Extension 11: Dialysis

1. Osmosis and dialysis

Osmosis and dialysis are related but different processes:

In osmosis, the *solvent* molecules (usually water) pass through a semipeameable membrane in an attempt to equalise the concentration of *solute* molecules (e.g. sugar) on either side of the membrane. (See book, p.189). The movement of solvent is from low concentration of solute to high concentration of solute ('low' to 'high').

In dialysis, *small solute* molecules and ions pass through a semipeameable membrane in an attempt to equalise the concentration of these molecules on either side of the membrane. The movement is from higher concentration of solute to lower concentration of solute ('high' to low'). Bigger molecules cannot get through the membrane, and for this reason dialysis is said to represent a type of ultrafiltration. In addition, *solvent* molecules also transfer osmotically across the membrane.

In both cases, the solvent is usually water. In both dialysis and osmosis the physical process causing movement is diffusion: the natural spreading out of particles so as to attempt to equalise concentrations on either side of the semipermeable membrane. In both the kidneys and in an artificial kidney, filtration is also used to eliminate solids in the blood.

The fact that dialysis involves the transfer of only *small* molecules across the semi-permeable membrane is important in renal dialysis where it is required to screen out low molecular mass metabolic by-products (e.g. urea and creatinine, see Fig. 11.1) without the blood losing larger molecules such as proteins, peptides and vitamins.

2. The kidneys

The kidneys:

(a) Maintain the body's equilibrium concentrations (the 'electrolyte balance') of sodium, potassium, calcium, phosphate, magnesium and sulfate ions. If the ion concentrations in the blood are too high, the kidneys transport the excess ions to be lost in the body via the urine.
(b) Remove the acidic end products of metabolism that cannot be lost in respiration (such as urea and creatinine, Fig 11.1). In the kidneys, such waste products are removed by dialysis and the waste utlimately appear in urine. Without this function, the body rapidly builds up toxic compounds.
(c) Filter and maintain water levels in the body.
(d) The kidneys have a fourth purpose unconnected with diffusion or filtration: they function as part of the endocrine system, producing renin (an enzyme that controls blood pressure), erythropoeitin (which controls red cell production in bone marrow) and calcitriol (a hormone required to aid the absorption of calcium in the intestine).

The kidney achieves (a) – (c) using both filtration and dialysis to separate the molecules or ions that will be removed from the body. Unseparated molecules or ions are returned to the circulating blood. If the body's kidneys fail, the consequences may be fatal. The symptoms of kidney failure include high blood pressure, acidosis (too much acid in the body) and a build-up of toxic nitrogen waste compounds, all of which are life-threatening if prolonged.

(a) (b)

Urea CH_4N_2O Creatinine $C_4H_7N_3O$

Fig. 11.1 Two of the main nitrogen-containing waste products that are removed by the kidneys in a healthy individual. Urea is a by-product of the metabolism of proteins in food. Creatinine is a by-product of the breakdown of creatine phosphate in muscle.

3. Renal dialysis

The most important application of dialysis is in replacing (wholly or partly) the function of the diseased human kidneys, a process called renal dialysis. Dialysis saves many lives every year and in many cases allows individuals to live relatively normal lives inbetween their dialysis sessions.

Renal dialysis is a medical technique used when the kidneys need help or have failed completely (‘renal failure’). The part of the dialysis machine that does the ‘cleaning’ of the patient’s blood is known by several names, including artificial kidney and dialyzer. Dialysis substitutes (although imperfectly) the liver functions (a), (b) and (c) in s2 above. Dialysis in the human kidney uses a semi-permeable membrane made of long-chain carboxylic acids with a phosphate ion head (‘phospholipids’). The artificial kidney uses an artificial (cellulose-based) semi-permeable membrane to replace the phospholipids found in the liver.

The most common type of renal dialysis is known as haemodialysis (also written as hemodialysis) (Fig. 11.2). The dialysate is the fluid pumped into the patient blood stream and it generally resembles blood plasma. It typically contains pure water, bicarbonate (which acts as a pH buffer), sodium chloride and glucose, although its composition depends on the precise needs of the patient. The diaysate replaces any lost electrolytes but it also acts as ‘the sink’ that accepts waste from the blood via dialysis with the waste being pumped out of the patient’s blood stream. In this way, the blood of the patient is purified.

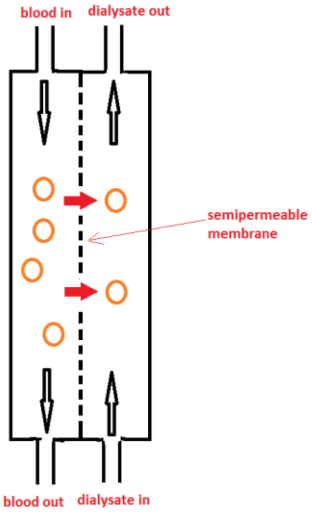

Fig. 11.2 Simplified diagram of human haemodialysis. The patient's blood vessels are connected to the 'blood in' and 'blood out' inlets. The small molecules (e.g. urea) and ions that are 'waste' are represented by the orange circles. Blood and dialysate are pumped in opposite directions as shown. The semipermeable membrane keeps the blood and dialysate from mixing. Since the dialysate does not contain waste, a difference in concentration exists across the membrane and waste moves through the semipermeable membrane into the dialysate, leaving purified blood to return to the patient. The dialysate is pumped away and disposed of.

Fig. 11.3 shows some of the species involved in dialysis of human blood. The symbol ↔ shows that the species may travel in either direction across the semipermeable membrane, depending upon the difference in concentration of that species in the blood and in the solution in the kidneys/artificial kidney. For example, if the patient's blood contains a high concentration of potassium ions, and the dialysate a lower concentration, then potassium ions will diffuse across the semipermeable membrane into the dialysate. In this way, excess K^+ ions are removed from the bloodstream. Equally, if the patient's blood is short of potassium ions, adding K^+ to the dialysate allows the ions to be transferred to the patient's blood. Note that since creatinine and urea are never to be found in dialysate, both creatinine and urea molecules move only 'one way': this is how these potentially toxic molecules are removed by both the kidneys and in an artificial kidney. Larger molecules, such as the protein albumin (molecular mass about 75,000 u) in blood plasma are too big to pass through the semipermeable membrane.

Species	**blood**	**semipermeable membrane**	**dialysate**
Sodium ions	Na^+	$\leftrightarrow$	Na^+
Potassium ions	K^+	$\leftrightarrow$	K^+
Calcium ions	Ca^{2+}	$\leftrightarrow$	Ca^{2+}
Bicarbonate ions	HCO_3^-	$\leftrightarrow$	HCO_3^-
Creatinine	Creatinine	$\rightarrow$	Creatinine
Urea	Urea	$\rightarrow$	Urea
Water	H_2O	$\leftrightarrow$	H_2O
Albumin	Alb	X	-

Fig. 11.3 Some of the species involved in human dialysis. Albumin is included as an example of a molecule that is too large to be transported by dialysis.

Water is included in Fig. 11.3. The movement of water across the membrane is encouraged by pressurizing the dialysate. Water will naturally flow across the pressure gradient and towards the higher hydrostatic pressure.

Fig. 11.4 Dialysis machine. Photograph © Getty Images/iStockphoto / Thinkstock\Asparuh Stoyanov