The Excretory System

OSMOREGULATION (WATER BALANCE)

- Most marine invertebrates are osmoconformers, meaning the concentration of solutes in their body fluid is equal to that of their environment. As a result, they do not gain or lose water.
  - Osmoconformers usually live in water that has a very stable composition (i.e., the ocean) and so their internal environment changes very little.
- Most vertebrates are osmoregulators, meaning they maintain a concentration of solutes in their body fluid different from that of the environment.

Problems faced by osmoregulators:
- Marine vertebrates
  - Maintain a lower salt concentration in the body than in the environment.
  - Having body fluids hypotonic to the environment means water tends to leave the body.
  - They must retain water to prevent dehydration.
  - Marine fishes solve this problem by...
    - Drinking large amounts of seawater.
    - They then excrete excess ions from the blood through the gills or skin. They produce very little urine.
Fresh Water Vertebrates

- Freshwater vertebrates
  - Maintain body fluids hypertonic to the environment, meaning they are constantly gaining water by osmosis and losing solutes by diffusion.
  - Freshwater fishes solve this problem by
    - Not drinking water and excreting a large volume of dilute urine.
    - They replace lost ions by active transport across the gills from the water into the blood.

![Diagram of Osmoregulation in a freshwater fish]

Terrestrial vertebrates

- Have bodies with a higher concentration of water than the surrounding air so they tend to lose water by evaporation from the skin and lungs.
  - The body covering helps prevent water loss.
- Efficient kidneys allow the excretion of concentrated urine to get rid of waste.

A loss of fluid of _____% results in ____________________________.

1
5
10
12
EXCRETION OF NITROGENOUS WASTES

- When animals metabolize amino acids (which contain nitrogen), the toxic byproduct ammonia is produced and must be excreted.
- Animals that excrete this waste as ammonia need access to lots of water because the very toxic chemical must be diluted.
  - For freshwater fish this is not a problem because they can just produce a large volume of dilute urine.
  - Marine fish and terrestrial vertebrates must conserve water so they cannot excrete the waste in the form of ammonia.
    - Instead, in these animals, the ammonia is converted to urea in the liver.
    - Urea is much less toxic (about 100,000 times less toxic than ammonia) and is excreted as a concentrated solution of urea rather than a dilute solution of ammonia.
  - Land snails, insects, birds, and many reptiles excrete uric acid as the main nitrogenous waste. It is also relatively nontoxic.
    - Uric acid does not dissolve very well in water so it crystallizes and is excreted as a semi-solid paste with very little water loss.
**ORGANIZATION OF THE VERTEBRATE KIDNEY**

- In humans, the kidneys are located in the lower back.
- Urine exits each kidney through a duct called the **ureter**, and both ureters drain to a common **urinary bladder**.
  - During **urination**, urine is expelled from the urinary bladder through a tube called the **urethra**, which empties to the outside near the vagina in females or through the penis in males.
- The mammalian kidney has an outer **renal cortex** and an inner **renal medulla**.
  - Both regions are packed with microscopic tubules called **nephrons**.

**Structure of the Nephron**

- Both regions are packed with microscopic tubules called **nephrons**.
- Each human kidney contains about a million nephrons, with a total tubule length of 80 km.
- Each nephron consists of a single long tubule and a ball of capillaries, called the **glomerulus**.
- The closed end of the tubule forms a cup, called **Bowman’s capsule**, which surrounds the glomerulus.
- From Bowman's capsule, the **filtrate** (i.e., the fluid that will become urine) passes through three regions of the nephron: the **proximal tubule**; the **loop of Henle**, a hairpin turn with a descending limb and an ascending limb; and the **distal tubule**.
- The distal tubule empties into a **collecting duct**, which receives processed filtrate from many nephrons.
- The many collecting ducts empty into the **renal pelvis**, which is drained by the ureter...
Filtration - accomplished by the movement of fluids from the blood into Bowman's capsule

Reabsorption - involves the selective transfer of essential solutes and water back into the blood

Secretion - involves the movement of wastes from the blood into the nephron
Blood flow to the kidney

- The many collecting ducts empty into the renal pelvis, which is drained by the ureter.

- Blood flow to the kidney
  - The kidneys are about 1% of body weight but get about 20% of resting cardiac output.
  - Blood enters the kidney through a branch of the aorta called the renal artery which then branches into the smaller afferent arterioles which bring blood to the capillaries of the glomerulus.
  - Blood leaves the capillaries of the glomerulus through an efferent arteriole and enters capillaries in the medulla, where they collect much of the water that was lost through the glomerulus.
  - Venules from these capillaries lead to the renal vein, which exits the kidney and returns blood to the inferior vena cava.

Human water balance

- Water balance in a human (2,500 mL/day = 100%)
  - Ingested in food (750)
  - Ingested in liquid (1,500)
  - Derived from metabolism (250)
  - Feces (100)
  - Urine (1,500)
  - Evaporation (900)
THE KIDNEY AND WASTE REMOVAL FROM THE BLOOD

- **Filtration**
  o As blood passes into the capillaries of the glomerulus, blood pressure forces water and small molecules out of the blood into Bowman's capsule.
  - Proteins and large molecules cannot pass through the walls. Water and small solutes do pass through.
  o The filtrate in Bowman's capsule contains salt, glucose, amino acids, vitamins, nitrogenous wastes such as urea, and other small molecules.
- **Reabsorption** is necessary because filtration is nonselective and useful molecules must be recovered from the urine into the blood.
  o Fluid flows from the capsule to the proximal tubule in the renal cortex where most of the salt (NaCl) and water filtered into the capsule are reabsorbed immediately.
  o This occurs by active transport of Na\(^+\) out of the filtrate into the blood.
  o Water follows both because of osmosis.
  o Most of the water and dissolved solutes that enter the glomerulus are returned to the blood.
  - In humans, between 1000 and 2000 L of blood passes through the kidneys per day. About 180 L of water leaves the blood but most is reabsorbed, and only about 1.5 L of urine is produced.
  o The nephrons and collecting ducts reabsorb nearly all of the sugar, vitamins, and other organic nutrients from the initial filtrate and about 99% of the water.
Reabsorption Continued

- Reabsorption of water continues as the filtrate moves into the descending limb of the loop of Henle.
  - The loop of Henle is permeable to water but not very permeable to salt and other small solutes.
  - The concentration of salt increases as we move further into the medulla, so the loop of Henle continues to lose water.
- In contrast to the descending limb, the ascending limb of the loop of Henle is permeable to salt, but not water.
  - As filtrate ascends the ascending limb, NaCl diffuses out of the permeable tubule, increasing the salt concentration of the medulla.
  - In the upper part of the ascending limb salt is actively transported out of the filtrate.
  - By losing salt without giving up water, the filtrate becomes more dilute as it moves up to the cortex in the ascending limb of the loop.
- When the concentration of some substances in the blood reaches a certain level, the substance is not reabsorbed; it remains in the urine. This regulates the levels of several nutrients in the blood.
- In the distal tubule several different ions are actively transported into and out of the filtrate.

Secretion/Excretion

- Secretion
  - Because filtration is not selective, some things must be deliberately removed from the blood after filtration.
  - Certain ions, drugs and organic molecules not removed by filtration are actively transported from the blood to the filtrate.
  - This is similar to reabsorption but in the opposite direction.

- Excretion
  - By actively reabsorbing NaCl, the collecting duct plays a large role in determining how much salt is actually excreted in the urine.
  - The duct is permeable to water but not to salt and the permeability is under hormonal control.
  - As the filtrate travels through the collecting duct into the medulla, it encounters an increasing salt concentration: Water is lost by osmosis, making the filtrate more concentrated.
  - Potentially harmful substances are eliminated by the kidney.
  - Urine also contains nitrogenous wastes from the metabolism of protein.
  - It may also contain excess K⁺, H⁺ and other ions. Eliminating excess H⁺ helps maintain the pH of the blood.
  - Excretion of excess water maintains the blood volume and pressure.
**MAINTAINING WATER BALANCE**

- The kidneys control the concentration of urine to maintain water balance.
- By changing the amount of water eliminated or conserved, blood volume and blood pressure can also be maintained by the kidneys.
  - The kidneys excrete hypertonic urine when the body needs to conserve water.
  - The kidneys excretes hypotonic urine when too much water has been ingested.
  - One hormone important in regulating water balance is **antidiuretic hormone (ADH)**.
  - The hypothalamus in the brain produces ADH and it is stored in and secreted by the pituitary gland.
  - Sensor cells in the hypothalamus monitor the concentration of the blood.
    - If the body loses water, the concentration of the blood increases (i.e., becomes more salty). The sensors detect this and trigger the release of ADH.
      - ADH makes the distal tubules and collecting ducts become more permeable to water so that water is reabsorbed from the filtrate, decreasing the volume of urine.
  - Note that ADH can only reduce water loss. Lost water can only be replaced by eating or drinking.
    - If a large intake of water has reduced the blood concentration (i.e., becomes less salty) very little ADH is released.
      - This decreases the permeability of the distal tubules and collecting ducts, so water reabsorption is reduced, resulting in the production of more dilute urine.
  - Alcohol inhibits the secretion of ADH, increasing water loss. The resulting dehydration causes some symptoms of a hangover. It is important, therefore to always drink plenty of water if you are consuming alcohol.
ADH and thirst

ADH activity
Kidney Disorders

Diabetes Mellitus

Type 1
- Also called insulin dependent, juvenile or early onset diabetes.
- Approximately 10% of people with diabetes have type 1 diabetes.
- The immune system attacks the part of the pancreas that produces insulin.

Type 2
- Also called insulin independent, adult, or late onset diabetes.
- About 90% have type 2 diabetes.
- The pancreas does not produce enough insulin.
- A diet high in sugar can cause the body to become less sensitive to insulin.

Diabetes facts
- Approximately 80% of people with diabetes will die as a result of heart disease or stroke.
- The onset of type 2 diabetes may be prevented or delayed through increased physical activity, healthy eating, weight loss, not smoking and stress reduction.

Signs and symptoms
- Weight change (gain or loss)
- Extreme fatigue or lack of energy
- Blurred vision
- Frequent or recurring infections
- Cuts and bruises that are slow to heal
- Tingling or numbness in the hands or feet
- Trouble getting or maintaining an erection
- How is diabetes treated?
- Physical activity
- Nutrition
- Weight management
- Medication
- Lifestyle management
- Blood pressure

Diabetes insipidus
The hypothalamus is damaged and is unable to control water balance in the body. The result is production of large volumes of very dilute urine.

Kidney Diseases

Diabetes Mellitus

Type 1 diabetes
- The kidney can be damaged by physical trauma or by infection.
- If the kidneys fail, dialysis or a transplant are necessary.

Type 2 diabetes
- High blood pressure
- Impaired glucose tolerance or impaired fasting glucose

Frequent urination
- Unusual thirst
- Extreme fatigue or lack of energy
- Blurred vision
- Frequent or recurring infections
- Cuts and bruises that are slow to heal
- Tingling or numbness in the hands or feet
- Trouble getting or maintaining an erection

Risk factors
- Being:
  - Aborginal, Hispanic, Asian, South Asian or African descent
  - Overweight (especially if you carry most of your weight around your middle)

- Signs and symptoms
  - Unusual thirst
  - Frequent urination
  - Weight change (gain or loss)
  - Extreme fatigue or lack of energy
  - Blurred vision
  - Frequent or recurring infections
  - Cuts and bruises that are slow to heal
  - Tingling or numbness in the hands or feet
  - Trouble getting or maintaining an erection

- How is diabetes treated?
  - Physical activity
  - Nutrition
  - Blood pressure

- Diabetes insipidus
The hypothalamus is damaged and is unable to control water balance in the body. The result is production of large volumes of very dilute urine.