Excretion and Homeostasis

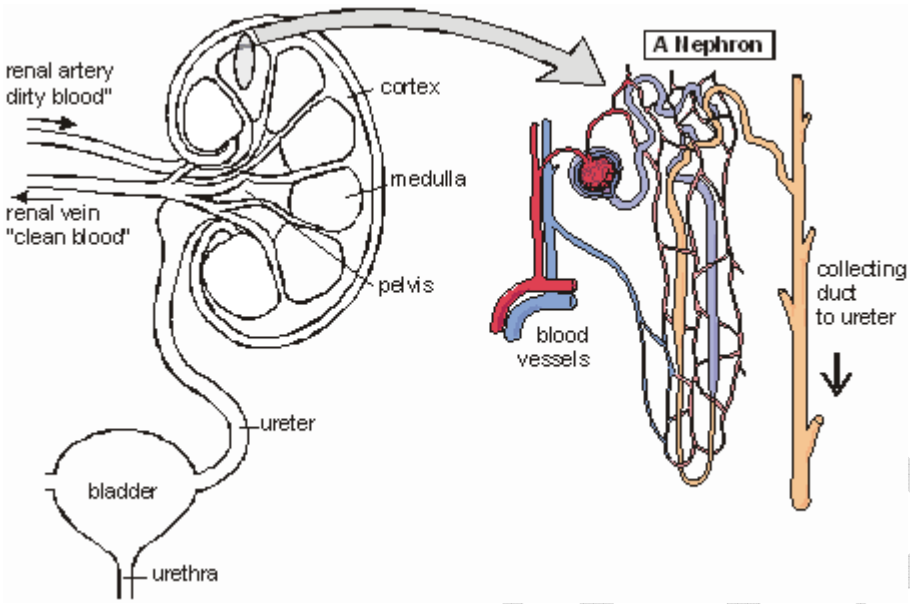
Excretion means the removal of waste products from cells. There are five important excretory organs in humans:

- Skin — excretes sweat, containing water, ions and urea
- Lungs — excrete carbon dioxide and water
- Liver — excretes bile, containing bile pigments, cholesterol and mineral ions
- Gut — excretes mucosa cells, water and bile in faeces. (The bulk of faeces comprises plant fibre and bacterial cells, which have never been absorbed into the body, so are not excreted but egested.)
- Kidneys — excrete urine, containing urea, mineral ions, water and other "foreign" chemicals from the blood.

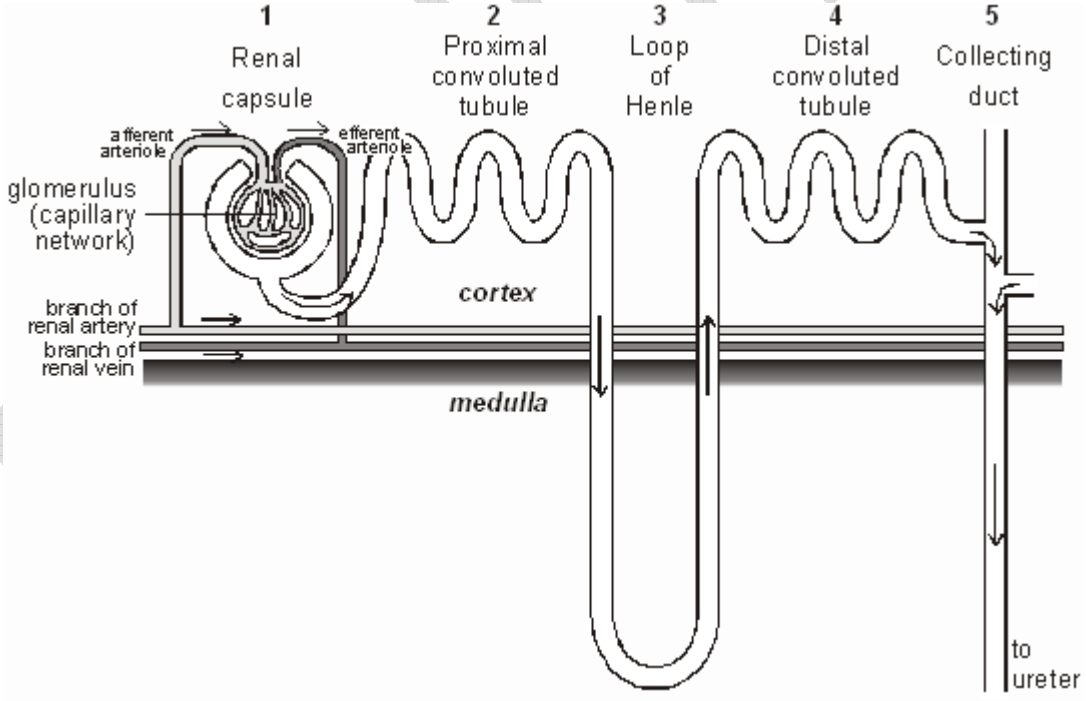
This section is mainly concerned with the excretion of nitrogenous waste as urea. The body cannot store protein in the way it can store carbohydrate and fat, so it cannot keep excess amino acids. The "carbon skeleton" of the amino acids can be used in respiration, but the nitrogenous amino group must be excreted.

The Kidney

The kidneys remove urea and other toxic wastes from the blood, forming a dilute solution called urine in the process. The two kidneys have a very extensive blood supply and the whole blood supply passes through the kidneys every 5 minutes, ensuring that waste materials do not build up. The renal artery carries blood to the kidney, while the renal vein carries blood, now with far lower concentrations of urea and mineral ions, away from the kidney. The urine formed passes down the ureter to the bladder.



The important part of the kidney is a folded tube called a nephron. There are a million nephrons in each kidney. There are five steps in producing urine in a nephron:



1. Renal capsule – Ultrafiltration

The renal artery splits into numerous arterioles, each feeding a nephron. The arteriole splits into numerous capillaries, which form a knot called a glomerulus. The glomerulus is enclosed by the renal capsule (or Bowman's capsule)- the first part of the nephron. The blood pressure in the capillaries of the glomerulus forces plasma out of the blood by ultrafiltration. Both the capillary walls and the capsule walls are formed from a single layer of

flattened cells with gaps between them, so that all molecules with a molecular mass of <70k are squeezed out of the blood to form a filtrate in the renal capsule. Only blood cells and large plasma proteins remain in the blood.

2. Proximal Convoluted Tubule – Reabsorption.

The proximal convoluted tubule is the longest (14mm) and widest (60µm) part of the nephron. It is lined with epithelial cells containing **microvilli** and numerous **mitochondria**. In this part of the nephron over 80% of the filtrate is reabsorbed into the tissue fluid and then to the blood. This ensures that all the "useful" materials that were filtered out of the blood (such as glucose and amino acids) are now returned to the blood.

- All glucose, all amino acids and 85% of mineral ions are reabsorbed by active transport from the filtrate to the tissue fluid. They then diffuse into the blood capillaries.
- Small proteins are reabsorbed by pinocytosis, digested, and the amino acids diffuse into the blood.
- 80% of the water is reabsorbed to the blood by osmosis.
- Surprisingly, some urea is reabsorbed to the blood by diffusion. Urea is a small, uncharged molecule, so it can pass through membranes by lipid diffusion and there isn't much the kidney can do about it. Since this is a passive process, urea diffuses down its concentration gradient until the concentrations of urea in the filtrate and blood are equal. So in each pass through the kidneys half the urea is removed from the blood and half remains in the blood.

3. Loop of Henle – Formation of a Salt Bath.

The job of the loop of Henle is to make the tissue fluid in the medulla hypertonic compared to the filtrate in the nephron. The purpose of this "salt bath" is to reabsorb water as explained in step 5. The loop of Henle does this by pumping sodium and chloride ions out of the filtrate into the tissue fluid. The first part of the loop (the descending limb) is impermeable to ions, but some water leaves by osmosis. This makes the filtrate more concentrated as it descends. The second part of the loop (the ascending limb) contains an Na^+ and a Cl^- pump, so these ions are actively transported out of the filtrate into the surrounding tissue fluid. Water would follow by osmosis, but it can't, because the ascending limb is impermeable to water. So the tissue fluid becomes more salty (hypertonic) and the filtrate becomes less salty (hypotonic). Since the filtrate is most concentrated at the base of the loop, the tissue fluid is also more concentrated at the base of the medulla, where it is three times more concentrated than seawater.

4. Distal Convoluted tubule – Homeostasis and Secretion

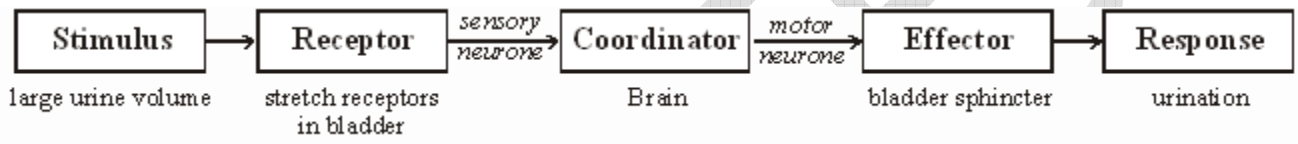
The distal convoluted tubule is relatively short and has a brush border (i.e. microvilli) with numerous membrane pumps for active transport. Final Na^+ reabsorption occurs and the process of water reabsorption explained next in step 5 also takes place to a degree in the distal convoluted tubule

5. Collecting Duct – Concentration

As the collecting duct passes through the hypertonic salt bath in the medulla, water leaves the filtrate by osmosis, so concentrating the urine and conserving water. The water leaves through special water channels in the cell membrane called aquaporins. These aquaporin channels can be controlled by the hormone ADH, so allowing the amount of water in the urine to be controlled. More ADH opens the channels, so more water is conserved in the body, and more concentrated urine is produced. This is described in more detail in water homeostasis later.

The Bladder

The collecting ducts all join together in the pelvis of the kidney to form the ureter, which leads to the bladder. The filtrate, now called urine, is produced continually by each kidney and drips into the bladder for storage. The bladder is an expandable bag, and when it is full, stretch receptors in the elastic walls send impulses to the medulla, which causes the sphincter muscles to relax, causing urination. This is an involuntary reflex response that we can learn to control to a certain extent when we are young.



Homeostasis

Homeostasis literally means "same state" and it refers to the process of keeping the internal body environment in a steady state. The importance of this cannot be over-stressed, and a great deal of the hormone system and autonomic nervous system is dedicated to homeostasis. In module 3 we saw how the breathing and heart rates were maintained. Here we shall look at three more examples of homeostasis in detail: temperature, blood glucose and blood water.

All homeostatic mechanisms use negative feedback to maintain a constant value (called the set point). Negative feedback means that whenever a change occurs in a system, the change automatically causes a corrective mechanism to start, which reverses the original change and brings the system back to normal. It also means that the bigger then change the bigger the corrective mechanism. Negative feedback applies to electronic circuits and central heating systems as well as to biological systems.

. The kidneys and water balance
   a. The kidneys control the concentration of urine to maintain water balance.
   b. By changing the amount of water eliminated or conserved, blood volume and blood pressure can also be maintained by the kidneys.
      i. The kidneys excrete hypertonic urine when the body needs to conserve water.
      ii. The kidneys excretes hypotonic urine when too much water has been ingested.
      iii. Antidiuretic hormone (ADH)
         (1) The hypothalamus in the brain produces ADH and it is secreted by the pituitary.

(2) Sensors in the hypothalamus monitor the concentration of the blood.

(3) If the body loses water, the concentration of the blood increases (becomes more salty). The sensors detect this and trigger the thirst sensation and the release of ADH.

(4) ADH makes the collecting ducts reabsorb more water.

(5) If blood concentration decreases (becomes less salty), ADH secretion is inhibited and more water is excreted in urine as less is reabsorbed.

(6) Alcohol inhibits the secretion of ADH, thus increases water loss. It is important, therefore to always drink plenty of water if you are consuming alcohol.

Kidney disorders

a. Kidney disease

i. The kidneys can be damaged by physical trauma or by infection.

ii. If they fail, dialysis or a transplant is necessary.

b. Diabetes

i. Mellitus

(1) Type 1

(a) Also called insulin dependent, juvenile or early onset diabetes.

(b) Approximately 10 % of people with diabetes have type 1 diabetes.

(c) The immune system attacks the part of the pancreas that produces insulin. Without insulin, blood sugar is abnormally high.

(2) Type 2

(a) Also called insulin independent, adult, or late onset diabetes.

(b) About 90 % have type 2 diabetes, which occurs when the pancreas does not produce enough insulin or when the body does not effectively use the insulin that is produced. Type 2 diabetes usually develops in adulthood, although increasing numbers of children are being diagnosed.

(c) A diet high in sugar can cause the body to become less sensitive to insulin. This causes a chronic, high blood sugar.

(3) High blood sugar causes increased sugar in the urine. This in turn causes more water to enter the urine by osmosis. The end result is increased urine production (and resulting water loss).

ii. Diabetes facts

(1) Approximately 80% of people with diabetes will die as a result of heart disease or stroke.

(2) The onset of type 2 diabetes may be prevented or delayed, through increased physical activity, healthy eating, weight loss, not smoking and stress reduction.

(3) If left untreated or improperly managed, diabetes can result in a variety of complications, including:

(a) Heart disease

(b) Kidney disease

(c) Eye disease

(d) Problems with erection (impotence)

(e) Nerve damage

(4) Risk factors

(a) Being:

(i) A member of a high-risk group (Aboriginal, Hispanic, Asian, South Asian or African descent)

(ii) Overweight (especially if you carry most of your weight around your middle)

(b) Having:

(i) A parent, brother or sister with diabetes

(ii) Health complications that are associated with diabetes

(iii) Given birth to a baby that weighed more than 4 kg (9 lb)

(iv) Had gestational diabetes (diabetes during pregnancy)

(v) Impaired glucose tolerance or impaired fasting glucose

(vi) High blood pressure

(vii) High cholesterol or other fats in the blood

(5) Signs and symptoms of diabetes include the following:

(a) Unusual thirst

(b) Frequent urination

(c) Weight change (gain or loss)

(d) Extreme fatigue or lack of energy

(e) Blurred vision

(f) Frequent or recurring infections

(g) Cuts and bruises that are slow to heal

(h) Tingling or numbness in the hands or feet

(i) Trouble getting or maintaining an erection

(6) How is diabetes treated?

(a) Physical Activity: Regular physical activity helps your body lower blood glucose levels, promotes weight loss, reduces stress and enhances overall fitness.

(b) Nutrition: What, when and how much you eat all play an important role in regulating blood glucose levels.

(c) Weight Management: Maintaining a healthy weight is especially important in the management of type 2 diabetes.

(d) Medication: Type 1 diabetes is always treated with insulin. Type 2 diabetes is managed through physical activity and meal planning and may require medications and/or insulin to assist your body in making or using insulin more effectively.

(e) Lifestyle Management: Learning to reduce stress levels in day-to-day life can help people with diabetes better manage their disease.

(f) Blood Pressure: High blood pressure can lead to eye disease, heart disease, stroke and kidney disease, so people with diabetes should try to maintain a blood pressure level at or below 130/80.

c. Diabetes insipidus
    i. In this disorder, the hypothalamus is damaged and is unable to control water balance in the body.
    ii. The result is production of large volumes of very dilute urine.
    iii. Extreme cases can mean 20 L of urine per day.
d. Kidney stones
    i. Minerals crystallize from the blood and form tiny stones.
    ii. If the stones become large enough they can block the ureter and/or urethra.