Adaptations to an arid climate

Water is the main component of cells, tissues and organs. Being hydrated is essential for life.

Two main body compartments contain water: the intracellular compartment (IC fluid or ICF) and the extracellular compartment (EC fluid or ECF). ECF is found in blood plasma; transcellular fluids such as synovial and cerebrospinal fluid; and fluid surrounding cells (interstitial fluid).

The body strives to maintain constancy of all body functions and systems, including regulation of pH, temperature, osmotic pressure and amount of body water, via homeostatic mechanisms. Total body water remains relatively constant, with only small fluctuations over a 24-hour period (Grandjean & Campbell, 2004).

Measurement of body water, water inputs and water outputs

Total body water of marsupials on Barrow Island was measured using isotopes (King & Bradshaw, 2008). Tritiated water (^3H_2O) was used to trace movement of water in and out of body compartments, to quantify changes in body water.

There are three main sources of water inputs: drinking; ingestion of food that contains water; and production of metabolic water. Water is lost from the body mainly through the kidney (as urine) but also via skin (as sweat), respiratory tract (as water vapour) and digestive system (as faeces).

Regulation of water balance

Regulation of body water balance, by the kidney, is complex for all animals. Hormonal regulation is involved and species may also have anatomical differences in kidney structure, such as differing tubule lengths. The hormone ADH (antidiuretic hormone, also known as vasopressin) acts on the kidney to increase water reabsorption and maintain body water levels if water inputs are reduced.

The kidney regulates water balance and solute concentration through a process that involves filtration. The functional unit in the kidney is the nephron. There are approximately one million nephrons in a human kidney.

The blind end of the nephron is Bowman's capsule (or glomerular capsule). It surrounds a tuft of capillaries known as the glomerulus. Blood enters the glomerulus via the afferent arteriole, and leaves the glomerulus via the efferent arteriole.

Solutes and water in blood are forced or filtered into the Bowman's capsule because of pressure created by differences in diameter of afferent and efferent arterioles.

Walls of the glomerular capillaries are impermeable to large molecules (such as red blood cells and proteins). As filtrate passes through the long tubule of the nephron, water and solutes required by the body are reabsorbed into a network of peritubular capillaries that surround the nephron. Filtrate passes from the nephron tubule system to a connected duct system, known as collecting ducts.

Hormonal action

Osmotic pressure increases if concentration of water in ECF decreases. Increasing pressure activates osmoreceptors in the hypothalamus and ADH is secreted.

The usual level of plasma ADH in humans is 1 pg mL^{-1}, however it shows significant diurnal variation. Values measured during the night are approximately two-fold greater than during the day (Bankir, 2001), so more water is absorbed, less urine produced, and you don't have to get up during the night. Plasma ADH levels in the Barrow Island marsupials study (King & Bradshaw, 2008) varied between 0.55 and 16.7 pg mL^{-1}. There is a trend that suggests that ADH levels are higher in animals that live in dry environments. However, as analysis of the Barrow island marsupial data demonstrates, other adaptations also significantly contribute to water conservation.

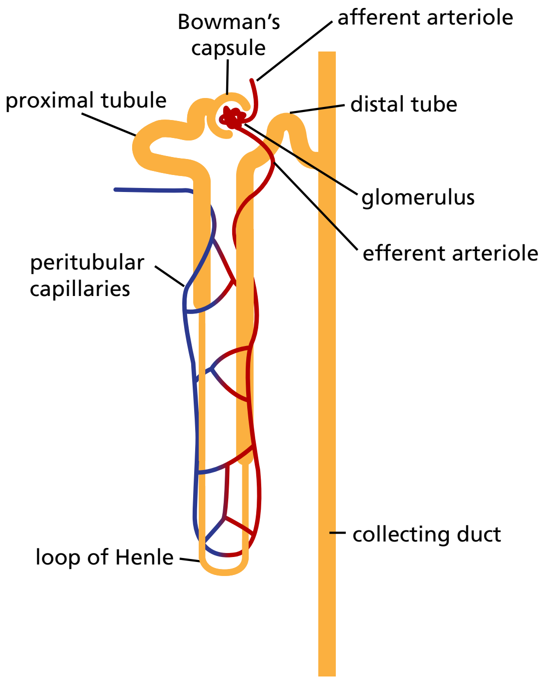

figure 1: diagram of a single nephron, the functional unit of the kidney

Mechanism of ADH action

All hormones require a receptor, which is a specific structure on a cell membrane to which the homone binds. There are two main types of ADH (vasopressin) receptors: V1, which is located on blood vessels, is involved in blood pressure regulation and central feedback mechanisms; whilst V2 is involved in water balance and electrolyte homeostasis (Böselt et al., 2009).

V2R (an acronym for V2 receptors) are specifically found in the basolateral membrane (the 'blood' side) of collecting duct cells.

Binding of ADH to the V2R receptor on the basolateral side of collecting duct cells stimulates a cascade of biochemical events resulting in the translocation of vesicles containing water channel proteins known as aquaporin 2 (AQP2) to the apical or 'urine' side plasma membrane. The apical membrane becomes permeable to water which moves from urine into collecting duct cells because of an osmotic gradient. Long-term exposure of ADH has been found to lead to an increase in AQP2 synthesis, which increases the body's ability to reabsorb and hence maintain water (Brown, 2003).

Importance of V2R

Animals with a mutated V2R gene (as in the disease, diabetes insipidus) produce large volumes of dilute urine as they are unable to concentrate urine. If V2R does not function normally ADH is unable to bind to the receptor and stimulate movement of AQP2 to the apical membrane.

However, increased activity of normal V2R enables animals to concentrate urine and therefore produce a reduced volume. It is suggested that, through saving water, this may provide an advantage to animals (Böselt et al, 2009).

Research by Böselt and colleagues (op cit) found that mammalian species with unlimited water access do not lose V2R function. The authors speculate that V2R activity must therefore have an essential role in survival. Interestingly, several marsupial species (eg red kangaroo, agile wallaby and long-nosed potoroo) showed a significant increase in V2R activity. The authors conclude that 'the gain of basal V2R function in several marsupials may contribute to the increased urine concentration abilities and therefore provide an advantage to maintain water and electrolyte homeostasis under limited water supply conditions.' (Böselt, 2009)

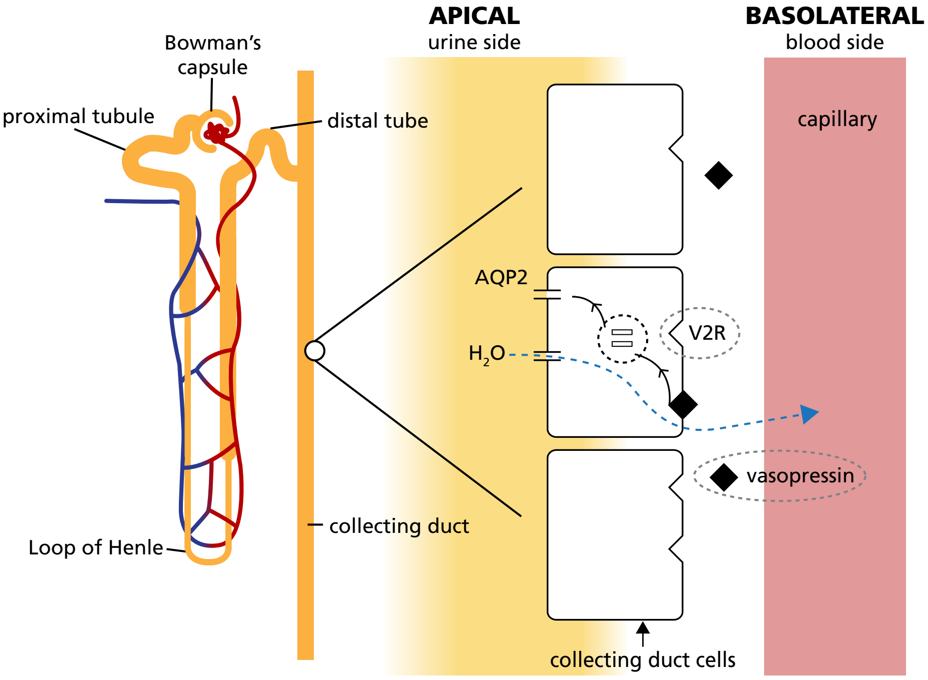

figure 2: mechanism of ADH action in the kidney

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