Lecture 10 - Excretory System

Function of the Excretory System

The excretory system functions in ridding the body of nitrogenous (nitrogen-containing, discussed below) and other wastes.

It also regulates the amount of water and ions present in the body fluids.

Review of Excretory Systems in Animals

Water Balance

Isotonic Animals

The concentration of solutes in isotonic animals is approximately equal to that of their environment. As a result, they do not gain or lose water.

Only marine invertebrates and cartilaginous fish (chondrichthyes) are isotonic.

The concentration of solutes in the tissues of isotonic animals is approximately equal to that of the ocean. This is 100 times higher than that found in the mammalian bodies. The high concentration of solutes in chondrichthyes is due mostly to the presence of urea.

Marine Bony Fish

The rate of water loss is high in marine bony fish. They drink water seawater at a rate of approx. 1% of their body weight/hour.

Specialized cells in the gills excrete excess salt.

Freshwater Bony Fish

Freshwater bony fish tend to gain water from their environment due to osmosis.

They produce large quantities of dilute urine (approx. 1/3 of their body weight/day) and do not drink water.

Salt-absorbing cells in he gills use active transport (energy is required) to pump salts into their body.

Birds and reptiles near the sea

Birds and reptiles living near the sea consume a large amount of salt in their diet. Nasal salt glands remove remove this excess salt from their body by secreting a concentrated salt solution.

Sea Mammals

The kidneys of sea mammals (ex: seals, whales, porpoises) are able to maintain a constant salt concentration in their bodies by producing urine that has a high concentration of salt.

They are able to drink seawater because the salt concentration of their urine is higher than that of sea water.

Terrestrial Animals

Most terrestrial animals drink water, some do not.

Metabolic water produced from cellular respiration may be sufficient to meet the needs of some animals. The equation below shows that six molecules of water are produced for every molecule of glucose oxidized.

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6\mathbf{H_2O} + 36\ ATP$

Example: Kangaroo Rat

Kangaroo rats of southwestern US deserts never have to drink. Their water comes from metabolic water released during cellular respiration and water present in their food.

They emerge from their burrows only at night, when the air is cooler and more humid than during the day. This helps prevent water loss from their bodies and reduces the amount needed to keep cool (sweating).

They avoid movement while in their burrow. This minimizes heat production and thus, the need for sweating.

Dry food stored in their burrows absorbs moisture lost in breathing. This moisture is taken back in when the food is eaten.

Their noses become cooled during inhalation as a result of evaporating water but the cooled membranes cause the moisture to condense during exhalation.

Their large intestine absorbs almost all water present in the digestive tract. Their feces are dry, hard pellets.

Their kidneys conserve water by excreting concentrated urine.

Organs of Excretion

Contractile Vacuoles

paramecium

Flame Cells, Protonephridia

Planarians have two protonephridia composed of branched tubules that empty wastes through excretory pores on their surface. The protonephridia contain numerous bulblike flame cells with clustered, beating cilia that propel fluid into the tubules.

These structures function in waste excretion and osmotic regulation.

Nephridia

Earthworms have two ***nephridia*** in almost all of the body segments.

Each nephridium consists of a tubule with ciliated opening (nephridiostome) on one end and an excretory pore (nephridiopore) that opens to the outside of the body at the other end. Fluid is moved in by cilia. Some substances and water are reabsorbed in a network of capillaries that surround the tubule.

This system produces large amount of urine (60% of body wt./day).

Malpighian Tubules

The excretory organs of insects are ***malpighian tubules***. They collect water and uric acid from surrounding hemolymph (blood) and empty it into the gut. Water and useful materials are reabsorbed by the intestine but wastes remain in the intestine.

Kidneys

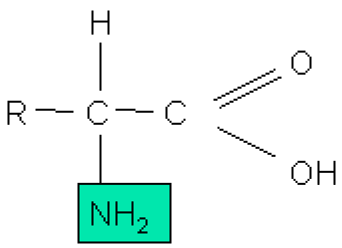
The kidneys of vertebrates (discussed below) function in the removal of nitrogenous and other wastes and in osmotic regulation of the body fluids.

Nitrogenous wastes

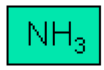
Cells use amino acids to construct proteins and other nitrogen-containing molecules. Amino acids can also be oxidized for energy or converted to fats or carbohydrates.

When amino acids are oxidized or converted to other kinds of molecules, the amino (NH_2) group must be removed. The nitrogen-containing compounds produced as a result of protein breakdown are toxic and must be removed by the excretory system.

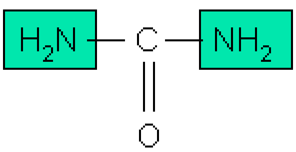
Nitrogenous wastes of animals are excreted in form of ammonia, urea, or uric acid.



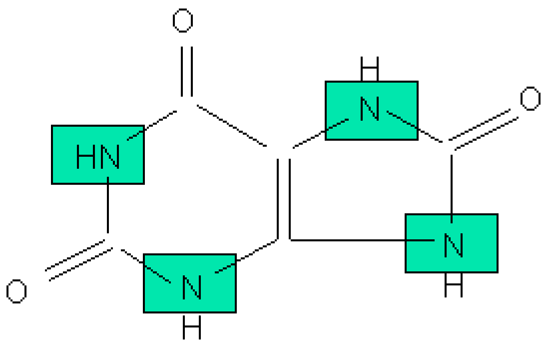
Amino Acid



Ammonia



Urea



Uric Acid

Ammonia

Ammonia is formed immediately after the amino group is removed from protein. This process requires very little energy.

Ammonia is highly soluble in water but very toxic. Aquatic animals such as bony fishes, aquatic invertebrates, and amphibians excrete ammonia because it is easily eliminated in the water.

Urea

Terrestrial amphibians and mammals excrete nitrogenous wastes in the form of urea because it is less toxic than ammonia and can be moderately concentrated to conserve water.

Urea is produced in the liver by a process that requires more energy to produce than ammonia does.

Uric Acid

Insects, reptiles, birds, and some dogs (Dalmatians) excrete uric acid. Reptiles and birds eliminate uric acid with their feces. The white material seen in bird droppings is uric acid.

It is not very toxic and is not very soluble in water. Excretion of wastes in the form of uric acid conserves water because it can be produced in a concentrated form due to its low toxicity.

Because it is relatively insoluble and nontoxic, it can accumulate in eggs without damaging the embryos.

The synthesis of uric acid requires more energy than urea synthesis.

Mammals

Structures of the excretory system

kidneys

ureters

urinary bladder

urethra

Regions of the Kidney

cortex (outer)

medulla (inner)

renal pelvis (innermost chamber)- collects the urine

Nephrons

microscopic; about 1 million/kidney

some are primarily in the cortex, others dip down into the medulla

Parts

glomerulus- a capillary tuft from which fluid leaves the circulatory system (filtration)

Bowman's capsule- a funnel-like structure that collects filtrate from the glomerulus

proximal convoluted tubule

loop of the nephron

distal convoluted tubule

collecting duct- delivers urine to renal pelvis

Blood Supply

The path of blood flow through a kidney is listed below.

Blood enters the kidney through a branch of the aorta called the ***renal artery***.

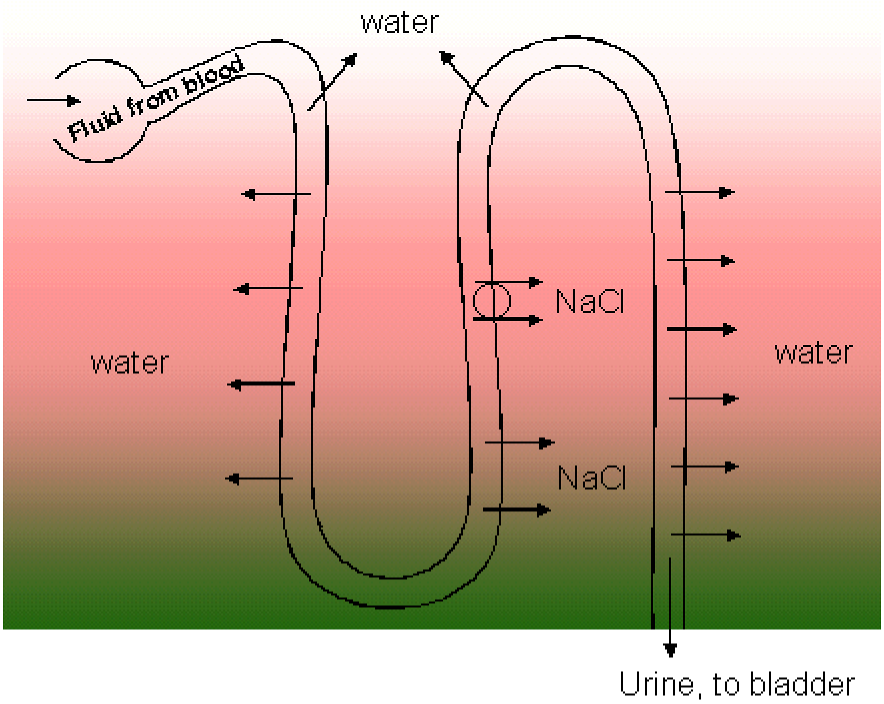
Branches of the renal artery within the kidney produce ***afferent arterioles***.

Each afferent arteriole leads to a network of capillaries called a ***glomerulus***. Fluid leaks out of the capillaries of the glomerulus but large molecules and cells do not fit through the pores. This process is called filtration.

Blood leaves the capillaries of the glomerulus via an ***efferent arteriole*** and enters capillaries in the medulla called ***peritubular capillaries***, which collect much of the water that was lost through the glomerulus.

Venules from the peritubular capillaries lead to the ***renal vein***, which exits the kidney and returns blood to the ***inferior vena cava***.

Urine Formation



Glomerulus

Pressure filtration occurs in the glomerulus.

Blood enters the glomerulus via an afferent arteriole where blood pressure forces water and small molecules out through pores in the glomerular capillaries.

The filtrate has approximately the same composition as tissue fluid.

Blood leaves the glomerulus via the efferent arteriole.

Approximately 45 gallons of liquid per day are filtered from the blood in the glomerulus.

Proximal Convoluted Tubule

A large amount of nutrients and water is filtered from the blood in the glomerulus. It is necessary to reabsorb most of the nutrients and water but leave wastes in the tubule.

Selective reabsorption occurs in the proximal convoluted tubule. Glucose, vitamins, important ions and most amino acids are reabsorbed from the tubule back into the capillaries near the proximal convoluted tubule.

These molecules are moved into the peritubular capillaries by ***active transport***, a process that requires energy.

Cells of the proximal convoluted tubule have numerous microvilli and mitochondria which provide surface area and energy.

When the concentration of some substances in the blood reaches a certain level, the substance is not reabsorbed; it remains in the urine. This prevents the composition of the blood from fluctuating. This process regulates the levels of glucose and inorganic ions such as sodium, potassium, bicarbonate phosphate, and chloride.

Urea remains in the tubules.

Without reabsorption, death would result from dehydration and starvation.

Loop of Henle

In mammals, the loop of Henle conserves water resulting in concentrated urine.

This is done by the gut in birds and reptiles.

Descending Loop

Water moves out of the descending loop as it passes through the area of high salt concentration produced by the ascending loop.

The descending loop is not permeable to ions.

Ascending Loop

Salt is actively pumped out in the ascending loop.

This part of the loop is impermeable to water reentry.

This creates a concentration gradient with a higher concentration in the medulla (interior region).

Countercurrent Mechanism, Collecting Duct

The movement of sodium out of the ascending loop and into the medulla results in water loss and concentrated urine in the descending loop. The concentrated urine further enhances the ability of the ascending loop to pump more salt out into the medulla. High salt in the medulla acts to help remove water in the descending loop. This phenomena is called the ***countercurrent multiplier***.

Urea is concentrated in the fluid; some is able to move out of the lower portion of the ***collecting duct***. It does not enter the blood stream, however, so little urea is lost once a concentration gradient is established.

The combination of urea and salt produces a high osmotic concentration in the medulla.

Length of the Loop of Henle

A longer loop of Henle will function to produce a greater concentration of urea and salt in the medulla. The higher concentration gradient enables the removal of more water as fluid moves through the collecting duct.

The length of the loop of Henle varies among mammals. The beaver, which does not need to conserve water, has a relatively short loop.

Desert-dwelling mammals have very long loops and are capable of producing extremely concentrated urine resulting in very little water loss.

Distal Convoluted Tubule

Some wastes are actively secreted into the fluid in the distal convoluted tubule by a process called ***tubular secretion***. Some of these are H^+, K^+, NH_4^+ toxic substances and foreign substances (drugs, penicillin, uric acid, creatine).

Secretion of H^+ adjusts the pH of the blood.

Collecting Duct

Several renal tubules drain into a common collecting duct.

The collecting ducts pass through the concentration gradient that was established by the loops of Henle. As fluid passes through the collecting ducts, much of the water moves out due to osmosis. The permeability of the collecting duct to water is regulated by hormones (discussed below).

Hormones that Regulate Water Loss

Antidiuretic Hormone (ADH)

ADH increases the permeability of the distal convoluted tubule and collecting duct.

It is released by posterior lobe of the pituitary.

If the osmotic pressure of blood increases (becomes more salty, not enough water); the posterior pituitary will release ADH and the permeability of the collecting ducts will increase, allowing water to leave by osmosis. The water returns to the blood.

If osmotic pressure of blood decreases, pituitary does not release ADH and more water is lost in urine due to decreased permeability of the collecting duct.

Alcohol inhibits the secretion of ADH, thus increases water loss.

Diuretic drugs cause increased water loss in urine, lowering blood pressure.

Aldosterone

Aldosterone secretion is not under the control of the anterior pituitary.

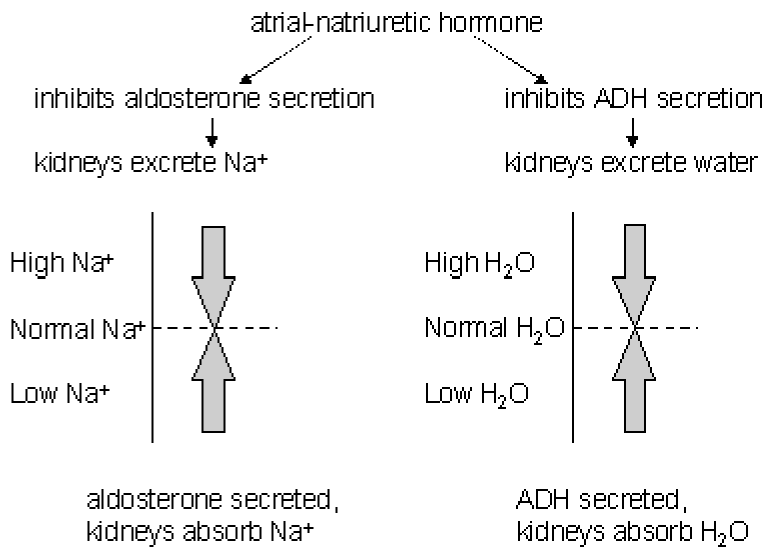
When pressure is low, the afferent arteriole cells secrete renin.

Renin initiates a series of chemical reactions that ultimately result in the adrenal cortex releasing aldosterone, which acts primarily on the distal convoluted tubule to promote absorption of sodium and excretion of potassium. (renin => adrenal cortex => aldosterone => distal convoluted tubule => reabsorption of sodium and excretion of potassium

The increased osmotic pressure associated with increased sodium levels contributes to the retention of water and thus increased blood volume. In the absence of aldosterone, sodium is excreted and the lower sodium levels result in decreased blood volume and lower blood pressure.

Atrial Natriuretic Hormone

The presence of too much blood in the circulatory system stimulates the heart to produce ***atrial natriuretic hormone***. This hormone inhibits the release of aldosterone by the adrenal cortex and ADH by the posterior pituitary causing the kidneys to excrete excess water. The loss of water and sodium contribute to lowering the blood volume.



pH of the Blood

Breathing

Adjustment of the breathing rate can make slight alterations in the pH of the blood by reducing the amount of carbonic acid. Rapid breathing moves the equation below to the left, thus increasing the pH (less acidic). Slow breathing results in less CO_2 being given off and the equation moves to the right..

$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+$

Kidneys

The kidneys provide a slower but more powerful means to regulate pH. They excrete or absorb hydrogen ions (H^+) and bicarbonate ions (HCO_3^-) as necessary for adjusting pH.

When the pH is low (acidic), hydrogen ions are excreted and bicarbonate ions are reabsorbed. The loss of hydrogen ions from the blood make it less acidic. Bicarbonate ions in the blood also reduce pH by taking up hydrogen ions (see the equation above).

When the pH is too high (too basic), fewer hydrogen ions are excreted and fewer sodium and bicarbonate ions are reabsorbed.