Excretory system

Components

The excretory system, or urinary system, is made up of the two kidneys, ureters, bladder and urethra, together with the branches of the two renal arteries and veins.

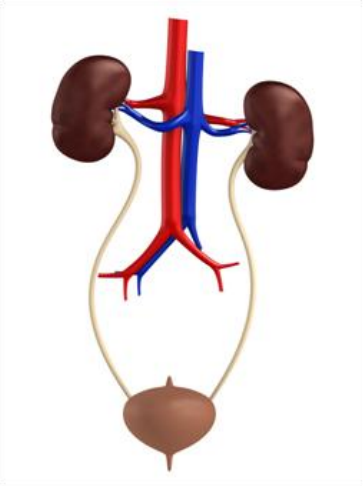

Figure 1 The excretory system.

Functions

The kidneys are responsible for osmoregulation and the elimination of toxic wastes, including nitrogenous excretion. Osmoregulation is important as extracellular fluid must not induce osmosis either by causing cells to lose water and shrink or to gain water and swell up.

Nitrogenous excretion is necessary as amino acids cannot be stored by the body. Proteins obtained in food invariably contain an imbalance of certain amino acids – they are not in the correct proportions for use in protein synthesis in the body. Those that cannot be assimilated are deaminated by the liver, forming fatty acids and ammonia. Most of the highly toxic ammonia is rapidly converted to urea to be removed from the body by the kidneys in urine.

The kidneys not only excrete metabolic wastes including ammonia, urea, uric acid and creatinine, but have the main responsibility for maintaining the stability of extracellular fluid volume, inorganic ion composition and osmolarity (solute concentration). They contribute to maintenance of pH and also secrete certain hormones.

Key mechanisms

The functional unit in a kidney is the nephron (kidney tubule).

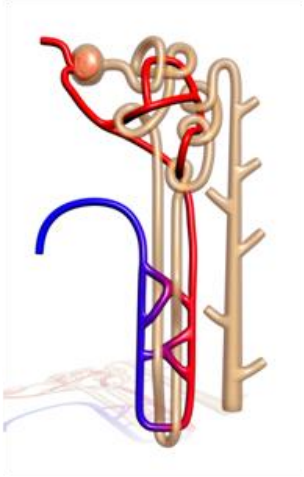

Figure 2 Structure of a nephron. Each kidney contains about one million nephrons.

Blood is filtered:

- Each nephron is made up of a filtering unit - Bowman's capsule, and a tubule.
- Each capsule contains a tight knot of capillaries, called the glomerulus.
- Blood flows into the glomeruli under pressure forcing a filtrate free of cells and protein through the capillary walls.
- Filtrate collects in the capsules and enters the tubules.

After filtration selective reabsorption and secretion take place:

- useful materials such as glucose are almost completely reabsorbed into capillaries and back into the blood plasma;
- homeostasis is achieved through the balanced reabsorption of inorganic ions and water;
- unwanted ions and molecules remain in the tubule;
- in addition, other unwanted materials are extracted from the blood by tubule cells and secreted into the filtrate as it flows through the tubule;
- Na^+ is actively transported out of the tubule epithelial cells by protein pumps and taken up by blood capillaries;
- Na^+ diffuses from the filtrate into the tubule cells, partly through ion channels and partly through facilitated diffusion using protein carriers that cotransport glucose or Cl^- (also absorbed) or countertransport H^+ (secreted);

- a hairpin countercurrent multiplier system concentrates Na^+ and vigorously reabsorbs water by osmosis from the final section of the tubule (the collecting duct).

The fluid that flows from the tubules is now urine which is more concentrated than blood plasma:

- Urine is carried by the ureters to the bladder where it is stored until it is eliminated from the body through the urethra.
- The composition of the urine will vary as is necessary to remove toxic wastes, unwanted inorganic ions and sufficient water to maintain the composition (including pH) and osmolarity of body fluids.

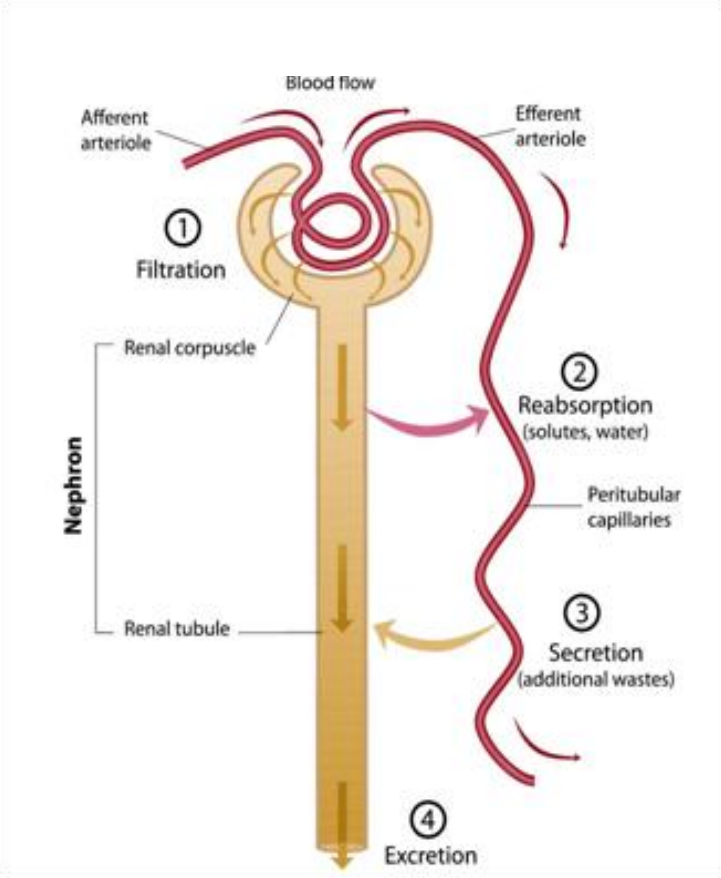

Figure 3 The four main stages of urine formation.

Role in homeostasis

By eliminating unwanted materials from the plasma in urine, but retaining those useful to the body, the kidneys contribute more to homeostasis than any other organ.

The kidneys maintain plasma constituents within the narrow range necessary to sustain living processes, even though there are wide variations in intake and losses. To achieve this, about 25% of the blood that passes through the systemic circulation is filtered through the kidney tubules.

Through the formation of urine, they regulate the inorganic ion composition, volume, water balance and pH of the internal environment and excrete waste products. The kidneys also secrete hormones affecting Na^+ reabsorption by nephrons, Ca^{2+} absorption from the gut and the oxygen content of blood.

Examples of what can go wrong

Water deficit

As the main route for eliminating potentially toxic metabolic wastes and foreign compounds from the body in solution, the kidneys must produce a minimum volume of around 500 cm^3 of urine every day containing water taken from blood plasma. Without water replacement, the plasma volume and blood arterial pressure fall to a fatal level.

Diabetes

The reabsorption of glucose is coupled to the reabsorption of Na^+ by membrane transport proteins. In diabetes mellitus, plasma glucose levels are so high that the filtrate is sufficiently concentrated to saturate the binding sites of the carrier molecules. Therefore, glucose appears in the urine.

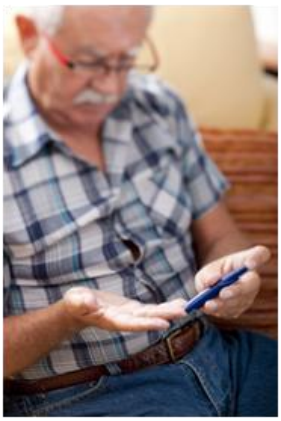

Figure 4 Diabetics regularly check their blood glucose levels.

Congestive heart failure, hypertension and diuretics

If a diseased heart is unable to pump sufficient blood, arterial blood pressure can fall even if the plasma volume is normal.

- Low blood pressure will trigger Na^+ and water retaining mechanisms in the kidneys.
- Normally this will increase plasma volume and raise arterial blood pressure back to normal.
- In this case the weakened heart will fail when it is unable to pump the additional plasma volume.

Diuretics are medicinal drugs that increase urinary output to remove excess water from the body and reduce plasma volume. They may also therefore be used to treat **high blood pressure** (hypertension). They include:

- thiazide diuretics (derived from benzothiadiazine). These block Na^+-Cl^- cotransporter molecules in tubule membranes, inhibiting reabsorption of Na^+ and Cl^-. Less water is reabsorbed by osmosis. Water retained in the filtrate is lost in the urine. These diuretics also cause loss of K^+;
- ACE inhibitor drugs block the action of angiotensin converting enzyme (ACE) which converts angiotensin I to angiotensin II. Angiotensin II stimulates the secretion of aldosterone by the adrenal cortex. Aldosterone increases Na^+ absorption by promoting the insertion of additional Na^+ channels and sodium-potassium pumps into the tubule membranes. Reduced aldosterone secretion inhibits Na^+ reabsorption and therefore water reabsorption, so more Na^+ and water are lost in urine. This does not cause the loss of K^+

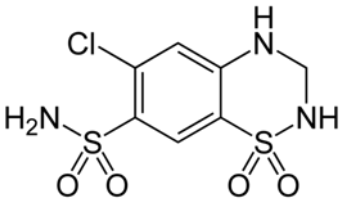

Figure 5 Hydrochlorothiazide is a diuretic drug.

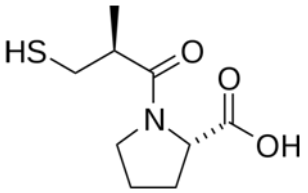

Figure 6 Captopril was the first synthetic ACE inhibitor.

Other diuretics use a variety of different mechanisms, some resulting in loss of sodium but retention of potassium. Such diuretics are therefore termed potassium sparing diuretics.

Finding out

Why high arterial blood pressure is also called hypertension.

Explain why a high salt intake might cause high blood pressure.