the excretory system. However, the skin and lungs also play a role in the process. Water and electrolytes are lost through sweat glands in the skin, which helps moisturize and cool the skin surface, while the lungs expel a small amount of water in the form of mucous secretions and via evaporation of water vapor.

The organs of the urinary system are in the abdomen with parts in the pelvic girdle. It includes:

- Two bean-shaped **kidneys** located dorsally to the right and left of the backbone. Your kidneys are roughly the size of your fist, and the male kidney is typically a bit larger than the female kidney. Kidneys receive about 20% of the cardiac output and filter out metabolic wastes from the blood forming urine.
- Two hollow muscular **ureters** which, through waves of peristalsis, convey urine to
- a **urinary bladder** where it is stored. The bladder contains sensory nerves, stretch receptors that signal when it needs to be emptied. These signals create the urge to urinate, which can be voluntarily suppressed up to a limit. The conscious decision to urinate sets in play signals that open the sphincters, rings of smooth muscle that close off the opening, to
- the **urethra** that allows urine to flow out of the bladder and the body. The male urethra passes through the prostate gland immediately inferior to the bladder before passing below the pubic symphysis. The length of the male urethra varies between men but averages 20 cm in length. The short length of the female urethra, about 4 cm, is less of a barrier to fecal bacteria than the longer male urethra and the best explanation for the greater incidence of UTI (urinary tract infections) in women.



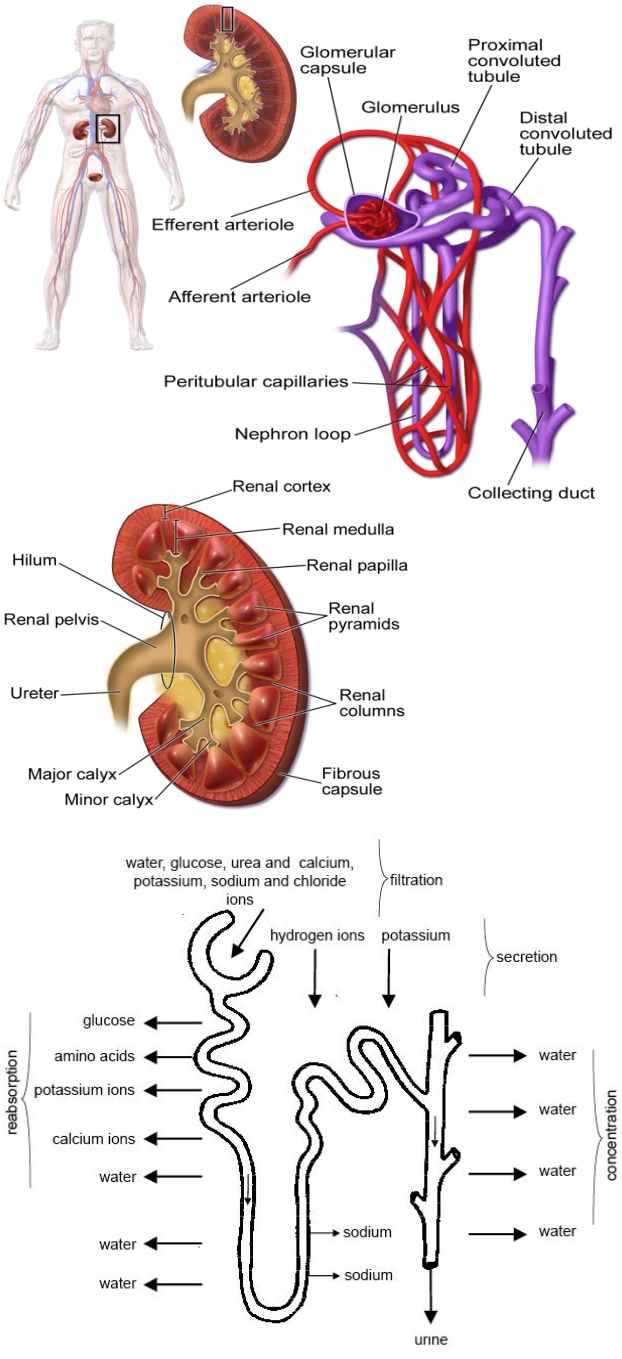
Human Urinary System. (Credit: NIH Image Gallery CC BY-SA NC 2.0)



Female and Male Urethras and Bladders. When the smooth muscles of the urinary bladder contract, urine is expelled through the urethra, a tube located behind the pubic bone for females (a) and extending into the penis for males (b) (Credit: OpenStax College, CC BY 3.0).

The Kidneys Have Important Functions

The main function of the kidney is **osmoregulation**, *i.e.* maintain the electrolytes balance and water content of the blood. This is done by filtration of blood, excretion of metabolic wastes, reabsorption of small molecules such as glucose, amino acids, ions and water. Other functions of the kidney include regulating the **blood pressure and pH**, secreting **hormones** (endocrine functions) and the final synthesis step of **vitamin D production.** Filtration, excretion and absorption all take place in the nephrons. One healthy kidney is enough to filter the blood and regulate fluid content for the body. Each day, the entire blood volume of an average human (7-8 liters) is filtered 20 to 25 times. However, failure of both kidneys is not uncommon, usually resulting from diabetes or high blood pressure complications. Dialysis can somehow mimic the functions of kidneys but must be performed regularly until death or successful kidney transplant.



Kidney Anatomy, the Nephron and Urine Formation. (Credit: top: Modified from BruceBlaus, CC BY-SA 4.0 and bottom: Sunshineconnelly, CC BY 3.0)

Kidney Structure

Each kidney empties into its own ureter which delivers urine to a single urinary bladder for storage. Each kidney contains about 1 million functional units called **nephrons**. A nephron is a tubule consisting of a **glomerular capsule** that surrounds a ball of capillaries called the **glomerulus**, a proximal convoluted tubule that leads to a U-shaped **loop of Henle** and a **distal convoluted tubule** that joins with a **collecting duct**. The outer portion of kidneys is called the **renal cortex** and contains many capillaries while the inner part, the **renal medulla**, contains the **renal pyramids** which are mainly composed of collecting ducts. The **renal pelvis** is a funnel-like structure where urine collects and that joins with the ureter.

Urine Formation

Small amounts of urine are produced by each nephron, collected in the pelvis to be carried and stored in the urinary bladder. Urine formation involves three steps:

i. the partial removal of materials from the glomerular blood by **filtration**; blood pressure and the thin lining of blood vessels, cause small molecules such a as glucose, salts, amino acids, water and urea to exit the blood and enter the glomerular. Cells and proteins are too large to pass through the glomerular capillaries and remain in the blood. The **filtrate** then enters the nephron tubule enveloped with a peritubular capillary.

ii. selective **reabsorption** of useful molecules from the tubules back into the blood occurs as needed to maintain blood volume and pressure, by diffusion and active transport mechanisms, and likewise,

iii. **secretion** of substances in excess from the blood into the nephron happens in the tubule. It is during tubular secretion that medication drugs such as penicillin, are removed from the blood. Hydrogen ions H+ and ammonia NH_3 are secreted as NH_4^+. As kidneys control the amount of H+ in the blood, they influence blood pH.

The remaining fluid flows from the nephron into a collecting duct and moves on to the renal pelvis. The fluid, now called urine, is moved by peristalsis by the ureter to the urinary bladder where it is stored until voided *via* the urethra. Urine formation is controlled by different hormones such as ADH (antidiuretic hormone) and aldosterone which affect urine concentration by modifying the permeability of the tubules.

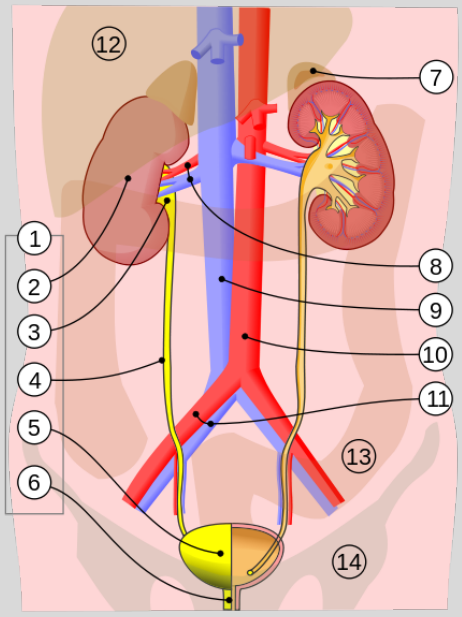
Activity 1 – The Urinary System

1.2 - List urinary/excretory system functions that contribute to homeostasis.

1.3 - Fill-in the blanks: The human urinary system has ____ kidneys, ____ ureters, one ____ _____ and ____ urethra

1.4 - Label the illustrations below:

1- _____
2- _____
3- _____
4- _____
5- _____
6- _____
7- _____
8- _____
9- _____
10- _____
11- _____
12- _____
13- _____
14- _____



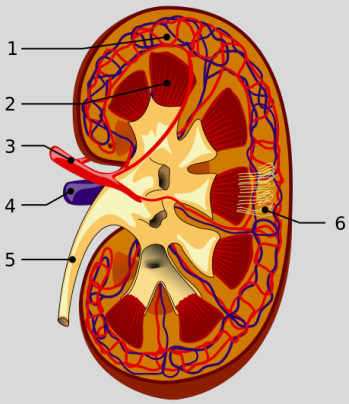
Urinary System Anatomy. (Credits: Jordi March i Nogue CC BY-SA 3.0).

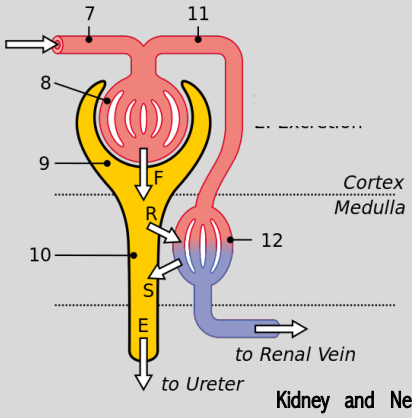
Activity 2 - Kidneys

2.1 - Fill-in the blanks: Kidneys filter the ____ and form urine through the collective work of millions of their functional units, the _____. Urine formation is a ___ steps process: 1. _____ _____, 2. _____ _____ and 3. _____ _____.

2.2 - Label the illustrations below:

15- _____
16- _____
17- _____
18- _____
19- _____
20- _____
21- _____
22- _____
23- _____
24- _____
25- _____
26- _____





Kidney and Nephron Anatomy. (Credits: Daniel Sachse CC BY-SA 3.0).

F: _____ R: _____ S: _____ E: _____

Activity 3 - Urinalysis

Diabetes mellitus (commonly known as diabetes) which means "passing honey-sweet water", is a common metabolic disorder. One of the consequences and symptoms of the disease is glucose being excreted in urine instead of being stored. The resulting high blood sugar leads to complications associated with diabetes (cardiovascular disease, strokes, kidney failure, ulcers, …). Diabetes is due to either the pancreas not producing enough insulin (type I) or the cells of the body not responding properly to the insulin produced (type II). In this activity you will analyze the urine of 3 patients and eventually determine if they have diabetes amongst other diseases that can be detected with such tests. For this, you will use dipsticks to analyze 3 simulated urine samples and determine if they are normal or if they suggest possible disease. Urinalysis can help determine if the kidneys are functioning properly and is also routinely use to detect diabetes mellitus. The test strips have indicator spots the produce specific color reactions when put in contact with certain substances.

3.1 - Obtain 3 test strips, a color key, and samples of each of the 3 urine samples in labeled test tubes and paper towel.

3.2 - Label your test strips.

3.3 - Test your samples by dipping the respective test strips in the tube containing the sample, no longer than 2 seconds. Make sure each square patch is totally immersed. Remove excess urine by gently blotting the strips on a dry piece of towel paper.

3.4 - Read the results after one minute by holding the strip next to the color chart.

3.5 - Enter your results in the table below:

Evaluation of a urine test strip. (Credits: www.medicalgraphics.de CC BY-ND 3.0).

	Sample A	Sample B	Sample C
Leucocytes (LEU)			
Nitrite (NIT)			
Protein (PRO)			
pH			
Blood (BLO)			
Ketones (KET)			
Glucose (GLU)			

4.1 - What are your conclusions for each sample/patient?

Notes:

- *Ketones* are in the urine when the cells are metabolizing fat instead of glucose.
- A urinary tract infection can lead to *leukocytes, blood and protein* in the urine. A bacterial infection of the urinary tract can also lead to *nitrites* in urine..
- Normal *urine pH* ranges from 4.6 to 8. A high pH can be due to kidneys that do not properly remove acids., kdney failure, urinary tract infections, vomiting. A low pH can be due to diabetic ketoacidosis, diarrhea, starvation.

Review Questions
1. What is dialysis? What body functions is it supposed to replace?
2. Is there any difference between the urinary system of male and female?
3. Why are females more likely to contract bladder infections than males?
4. Describe the structure of the kidneys. How do the kidneys contribute to homeostasis?
5. What symptoms might you expect in a person who has kidney failure?
6. How does urine form? Name the substances that are found in the blood, in the filtrate and in urine.
7. What is an urinalysis?
8. What is diabetes mellitus. How can it be easily detected?

With text modified from OpenStax Biology 2e, Anatomy and Physiology, Concepts of Biology and National Institute of Health / National Institute of Diabetes and Digestive and Kidney Disease (NIH/NIDDK)