Osmoregulation in aquatic vertebrates [4^{th} sem, ZooA:UG]

Introduction

Osmoregulation refers to the process by which living organisms maintain the constant osmotic conditions in the body. It involves the regulation of water and solute concentration of the body fluids such as potassium, sodium and chlorides so that their body fluids are maintained within homeostatic limits. In order for the cells in the body of an organism to function effectively the body fluids such as the cell contents as well as fluids outside cells such as tissue fluids, lymph and blood plasma must remain constant. Freshwater, marine and terrestrial organisms consists of varying modes adaptations for Osmoregulation that meet the challenges of these diverse environments. Therefore, this essay will disclose the patterns of Osmoregulation in aquatic and terrestrial environments.
So, osmoregulation is the regulation of water and ion concentrations in the body. Keeping this regulation precise is critical in maintaining life in a cell. Balance of water and ions is partly linked to excretion, the removal of metabolic wastes from the body.

The environment of an organism influences the process of Osmoregulation and the nature of excretion because Osmoregulation involves the same body structures with nitrogenous wastes. This is attributed to the fact that the elimination of nitrogen wastes is usually associated the problem of losing and gaining water. Different organisms live in different environments such as aquatic which includes fresh water and marine environment, and terrestrial environment. In all these environments, organisms employ specific patterns of controlling the concentration of water and salt so that their body fluids do not become too dilute or too concentrated through their environment as a media, (Solomon, P.E et-al 1069).

Osmoconformers and Osmoregulators

Not all organisms osmoregulate. Some marine animals such as the sea stars are osmoconformers; their body fluids are similar to seawater in osmolarity, so they gain and lose water at equal rates and have no need to expend energy expelling water or salt from the body. However, if they are placed in water more or less concentrated than seawater, their tissues shrink or swell, their **organelles** and cell membranes are damaged, and they die. This is why echinoderms are not found in estuaries, or river mouths where fresh and salt water meet and the salinity fluctuates greatly. Osmoconformers are stenohaline (*steno* means "narrow range," and *hal* means "salt"), unable to tolerate much variation in environmental salinity.

Osmoregulators, on the other hand, maintain a more or less stable internal osmolarity by physiological means. Terrestrial animals must osmoregulate because they unavoidably lose water by evaporation and excretion, and replacement water is not always immediately available. Marine osmoregulators maintain an internal salinity lower than that of seawater, and freshwater osmoregulators maintain an internal salinity higher than that of fresh water. Euryhaline (*eury* means "broad") animals, those able to tolerate a broad range of environmental salinity, must be good osmoregulators. The blue crab, *Callinectes sapidus,* for example, thrives in estuaries and requires efficient osmoregulation to survive there.

Osmoregulatory Mechanisms

Water cannot be actively transported across cell membranes because there are no carrier **proteins** capable of binding and transporting it. Water can, however, pass directly through membranes in response to changes in **ion** concentration. Water movement is therefore controlled indirectly, by pumping ions such as sodium and potassium across cell membranes, creating a concentration **gradient** that causes water to follow by **osmosis** . If sodium is **excreted** from the body, for example, water tends to follow it. The rate of water loss can thus be regulated by **hormones** that control the rate of sodium excretion or the water permeability of the excretory ducts.

Osmoregulation is usually achieved by excretory organs that serve also for the disposal of metabolic wastes. Thus, urination is a mechanism of both waste excretion and osmoregulation. Organelles and organs that carry out osmoregulation include contractile vacuoles, nephridia, antennal glands, and malpighian tubules of invertebrates, and salt glands and kidneys of vertebrates.

Salt glands are associated with the eyes, nostrils, or tongue of marine reptiles (sea snakes, sea turtles, marine iguanas, saltwater crocodiles) and birds (gulls, albatrosses). These animals ingest excess salt with their food and water and excrete it by way of these glands.

Kidneys are vertebrate osmoregulatory organs in which blood pressure forces fluid to filter through the walls of blood capillaries into tubules that process the filtrate into urine. Each human kidney has about 1.2 million tiny balls of capillaries called glomeruli, where the blood pressure is very high. A filtrate of the blood plasma, free of cells and protein, seeps from these capillaries into a hollow ball called a glomerular (Bowman) capsule. From there, it flows into a series of tubules that remove most of the salt and water along with useful material such as glucose and vitamins, while secreting hydrogen and potassium ions, urea, and drugs (for example, penicillin and aspirin) into the tubular fluid. A final tube in the pathway, called the collecting duct, adjusts the salinity of the urine by reabsorbing variable amounts of water, before the urine leaves the kidney for storage in the urinary bladder and eventual elimination from the body.

Two hormones, aldosterone and antidiuretic hormone, regulate the amounts of salt and water reabsorbed, enabling the human kidney to adjust water loss or retention to the body's state of hydration. Human blood plasma and tissue fluid normally has an osmolarity of 300 milliosmoles per liter (mOsm/L); that is, 0.3 mole of dissolved particles per liter of solution. Human urine can be as dilute (hypoosmotic) as 50 mOsm/L when the body is voiding excess water, or as concentrated (hyperosmotic) as 1,200 mOsm/L when conserving water.

Freshwater fish, by contrast, cannot produce hyperosmotic urine, but they have no need to. Surrounded by water, they can afford to produce abundant, dilute urine to flush away their metabolic wastes. Among mammals, the ability to concentrate the urine is also little developed in aquatic forms such as beavers and muskrats. Kangaroo rats, by contrast, are desert rodents that need never drink water (they obtain it from food), and can concentrate their urine to as much as fourteen times the osmolarity of their blood plasma (compared to four times for humans).

Osmoregulation in Aquatic environment

Aquatic organisms include those which live in marine water and also those which live in fresh water environment.

Osmoregulation in marine environments

Osmoregulation in aquatic organisms occurs in marine species which involves the losing of water and gaining of salts to maintain a favourable and constant internal environment. To this, aquatic organisms adapt successfully. These organisms live in a hypertonic environment meaning that their inner water content is higher than the surrounding environment, hence they lose water by osmosis and then they gain salts from the seawater they drink by diffusion. Solomon, P.E et-al (2011:1073) adds that, "to compensate for fluid loss marine fishes drink a lot of sea water, excrete the salts through the gills and also produce a small volume of urine thereby osmoregulating their body fluids.

Then also, other marine species such as those of marine cartilaginous fishes i.e. sharks and rays have their own pattern of carrying out Osmoregulation. They have different osmoregulatory adaptations that allow them to tolerate the salt concentration of their environment. These organisms are able to accumulate and tolerate urea because their kidneys undertake the reabsorption of urea in high concentration such that their body tissues become hypertonic to their surrounding medium resulting in a net inflow of water by osmosis. Then also they excrete quantities of dilute urine and excess salt is excreted also by the kidneys and in most species by a rectal gland, hence osmoregulating the body fluids.

For **marine snakes** they carry out Osmoregulation by using **salivary sublingual gland** to get rid of excess leaving a normal blood concentration. Additionally, some reptiles, snakes and marine birds ingest sea water and take in a lot of salt in their food. To control the concentration of salts and water they posses glands in their heads which undertake the excretion of excess salts from their blood plasma.

Elasmobranchs, marine birds, and some reptiles have a structure called a ***salt gland*** to secrete NaCl from their bodies. These animals require a lower internal NaCl concentration than the surrounding seawater, which causes a concentration gradient favouring the influx of salt. Therefore, they need a way to secrete it. The solution is provided by glands in the rectum of sharks and the skulls of marine birds and reptiles which produces a concentrated salt solution for secretion. The sodium ions are removed from the blood by these glands not by filtration, but by the sodium-transport mechanism (the sodium-potassium pump). This Na^+/

K^+/ ATPase activity allows for the movement of NaCl from the blood across the **epithelium** into the **lumen** of the salt gland for secretion. Interestingly, the shark rectal gland, bird nasal gland, fish gill, and the thick ascending Loop of Henle in the kidney all contain salt-secreting cells that transport NaCl by the same basic mechanism. Active transport produces an increase in the chloride concentration in the cytoplasm of epithelial cells. This results in the diffusion of chloride ions out of the cell across the apical surface. The build-up of chloride ions at the apical surface attracts sodium ions to diffuse between the cells (the paracellular route).

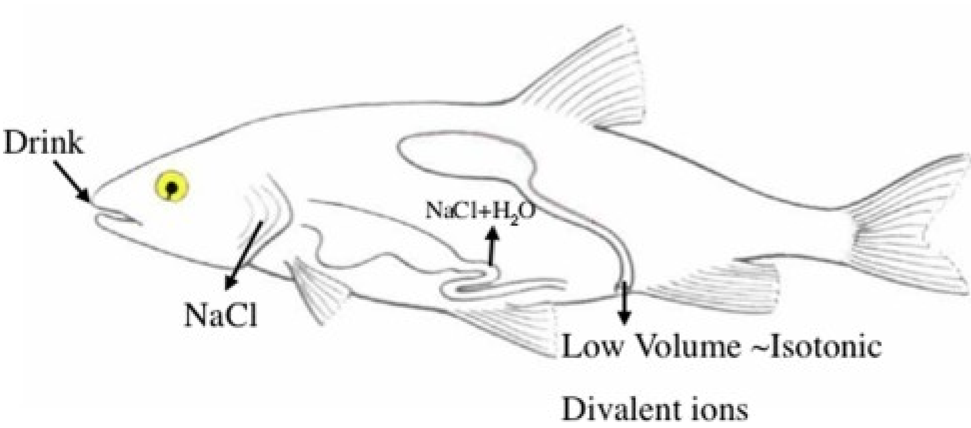

Figure 1 : Basic pattern of marine teleost osmoregulation. To offset the osmotic loss of water across the gill epithelium, the fish ingests seawater and absorbs NaCl and water across the esophageal and intestinal epithelium. Urinary water loss is kept to a minimum by production of a low volume of urine that is isotonic to the plasma, but contains higher concentrations of divalent ions than the plasma. Excess NaCl is excreted across the gill epithelium (Evans (2008).

Osmoregulation in freshwater organisms

Another pattern of organisms which live in fresh water are able to regulate the concentration of water and salts in their bodies through the pattern of gaining water and losing salts. This is because fresh water organisms in **hypotonic medium**. This is attributed to the fact that these organisms have a lower water potential than the surrounding environment, (Taylor D.J et-al 2011). As a result, there a constant tendency for water to enter the cells by osmosis through the cell surface membrane which poses a constant threat of organisms becoming water logged. To overcome this challenge, different organisms employ particular mechanisms.

In **fresh water organisms** such as fishes undertake **Osmoregulation through** the release of excess water through the **gills** and through the **excreting of large amounts** of **dilute urine**. Solomon, P.E *et-al* (2011) adds that "these organisms tend to lose salts by diffusion through the gills into the water". In this way such organisms control the concentration of body water and salts. In addition to this, some amphibians such as frogs have their pattern of osmoregulating the body environment which is through producing large amounts of dilute urine and also active transport of salts into the body by specialised cells in the skin compensates for the loss of salt through the skin and urine.

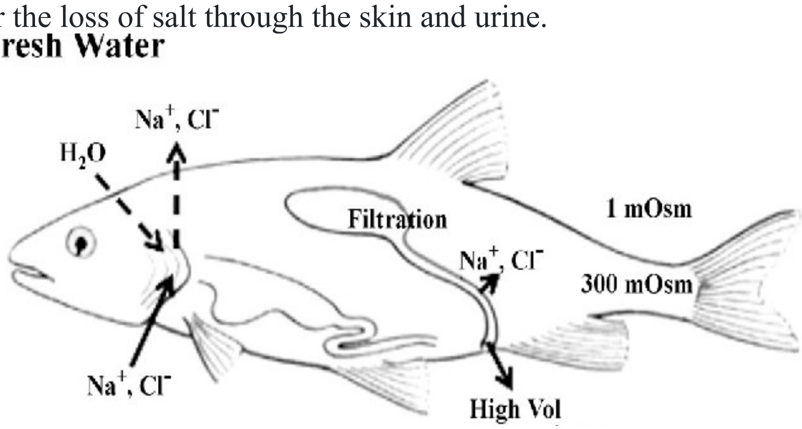

Fig. Mechanisms of osmoregulation by teleost fishes. Freshwater teleosts are hyperosmotic to the surrounding solution, so they face osmotic gain of water and diffusional loss of NaCl across the permeable gill epithelium. These potentially disruptive osmotic and ionic movements are compensated for by excretion of relatively large volumes of a dilute urine, and active uptake of NaCl across the gill epithelium.

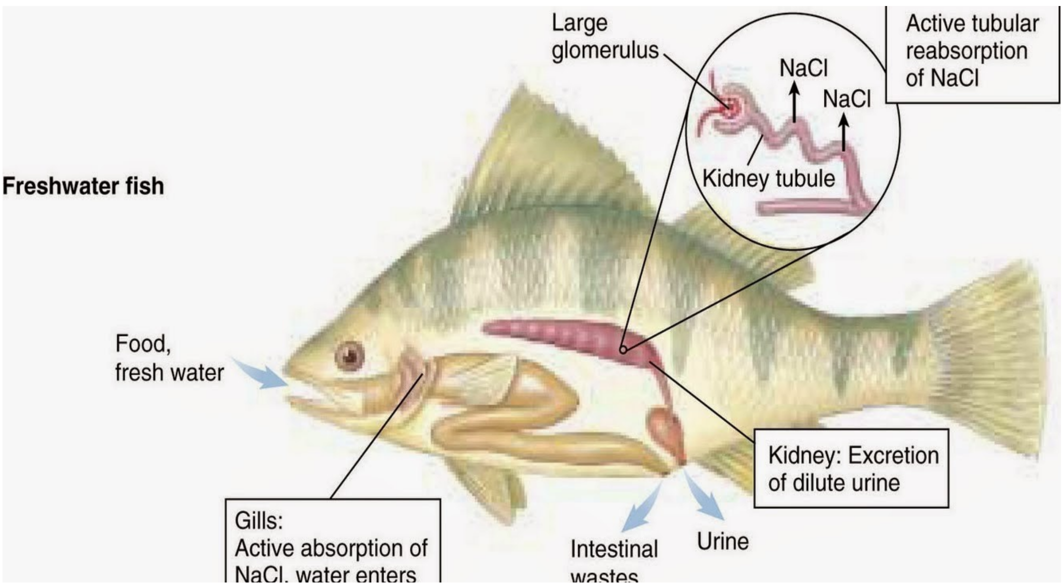

Figure : Osmoregulation in freshwater fish

Conclusion

As indicated above Osmoregulation is the process by which organisms control the concentration of water and salts in the body so that their body fluids are maintained within homeostatic limits. This process occurs in organisms depending on the environment in which an organism live i.e. aquatic which include fresh water and marine water, and also terrestrial environment.

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