Chapter 8
Application of Ion Exchange Resins in Kidney Dialysis

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Abstract Besides the proved applications of ion exchange resins (IER) in various industries, biochemists have found their uses in medicines also. The development and use of synthetic ion exchange resins for kidney dialysis is a relatively recent achievement. The artificial kidney uses cellulose membranes in place of the phospholipid-bilayer membranes used by real kidneys to separate the components of blood. Polymeric ion exchange resins are insoluble, so when taken orally, pass through gastrointestinal tract (GIT) without being absorbed. In malfunctioned kidney, sodium and calcium polystyrene sulfonate resins are designed to exchange sodium for potassium in the colon, for use in the treatment of hyperkalemia. It is predicted that additional therapeutic applications may be found for ion exchange resins in the coming years.

8.1 Introduction

Ion exchange membranes are one of the advanced separation membranes, used in electrodialysis and in artificial dialysis (such as artificial kidney) in medical field. The function of the ion exchange membrane process is based on the Donnan membrane equilibrium principle, i.e., recovery of valuable ions and removal of undesirable ions from wastewater. Artificial kidney is a machine that performs treatment known as hemodialysis. The artificial kidney, or hemodialyzer, provides a means

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for removing certain undesirable substances from the blood or of adding needed components to it, i.e., hemodialysis (HD) membranes are used to remove accumulated uremic toxins, excess ions, and water from the patient via the dialysate and to supply (deficit) insufficient ions from the dialysate. In a dialysis machine, a person's blood flows between partially permeable membranes. Waste urea passes out from the blood into the dialysis fluid. Treatment by dialysis restores the concentrations of dissolved substances in the blood to normal levels and has to be carried out at regular intervals. During dialysis, it is important that useful substances in the blood, such as glucose and mineral ions, are not lost. To prevent this, dialysis fluid contains the same concentrations of these substances as blood. This ensures that only waste substances and excess ions and water diffuse into the dialysis fluid. By these processes, it can control the acid–base balance of the blood and its content of water and dissolved materials. Modern dialyzers rely on two physicochemical principles, dialysis and ultrafiltration.

The membranes first used in dialysis were obtained from animals or prepared from collodion; cellophane has been found to be more suitable, and tubes or sheets of it are used in many dialyzers. In the late 1960s, hollow filaments of cellulosic or synthetic materials (polymers) were introduced for dialysis; bundles of such filaments provide a large membrane surface in a small volume, a combination advantageous in devising compact dialyzers. Almost all dialyzers now in use are of the hollow-fiber type. A hollow-fiber dialyzer contains a bundle of approximately 10,000 hollow fibers, each with an inner diameter of about 200 μm when wet. The membrane thickness is about 20–45 μm, and the length is160–250 mm. The walls of the hollow fibers function as the dialysis membrane.

Dialysis was first described by Thomas Graham in 1854, which was first used to treat human patients in 1945 – replaces or supplements the action of the kidneys in a person suffering from acute or chronic *renal failure* or from poisoning by diffusible substances, such as aspirin, bromides, or barbiturates.

8.2 Terminology

Biocompatible membrane – defined as one that elicits the least degree of inflammatory response in patients exposed to it.

Semipermeable membrane – is a thin layer of material that contains various size holes, or pores; it allows the smaller solute and fluid pass through membrane, but the membrane block the passage of large substances (e.g., RBC, large proteins).

Ion exchange polymer – polymer that is able to exchange ions (cations or anions) with ionic components in solution; ion exchange (IE) polymer in ionized form may also be referred as a polyanion or a polycation. Synthetic ion exchange organic polymers are often network polyelectrolytes. A membrane having ion exchange groups is called an ion exchange membrane.

Diffusion – diffusion describes a property of substances in water. Substances in water tend to move from an area of high concentration to an area of low concentration.

Dialysis – is used to provide an artificial replacement for lost kidney.
Dialyzer – is used in hemodialysis and is an external filter that contains a semipermeable membrane.

8.3 Electrodialysis

Electrodialysis (ED) is a very versatile technology for the separation of difficult mixtures. Electrodialysis is defined as an electromembrane process in which ions are transported through ion-permeable membranes from one solution to another under the influence of a potential gradient. The electrical charges on the ions allow them to be driven through the membranes fabricated from ion exchange polymers.

8.4 Kidney

Healthy kidneys maintain the body's internal equilibrium of water and minerals (sodium, potassium, chloride, calcium, phosphorus, magnesium, and sulfate). The acidic metabolism end products which the body cannot get rid of via respiration are also excreted through the kidneys. The kidneys also function as a part of the endocrine system producing erythropoietin and calcitriol. Erythropoietin is involved in the production of red blood cells, and calcitriol plays a role in bone formation. If we compare the dialysis with kidney, then dialysis is an imperfect treatment to replace kidney function because it does not correct the endocrine functions of the kidney. Dialysis treatments replace some of these functions through diffusion (waste removal) and ultrafiltration (fluid removal).

8.4.1 Essential Functions of the Major Segment of the Kidney

Nephron segment	Function
Bowman's capsule	Filtration

Glomerulus filters proteins and cells from the blood. All other blood components pass into Bowman's capsule, then into the tubule.

U-shaped tubule	Reabsorption and secretion

Semipermeable membranes surrounding the tubule allow selective passage of particles back into the blood (reabsorption) or from the blood into the tubule (secretion). The fluid entering the tubule is identical to the blood, except that it contains no proteins or cells.

Collecting duct collects all material that has not returned to the blood through the tubular membranes. This material exits the kidney as urine.

The tubule functions as a dialysis unit, in which the fluid inside the tubule is the internal solution and the blood (in capillaries surrounding the tubule) acts as the external solution. Particles may pass through the membrane and return to the bloodstream in the process known as reabsorption, which is analogous to the movement of particles from the internal to the external solution in the dialysis experiment you performed in laboratory. The reabsorption of many blood components is regulated physiologically, as discussed below. Alternatively, particles may pass through the membrane from the blood into this tubule in the process known as secretion, which is analogous to the movement of particles from the external solution into the dialysis bag in the experiment you performed in lab. The most important particles, which are secreted from the blood back into the tubules, are H^+ and K^+ ions, as well as organic ions from foreign chemicals or the natural by-products of the body's metabolism.

8.5 Diffusion and Concentration Gradients

The direction of the passage of particles through the channel is also dependent on concentration gradients. Diffusion is defined as the mixing of two different substances that are placed in contact, which continues until the concentrations of the two solutions are equal. This state is known as dynamic equilibrium. When the two solutions are in dynamic equilibrium, particles continue to move between the two solutions, but there is no net flow in any one direction, i.e., the concentrations do not change.

In biological systems such as the kidney, the two solutions are often separated by a membrane; protein channels in the membrane allow particles to cross the membrane, flowing "down the concentration gradient" until equilibrium is reached. Once the channels are closed, particles will not travel across the membrane, even if there is a strong concentration gradient. (In effect, the two solutions are no longer in contact.) There are some proteins in the membranes that act like "pumps" using energy to move particles "against the concentration gradient" (i.e., the concentrated solution becomes even more concentrated).

8.6 Dialysis

Dialysis is primarily used to provide an artificial replacement for lost kidney function in people with renal failure. It may be used for acute renal failure or chronic kidney disease stage (previously chronic renal failure or end-stage kidney disease). In dialysis, blood flows by one side of a semipermeable membrane, and a dialysate, or special dialysis fluid, flows by the opposite side.

Dialysis membranes clear toxins such as urea from the blood and preserve water balance and serum protein levels in blood, all while leaving red and white blood cells intact.

Dialysis is the movement of molecules by diffusion from high concentration to low concentration through a semipermeable membrane. Only those molecules that are small enough to fit through the membrane pores are able move through the membrane and reach equilibrium with the entire volume of solution in the system. Once equilibrium is reached, there is no further net movement of the substance because molecules will be moving through the pores into and out of the dialysis unit at the same rate. By contrast, large molecules that cannot pass through the membrane pores will remain on the same side of the membrane as they were when dialysis was initiated. To remove additional unwanted substance, it is necessary to replace the dialysis buffer so that a new concentration gradient can be established. Once the buffer is changed, movement of particles from high (inside the membrane) to low (outside the membrane) concentration will resume until equilibrium is once again reached. With each change of dialysis buffer, substances inside the membrane are further purified by a factor equal to the volume difference of the two compartments [1–4].

8.6.1 Goals of a Dialysis Procedure

1. To get rid of the water that was ingested and produced (during metabolism); this is done by convection
2. To get rid of salts (e.g., sodium chloride, potassium chloride)
3. To maintain acid–base balance
4. To get rid of nitrogenous waste products (e.g., urea)

8.6.2 Factors Affecting Dialysis Rate

The factors include (1) dialysis buffer volume, (2) buffer composition, (3) the number of buffer changes, (4) time, (5) temperature, and (6) particle size vs. pore size. Substances that are very much smaller than the pore size will reach equilibrium faster than substances that are only slightly smaller than the pores.

Dialysis works on the principles of the diffusion of solutes and ultrafiltration of fluid across a semipermeable membrane.

8.6.3 Types of Dialysis

8.6.3.1 Hemodialysis

The principles that underlie the HD procedure are simple in practice. Blood and dialysate are circulated on opposite sides of a semipermeable membrane, thereby permitting the passage of solutes elevated as a consequence of renal failure but

restricting the transfer of blood proteins and cellular elements. The device containing the semipermeable membrane is the hemodialyzer. Removal of water occurs by controlling the hydrostatic pressure gradient across the semipermeable membrane and is augmented by increasing the osmolality of the dialysate fluid.

HD removes wastes and water by circulating blood outside the body through an external filter, called a dialyzer, that contains a semipermeable membrane. The dialyzer is composed of thousands of tiny synthetic hollow fibers. The fiber wall acts as the semipermeable membrane. Blood flows through the fibers, dialysis solution flows around the outside of the fibers, and water and wastes move between these two solutions. The cleansed blood is then returned via the circuit back to the body. Ultrafiltration occurs by increasing the hydrostatic pressure across the dialyzer membrane. This is usually done by applying a negative pressure to the dialysate compartment of the dialyzer. This pressure gradient causes water and dissolved solutes to move from blood to dialysate and allows the removal of several liters of excess fluid during a typical 3- to 5-h treatment. The blood flows in one direction, and the dialysate flows in the opposite. The countercurrent flow of the blood and dialysate maximizes the concentration gradient of solutes between the blood and dialysate, which helps to remove more urea and creatinine from the blood. The concentrations of solutes (e.g., potassium, phosphorus, and urea) are undesirably high in the blood, but low or absent in the dialysis solution and constant replacement of the dialysate ensures that the concentration of undesired solutes is kept low on this side of the membrane. The dialysis solution has levels of minerals like sodium and calcium that are similar to their natural concentration in healthy blood. For another solute, bicarbonate, dialysis solution level is set at a slightly higher level than in normal blood, to encourage diffusion of bicarbonate into the blood, to act as a pH buffer to neutralize the metabolic acidosis that is often present in these patients. The levels of the components of dialysate are prescribed and monitored by a nephrologist according to the requirement of the individual patient. Thus, artificial kidney dialysis uses the same chemical principles that are used naturally in the kidneys to maintain the chemical composition of the blood. The main aim of HD is the restoration of normal ion concentrations. Normally, the levels of individual ions in the dialysate can be set to their desired plasma levels; however, in some instances, dialysate levels are set for the diffusible fraction of the ion found in plasma.

The goal of HD in patients with end-stage renal disease (ESRD) is to restore the body's intracellular and extracellular fluid environment toward the body composition of healthy individuals with functioning kidneys to the extent possible. On a biophysical level, the use of HD as renal replacement therapy is accomplished via solute removal from the blood into the dialysate, as exemplified by intradialytic removal of potassium, urea, and phosphorous, as well as the addition of solute from the dialysate into the blood, as is exemplified by bicarbonate and calcium. An additional goal of the dialysis procedure is the elimination of excess water volume from the patient via ultrafiltration (UF.)

Thus, diffusion across semipermeable membranes, polarity, and concentration gradients are central to the dialysis process for both natural and artificial kidneys [5, 6].

Dialyzer Choice

In making a decision about the choice of dialyzer, the three most critical determinants are its capacity for solute clearance, capacity for UF or fluid removal, and the nature of dialyzer membrane interactions with components of the blood and their potential clinical sequelae, i.e., biocompatibility. The ideal HD membrane would have high clearance of LMW and middle-molecular-weight uremic toxins, negligible loss of vital solutes, and adequate UF in an effort to maximize efficiency and reduce adverse metabolic effects from the HD procedure. Additional characteristics of the ideal dialyzer would be a low blood volume compartment, beneficial biocompatibility effects, high reliability, and low cost. In evaluating dialyzer solute clearance characteristics, urea is the solute most often used owing to its relevance to kinetic models of dialysis adequacy.

Anticoagulation for Hemodialysis

Interaction of plasma with the dialysis membrane produces activation of the clotting cascade, characterized by the development of thrombosis in the extracorporeal circuit, thrombin deposition in dialyzer hollow fibers, and resulting dialyzer dysfunction. Dialyzer thrombogenicity is determined by dialysis membrane composition, surface charge, surface area, and configuration. In addition, the rate of blood flow through the dialyzer, the UF rate prescribed (owing to hemoconcentration), and the length, diameter, and composition of blood lines all affect thrombogenicity. In addition, a number of patient-specific variables influence thrombogenicity and determine anticoagulation requirements during HD. These include acquired and inherited coagulopathies, neoplasia, malnutrition, hemoglobin concentration, and the presence or absence of CHF.

By far the most widely used anticoagulant for dialysis is heparin. Heparin is easy to administer, has a low cost, and has a relatively short biologic half-life.

Summary Hemodialysis Procedure

Kidneys filter the blood, clearing it of waste products. Twenty percent of the heart's output is directed to the kidneys, which filter ~180 L plasma per day. Kidneys also regulate water and salt balance. Loss of kidney function leads to death within days due to excessive buildup of nitrogenous waste, acid, potassium, sodium, and water. Kidney function can be partially replaced by hemodialysis, first performed by Willem Kolff in the early 1940s. Procedure is typically performed for 4 h thrice weekly (e.g., Monday, Wednesday, Friday), in which blood flows into tubing that divides into thousands of parallel hollow fibers. Each fiber is a semipermeable membrane. Outside of the fibers runs the "dialysate" solution.

Clearance during dialysis is done by convection (negative pressure applied, water and dissolved small solutes (<40 kDa) pass across membrane into the dialysate fluid

which is then discarded) and by diffusion (solutes travel across membrane down concentration gradient). Sodium moves down its concentration gradient (in either direction, depending on plasma concentration; dialysate sodium usually fixed). Blood and dialysate flow in opposite directions, maximizing concentration gradient. The parameters for the hemodialysis are given below:

Blood flow ~400 mL/min
40% red blood cells, 60% plasma
Plasma: 93% water, 7% protein and lipids
Dialysate flow ~800 mL/min
Typically 2–4 L of "ultrafiltration" (volume removed during a 4-h procedure)

8.6.3.2 Peritoneal Dialysis (PD)

Waste fluids and water are removed from the blood inside the body using the peritoneal membrane of the peritoneum as a natural semipermeable membrane. Wastes and excess water move from the blood, across the peritoneal membrane, and into a special dialysis solution, called dialysate, in the abdominal cavity which has a composition similar to the fluid portion of blood.

Peritoneal Dialysis Principle

- Peritoneum (capillary endothelium, matrix, mesothelium) = semipermeable dialysis membrane through which fluid and solute move from blood to dialysis solution via diffusion and convection
- Effective peritoneal surface area = perfused capillaries closed to peritoneum (decreased in peritonitis)
- Ultrafiltration (movement of water) enabled by osmotic gradient generated by glucose or glucose polymers (isodextrin)

Composition of Standard Peritoneal Dialysis Solution

Na	132 mmol/L
Ca	1.25 mmol/L
Mg	0.5 mmol/L
Cl	100 mmol/L
Lactate	35 mmol/L
Glucose	1.36–4.25 g/dL
Osmolarity	347–486
pH	5.2
GDP (degradation products of glucose)	

Advantage of PD to HD

Better maintenance of residual renal function
Saves vascular access
Preferred for children (APD)

Absolute Contraindications of PD

Peritoneal fibrosis and adhesions following intra-abdominal operations
Inflammatory gut diseases

8.6.4 Primary and Secondary Types of Dialysis

Primary: Hemodialysis, peritoneal dialysis, and hemofiltration
Secondary: Hemodiafiltration and intestinal dialysis

8.6.5 Indications for Dialysis

8.6.5.1 In the Patient with Acute Kidney Injury

1. Metabolic acidosis in situations where correction with sodium bicarbonate is impractical or may result in fluid overload.
2. Electrolyte abnormality, such as severe hyperkalemia, especially when combined with acute kidney injury.
3. Fluid overload not expected to respond to treatment with diuretics.
4. Complications of uremia, such as pericarditis, encephalopathy, or gastrointestinal bleeding.
5. Intoxication, i.e., acute poisoning with a dialyzable substance. These substances can be represented by the mnemonic SLIME: salicylic acid, lithium, isopropanol, magnesium-containing laxatives, and ethylene glycol.

8.6.5.2 Chronic Indications for Dialysis

1. Symptomatic renal failure
2. Low glomerular filtration rate (GFR) (renal replacement therapy often recommended to commence at a GFR of less than 10–15 mL/min/1.73 m^2). In diabetics, dialysis is started earlier.
3. Difficulty in medically controlling fluid overload, serum potassium, and/or serum phosphorus when the GFR is very low.

When the kidneys do not function properly, dialysis must be performed artificially. Without this artificial kidney dialysis, toxic wastes build up in the blood and tissues and cannot be filtered out by the ailing kidneys. This condition is known as uremia, which means literally "urine in the blood"; this waste buildup leads to death.

8.7 Ion-Permeable Membranes

The ion-permeable membranes used in electrodialysis are essentially sheets of ion exchange resins. They usually also contain other polymers to improve mechanical strength and flexibility. The resin component of a cation-exchange membrane would have negatively charged groups (e.g., $-SO_3^-$) chemically attached to the polymer chains (e.g., styrene/divinylbenzene copolymers). Ions with a charge opposite to the fixed charge (counterions) are freely exchanged at these sites. The concentration of counterions (e.g., Na^+) is relatively high; therefore, counterions carry most of the electric current through the membrane. The fixed charges attached to the polymer chains repel ions of the same charge (co-ions), in this case the anions. Since their concentration in the membrane is relatively low, anions carry only a small fraction of the electric current through a cation-permeable membrane. Attachment of positive fixed charges (e.g., $-NR_3^+$ or $C_5H_5N^+R$ where commonly $R = CH_3$) to the polymer chains forms anion-permeable membranes, which are selective to transport of negative ions, because the fixed $-NR_3^+$ groups repel positive ions. This exclusion, as a result of electrostatic repulsion, is called Donnan exclusion.

Ion exchange membranes have been used in various industrial processes, e.g., in the electrodialytic concentration of seawater to produce edible salt, as a separator for electrolysis, in the desalination of saline water by electrodialysis, in the separation of ionic materials from nonionic materials by electrodialysis, in the recovery of acid and alkali from waste acid and alkali solution by diffusion dialysis, in the dehydration of water-miscible organic solvent by pervaporation, etc. For these wide applications, successful ion exchange membranes must have the following properties: (1) high permeable selectivity – an ion exchange membrane should be highly permeable to counterion and impermeable to co-ions; (2) low electrical resistance – permeability for the counterions under the driving force of an electrical potential gradient should be as high as possible; (3) good mechanical stability and should have a low degree of swelling or shrinkage in transition from dilute to concentrated ionic solutions; and (4) high chemical stability – membrane should be stable over a wide pH range from 0 to 14 and in the presence of oxidizing agents.

Thus, for industries and for day-to-day life, innumerable membranes have been developed for the use in reverse osmosis, nanofiltration, ultrafiltration, microfiltration, pervaporation separation, electrodialysis, and in medical use such as artificial kidney. Among these membranes, ion exchange membranes are one of the advanced separation membranes. The basic applications of the ion exchange membrane process are based on the Donnan membrane equilibrium principle and have been paid attention to solve two environmental problems: (a) recovery and enrichment of

valuable ions, and (b) removal of undesirable ions from wastewater, especially to extract toxic metal ions.

Ion exchange polymers such as poly(styrene sulfonic acid) are water soluble, so cross-linking is needed to prevent dissolution of ion-permeable membranes. Divinylbenzene is used to cross-link polystyrene chains. The degree of cross-linking and the fixed-charge density affect the membrane's properties in opposite ways. Higher cross-linking improves selectivity and membrane stability by reducing swelling, but it increases electrical resistance. High charge density reduces resistance and increases selectivity, but it promotes swelling and thus necessitates higher cross-linking. A compromise between selectivity, electrical resistance, and dimensional stability is achieved by proper adjustment of cross-linking and fixed-charge densities [7].

8.8 Bipolar Membrane

Bipolar membranes consist of an anion-permeable membrane and a cation-permeable membrane laminated together. There are substantial advantages to water splitting with bipolar membranes. Since there are no gases evolved at the surface or within the bipolar membranes, the energy associated with conversion of water to O_2 and H_2 is saved, and the power consumption is about half that of electrolytic cells. Compared to the electrodes used in conventional electrolytic cells, the bipolar membranes are inexpensive. Where dilute (e.g., <1 M) acids or bases are needed, bipolar membranes offer the prospect of low cost and minimum unwanted by-products.

8.9 Artificial Membranes

There are three types of membranes currently used to manufacture dialyzers: cellulose, substituted cellulose, and synthetic noncellulose.

Cellulose – Cellulose, primarily manufactured as cuprophan (or cuprophane), is a polysaccharide-based membrane obtained from pressed cotton. Cuprammonium is primarily used in the manufacturing process of this membrane (hence the name), but other methods of manufacturing exist.

The artificial kidney uses cellulose membranes in place of the phospholipid-bilayer membranes used by real kidneys to separate the components of blood. Cellulose is a polymer of glucose molecules that form long, straight chains, i.e., chains of glucosan rings with abundant free hydroxyl groups. Parallel chains form linkages with one another by hydrogen bonding to make strong fibers. These fibers in turn interact to form the strong, sheet-like structure of the membrane.

The arrangement of the cellulose fibers may contain gaps, creating tunnels through the membrane. These form the pores through which particles may pass from one side of the membrane to the other. The size of the gaps determines the size of the particles that will be able to pass through the membrane.

In present time, more than 30 different polymers or polymer blends are used as materials for dialysis membranes. Alternatively, they can be categorized as scheme of a family tree of hemodialysis membranes. The trunk represents membranes from regenerated cellulose; major branches show either synthetically modified cellulose membranes or membranes manufactured from synthetic polymers. As the latter are standardly hydrophobic, small branches elucidate the technique on how these materials have been rendered partially or completely hydrophilic.

Complications may arise, when comparing membranes only following their polymer names, such as polysulfone, polyacrylonitrile, or polyamide. Due to varying polymer compositions, membranes with the same polymer names may differ in their hemocompatibility, flux properties, and adsorption characteristics. Proteins, e.g., beta-2-microglobulin, fibrinogen, and coagulation factors, complement proteins, or hormones like parathyroid hormone and erythropoietin are differently adsorbed by dialysis membranes, and thus, adsorption contributes to the removal characteristics.

8.9.1 Dialysis Membrane Summary

- Hollow fibers ~12,000 in parallel, 20–24 cm length, diameter 180–220 um, 6–15 um thickness, pores: average diameter 30 Å, 10^9 in number
- Old: Cellobiose (saccharide)
- New: Synthetic membranes (e.g., polysulfone, polyamide, polymethylmethacrylate)

Manufactured polymers classified as thermoplastics

Both the artificial kidney and ion exchange resins afford means for radioelement removal. The advantages of the ion exchange column over the artificial kidney are its simplicity, its potentialities for more widespread use, and its greater selectivity for polyvalent cations over divalent and monovalent cations.

Ion exchange resins have been used in many instances, where it has been necessary to remove ions from solutions of uncharged molecules, and it was thought that the same methods might be used for charged molecules provided these were too large to penetrate the resin particles. The use of ion exchange resins would then be an alternative to normal dialysis.

Experiments were carried out to see if proteins could be “dialyzed” in this way, and it was found that egg albumin could be freed from ions by passing it through columns of cation- and anion-exchange resins without significant loss. The nonabsorption of proteins by resins has been applied to the fractionation of blood serum by Reid and Jones (1949). It was also found that proteins can be damaged when they came in contact with the resins. Resins can be used for dialysis if special precautions are taken; membrane must be used to separate the resins from the solution to be dialyzed, and the tendency of the solution to become acid must be prevented

by modification of the membrane or by other means. It is then possible to remove ions from enzyme solutions with resins without denaturation.

The healthy kidneys continuously remove potassium. In malfunctioned kidneys, it may be necessary to remove potassium from the intestinal tract by artificial means. This can be achieved by using polystyrene sulfonates, in either the sodium or calcium form (Purolite C100NaMR and Purolite C100CaMR are examples for sodium and calcium polystyrene sulfonates resins, respectively). Kayexalate (sodium polystyrene sulfonate [SPS]), an ion exchange resin designed to exchange sodium for potassium in the colon, is approved for use in the treatment of hyperkalemia. As the resins pass through the intestinal tract, they exchange the sodium or calcium on the resin for potassium. The adsorbed potassium cannot pass into the blood and continues through the body without being released. Such resins are now widely used in the treatment of acute and chronic hyperkalemia and in controlling serum potassium levels in patients undergoing renal dialysis. The powder resin is flavored and prepared in doses to be taken orally.

Hyperkalemia is a common clinical problem that is most often a result of impaired urinary potassium excretion due to acute or chronic kidney disease and/or disorders or drugs that inhibit the renin–angiotensin–aldosterone axis. The most serious manifestations of hyperkalemia are muscle weakness or paralysis, cardiac conduction abnormalities, and cardiac arrhythmias including sinus bradycardia, sinus arrest, slow idioventricular rhythms, ventricular tachycardia, ventricular fibrillation, and asystole. These manifestations usually occur when the serum potassium concentration is ≥7.0 mEq/L with chronic hyperkalemia or possibly at lower levels with an acute rise in serum potassium.

8.10 Phosphorus Control in Chronic Kidney Disease

Hyperphosphatemia was identified as a risk predictor of mortality in patients with chronic kidney disease (CKD) on hemodialysis. In addition to its potential to trigger parathyroid hormone secretion in the development of secondary hyperparathyroidism, it became clear that hyperphosphatemia may indirectly and directly promote vascular calcification. Hyperphosphatemia appears to be one of the key threats to the event-free survival of dialysis. The mainstay of therapy is the use of phosphorus binders, while management of hyperphosphatemia by balanced diets should be used in conjunction. Combinations of the different P binders may improve P control and consequently limit side effects (e.g., Ca load, gastrointestinal complaints). Nonaluminum-, noncalcium-based binders such as sevelamer hydrochloride and lanthanum carbonate seem to offer advantages in the context that no bone and brain damage and no cardiovascular calcification progression occur as does in aluminum-based binding and calcium (Ca)-containing binders, respectively [8]. They are also being closely observed with regard to their gastrointestinal tolerability and potential hepatic accumulation, respectively [9].

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