UNIT 15

HOMEOSTASIS

KEY CONCEPTS

15.1 Mechanism of homeostasis
15.2 Osmoregulation
15.3 Osmoregulation in animals of different environments
15.4 Excretion
15.5 Urinary system of man
15.6 Urinary tract infections
15.7 Urinary stones
15.8 Renal failure / kidney failure
15.9 Renal dialysis
15.10 Kidney transplantation
15.11 Thermoregulation

Animals have really two environments: an **external environment** in which the organism is situated, and an **internal environment** in which the tissue of the body live. The external environment consists of varying conditions of environment. The internal environment is formed by the circulating organic liquid called lymph or plasma which surrounds and bathes all the tissues. **Homeostasis** is the tendency of an organism or cell to regulate its internal conditions, such as the chemical composition of its body fluids, so as to maintain health and functioning, regardless of outside conditions. The organism or cell maintains homeostasis by monitoring its internal conditions and responding appropriately when these conditions deviate from their normal state.

15.1 MECHANISM OF HOMEOSTASIS

Homeostatic mechanism operates just like physical control system having three components; receptors, control center and effectors.

Receptor (sensor) detects changes in variable and feeds that information back to the control center (integrator).

Control center (integrator) integrates (puts together) data from sensor and stored "set point" data.

Effector is the mechanism (heating coil in this example) that has an "effect" on the variable.

In a common lab incubator, if temperature is decreased from set point, the thermometer (receptor) detects the change in temperature and signals the thermostat (control center), which in turn activates the heating coil (effector). Similarly if temperature is increased from the set point again thermometer detects the change and signals the thermostat to switch off heating. Likewise, in human body thermoreceptors are involved in the detection of temperature change. Hypothalamus in fore brain is a body thermostat.

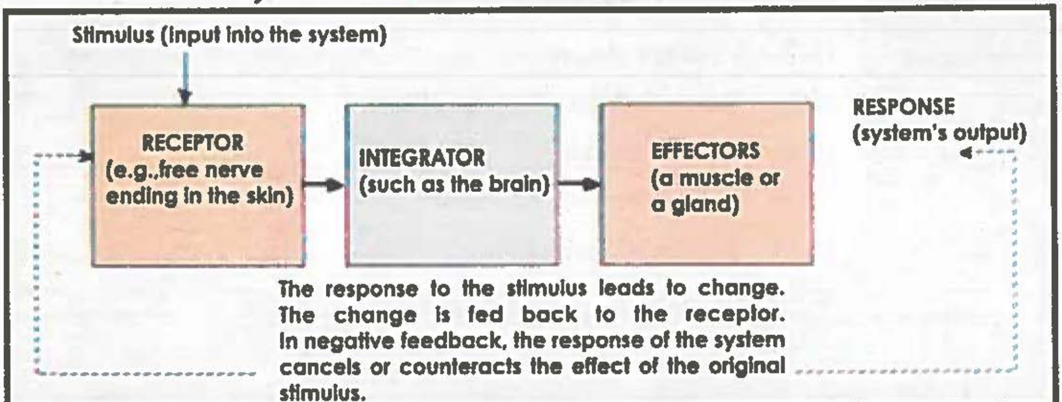


Fig: 15.1 Mechanism of homeostasis.

Stimulated once, hypothalamus acts on effectors for cooling (e.g. sweat glands) or heating (e.g. muscles) the body to reverse the change to the set point. After receiving the signal, a change occurs to correct the deviation either by depressing it with negative feedback or enhancing it with positive feedback.

15.1.1 Negative Feedback

Negative feedback is mainly how homeostasis is maintained. This feedback results in a reversal of the direction of change. Negative feedback tends to stabilize a system, correcting deviations from the normal state. In example, negative feedback mechanism is applied to control water content in the body. When body is deficient in water, hypothalamus stimulates posterior pituitary lobe to release antidiuretic hormone (ADH). ADH makes collecting tubules and distal convoluted tubules of nephrons permeable to water, thus more water is absorbed, and maximum amount of water is retained in the body. The blood water content rises, which is sensed by hypothalamus, so ADH secretion slows down.

15.1.2 Positive Feedback

In contrast to negative feedback, **positive-feedback** involves a change in some variable that triggers mechanisms that amplify rather than reverse the change. During childbirth, for instance, the pressure of the baby's head against sensors near the opening of the uterus stimulates; uterine contractions, which cause greater pressure against the uterine opening, heightening the contractions which causes still greater pressure. Positive feedback brings childbirth to completion, a very different sort of process from maintaining a physiological steady state.

15.1.3 Harmful Positive Feedback

Although Positive Feedback is needed within homeostasis, it also can be harmful at times. When you have a high fever it causes a metabolic change that can push the fever higher and higher. In rare cases the body temperature reaches 113^0 F and the cellular proteins stop working and the metabolism stops, resulting in death. If a person breathes air that has very high carbon dioxide content, this produces a high concentration of carbon dioxide in blood.

This is sensed by carbon dioxide receptors, which cause the breathing rate to increase. So the person breathes faster, taking in more carbon dioxide, which stimulates the receptors even more, so they breathe faster and faster.

> **Skills**
>
> **Interpreting and Communicating**
>
> Draw a flow chart to show negative feedback of homeostasis mechanisms by taking an example of hormone.

15.2 OSMOREGULATION

A type of homeostasis in which water and ions (electrolytes) concentration is maintained in the cells and in the intercellular fluids is called **osmoregulation**. Balance of water and electrolytes is very critical to the health of animals. The mechanisms involved in regulating water and electrolytes balance vary widely among the animal groups as different habitats present different challenges.

15.2.1 Water and solutes Relation to the Cells:

Animal body is composed of 70% of water. However the quantity of water may vary from cell to cell. Water has a number of physiological properties that are of significance to the life. It is also the medium in which biochemical reactions occur. So it is very important to have a proper balance of water in the body. Osmoregulation involves the movement of water by osmosis. Therefore a proper balance of solutes is also important in order to maintain water movement.

Animals may be either osmoregulators or osmoconformers with respect to their osmoregulatory characteristics.

15.2.2 Osmoregulators

Some animals like all land animals and most marine vertebrates have body fluids whose solute concentration is different from that of the external environment. Therefore they must use energy in controlling water loss or gain to keep the balance of water and solutes. Such animals are called osmoregulators. Whether an animal inhabits land, fresh water or salt water, its cells cannot survive without water.

15.2.3 Osmoconformers

Some aquatic animals that live in the sea have the body fluids with a solute concentration equal to that of external environment. Such animals do not undergo a net gain or loss of water because equal amounts of water move back and forth between two solutions with equal solute concentration i.e. the animal body fluids are kept isotonic. Such animals are called osmoconformers.

15.3 OSMOREGULATION IN ANIMALS OF DIFFERENT ENVIRONMENTS

15.3.1 Fresh Water animals:

Almost all of the fresh water animals are osmoregulators. These animals are generally hypertonic to their outer environment.

These animals face the problem of swelling up by the passive movement of water into their bodies from the surrounding environment. Therefore these animals have no need to drink water. They also face the continual loss of body salts to the surrounding fresh water environment which has low salt concentration.

These animals deal with these problems by producing large volume of diluted urine. Their kidney reabsorbs the salts that are required. Salts are also obtained from the food they eat.

These animals also actively transport salts from the external dilute medium with the help of special salt cells called ionocytes. Ionocytes are found in the Amphibian's skin and gills of fishes.

15.3.2 Marine animals:

As described earlier that marine environment has both osmoconformers and osmoregulators, osmoregulatory adaptations of these animals are very different from each other. Cartilaginous fishes such as sharks, rays and skates and some cyclostomes like Myxine (Hag fishes), have plasma that is approximately isotonic to sea water.

On the other hand most of the marine teleosts (bony fishes) are hypotonic to sea water. So these fishes have tendency to lose water to the environment, especially across the gill's epithelium.

For Your Information

Osmolarity of sea water is very high and is about 1000 mosm/L while the blood osmolarities of marine animals range between 200-300 milli mole/litre.

They also have problem of excess of salts in the body due to drinking of sea water. In order to replace the water loss these fishes usually drink large amount of water unlike fresh water fishes. Among the excess salts, Na^+, Cl^- and some amount of K^+ are removed across the gill's epithelium while divalent ions like Mg^{++}, Ca^{++} are excreted by the kidney.

Some fishes also have special salt secreting glands in the wall of rectum called rectal glands that remove salts into the digestive tract which are then eliminated from the body during egestion.

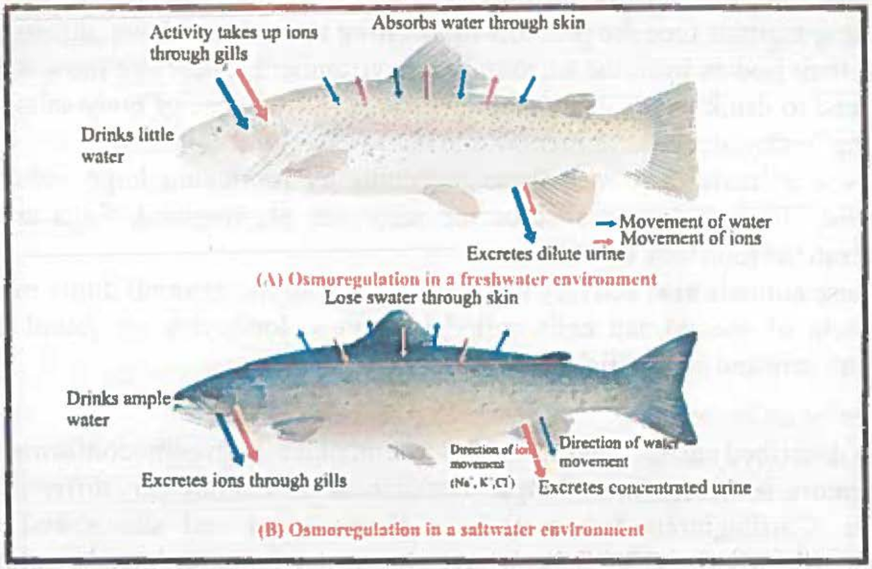


Fig: 15.2 Osmoregulation in marine animals.

15.3.3 Terrestrial animals:

In terrestrial animals evaporation of water leads to the dehydration which is the major problem faced by these animals. The successful groups of land animals are arthropods among the invertebrates and reptiles, birds and mammals among the vertebrates. The presence of chitinous exoskeleton in arthropods and dead keratinized skin in vertebrates are adaptation to reduce water loss by their bodies.

Desert mammals are very much resistant in this regard. They can tolerate against strong degree of dehydration by special **metabolic and behavioral adaptation.** This characteristic is called **anhydrobiosis**. Actually these animals feed upon seeds of desert plants in which large amount of carbohydrate is stored, during the breakdown of these compounds, water is produced as by-product that is utilized by these animals. Best example of such animals is kangroo rat. Desert animals avoid day time heat, and emerge at night. 90% of the water that they use is metabolic water derived from cellular oxidation.

Skills

(Initiating and Planning)

List some of the behavioral responses of the animals to maintain homeostasis.

Fig: 15.3 Kangroo rat; master of water conservation in the desert.

15.4 EXCRETION

Metabolism of food and other chemicals in the body produces large amount of toxic by-products. Water and Carbon dioxide are produced in metabolism of all, sugars, lipids and even proteins. The most troublesome is the nitrogen-containing waste from the metabolism of proteins and nucleic acids. Nitrogen is removed from these nutrients when they are broken down for energy or when they are converted to carbohydrates or fats. The primary nitrogenous waste product is ammonia, a small and very toxic molecule. Some animals excrete their ammonia directly; others first convert it to less toxic wastes such as urea or uric acid and then excrete it.

The form of nitrogenous waste an animal excretes depends on its habitat.

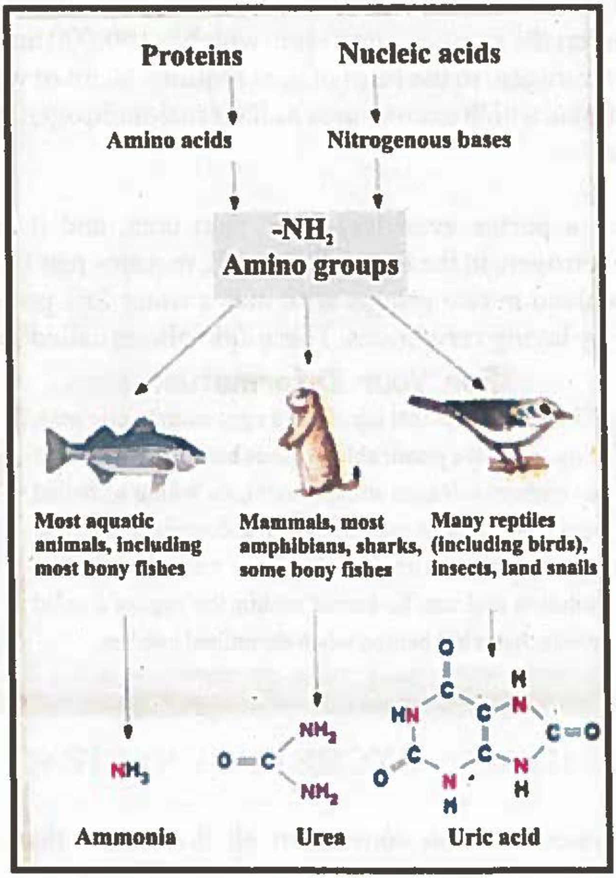


Fig: 15.4 Different types of nitrogenous wastes excreted by animals according to their habitat.

15.4.1 Ammonia

Ammonia is highly toxic and highly soluble in water. 1 g of nitrogen, in the form of ammonia, requires 500 ml of water to dissolve it to nontoxic level. If the organism has a sufficient source of water, ammonia can simply be excreted out. This is the course taken by many aquatic organisms, particularly those in fresh water.

Animals which excrete ammonia as their major nitrogenous waste product are called **ammonotelic** e.g. most fishes, protozoans, sponges, coelenterates, echinoderms.

15.4.2 Urea

Organisms with less fresh water available, such as some marine organisms and all terrestrial organisms, could not afford to waste water. They will often invest some energy to convert the ammonia into *urea*, which is 100,000 times less toxic than ammonia. One g of nitrogen, in the form of urea requires 50 ml of water to dilute it to nontoxic level. Animals which excrete urea as their major nitrogenous waste product are called **ureotelic.**

15.4.3 Uric Acid

Uric acid is a purine even less toxic than urea, and it precipitates from solution. 1 gram of nitrogen, in the form of uric acid, requires just 1 ml of water for its excretion. It has evolved in two groups with major water loss problems, terrestrial invertebrates and egg-laying vertebrates. These animals are called as **uricotelics.**

For Your Information

The vertebrates that lay shelled eggs excrete uric acid. Egg shells are permeable to gases but not to liquids. If an embryo released ammonia or urea within a shelled egg, the soluble waste would accumulate to toxic concentrations. Uric acid, however, precipitates out of solution and can be stored within the egg as a solid waste that is left behind when the animal hatches.

15.5 HUMAN EXCRETORY SYSTEM

Excretory system of man consists of all the organs that aid the body in removing waste products. Skin, lungs, liver and kidneys work to dispose of metabolic wastes.

15.5.1 Kidneys

The kidneys are dark-red, slightly flattened, bean shaped organs about 12 cm long, 6 cm wide and 4 cm thick each weighing about 150 gms. They are placed against the back wall of the abdominal cavity just below the diaphragm, one on either side of the vertebral column, between the last thoracic vertebra and the third lumbar vertebra.

The upper parts of the kidneys are partially protected by the eleventh and twelfth ribs. Their position is slightly asymmetrical, the right kidney being a little lower than the left one because of a liver lobe above it. The kidney has a bean-shaped structure. The outer surface is convex and the inner surface is concave. The inner surface has a deep notch called **hilus.** The renal artery and nerves enter the kidney, and the renal vein and ureter leave the kidney through hilus. The kidney is surrounded by tough membrane, **the renal peritonium.**

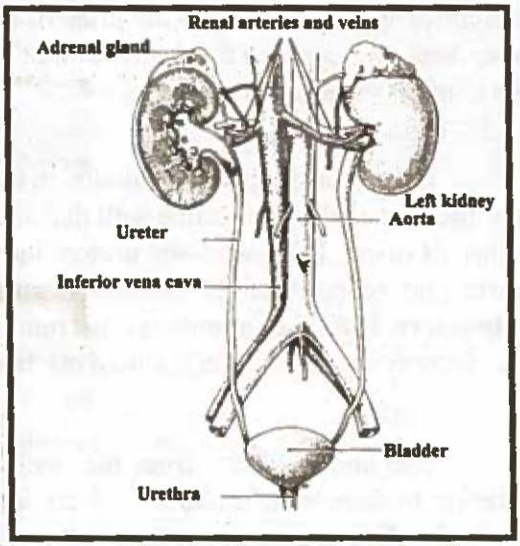


Fig: 15.5 Human urinary system

Transverse section of kidney shows two distinct regions, an outer **cortex** and an

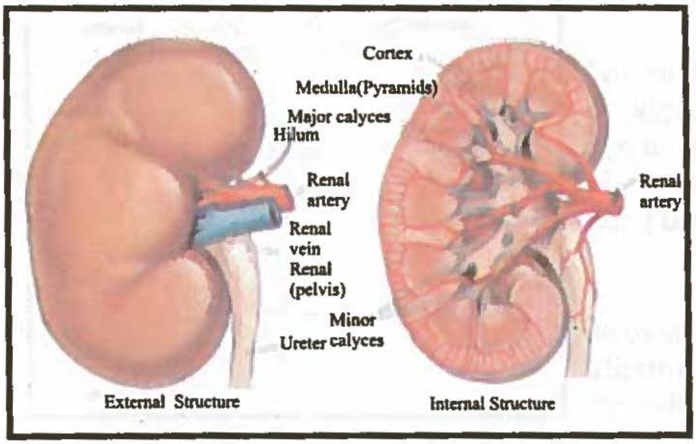


Fig:15.6 Human Kidney

tidbit

The kidney receives about 20 percent of the blood coming from the heart each time it beats. The rate of blood flows through both kidneys is approximately 1.2 liters per minute.

inner **medulla.** The cortex contains renal corpuscles and convoluted tubules of nephrons. The medulla contains conical structures called pyramids. All the pyramids project into the pelvis. The pelvis leads into the ureter.

15.5.2 Ureters

Ureters are about 28 cm long. They are a pair of narrow, muscular, tubular structures which arise from the hilus of the kidney, run backward along the dorsal body wall and open on the dorsal wall of the urinary bladder. These pass urine from the kidneys to the urinary bladder.

15.5.3 Urinary Bladder

It is a pear shaped sac situated in the pelvic region of the abdominal cavity. It has thick muscular distensible wall that allows its expansion. It can store about 0.5 to 1 litre of urine. It receives the ureters through the lower part of its back wall. The lower part or neck of the bladder is guarded by 2 rings of muscle fibres called **sphincters.** Both the sphincters must relax to let urine pass out from the bladder. The act of emptying the bladder is called **micturition.**

15.5.4 Urethra

The urethra starts from the neck of the urinary bladder and leads to the exterior. In females it is about 2 - 3 cm long and carries only urine. It opens by the urethral orifice or urinary aperture in the vulva in front of the vaginal aperture.

In male, urethra is about 20 cm long and carries urine as well as the spermatic fluid. It passes through the penis and opens out at the tip of the penis by a urinogenital aperture.

15.5.5 Nephron

The basic unit of structure and function of the kidney is the nephron. Each human kidney contains about one million nephrons. Each nephron is composed of renal corpuscle and renal tubule

15.5.6 Renal Corpuscle

Renal corpuscle is composed of a **glomerulus** and the **Bowman's capsule.** It is the initial filtering component of the nephron.

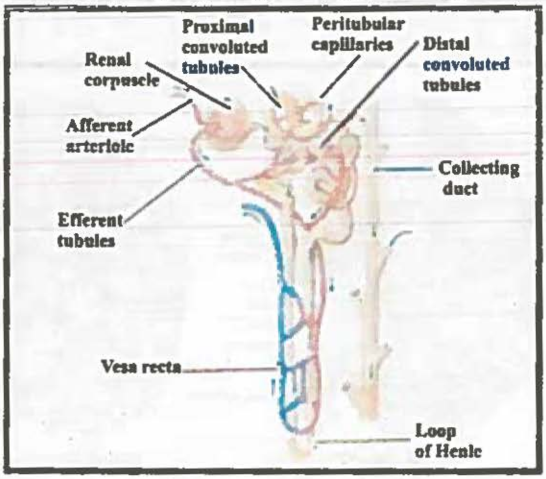


Fig: 15.7 Structure of nephron

The glomerulus is a capillary tuft that receives its blood supply from an afferent arteriole of the renal circulation. Bowman's capsule is a cup shaped structure that encloses glomerulus. The cells of Bowman's capsule in the kidneys that wrap around the capillaries of the glomerulus are called **podocytes.** The pores in the capillary endothelium and the gaps in between podocytes are quite large, and make it easy for any substance dissolved in the blood plasma to get through from the blood into the capsule. However, basement membrane of blood capillaries stops large protein molecules from getting through.

15.5.7 Renal Tubule

The components of the renal tubule are:

Proximal convoluted tubule: It is the portion of the duct system of the nephron of the kidney which leads from Bowman's capsule to the loop of Henle. It is the longest part of the nephron. The proximal tubule is lined by epithelial cells having brush boarder composed of microvilli. It increases surfa ce area for reabsorption.

Loop of Henle: It is a long U shaped tube of the nephron. The loop of Henle is more prominent in juxtamedullary nephrons where it descends down to the tips of pyramids in medulla. It is an important part of the whole system, as it allows the kidneys to filter out salt and maintain the correct balance of water in the body.

Distal convoluted tubule: The distal convoluted tubule is the most distal portion of the nephron

Collecting ducts: Each distal convoluted tubule leads to a system of collecting ducts, the first segment of which is the collecting tubule. The collecting duct system begins in the renal cortex and extends deep into the medulla. Finally it delivers urine to renal pelvis.

15.5.8 Types of Nephron

Two general classes of nephrons are **cortical nephrons** and **juxtamedullary nephrons,** both of which are classified according to the location. Cortical nephrons are found in the cortex. They have their renal corpuscle in the superficial renal cortex and have relatively short loops of Henle. 70 to 80% nephrons in human kidney are cortical. Under normal conditions of water availability the cortical nephrons deal with the control of blood volume. Juxtamedullary nephrons have their renal corpuscle close to the junction of the cortex and medulla. They have long loop of Henle which extends deep into the medulla.

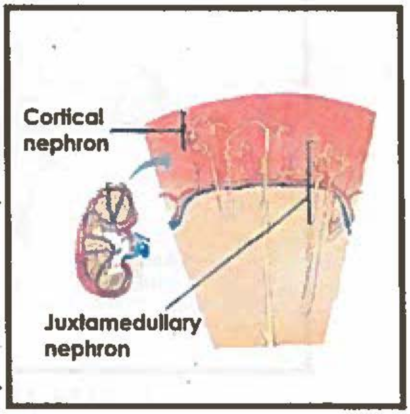


Fig: 15.8 Types of nephron.

This type of nephron is relatively rare, and only comprise 20-30% of the nephrons in the human kidney. The greater gradient in the deep medulla make this type of nephron do more work than cortical nephrons. It is these nephrons which are responsible for the development of the osmotic gradients in the renal medulla, which are used to concentrate urine. When water is in short supply, increased water retention occurs through juxtamedullary nephrons.

Blood enters the kidney by the renal artery which branches into finer and finer arteries before entering the glomerulus as an **afferent arteriole.** Filtered blood leaves the the glomerulus by an **efferent arteriole.** It flows to form a network of **peritubular capillaries** around the proximal and distal convoluted tubules in the cortex region. The capillaries of **vasa recta** run antiparallel to the loops of Henle and the collecting ducts in the medulla.

5.5.9 Excretory Function of Nephron

The human kidneys perform a variety of functions; nearly all are carried out by nephrons. The nephrons filter blood; remove wastes which are passed out as urine. Formation of urine involve three key processes, ultrafiltration, selective reabsorption and tubular secretion.

Ultrafiltration:

It is filtration under pressure. The diameter of efferent arteriole is half as compared to the afferent arteriole. It results in a high blood pressure in glomerulus. About 20% of the plasma is filtered into Bowman's capsule. This filtered fluid is called **glomerular filtrate.**

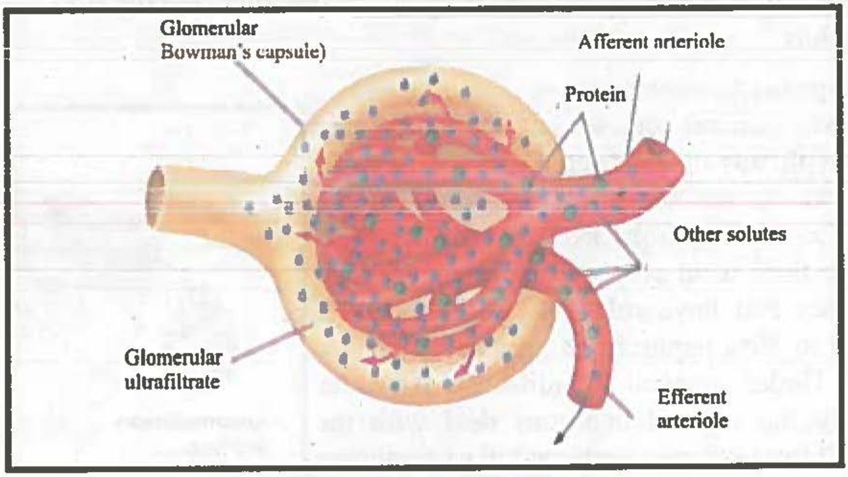


Fig: 15.9 Mechanism of ultrafiltration.

This filtrate has to cross endothelium of the glomerular capillaries, basement membrane of capillaries, and endothelium of Bowman's capsule.

It has chemical composition similar to that of blood plasma. It contains glucose, amino acids, vitamins, ions, nitrogenous wastes, some hormones and water.

Selective reabsorption

Ultrafiltration produces about 125 ml of glomerular filtrate per minute in humans. This is equivalent to about180 liters per day. In fact, of the 125 ml of filtrate produced per minute 124 ml is reabsorbed on average. The reabsorption process in the nephron is very selective. The useful substances for the body are reabsorbed.

Over 80% of the glomerular filtrate is reabsorbed in proximal convoluted tubules. Here all of the glucose, amino acids, vitamins, hormones and about 80% of the sodium chloride and water are reabsorbed.

The function of loop of Henle is to conserve water. The wall of ascending limb is impermeable to water, however, sodium, chloride, potassium and other ions are absorbed actively here. The plasma becomes concentrated and fluid in the ascending limb becomes very dilute. The descending limb is highly permeable to water. **The counter current multiplier system here results in reabsorption of a lot of water and solutes.**

The distal convoluted tubules have osmoregulatory role and also control blood pH by secreting hydrogen ions. The collecting ducts are impermeable in nature. ADH opens water channels in collecting ducts to allow water to move out of the filtrate. It reduces the volume of urine making it more concentrated.

Tubular Secretion

Tubular secretion is the transfer of materials from peritubular capillaries to renal tubular lumen. Tubular secretion is caused mainly by active transport. Usually only a few substances are secreted. These substances are present in great excess, or are natural poisons.

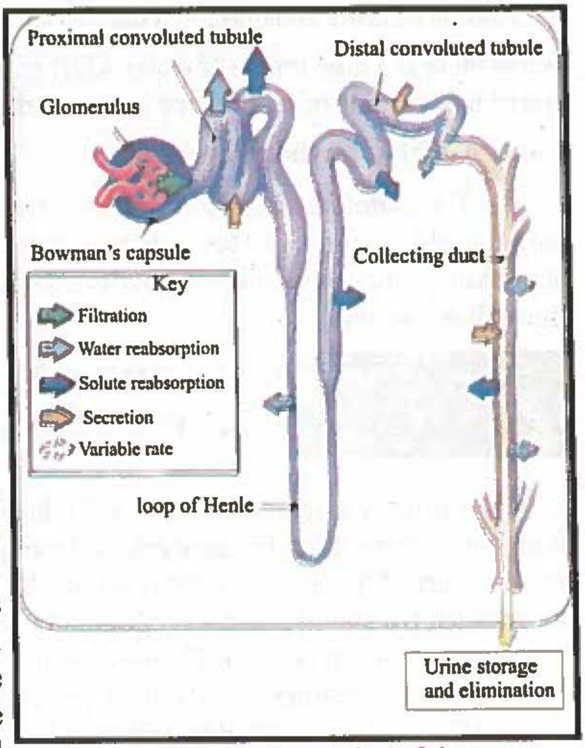


Fig: 15. 10 An overview of the process of urine formation

Most important substances secreted by the tubules are hydrogen ions, potassium ions, and organic ions which are foreign to the body. Many drugs are eliminated by tubular secretion. Hydrogen ion secretion is important in acid-base balance of the body.

15.5.10 Kidney as Osmoregulatory Organ

Control of water level:

Body maintains the solute potential of blood at an approximately steady state. It is done by balancing water uptake from the diet with water lost in evaporation, sweating, egestion and urine. The solute potential is primarily achieved by the effect of antiduretic hormone.

ADH is secreted by the posterior lobe of pituitary gland. When body is deficient in water, hypothalamus detects a fall in blood solute potential and directs pituitary to release ADH. This hormone increases the permeability of the distal convoluted tubules and collecting ducts to water. More water is absorbed, reducing the volume of urine and making it more concentrated.

When there is a high intake of water ADH release is inhibited. Less water is absorbed and a large volume of dilute urine is excreted.

Control of blood sodium level

The maintenance of sodium level at a steady state is controlled by the steroid hormone aldosterone. It is secreted by adrenal cortex. Aldosterone activates sodium-potassium pumps in the distal convoluted tubules. Sodium is pumped back to blood from filtrate actively.

15.6 URINARY TRACT INFECTIONS (UTIs)

A urinary tract infection, or UTI, is an infection that can happen anywhere along the urinary tract. Urinary tract infections have different names, depending on what part of the urinary tract is infected. Almost all parts of the urinary tract are affected by the infection except ureters which are rarely the site of infection. Following are the types of UTIs depending upon the site.

(i) Pyelonephritis (kidney infection)

(ii) Cystitis (bladder infection)

(iii) Urethritis (urethral infection)

15.6.1 Causes

The bacterial and fungal strains that cause most common type of UTIs include:

- *Escherichia coli*
- *Staphylococcus saprophyticus*
- *Klebsiella*, *Enterococci* bacteria, and *Proteus mirabilis*
- Fungal organisms, such as *Candida albicans* that also causes the infections in mouth, digestive tract, and vagina.)

15.7 URINARY STONES

Urinary stones are hard, crystalline mineral materials that stick together to form small "pebbles" within the kidney or urinary tract. They may stay in kidneys or travel out of the body through the urinary tract.

15.7.1 Symptoms / Indications

Kidney stones often cause no pain while they are in the kidneys, but they can cause sudden, severe pain as they travel from the kidneys to the bladder. Usually pain appears at side belly or groin and the colour of urine becomes pinkish or reddish. These are common indications of kidney stones.

Anyone may develop a kidney stone, but people with certain diseases and conditions or those who are taking certain medications are more susceptible to the stone development. Kidney stones form when there is a decrease in urine volume and/or an excess of stone-forming substances in the urine.

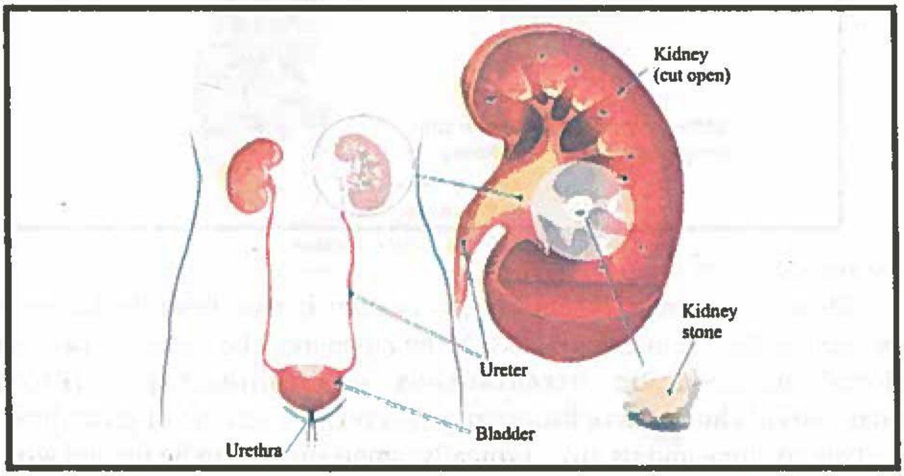


Fig: 15.11 Formation of Kidney stones in various places in the urinary system.

15.7.2 Chemical Nature of stone

The most common type of kidney stone contains **calcium** in combination with either **oxalate** or **phosphate** (70% of all stones). Other chemical compounds that can form stones in the urinary tract include **uric acid** (5-10% of all stones) and the amino acid **cystine** (1-3% of all stones). Kidney stones can also result from infection in the urinary tract; these are known as **struvite** or **infection stones** (15-20% of all stones).

15.7.3 Causes: A number of different medical and environmental conditions can lead to an increased risk for developing kidney stones:

- **Hypercalcemia: It is characterized by** increased calcium level in the blood that in turn causes **hypercalciuria** (high calcium in the urine). These conditions may also arise in case of **Hyperparathyroidism,** which is the over secretion of parathormone from parathyroid gland.

In this condition, too much calcium is absorbed from food and excreted into the urine, where it may form calcium phosphate or calcium oxalate stones.

- **Hyperoxaluria: It is characterized by** increased oxalate level in the urine. This condition is usually associated with over use of tomato and other green leafy vegetables in the diet.
- **Hyperuricemia: It is characterized by** increased amount of uric acid in the blood that can lead to the formation of uric acid stones. The level of uric acid may arise in gout(genetic disorder) or due to high intake of protein in the form of meat products.

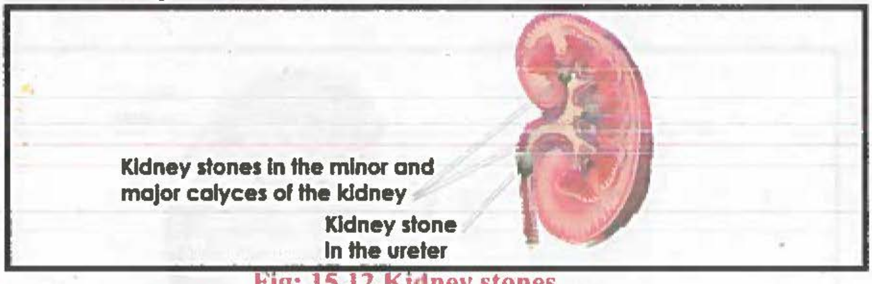


Fig: 15.12 Kidney stones

15.7.4 Treatment of urinary stones

Most stones under 0.5cm can spontaneously pass from the kidney but most stones greater than 1cm cannot pass. If the stone must be removed two commonly employed methods are **percutaneous nephrolithotrypsy (PCNL)** and **extracorporeal shock wave lithotripsy (ESWL).** The type of procedure depends on the type of stone and its size. Typically, small stones can be treated with ESWL, while larger stones require PCNL. ESWL uses sound waves to break the stone. A

PCNL procedure is more commonly used when ESWL is not successful. First a tube is inserted into the patient's back into the kidney to create a tract. A scope is run through the tract to directly see the stone inside the kidney.

Ultrasound equipment can then be inserted to break up the stone. While watching the stone through the scope, the stone fragments can be grasped with special equipment and pulled through the tract out from the kidneyBefore the advent of PCNL and ESWL, open surgical procedures were performed. This is less often necessary now, but sometimes is still performed especially for large complicated staghorn (branched) stones.

Fig: 15.13 Stagehorn stone

15.8 RENAL FAILURE/KIDNEY FAILURE

Renal failure or **kidney failure** is a medical condition in which the normal functions of kidneys (filtration of toxins and waste products from the blood) is gradually decreased. There are two forms of kidney failure:

15.8.1 Acute Kidney Failure:

Acute kidney failure occurs when kidneys suddenly become unable to filter wastes from blood. It develops rapidly over a few hours or in few days. Acute kidney failure is most common in people who are already hospitalized, particularly in critically ill people who need intensive care. Acute kidney failure can be fatal and requires intensive treatment. However, acute kidney failure may be reversible in that case, if patient otherwise in good health.

15.8.2 Causes

Acute kidney failure can occur when something damages the kidneys like blood clots or cholesterol deposits that block blood flow in the kidneys, similarly certain chemotherapy drugs, antibiotics and toxins, such as alcohol, heavy metals and cocaine can also cause kidney failure.

15.8.3 Chronic Renal Failure

Chronic kidney failure, also called chronic kidney disease is the gradual loss of kidney function. Chronic kidney failure may not become apparent until the kidney function is significantly impaired. Chronic kidney failure can progress to **end-stage renal disease (ESRD)** and **uremia**, which is fatal without artificial filtering (dialysis) or a kidney transplant.

15.8.4 Causes

Chronic renal failure develops gradually over time, often years to decades. The most common causes of chronic renal failure are diabetes and hypertension. Other causes include long-term daily use of anti-inflammatory drugs and other analgesic medications (pain relievers).

15.8.5 Renal Failure Treatment

Treatment targets the underlying cause. Acute renal failure requires immediate and intensive medical care, often including dialysis. Dietary modifications (such as reduced sodium, protein, and fluid intake) and medications to control conditions such as diabetes and hypertension allow many people to live with chronic renal failure for years to decades. When chronic renal failure progresses to ESRD, renal dialysis or kidney transplantation become necessary to sustain life.

15.9 RENAL DIALYSIS

Procedures to filter toxins from the blood when the kidneys are unable to perform this function is called renal dialysis. It can be short term or long term. Though in theory renal dialysis could sustain life indefinitely, but in practice most people experience a steady decline of overall health with long-term dialysis because artificial methods of cleansing toxins from the blood are not as effective, efficient, or thorough as the natural processes the kidneys perform. There are two general types of renal dialysis: peritoneal dialysis and haemodialysis.

15.9.1 Peritoneal Dialysis

Peritoneal dialysis makes use of a natural membrane in the body, the peritoneum, which encloses the abdominal cavity. In this process two catheters are surgically inserted into the abdominal cavity that serve as the portals through which dialysate (dialysis fluid) enters and leaves the cavity.

The molecules of the dialysate are too large to pass through the peritoneum so the solution remains contained in the abdominal cavity. During circulation, when blood passes through the blood vessels (capillary networks) within the peritoneum, the dialysate attracts certain molecules to cross the membrane into the dialysate. A second catheter carries dialysate out of the abdominal cavity. There are two stages of peritoneal dialysis, the **exchange** (draining the dialysate into and out of the abdominal cavity) and the **dwell** (the time during which the dialysate remains in the abdominal cavity)

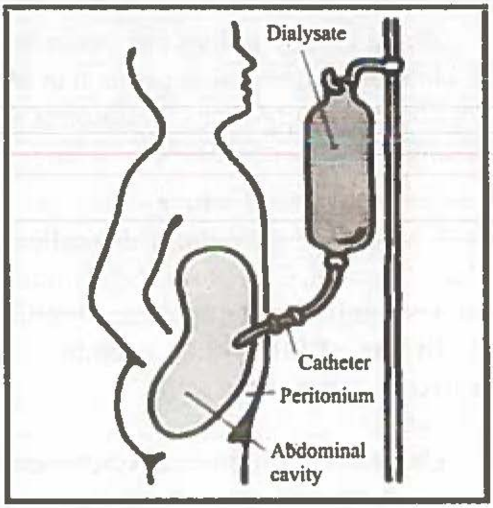


Fig: 15.14 Peritoneal dialysis

The primary advantage of peritoneal dialysis is mobility. Most people are able to participate in regular activities, including work, while peritoneal dialysis is under way and it can be performed at home. The success of peritoneal dialysis is variable than that of haemodialysis because the permeability of the peritoneum varies among individuals. Some doctors believe peritoneal dialysis is less effective than haemodialysis at clearing toxins from the body.

15.9.2 Haemodialysis

Haemodialysis removes wastes and water by circulating blood outside the body through an external filter, called a **dialyzer**, that contains a semipermeable membrane. In this process, a catheter is inserted into a blood vessel, usually in the arm, it routes the blood circulation externally through a machine that removes toxins. The cleansed blood then returns to the body through a second catheter.

Fig: 15.15 Patient being treated by haemodialysis.

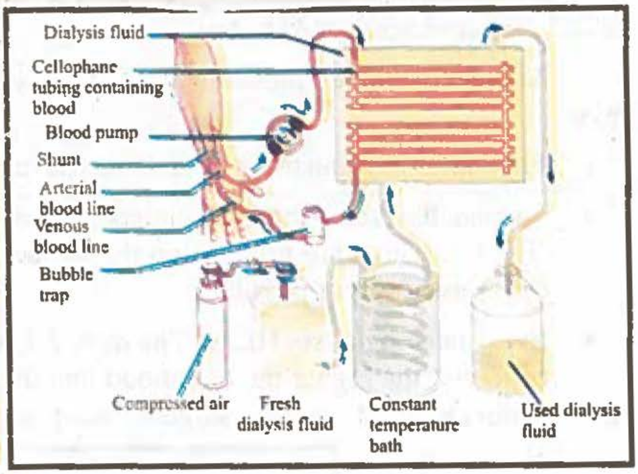


Fig:15.16 Mechanism of haemodialysis.

Many nephrologists feel that haemodialysis is more effective than peritoneal dialysis. However, haemodialysis entails significant risks like infection with hepatitis and other blood borne conditions, injury to the blood vessels used to shuttle blood between the person and the dialysis machine, and microscopic damage to the blood cells.

15.10 KIDNEY TRANSPLANTATION

Replacement of a diseased, damaged, or missing kidney with a donor kidney also called a renal transplant. Patients with end-stage renal failure are candidates for transplantation. A successful transplant frees the patient from dialysis and provides the kidney's other metabolic functions.

For Your Information

The first successful kidney transplantation took place between identical twin brothers in 1954. However, until the discovery of the immunosuppressive drug cyclosporine in 1983, the risk of organ rejection was very high, and kidney transplantation was a treatment of last resort. With current immunosuppressive therapy the recipient of a transplanted kidney can expect to live 5 to 20 years or longer with relatively normal kidney function.

15.10.1 Donor-Recipient Match

The donor kidney must match the recipient as closely as possible in three ways.

- First, the donor and the recipient must have the same blood type.
- Second, the donor and the recipient must match Human Leukocyte Antigens (HLAs), which are proteins on the surfaces of leukocytes (white BLOOD cells), as closely as possible.
- Every person has six HLAs. The more HLAs that match between donor and recipient, the higher the likelihood that the recipient's body will accept the donor kidney Transplant surgeons like to see a match of three or more HLAs.

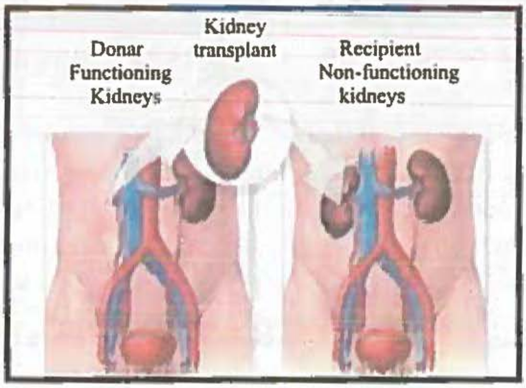


Fig: 15.14 Recipient non functioning kidney is replaced by donor functioning kidney.

- Third, the donor's blood must not initiate an antibody response with the recipient's blood (called a negative cross match), which the transplant team tests by mixing samples of blood from each in a test tube.

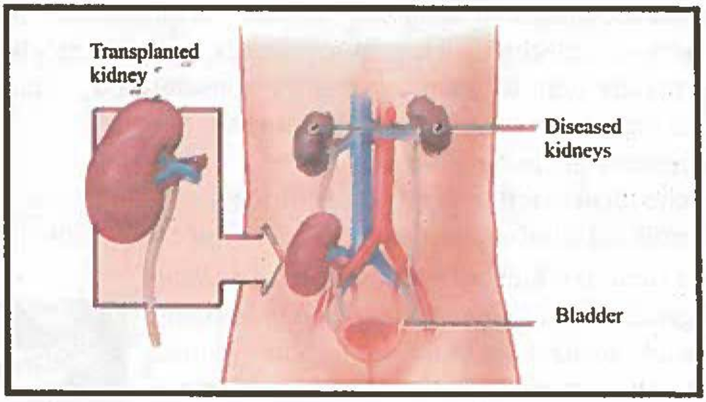
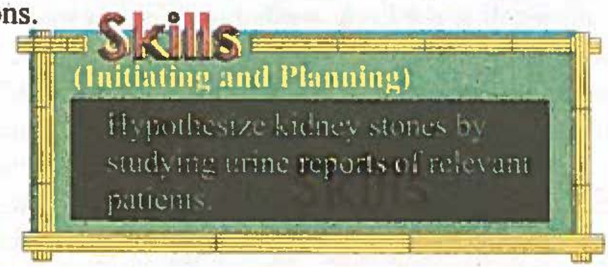


Fig: 15.18 Location where the healthy kidney is placed in the patient body.

15.10.2 Risks and Complications

The risks of transplantation surgery include bleeding during or after the operation and postoperative infection. Because the transplanted kidney is lower in the abdomen than the native kidneys it lacks the protection of the rib cage and is more vulnerable to traumatic injury. Most people recover fully from the surgery without complications, though there is always the risk of organ rejection can be treated with various medications.



15.11 THERMOREGULATION

The maintenance of body temperature by living organisms is termed as thermoregulation. The temperature influences the metabolic activity of animals in a number of ways. The main effect is on the rate of enzyme activity and the rate of movement of atoms and molecules. This directly affects the health and growth of animals. Temperature may also affect the geographical distribution of animals through its influence on plants as primary producers in the food chain.

The effect of hyperthermia on organ system of animals may be profound, and if heat stress has been severe or prolonged it may alter organ function and even kill the animals. Animals are classified into two groups on the basis of maintaining their body temperature.

Poikilotherms are unable to maintain their body temperature within narrow limits using physiological mechanism e.g. invertebrates, fishes, amphibians, and reptiles.

Homeotherms are able to maintain a fairly constant body temperature by using physiological mechanisms e.g. birds and mammals.

Animals gain heat from two sources.

- The chemical reaction of ingested nutrients
- The external environment, especially radiant energy from the sun.

The extent to which different groups of animals are able to generate and conserve this heat is variable. **Ectotherms** rely on heat derived from the environment than metabolic heat to raise their body temperature e.g. reptiles, amphibians, fishes and invertebrates. Homeothermic animals are relatively independent of external sources of heat and rely on a high metabolic rate to generate heat which is conserved. They are described as **endothermic e.g.** the great white shark, flying insects, birds and polar bear.

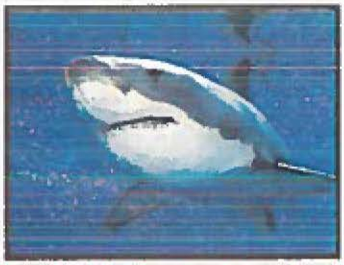


Fig: 15.19 Great white shark an endothermic animal.

15.11.1 Thermoregulation in Human

The ability to regulate body temperature is critical to sustain normal life. Death is the ultimate result if the body temperature strays to far from the normal. Core body temperature, the temperature of structures below the skin and subcutaneous tissue, should be maintained between 36.4 and 37.3 °C.

Respiratory metabolism is major source of heat energy in human. This energy is mainly released by breakdown of carbohydrates and fats. The process of heat production in organisms is called **Thermogenesis.** This process is regulated by nervous system and hormones. There are two types of thermogenesis , shivering thermogenesis and non-shivering thermogenesis.

Shivering thermogenesis involves repeated stimulation of voluntary muscles by motor neurons. It produces shivering response in muscles which can increase heat production by up to five times the basal level.

Non-shivering thermogenesis is the heat production caused by the high metabolic rate. Thyroxin, a thyroid hormone increases metabolic rate which result in heat production. Its effects are long term. Adrenaline produces short term increase in metabolic activity.

15.11.2 Heat loss

Heat is lost from the general body surface by a number of processes like radiation, convection, and conduction. Radiation accounts for about 50% of the total heat loss in humans. In vasodilation, certain of the arterioles beneath the epidermis dilate. Consequently more blood flows near the body surface, losing heat through the epidermis. Evaporation is another mechanism of heat loss. In humans water loss by evaporation takes place continuously through the skin even when a person is not sweating. Activation of sweat glands enhances this process. Heat loss also occurs by evaporation from the lungs. Partial control of heat loss is possible by regulating sweating.

For Your Information

The hairs in mammals act as insulating organs and reduce the heat loss. Thus the heat is retained in the body to certain extent. To increase the effect of insulation, the hairs are erected. This occurs involuntarily when the body is over cooled. In human, it produces "goose-pimples" or "goose bumps"

15.11.3 Heat conservation

There are a number of physiological and morphological adaptations in human to conserve body heat. A fatty layer in the hypodermis of skin provides insulation and is very significant to conserve heat. Additional fat insulation of vital organs like kidneys and heart helps heat conservation in respective organs. Vasoconstriction is constrictions of arterioles that supply the surface capillaries in the skin reduces the volume of blood flowing near the surface and hence diminish heat losses. Human body is covered by hair. However, distribution of hair in humans is much more restricted than in other mammals. At the base of hair follicle is a smooth muscle, the hair erector muscle. Contraction of this muscle pulls the hair upright. The hair stand on end air is trapped above the skin. It helps to conserve body heat.

15.11.4 Role of the hypothalamus

Human have a well-developed temperature control system involving receptors and effectors and an extremely sensitive control centre, the hypothalamus. Hypothalamus monitors the temperature of the blood flowing through it. This blood is at core temperature. Also skin has hot and cold thermoreceptors.

When suitably stimulated they generate nerve impulses some of which pass to the hypothalamus and others to the sensory areas of the cortex. In most cases the activity of both skin and hypothalamus receptors combine to control body temperature. This enables the body to make rapid and precise adjustment to maintain constant body temperature.

If body temperature increases the set point in hypothalamus, a set of responses is organized by hypothalamus.

- Vasodilation to increase blood flow to the skin. It increases heat loss from the skin by radiation, convection, and conduction
- Activation of sweat glands
- Decreased metabolic activity

Cold temperature responses regulated by hypothalamus are;

- Vasoconstriction to decrease blood flow to the skin, to reduce heat loss by radiation, convection, and conduction
- Inhibit sweating
- Inhibit panting
- Increased metabolism for shivering and release of thyroxin and adrenaline

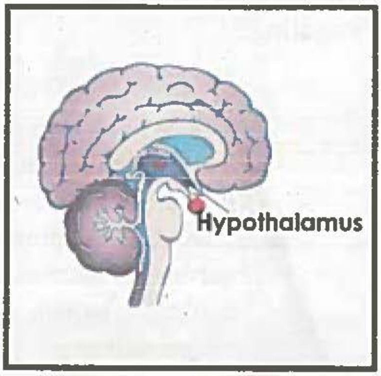


Fig: 15.20 Hypothalamus in the brain.

15.11.5 Fever

An increase in core temperature is known as fever or pyrexia. It happens in certain diseases like malaria, and typhoid. Substances known as pyrogens, which may be toxins produced by pathogenic organisms or chemicals released by neutrophils, directly affect the hypothalamus and increase the temperature set point. The raised body temperature stimulates the defence responses of the body and helps the destruction of pathogens.

DO YOU KNOW?

Antipyretic drugs such as aspirin and paracetamol lower the set point and provide relief from the unpleasant symptoms of fever, but probably slow down the normal defence mechanism.

KEY POINTS

- **Homeostasis** is the tendency of an organism or cell to regulate its internal conditions, such as the chemical composition of its body fluids, so as to maintain health and functioning, regardless of outside conditions.
- Homeostatic mechanism operates just like physical control system having three components; receptors, control center and effectors.
- Negative feedback results in a reversal of the direction of change. Negative feedback tends to stabilize a system, correcting deviations from the normal state.
- **Positive-feedback** involves a change in some variable that triggers mechanisms that amplify rather than reverse the change.
- A type of homeostasis in which water and ions (electrolytes) concentration is maintained in the cells and in the intercellular fluids is called **osmoregulation.**
- Aquatic animals that live in the sea have the body fluids with a solute concentration equal to that of external environment so that animal body fluids are kept isotonic. Such animals are called osmoconformers.
- Desert mammals are very much resistant in this regard. They can tolerate against strong degree of dehydration by special **metabolic and behavioral adaptation**. This characteristic is called **anhydrobiosis**.
- The primary nitrogenous waste product is ammonia. Some animals excrete their ammonia directly; others first convert it to less toxic wastes such as urea or uric acid and then excrete it.
- Animals which excrete ammonia as their major nitrogenous waste product are called **ammonotelic.**
- Animals which excrete urea as their major nitrogenous waste product are called **ureotelic.**
- Animals which excrete uric acid as their major nitrogenous waste product are called **uricotelics.**
- Skin, lungs, liver and kidneys work to dispose off metabolic wastes.
- The act of emptying the bladder is called **micturition.**
- Formation of urine involve three key processes, ultrafiltration, selective reabsorption and tubular secretion.
- A urinary tract infection can happen anywhere along the urinary tract. Types of UTIs depending upon the site includes: pyelonephritis (kidney infection), cystitis (bladder infection) and urethritis (urethral infection).

KEY POINTS

- The most common type of kidney stone contains **calcium** in combination with either **oxalate** or **phosphate** (70% of all stones). Other chemical compounds that can form stones in the urinary tract include **uric acid** (5-10% of all stones) and the amino acid **cystine** (1-3% of all stones).

- Two commonly employed methods for kidney stones removal are **percutaneous nephrolithotripsy (PCNL)** and **extracorporeal shock wave lithotripsy (ESWL).**
- **Renal failure** or **kidney failure** is a medical condition in which the normal functions of kidneys (filtration of toxins and waste products from the blood) are gradually decreased.
- Procedures to filter toxins from the blood when the kidneys are unable to perform this function is called renal dialysis.
- The maintenance of body temperature by living organisms is termed as *thermoregulation.*
- **Poikilotherms** are unable to maintain their body temperature within narrow limits using physiological mechanism e.g. invertebrates, fishes, amphibians, and reptiles. **Homeotherms** are able to maintain a fairly constant body temperature by using physiological mechanisms e.g. birds and mammals.
- The process of heat production in organisms is called **Thermogenesis.**

EXERCISE

1- Multiple choice questions.

(i) ***Shifts in water-solute balance are managed primarily by***

(a) respiratory system (b) the urinary system
(c) endocrine adjustments (d) the circulatory system

(ii) ***Which is the most important mechanism for water loss from the body?***

(a) excretion in urine (b) sneezing
(c) sweating (d) elimination in feces

(iii) ***The process that normally exerts the greatest control over the water balance of an individual is***

(a) sweating. (b) kidney function.
(c) evaporation through the skin. (d) respiratory loss.

(iv) ***Which of the following does NOT dispose off a type of waste directly to the environment?***

(a) digestive system (b) respiratory system
(c) circulatory system (d) urinary system

(v) ***The most toxic substances routinely found in the blood are metabolites of what type of molelcules?***

(a) proteins (b) carbohydrates
(c) nucleic acids (d) Fats

(vi) ***Which of the following is the last structure that urine passes through during its excretion from body?***

(a) distal tubule (b) urethra
(c) urinary bladder (d) ureter

(vii) ***The process during which potassium and hydrogen ions and some toxic substances are put into urine is called***

(a) tubular secretion. (b) reabsorption.
(c) filtration. (d) countercurrent multiplication.

EXERCISE

(viii) ***Kidney health is described in terms of***

(a) the number of kidney stones. (b) rate of filtration.
(c) water retention. (d) blood clot

(ix) ***Why is there no glucose present in the filtrate in the distal tubule of a nephron?***

(a) its molecules are too large to pass across the basement membrane
(b) it is removed by osmosis from the tubule
(c) it is passively absorb by the cells lining the descending the loop of Henle
(d) it is actively absorb by the proximal tubule cells

(x) ***In case of overheating, the body temperature is regulated by:***

(a) more sweating and more urination
(b) more sweating and less urination
(c) less sweating and more urination
(d) less sweating and less urination

(xi) ***An animal that warms itself mainly by absorbing heat from its surroundings is known as:***

(a) homoiotherm (b) ectotherm
(c) endotherm (d) none of them

2- Short Questions.

(i) Why it is necessary for a living being to maintain its internal environment at a fairly constant level?

(ii) How positive feedback can be harmful at times?

(iii) Describe mechanism of ultrafiltration.

(iv) How regulation of blood flow to skin is meaningful to maintain body temperature?

EXERCISE ?

(v) Why Juxtamedullary nephrons are more important in osmoregulation?

(vi) How ADH controls concentration of urine?

(vii) Why do marine fishes drink water unlike fresh water fishes?

(viii) How do some terrestrial mammals become so resistant that they are able to survive without drinking water?

(ix) What is the benefit of Extracorporeal Shock Wave Lithotripsy (ESWL) over Per Cutaneous Nephro Lithotrypsy (PCNL).

(x) Why is the excretion of uric acid advantageous to birds and reptiles?

3- Extensive Questions

(i) Explain the working of feedback system in a living body and compare it with a non-living physical feedback system.

(ii) Describe different parts of urinary system of human with main emphasis on their role in excretion.

(iii) Describe the challenges and osmoregulatory adaptations of osmoconformers and osmoregulators in marine environment.

(iv) Describe the role of kidney as osmoregulatory organ.

(v) What is renal failure? Describe its types and causes.

(vi) Explain the procedure of peritoneal and hemodialysis.

(vii) Describe various type of kidney stones and their causes.

4- Science, Technology, and Society Connections

- Describe the importance of kidney donation for the benefit of kidney failure patients.

EXERCISE

- Name the important kidney transplant centers in your province.

5- **Online Learning**

- **http://www.emedicinehealth.com**
- **http://www.medicinenet.com**
- **https://www.nyu.edu**
- **http://www.webmd.com**