Role of kidney in osmoregulation

Water is a vital molecule for the human body. Approximately 98% of the human body is made up of water. Human beings cannot survive if their water content decreases below 12%; hence the homeostasis of water is an important mechanism. Water has many important functions in our body. Water acts as a transport medium in blood and secretion e. g. in digestive juices, tears. Water is a good lubricant and acts to reduce friction when combined with particular proteins e. g. mucus to aid external movement. Many chemical reactions take place in an aqueous medium (Jones M. et al. 2000)

The kidneys are highly specialised organs of the body and play an important role in homeostasis. Fig 1a shows the location of the kidney in the human body. The kidney maintains homeostasis by regulating water balance, waste removal and blood composition and pressure. The kidneys dispose of waste by-products of metabolism and hence prevent the build up of toxic products in the body and to regulate the chemical components of the body's fluids by responding to any imbalances of body fluids. These functions are fulfilled by a process of filtration of blood, which mainly includes the movement of solutes between the internal fluid and external environment. The movement of solutes is normally through a transport epithelium, in the case of the kidney it is in the form of a tubular channel; this tubular channel gives the kidney a large surface area.

As Fig 1b shows blood enters each kidney via the renal artery and leaves via the renal vein. The kidneys weigh less than 1% of the human body, they receive approximately 2 % of blood pumped with each heartbeat. Urine exits the kidney through a duct called the ureter. The ureters of both kidneys drain into a common urinary bladder. Urine leaves the body from the urinary bladder to the urethra which empties near the vagina in females or through the penis in males. (Campbell N. A. et al. 1999, Michael F. et al. 2001)

At one end the nephron forms a cup-shaped structure called glomerulus.

From the glomerulus a tube runs towards the centre of the kidney first forming a twisted region called the proximal convoluted tubule and then a long hair-pin loop in the medulla, it runs back upwards into the cortex where it forms another twisted region called the distal convoluted tubule, this then joins a collecting duct which leads down the medulla and into the renal pelvis

The functional unit of the kidney is a nephron. Microscopic sections of the kidney show that the kidney is made up of thousands of nephrons. Fig1b shows the location of a nephron and Fig2 shows the detailed structure of a nephron. Each renal capsule is supplied with blood by the afferent arteriole – a branch of the renal artery this splits into many capillaries in the capsule which then rejoin to form the afferent arteriole. The nephrons structure is closely related to its function of regulating solutes

Osmoregulation is maintaining constant levels of water in the body. Cells cannot survive a huge deviation from its osmolality. Hence, cells have a continuous movement of water across their plasma membranes. A net gain of water will cause the cell to swell up and burst, while a net loss of water will cause the cell to shrivel up and die. Water is transported by osmosis around the body. Osmoregulation is accomplished by creating an osmotic gradient; this requires lots of energy and is done by maintaining solute concentrations in the body fluids.

The osmolality of the body is fixed at a mean of 290±5 mosmos/g. The kidney is able to maintain a constant osmolality as it's able to adjust the rate of water excretion over a wide range. The volume of the extra-cellular fluid is mainly determined by the concentration of sodium ions, hence slight adjustments to the renal excretion rate have a major impact on the extracellular fluid volume. Changes in tubular sodium transport is accompanied by parallel movements of water, this results in no net change in body fluid osmolality (Campbell N. A. et al. 1999, Frederic H. M. 2006, Michael F. et al. 2001)

The loop of Henle creates a longitudinal osmotic gradient across the medulla; this aids the reabsorption of water and other important solutes. Ascending and descending limb are parallel and adjacent to each other with a layer of tissue fluid in between. Fluid enters from the proximal convoluted tubules flows down the descending limb and then up the ascending limb. This is known as a counter-current flow. Thewalls of the descending limb are permeable to water, while the walls of the ascending limb are impermeable to water. The ascending limb of the Loop of Henle is made up of a thick walled tubule which is impermeable to the outward movement of water but not salt. The red arrows on fig3 show the movement of water amd solutes along the loop of Henle and the collecting duct. Also, the walls of the ascending limb contain pumps to remove sodium chloride from the lumen and add it to the surrounding interstitial fluid. Hence sodium and chloride ions are actively transported out of the ascending limb.

This is the site of reabsorption in the kidney, here fluid from the…enters and the kidney reabsorbs all the useful solutes and water. The permeability of the loop and the collecting duct depends on the osmolality of the blood and is controlled by a negative feedback mechanism by osmoreceptors in the hypothalamus

A high concentration of salt builds up in the medullary tissue, this together with urea retention by these tissues, helps build up a high osmotic pressure in the medullary tissue. This creates a gradient of 200 mosm/g across the tubular wall at any point and causes a loss of water from the descending limb. The loss of water concentrates sodium and chloride ions in the descending limb. Salt concentration in the medullary tissue is highest at the apex of the loop, the tissue in the deeper layers of the medulla contain a very concentrated solution of sodium ions, chloride ions and urea. The fluid leaving the ascending limb is hypo-osmolar as compared to the fluid that enters and has a osmolality of approximately 100 mosm/g . Sodium and chloride ions diffuse out in the lower part of the ascending limb. Fluid passes down the collecting duct through the medullary tissue of increasing salt concentration, water can pass out of it by osmosis. The reabsorbed water is carried away by blood capillaries (Campbell N. A. et al. 1999, Frederic H. M. 2006, Michael F. et al. 2001)

Control of water regulation

Osmoregulation by the kidney involves a negative feedback mechanism. The osmoreceptors are in the hypothalamus and the effectors are the pituitary gland and the walls of the distal convoluted tubules. Osmoreceptors detect alterations of water levels and send impulses to the pituitary gland which then increase or decrease the production of antidiuretic hormone (ADH). In the case of a low osmolality, when the nerve cells are stimulated by osmoreceptors action potentials travel down them, this causes ADH to be released from their endings into the blood capillaries in the posterior pituitary gland from here it is distributed throughout the body. ADH acts on the plasma membranes of the cells of the collecting ducts. ADH is picked up by a receptor on the plasma membrane which then activates an enzyme. This causes vesicles with water permeable channels to fuse with the plasma membrane hence ADH makes the membrane more permeable to water than usual. Hence more water will be reabsorbed by the collecting duct and more concentrated urine will be produced.

On the other hand, when the blood water content rises the osmoreceptors are no longer stimulated and hence do not lead to the secretion of ADH. Hence, ADH secretion slows down and the collecting duct cells become less permeable to water, so less water is reabsorbed and more diluted urine is produced (Campbell N. A. et al. 1999, Frederic H. M. 2006, Michael F. et al. 2001)

In conclusion, the regulation of water is essential for the survival of human beings and is carried out by the kidneys and monitored by osmoreceptors in the hypothalamus and controlled by the pituitary gland. Each of these plays an equally important role in the regulation of water and without any one of them the body will not be able to function in a normal manner.

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