Excretory system: Comparative physiology of excretion, kidney, urine formation, urine concentration, waste elimination, micturition, regulation of water balance

The excretory system is responsible for filtering wastes from the blood and both forming and secreting urine. These functions help to maintain the composition and volume of body fluids. Although it has far-reaching effects, the urinary system is relatively simple anatomically and consists of: Kidneys, Ureters, Bladder, and Urethra.

The main organs are the kidneys, which filter blood and produce urine. The other parts are simply accessory structures for the transport and storage of urine.

During the normal breakdown of protein and nucleic acids, nitrogen is released into the bloodstream. Some of this nitrogen is recycled to make new cellular products, but most of it is disposed of. The body has to have a way to rid itself of this unused nitrogen, as high levels in the blood can be toxic. Most of the nitrogen is bound with hydrogen as NH3 (ammonia), which is readily dissolved in water. For this reason, fish are able to excrete much of their nitrogen by simple diffusion into the surrounding water. The build-up of nitrogen in the water is one of the reasons that tank water needs to be changed regularly. Terrestrial animals have a different way of ridding their bodies of excess nitrogen. It is either excreted as uric acid or urea. Animals that are concerned about water loss, such as birds and reptiles, excrete the more concentrated uric acid as a pasty white material. Mammals, on the other hand, can excrete urea, along with more water. The mixture of urea, water, and other wastes is called 'urine.' Urine is still very concentrated in comparison to the blood, and the system that facilitates this concentration is the 'urinary system.'

Kidneys

The kidneys of mammals are round or bean-shaped organs. They are located outside of the peritoneum – the membrane that encloses the organs of the abdominal cavity. Because of this position, they are referred to as 'retroperitoneal.' They are surrounded by fat tissue known as 'perirenal fat.' A fibrous capsule covers the kidney. The indentation of the bean shape is called the 'hilum.' The hilum is the site where the renal artery enters the kidney and both the renal vein and ureter exit.

Each kidney receives blood from a renal artery, and it is from this blood that urine is produced. Urine drains from each kidney through a ureter, which carries the urine to a urinary bladder. Urine passes out of the body through the urethra. Within the kidney, the mouth of the ureter flares open to form a funnel-like structure, the renal pelvis. The renal pelvis, in turn, has cup-shaped extensions that receive urine from the renal tissue. This tissue is divided into an outer renal cortex and an inner renal medulla. Together, these structures perform filtration, reabsorption, secretion, and excretion.
The mammalian kidney is composed of roughly 1 million nephrons— the structural and functional unit of kidneys. Each of which is composed of four regions:

1. **Bowman’s Capsule**: The filtration device at the top of each nephron is called a Bowman’s capsule. Within each capsule an arteriole enters and splits into a fine network of vessels called a glomerulus. The walls of these capillaries act as a filtration device. Blood pressure forces fluid through the capillary walls. These walls withhold proteins and other large molecules in the blood, while passing water, small molecules, ions, and urea, the primary waste product of metabolism.

2. **Proximal tubule**: The Bowman’s capsule empties into the proximal tubule, which reclaims most of the water (75%), as well as molecules useful to the body, such as glucose and a variety of ions.

3. **Renal tube**: The proximal tubule is connected to a long, narrow tube called a renal tubule, which is bent back on itself in its center. This long, hairpin loop, called the loop of Henle, is a reabsorption device. As the filtrate passes, the renal tubule extracts another 10% of water in the descending loop.

4. **Collecting duct**: The tube empties into a large collection tube called a collecting duct. The collecting duct operates as a water conservation device, reclaiming another 14% of water from the urine so that it is not lost from the body. Human urine is four times as concentrated as blood plasma—that is, the collecting ducts remove much of the water from the filtrate passing through the kidney.

The kidneys achieve this remarkable degree of water conservation by a simple but superbly designed mechanism: The duct bends back alongside the nephron tube, and the duct is permeable to urea. Urea passes out of the collecting duct by diffusion. This greatly increases the local salt (urea) concentration in the tissue surrounding the tube, causing water in urine to pass out of the tube by osmosis. The salty tissue sucks up...
water from the urine like blotting paper, passing it on to blood vessels that carry it out of the kidneys and back to the bloodstream.

Fig. The mammalian urinary system contains two kidneys, each of which contain about a million nephrons that lie in the renal cortex and renal medulla.

Urine formation:

The formation of urine within the mammalian kidney involves the movement of several kinds of molecules between nephrons and the capillaries that surround them. It involves

1. Ultrafiltration
2. Reabsorption
3. Tubular secretion
4. Excretion (Micturition)
Ultrafiltration: Driven by the blood pressure, small molecules are pushed across the thin walls of the glomerulus to the inside of the Bowman’s capsule. Blood cells and large molecules like proteins cannot pass through, and as a result the blood that enters the glomerulus is divided into two paths: nonfilterable blood components that are retained and leave the glomerulus in the bloodstream, and filterable components that pass across and leave the glomerulus in the urine. This filterable stream is called the glomerular filtrate. It contains water, nitrogenous wastes (principally urea), nutrients (principally glucose and amino acids), and a variety of ions.
**Reabsorption:** Filtrate from the glomerulus passes down the proximal tubule into the descending limb of the loop of Henle. The walls of this descending limb are impermeable to either salts or urea but are freely permeable to water. Because the surrounding tissue has a high concentration of urea, water passes out of the descending limb by osmosis, leaving behind a more concentrated filtrate.

At the turn in the loop, the walls of the tubule become permeable to salts but much less permeable to water. As the concentrated filtrate passes up the ascending limb of loop of Henle, these nutrients pass out into the surrounding tissue, where they are carried away by blood vessels. In the upper region of the ascending limb are active transport channels that pump out salt (NaCl). Left behind in the filtrate is the urea that initially passed through the glomerulus as nitrogenous waste. At this point in the tubule, the urea concentration is becoming very high.

**Tubular Secretion:** In the distal tubule, substances are also added to the urine by a process called tubular secretion. This active transport process secretes into the urine other nitrogenous wastes such as uric acid and ammonia, as well as excess hydrogen ions.

The tubule then empties into a collecting duct that passes back through the tissue of the kidney. Unlike the tubule, the lower portions of the collecting duct are permeable to urea, some of which diffuses out into the surrounding. The high urea concentration in the tissue causes even more water to pass outward from the filtrate by osmosis. The filtrate that is left in the collecting duct after salts, nutrients, and water have been removed is urine.

**Excretion (Micturition):** The urine is transported and stored in the urinary bladder wherefrom it is voided out from time to time and the process is termed as micturition.
Water balance by kidneys (Osmoregulation):

As in all mammals, the amount of water excreted in urine varies according to the changing needs of the body. Mammals may excrete hypotonic, hypertonic or isotonic urine to maintain homeostasis of the body. If you drink a lot of water, your kidneys will excrete hypotonic urine. As a result, the volume of your blood, your blood pressure, and the salt levels of your blood plasma are all maintained relatively constant by the kidneys, no matter how much water you drink. The kidneys also regulate the plasma Na+ and K+ concentrations and blood pH within narrow limits. These homeostatic functions of the kidneys are coordinated primarily by hormones.
Antidiuretic hormone stimulates the reabsorption of water by the kidneys. This action completes a negative feedback loop and helps to maintain homeostasis of blood volume and osmolality.

Antidiuretic hormone (ADH) is produced by the hypothalamus. The primary stimulus for ADH secretion into the bloodstream is an increase in the osmolality (concentration of salt) of the blood plasma. The salt concentration in plasma increases when you are dehydrated or when you eat salty food. Consider the stimulus of dehydration shown in the figure above. Dehydration causes an increase in the solute concentrations in the blood. Osmoreceptors in the hypothalamus respond to the elevated blood osmolality by triggering a sensation of thirst and by an increase in the secretion of ADH.

ADH causes the walls of the distal tubules and collecting ducts in kidneys to become more permeable to water, thus increasing the amount of water they absorb from the urine as it passes through your kidneys. The increased absorption of water from the kidneys feeds back to the osmoreceptors, causing a reduction in the secretion of ADH. When the secretion of ADH is reduced, the walls become less permeable, and more water excreted in urine.

Sodium ion is the major solute in blood plasma. When the blood concentration of Na\(^+\) falls, the blood osmolality also falls. This drop in osmolality inhibits ADH secretion, causing more water to remain in the collecting duct for excretion in urine. As a result, the blood volume and blood pressure decrease. A decrease in extracellular Na\(^+\) also causes more water to be drawn into the cells by osmosis, partially offsetting the drop in plasma osmolality but further decreasing the blood volume and blood pressure. If Na\(^+\) deprivation is severe, the blood volume may fall so low that there is insufficient blood pressure to sustain life.
A drop in blood Na\(^+\) concentration is normally compensated by the kidneys under the influence of another hormone, aldosterone. Indeed, under conditions of maximal aldosterone secretion, Na\(^+\) may be completely absent from the urine.

The reabsorption of Na\(^+\) is followed by Cl" and by water, so aldosterone has the net effect of promoting the retention of both salt and water. It thereby helps to maintain the blood volume, osmolality, and pressure.

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