MODULE 4:
Hemodialysis Devices
Objectives

After completing this module, the learner will be able to:

1. Identify the purpose and characteristics of dialyzers.
2. Describe the purpose and chemical composition of dialysate.
3. Describe dialysate preparation and the three monitoring functions of the dialysate delivery subsystem.
4. Describe the extracorporeal blood circuit functions and monitoring systems.

Module 4 cover photo credit:

Photo of dialyzers reprinted with permission from Jim Curtis, 2005.
Introduction

A dialyzer (see Figure 1) lets the patient’s blood interact with dialysate through a semipermeable membrane. Dialysate is a blend of treated water and chemicals; it removes wastes and fluid, and balances electrolytes. A delivery system supplies fresh dialysate and removes used dialysate.

Modern, high-tech delivery systems include a blood pump, an ultrafiltration pump, a dialysate conductivity monitor, alarms, and pressure gauges. Better membranes, safety monitors, and the use of computers have made dialysis safer.

These advances allow today’s staff to turn more of their time to patients. Trained staff who know dialysis principles, equipment, and procedures are the most vital monitors of patient safety.

This module covers hemodialysis devices, including dialyzers, dialysate, and delivery systems. If you carefully follow your center’s procedures and apply the principles reviewed in this module, you can master the use and maintenance of each device and help deliver safe dialysis treatments.

Dialyzers

FUNCTIONS AND COMPONENTS

Healthy kidneys play a key role in one of the body’s most complex tasks—keeping a constant, stable setting for cell survival, even with changes in diet and fluids, exercise, and health or illness. This stable environment is called homeostasis.

The dialyzer, dialysate, and delivery system replace some tasks that failed kidneys can no longer do. Today’s dialysis treatment can remove wastes and excess fluid and help keep electrolytes and pH (acid and base balance) at levels that sustain life.

Every dialyzer has a blood and a dialysate compartment. The semipermeable membrane keeps the two compartments apart. The membrane is housed in a plastic case, which holds the dialyzer together and forms pathways for blood and dialysate to flow in and out.1

During a treatment, the patient’s blood—with high levels of electrolytes, water, and wastes—flows through the blood compartment. Dialysate, a solution made of chemicals much like those in blood, flows through the dialysate compartment on the other side of the membrane.1

DIALYZER CHARACTERISTICS

Many aspects of a dialyzer can affect treatment effectiveness, comfort, and patient safety. These include biocompatibility (how much a membrane is compatible with the human body), membrane
surface area, molecular weight cutoff (the solute size that can pass through the membrane), ultrafiltration coefficient, and clearance (the rate of solute removal).

**Biocompatibility**

Biocompatible means not harmful to biological function. When blood touches a foreign substance, immune cells in the blood react to defend the body. This defense, which involves complement activation and other mechanisms, can vary from clotting, which prevents blood loss, to severe allergic reactions.

All materials used to make dialysis membranes react to some degree with immune cells in the blood. These effects may be so subtle that the patient does not notice them. They may cause minor symptoms during a treatment. Or, major life-threatening allergies (anaphylaxis) can occur. It is vital to use a membrane the patient can tolerate.

Biocompatibility of a membrane can be tested by checking the patient's blood for certain proteins and chemicals. The body releases these when blood meets a foreign substance. Their levels suggest how biocompatible a membrane is with the patient’s blood.

A membrane's ability to adsorb (attract and hold) proteins into the fiber wall is key to its biocompatibility. Adsorbed proteins coat the surface so blood does not touch the “foreign” membrane. This protein coating explains why reprocessed (cleaned and reused) dialyzers can be more biocompatible than new ones (note: reprocessing dialyzers with bleach can strip the protein coating off the membrane).

In general, synthetic membranes are more biocompatible than cellulose membranes. Synthetic fibers are hydrophobic (water-repelling); this makes them better able to adsorb blood proteins.

**Surface Area**

Surface area is key to how well a dialyzer can remove solutes. If all other aspects are equal, dialyzers with more surface area can expose more blood to dialysate. This means more solutes can be removed from the blood. Total dialyzer surface area can range from 0.5–2.4 square meters.

**Mass Transfer Coefficient**

Mass transfer coefficient (KoA) is the ability of a solute to pass through the pores of a dialyzer. The KoA, in theory, is the highest possible clearance of a given dialyzer at infinite blood and dialysate flow. The higher the KoA, the more permeable the dialyzer.

**Molecular Weight Cutoff**

Each membrane has a molecular weight cutoff which determines the largest molecule that can pass through the membrane (see Figure 2). Molecular weight is measured in daltons (Da). It is the average weight of a molecule, expressed as the sum of the atomic weights of all the atoms in the molecule. Larger molecules have higher molecular weights; smaller molecules have lower ones (see Table 1). Knowing the range of molecular weights that each membrane will allow through helps doctors choose membranes that will remove certain molecules from the blood. Dialyzers can be chosen with molecular weight cutoffs ranging from 3,000 Da to more than 15,000 Da.
**Ultrafiltration Coefficients**

Another key aspect of a dialyzer is how much ultrafiltration (UF) of water can occur across the membrane. UF is a way to remove excess water from a patient during hemodialysis by applying pressure. Hydraulic pressure applied to the blood or dialysate compartment forces water across the membrane. The dialysis machine can vary the hydraulic pressure to control the ultrafiltration rate (UFR) and amount of water removed. High pressure in the blood compartment forces more fluid out of the blood and into the dialysate. The pressure difference across the membrane (blood compartment pressure minus dialysate compartment pressure) is transmembrane pressure (TMP).

Each dialyzer has a manufacturer’s ultrafiltration coefficient ($K_{UF}$). The $K_{UF}$ is the amount of fluid that will pass through the membrane in one hour, at a given pressure.

The $K_{UF}$ helps the staff member predict how much fluid will be removed from the patient during a treatment.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Molecular Weight (Da)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albumin</td>
<td>66,000</td>
</tr>
<tr>
<td>Calcium (Ca++)</td>
<td>40</td>
</tr>
<tr>
<td>Creatinine</td>
<td>113</td>
</tr>
<tr>
<td>Nitric Oxide (NO$_3^-$)</td>
<td>62</td>
</tr>
<tr>
<td>Phosphorus (PO$_4^{3-}$)</td>
<td>94.9</td>
</tr>
<tr>
<td>Urea</td>
<td>60</td>
</tr>
<tr>
<td>Water [H$_2$O]</td>
<td>18</td>
</tr>
<tr>
<td>Zinc (Zn$^{2+}$)</td>
<td>65.3</td>
</tr>
</tbody>
</table>

For example, a dialyzer with a $K_{UF}$ of 10 will remove 10 mL of fluid per hour for each millimeter of mercury (mmHg) of pressure. This is stated as mL/mmHg/hr. Let’s say a dialyzer has a $K_{UF}$ of 10, and a TMP of 100 mmHg. In this case, the patient would lose 1,000 mL of fluid per hour of dialysis ($10 \times 100 = 1,000$).

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**Figure 2: Molecular weight cutoff**

*Drawing adapted with permission from Althin Academy, Miami Lakes, FL*

*See page 94 for a definition of sieving coefficient.*
Clearance

Dialyzers vary in how well they remove solutes from the blood. The amount of blood that can be cleared of a solute in a given period of time is called clearance (K).\(^1\) Clearance rates for different molecules are given by the manufacturer for certain blood and dialysate flow rates. The Appendix on page 116 describes the formula for determining dialyzer solute clearance.

There are three main ways to remove solutes that affect a dialyzer’s clearance: diffusion, convection, and adsorption.

Diffusion

Most solutes are removed during dialysis by diffusion: movement of solutes across a semipermeable membrane from an area of greater concentration to an area of lesser concentration,\(^1\) until both sides are equal. Diffusion is the best way to remove small—low molecular weight—solutes. The diffusion rate depends on blood and dialysate flow rates; membrane surface area and thickness; number of pores; solution temperature; membrane resistance; concentration gradient; and size, weight, and charge of the solutes.\(^1\)

Convection

When fluid crosses a semipermeable membrane, some solutes are pulled along with it. This is called convection, or solvent drag.\(^7\) Convection is the best way to remove larger solutes.\(^7\)

A sieving coefficient (see Figure 2 on page 93) is used to say how much solute is expected to be removed by convection. A sieving coefficient of 0.5 for a solute means that 50% of the solute will pass through the membrane to the dialysate side. The other 50% will be adsorbed or rejected by the membrane. Convective clearance depends on the molecular weight cutoff of the membrane, the membrane surface area, and the ultrafiltration rate (UFR).\(^7\)

Adsorption

Adsorption, as you’ve learned, occurs when material sticks to the dialyzer membrane. All dialyzers adsorb materials, usually small proteins, to some extent. Hydrophobic synthetic membranes adsorb more than cellulose membranes.

Adsorption in dialysis has pros and cons. It is useful because the adsorbed protein keeps the membrane away from the blood, for better biocompatibility. But, adsorbed material can build up on the membrane and may prevent some diffusion and convection. Highly adsorptive membranes may become less effective when they are reprocessed many times. Testing dialyzers for total cell volume (also called fiber bundle volume) may not reveal this problem.\(^3\) Total cell volume is an indirect measure of changes in solute transport for hollow fiber dialyzers that are reused.\(^8\)

A dialyzer’s adsorptive ability depends on the membrane material, surface area, and how much material has already adsorbed to the membrane.

DIALYZER DESIGN

A hollow fiber dialyzer is a clear plastic cylinder that holds thousands of fiber tubes almost as thin as strands of hair. These fibers are held in place at each end by polyurethane, clay-like “potting” material that holds the fibers open so blood can flow inside them.\(^9\) Hollow fiber dialyzers allow for well-controlled, predictable UF.\(^1\)
During dialysis, blood enters the dialyzer at the top, flows through each fiber, and leaves at the bottom. Dialysate flows around the fibers in the opposite direction, in a countercurrent flow (see Figure 3).

Because the fibers are rigid, there is no membrane compliance (change in shape or volume due to pressure). Instead, the fibers hold almost the same amount of fluid at high pressures as they do at low pressures. Resistance to blood flow is low in hollow fiber dialyzers.¹

**MEMBRANES**

The semipermeable membrane acts in some ways like the vessel wall of a human nephron, because it is selective. Riddled with microscopic pores, the membrane allows only certain solutes and water to pass through. Large substances, such as protein and blood cells, simply won't fit through the small pores.³

There are other membrane factors that affect removal of solutes and fluids during dialysis (see Figure 4). These include the membrane material and characteristics of each dialyzer. Each of these will be discussed below.

**Membrane Materials**

What the dialyzer membrane is made of can affect diffusion and UF. The dialyzer material can also affect the efficiency of dialysis and the patient’s comfort during treatment.

**Cellulose membranes**

Cellulose membranes are made from cotton-based material that is spun into hollow fibers.¹⁰ Dialyzers with cellulose membranes have thin fiber walls (8–15 microns).³ Solutes pass
through them mainly by diffusion. Low molecular weight substances readily pass from one side of the membrane to the other, with little regard to applied transmembrane pressure. The size of molecules cleared by these dialyzers is quite limited—about 3,000 Da.

Removal of molecules in the larger molecular weight range, such as beta-2-microglobulin (β2m, 11,800 Da), is slower. Cellulose dialyzers have surface areas that range from 0.5–2.1 meters. Larger cellulose membranes have in vitro (tested in a laboratory) urea and creatinine clearances that compare to synthetic dialyzers. Cellulose dialyzers are the least biocompatible, and cause the most complement activation. This type of membrane is also least able to remove solutes by adsorption.

**Modified cellulose membranes**
Changes have been made to improve the way cellulose membranes work. The hydroxyl groups (OH⁻) are removed and replaced with acetate (cellulose acetate), amino acids, or synthetic molecules. Modified cellulose dialyzers have much thicker fiber walls, 22–40 microns. They use convection, diffusion, and adsorption to remove solutes. Clearance of solutes, especially middle molecules, depends mainly on UF rates. These dialyzers do a good job of removing solutes up to 15,000 Da, clearing β2m to some extent. Biocompatibility of these membranes ranges from good to very good. The best of these are close to pure synthetics.

**Synthetic membranes**
Synthetic membranes are made from polymers that are formed into hollow fibers. The materials used in synthetic membranes are: polycarbonate, polyacrylonitrile (PAN), polysulfone (PSF), and polymethylmethacrylate (PMMA). These dialyzers have the thickest fiber walls, 30–55 microns. Solutes are removed by convection, diffusion, and adsorption. Clearance of solutes, especially middle molecules, depends mainly on UF rates. Synthetic membranes do a good job of removing solutes up to 15,000 Da, clearing β2m to some extent. Biocompatibility of these membranes is very good. They are highly adsorptive, so they can quickly keep the blood from touching the membrane.

**Measuring Dialyzer Effectiveness**
A dialyzer’s effectiveness is checked by testing its clearance (K). Clearance is expressed as the amount of blood (in mL) that is completely cleared of a certain solute in one minute of treatment, at a given blood flow rate (Qb) and dialysate flow rate (Qd).

For example, a dialyzer has a stated urea clearance of 250 mL/min at a Qb of 300 mL. In one minute, 250 mL of blood would be cleared of urea by the dialyzer. If 300 mL of blood is pumped through the dialyzer in one minute, only 250 mL of blood will be cleared of urea. During dialysis, the patient’s blood passes through the dialyzer many times, so much of the urea in the blood can be removed.

The dialyzer’s surface area is fixed. So, either Qb or Qd must be increased to improve clearance. The Qb is always a factor that limits clearance, since there is a limit to how quickly blood can flow out of the patient’s vascular access.
A higher Qd provides some increase in dialysis clearance; how much depends on dialyzer size and membrane permeability.\(^1\)

**DETERMINING DIALYZER CLEARANCE**

Manufacturers test dialyzers in a lab (in vitro), using watery fluids that are thinner than blood. When measured during actual use on patients, a dialyzer's real clearance can differ from the manufacturer's stated values by ±10–30%. The clearance of urea—a small molecular weight solute—is most often used to test the overall effectiveness of a dialyzer.

Clearance of a certain solute is checked by drawing samples of blood going into and leaving the dialyzer. Once the solute concentration of the blood samples is tested, actual clearance can be calculated (see Appendix on page 116).

**Dialysate**

**PURPOSE OF DIALYSATE**

Dialysate is a fluid that helps remove uremic wastes, such as urea and creatinine, and excess electrolytes, such as sodium and potassium, from the patient’s blood. Dialysate can also replace needed substances, such as calcium and bicarbonate, which helps keep the body’s pH balance.

During a treatment, the patient’s blood is on one side of the membrane, in the blood compartment. The dialysate is on the other side, in the dialysate compartment. Dialysate and blood never mix, unless the membrane breaks.

Dialysis patients’ blood has high concentrations of waste products and excess water. Dialysate is prescribed to have desired levels of solutes the patient needs and none of the ones that must be removed completely. The osmolality (solute particle concentration) of dialysate should closely match the blood to keep too much fluid from moving across the membrane. The concentration gradients created decide the diffusion rates of each solute across the membrane. Unwanted solutes leave the blood and move into the dialysate; desired solutes stay in the blood.\(^1\)

Some solutes are added to dialysate in amounts that can cause them to enter the patient’s blood. Most often, these are sodium, bicarbonate, and chloride.

**COMPOSITION OF DIALYSATE**

The doctor prescribes the dialysate. Dialysate starts out as two concentrated salt solutions: acid and bicarbonate (see Figure 5).

- The **acid concentrate** has precise amounts of sodium chloride, potassium chloride, magnesium chloride, calcium chloride, glucose, and acetic acid. The acetic acid is added to lower the dialysate’s pH.

- The **bicarbonate concentrate** has sodium bicarbonate and in some cases, sodium chloride.
The two concentrates are diluted with precise amounts of treated water to make the final dialysate. The concentrates come in three different formulations. Because there are three formulations, care must be taken to match the right acid concentrate with the right bicarbonate concentrate. The Association for the Advancement of Medical Instrumentation (AAMI) has set standard symbols to help match the concentrates. These symbols are shown in the right column of Table 2, above.\(^1\) The companies listed in the first column introduced a certain formulation to the American market. Today, almost all of the hemodialysis machines can use any of the formulations.

When the concentrates are diluted with the prescribed amount of water, they will have the right concentration of electrolytes (particles that carry an electrical charge). Electrolytes are vital for cell function. Precise levels of sodium and potassium are needed on each side of cell membranes to allow nerve signals and other cell functions in the body. These levels are shown in Table 3. We will cover each substance briefly.

### Sodium (Na\(^+\))

Sodium is a major electrolyte of the body’s blood plasma and interstitial (between the cells) fluid. In the body, sodium causes fluid to move across cell membranes. In this way, fluid shifts between the intracellular (inside the cells) space and the plasma and interstitial space. This fluid movement includes the intravascular space (in the blood vessels). Fluid and solutes must be in the plasma to be removed by dialysis.

Normal sodium concentration in the blood is from 135–145 mEq/L. Sodium concentration in dialysate is most often kept in the same range. Higher levels are sometimes used; if so, a careful patient assessment and a doctor’s prescription are needed. Dialysate delivery systems can adjust the dialysate sodium level during a treatment. The dialysate sodium level is changed according to a doctor’s prescription. This is called sodium modeling.

These systems can, for example, start a treatment at a high sodium concentration and then slowly reduce it. This sodium change has been shown to create more efficient fluid shifts in the body, to remove fluid faster. Sodium modeling also provides for better control of blood pressure and fluid removal. This helps

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### Table 2: Concentrate Proportioning Ratios

<table>
<thead>
<tr>
<th>Type/Style</th>
<th>Parts Acid</th>
<th>Parts Bicarb</th>
<th>Parts Water</th>
<th>Parts Dialysate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drake-Willock</td>
<td>1.00</td>
<td>1.83</td>
<td>34.00</td>
<td>36.83X</td>
</tr>
<tr>
<td>COBE Laboratories</td>
<td>1.00</td>
<td>1.72</td>
<td>42.28</td>
<td>45X</td>
</tr>
<tr>
<td>Fresenius</td>
<td>1.00</td>
<td>1.225</td>
<td>32.775</td>
<td>35X</td>
</tr>
</tbody>
</table>

Table adapted with permission from AAMI

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### Table 3: Typical Range of Substances in Dialysate

<table>
<thead>
<tr>
<th>Substance</th>
<th>Concentration in Dialysate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>135 to 145 mEq/L</td>
</tr>
<tr>
<td>Potassium</td>
<td>0 to 4 mEq/L</td>
</tr>
<tr>
<td>Calcium</td>
<td>2.5 to 3.5 mEq/L</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.5 to 1.0 mEq/L</td>
</tr>
<tr>
<td>Chloride</td>
<td>100 to 124 mEq/L</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>32 to 40 mEq/L</td>
</tr>
<tr>
<td>Glucose</td>
<td>0 to 250 mg/dL</td>
</tr>
</tbody>
</table>
some patients tolerate more UF with fewer complications. However, the use of sodium modeling can increase thirst and body weight, and hypertension between dialysis treatments.\textsuperscript{12}

### Potassium (K\textsuperscript{+})
Potassium is a major electrolyte of the intracellular fluid. The body keeps precise amounts on both sides of cell membranes to send nerve signals. Just enough potassium is added to dialysate to bring the patient to a normal plasma potassium level: from 3.5–5.5 mEq/L.\textsuperscript{13} Potassium in the dialysate ranges from 0–4 mEq/L, based on the patient’s needs.\textsuperscript{1}

### Magnesium (Mg\textsuperscript{2+})
Magnesium is vital to the nerves and muscles. It also triggers enzymes that are key to carbohydrate use. Magnesium is found in the plasma at levels from 1.4–2.1 mEq/L.\textsuperscript{13} The magnesium range in dialysate is 0.5–1.0 mEq/L.\textsuperscript{1}

### Calcium (Ca\textsuperscript{2+})
Calcium is found in the body in extracellular (outside the cells) and intracellular (inside the cells) fluid. It builds bones and teeth, helps muscles move, is needed for blood clotting, and helps send nerve signals.\textsuperscript{13} The normal range of calcium in the plasma is 8.5–10.5 mg/dL (4.5–5.5 mEq/L); dialysate calcium is most often 2.5–3.5 mEq/L.\textsuperscript{1} Sometimes the lower range is used if patients take calcium-based phosphate binders and/or calcitriol (active vitamin D), which can raise serum calcium levels. Patients whose predialysis calcium levels are quite high or low may have their dialysate calcium changed by a doctor.

### Chloride (Cl\textsuperscript{−})
The concentration of chloride in dialysate depends on the contents of chemicals such as sodium chloride, potassium chloride, magnesium chloride, and calcium chloride. Dialysate chloride ranges from 100–124 mEq/L. Normal plasma chloride levels are 98–111 millimoles per liter (mM/L).\textsuperscript{14}

### Glucose (C\textsubscript{6}H\textsubscript{12}O\textsubscript{6})
Glucose may be added to dialysate to prevent loss of serum glucose and to reduce catabolism (muscle breakdown). Adding glucose calories can help patients who are diabetic or malnourished. Dialysate glucose levels may range from 0–250 mg/dL. The glucose in dialysate can be two to three times higher than in normal blood (70–105 mg/dL). This means that dialysate with glucose has an osmotic (water-pulling) effect that aids UF.

### Bicarbonate (HCO\textsubscript{3}−)
Bicarbonate is a buffer—a substance that tends to maintain a constant pH in a solution, even if an acid or base is added. Healthy kidneys keep the body’s pH within the very tight limits that cells need to survive. The kidneys do this by making and regulating bicarbonate. Bicarbonate is added to dialysate to help maintain patients’ pH. Bicarbonate is used by the body to neutralize acids that are formed when cells metabolize proteins and other foods used for fuel. People with chronic kidney disease can’t excrete enough acids in the urine, so they are in a constant state of metabolic acidosis (i.e., having too much acid in the blood).

In dialysate, bicarbonate is used to replace the body’s stores of buffer. Bicarbonate can reduce
dialysis-related problems like hypotension, muscle cramps, nausea, and fatigue after treatment.

**Hemodialysis Delivery Systems**

**PURPOSE**

A delivery system is a machine that mixes and delivers dialysate, pumps blood through the dialyzer, and monitors various dialysis parameters to ensure a safe treatment (see Figure 6). Most delivery systems monitor patient and machine safety parameters. These include blood flow, dialysate flow, dialysate temperature, conductivity, venous and arterial pressure, blood in dialysate leaks, patient blood pressure, etc. The delivery system is two major subsystems: the dialysate delivery system and the extracorporeal blood circuit. We'll cover each one and its parts.

**DIALYSATE DELIVERY SYSTEM**

A dialysate delivery system controls the amounts of water and chemicals in dialysate, and checks its conductivity, temperature, pH, flow rate, and pressure. It also tests the dialysate for the presence of blood.

**The Proportioning System**

In a proportioning system, dialysate is made by mixing fresh concentrate with fixed amounts of treated water. The mixing is controlled by the internal mechanical and hydraulic design of the delivery system. The exact amount of water and concentrate is set by your center’s policies and procedures (see Table 2, page 98).

Proportioning systems make dialysate in two ways. Both rely on a continuous supply of fresh concentrate and treated water:

- The first type of system mixes concentrate and water using fixed-ratio pumps. Fixed-ratio mixing uses diaphragm or piston pumps to deliver set volumes of concentrate and water to a mixing chamber.15
- The other type of proportioning system uses servo-controlled mechanisms: these have conductivity control sensors that constantly check the dialysate’s total ion concentration. Electronic circuits compare the solution’s real conductivity to the prescribed level, and adjust the proportioning to reach the prescribed value.15

Once mixed, dialysate is warmed and monitored for conductivity, temperature, pressure, and flow rate (see Figure 7).
After dialysate leaves the dialyzer, it passes through a blood leak detector. Blood in the dialysate could mean a tear in the membrane. So, blood leak detectors are often treated as extracorporeal—outside the body—alarms, even though they check the dialysate. Used dialysate that has passed through the blood leak detector is discarded down a drain.

The Monitoring System
Using the wrong dialysate can make a dialysis treatment less effective. This mistake may even cause illness or death to a patient. Dialysate must be checked throughout each treatment to ensure that it is the right concentration and temperature, and that it is flowing at the right rate. Some delivery systems also check the dialysate pH continuously.

The following descriptions include general information that suits most dialysis machines. To learn how to check alarms on the equipment you will be using, see your center’s procedures manual.

Conductivity
Except for glucose, the chemicals in dialysate are all salts (electrolytes). Salts break apart in water to form positive and negative charged particles called ions. Dialysate electrolyte levels must be kept within certain limits to keep patients safe. The dialysate proportioning system checks the total electrolyte level in dialysate by testing conductivity (how much electricity the fluid will conduct). Conductivity is checked by placing a pair of electrodes in the dialysate. Voltage is applied to the electrodes, and the current is measured. The measurement gives the estimated total ion concentration of the dialysate.\textsuperscript{13} A sensor cell may be used instead of the electrodes.

Most hemodialysis delivery systems have two or more independent conductivity monitors—with separate sensors and monitoring circuits. One sensor measures the mixture of the first concentrate (most often acid) with water. The other sensor measures the final dialysate after the second concentrate is added. Some machines use conductivity sensors to make the dialysate itself. These have a second set of sensors to check the mixtures, apart from the ones that control the mixing. This multiple

![Figure 7: Single-patient dialysate delivery system](image-url)
monitoring system, called redundant monitoring, is used so two sensors would have to fail before a patient could be harmed.\textsuperscript{15}

Conductivity is usually checked at the point of mixing and again before the dialysate enters the dialyzer. Depending on the equipment at your center, conductivity may be stated in micromhos/cm, millimhos/cm, microsiemens/cm, or millisiemens/cm.\textsuperscript{16} A millisiemens/cm is 1/1000 of a siemens/cm and a microsiemens/cm is 1/1,000,000 of a siemens/cm. Siemens was formerly called “mho” because conductance in siemens is the reciprocal of resistance in ohms.\textsuperscript{16}

Most dialysate delivery systems have internal, preset conductivity limits. When the dialysate concentration moves outside the preset safe limits, it triggers a conductivity monitoring circuit. The circuit stops the flow of dialysate to the dialyzer and shunts it to the drain. This is called bypass. Bypass keeps the wrong dialysate from reaching the patient. The circuit also sets off audible and visual alarms to alert the staff. The most common type of conductivity alarm is low conductivity. The most frequent cause is a lack of concentrate in one or both of the concentrate jugs. A high conductivity alarm is most often due to:\textsuperscript{15}

- Poor water flow to the proportioning system
- Untreated incoming water
- Use of the wrong dialysate concentrate

\textit{Before each treatment, check the conductivity alarm to be sure it is working, and check the machine readings against an independent meter.} There must always be enough of both concentrates in the proportioning system to complete the whole treatment.\textsuperscript{15}

**Temperature**

Too-hot dialysate can cause hemolysis (bursting of red blood cells). Too-cool dialysate is not life threatening, but it can make the patient cold and reduce diffusion so the treatment is less efficient. In all dialysate delivery systems, dialysate is kept in the range of 37°C to 38°C (98.6°F to 100.4°F).\textsuperscript{15} Water must be heated to a certain temperature before mixing with the concentrates.

The method of warming the water depends on the delivery system design. Some systems use a heat exchanger before the heater, to save energy. In these systems, used dialysate transfers its heat to the incoming cold water, warming it before it enters the heater. Most systems use a heater controlled by a thermistor, a type of thermostat.

To check dialysate temperature, a separate temperature monitor is placed in the dialysate path before the dialyzer. This monitor’s limits are preset, and it works independently of the heater control thermistor. Many alarm systems have a low setting, which should not be below 33°C (91°F). (With some delivery systems, the patient is the only “monitor” of low temperature.) The high limit should be set at no higher than 41°C (105°F).\textsuperscript{15} If the temperature is too hot or cold, a circuit sets off audible and visual alarms.\textsuperscript{15} The circuit also triggers bypass to shunt dialysate to a drain.\textsuperscript{15}

\textit{Before each dialysis treatment, check the dialysate temperature alarm to ensure that it is working properly.}

**Flow rate**

Dialysate flow rate to the dialyzer is controlled by a flow pump. Some delivery systems have a preset flow rate; others let the flow vary as the
doctor prescribes. In general, higher dialysate flow rates improve dialyzer efficiency, though little improvement occurs above 800 mL/min.

Dialysate flow rates range from 0–1,000 mL/min. Some systems have flow meters that continuously display the dialysate flow rate on a gauge or a digital display. Others do not display flow rate at all.

Dialysate flow rate audible and visual alarms may be set off by:
- Low water pressure
- Dialysate pump failure
- A blockage in the dialysate flow path
- A power failure

A high/low conductivity, high/low pH, high temperature, or in some cases blood leak alarm, can trigger the delivery system to switch into bypass mode.\(^{15}\)

*Check the delivery system before each treatment to be sure that the bypass mode works properly for all dialysate alarm conditions.*

**Blood leak detector**

Dialyzer membranes are fragile and can tear, letting blood and dialysate mix. If this occurs, the patient could have major blood loss and/or the blood could be contaminated by the nonsterile dialysate. A blood leak detector (see Figure 8) is used to check for blood in the used dialysate. The detector can sense very small amounts of blood, less than can be seen with the naked eye.

The blood leak detector shines a beam of light through the used dialysate and onto a photocell or photoresistor. Normally, dialysate is clear, so the light can pass through. But even a tiny amount of blood will break the light beam. The detector will sense such a break, triggering audible and visual alarms.\(^{16}\)

When a blood leak alarm occurs, the blood pump stops and the venous line clamps to prevent further blood loss.\(^{15}\) In some systems, a bypass mode shunts dialysate to the drain. This reduces negative pressure and keeps blood from being drawn through the tear into the dialysate.

A Hemastix\(^{®}\) (strip that reacts to blood) should be used to check the extent of the leak. The test must be taken where the dialysate leaves the dialyzer:\(^{15}\)
- If blood or pink color can be seen in the dialysate path, there is a major leak.
- Clear dialysate and a positive Hemastix test suggest a minor leak.
- Clear dialysate and a negative Hemastix test mean a false alarm.

Depending on your center’s procedures for a blood leak, you stop the treatment without returning the patient’s blood. This keepspossibly contaminated blood from reaching the patient, where it could cause an infection.

---

*Figure 8: Photoelectric blood leak detector*

If the light beam is interrupted by blood, an alarm will sound, and the blood pump will stop.
The blood leak detector’s basic sensitivity is usually preset by the manufacturer. Adjustments can be made within this limited range.\textsuperscript{17}

**pH**

pH is a measure of how acidic or alkaline (basic) a solution is. The pH of a solution is based on the number of acid ions (hydrxonium ions) or alkali (base) ions (hydroxyl ions) it contains. A solution with:

- An equal number of acid and base ions is **neutral** and has a pH value of 7.0.
- More acid ions is **acidic** and the pH value will be less than 7.0.
- More base ions is **alkaline** and the pH will be greater than 7.0.

Bleach (sodium hypochlorite) is alkaline, with a pH of 11.0. White vinegar is an acid, with a pH of 2.9. The pH of blood is normally from 7.35–7.45; a weak base. Dialysate must have a pH close to blood so it does not change the blood pH. In general, the range of dialysate pH is from 7.0–7.4.

Some delivery systems monitor pH continuously throughout the treatment. Dialysate pH affects the patient’s blood pH. Whether or not the delivery system has a pH monitor, at the start of each treatment, an **external test must be done to ensure that the dialysate pH is in a safe range**. The most accurate pH measure uses a pH electrode, which puts out a small voltage when placed in a solution. The voltage is read by a detection circuit that converts the signal into a pH value and displays it. Test strips coated with a chemical that changes color based on pH are another way to measure pH. For any method, you must have known test fluids on hand that can be used to check that the meter or strips are still accurate.

### Ultrafiltration Control

**Ultrafiltration**

Removing excess fluid is another key part of an adequate treatment. Fluid removal is achieved through ultrafiltration (UF) (the movement of fluid across the dialyzer membrane in response to positive and negative pressures). UF occurs during the treatment when the pressure on the blood side of the dialyzer membrane is more positive than the pressure on the dialysate side. This pushes fluid in the blood across the membrane into the dialysate compartment where it is then expelled in the drain. The difference between these pressures (the pressure gradient) is the transmembrane pressure, or TMP.

**TMP and dialysate pressure**

The TMP determines how much fluid from the blood is forced across the membrane. In the past, dialysis machines used a manual system of setting the TMP or a negative dialysate pressure for achieving fluid removal. A technician or nurse needed to determine the total fluid loss required for the patient and then calculate the hourly UFR. Mathematical equations were used to find the TMP needed for the $K_{UF}$ of the dialyzer being used (see Module 6: Hemodialysis Procedures and Complications for TMP calculation). Depending on the type of machine, the technician or nurse would set the TMP or a negative dialysate pressure to achieve the calculated TMP. With today’s volumetric dialysis, TMP is calculated and set for you. All you need to enter is the desired fluid removal amount (in mL) and the treatment time. Fluid removal accuracy of the
older systems was not nearly as precise as today’s UF control systems due to variables including:

- The $K_{UF}$ values reported by dialyzer companies are usually in vitro values. In practice, the in vivo $K_{UF}$ is often somewhat lower (5%–30%).
- Clotting of the dialyzer fibers reduces the $K_{UF}$ by reducing the surface area of the membrane.
- Increasing or decreasing the blood pump speed changes the venous pressure.
- An increase or decrease in the dialysate flow, or a kink or blockage in the dialysate lines changes the dialysate pressure.

These conditions have no effect on fluid removal accuracy with UF control machines.

**UF control systems**

UF control is the means by which the dialysis machine removes fluid from the patient and accurately measures it. The amount of fluid removed in a specific period of time is the ultrafiltration rate (UFR). Most dialysis machines use a volumetric fluid balancing system (see Figure 9). This type of system uses two chambers that fill and drain to control the volume of dialysate going to and coming from the dialyzer. This is known as volumetric control. Another type of machine uses sensors in the fluid path to and from the dialyzer to control and monitor the flow rate of the dialysate. This is known as flow control.

**Figure 9:** Volumetric UF control system

![Diagram of Volumetric UF control system](image-url)
Volumetric UF Control

One of the main components of the volumetric UF control system is the balance chambers or balancing chambers. There are two identical chambers. Each chamber is divided in half by a flexible diaphragm. Each chamber half has an inlet and an outlet. One side of each chamber is in the “to dialyzer,” or fresh dialysate flow path. The other side is in the “from dialyzer,” or used dialysate flow path. There are valves on each inlet and outlet. These valves open and close so that as fluid enters on one side of the chamber, it pushes on the diaphragm and forces fluid out on the other side. The timing of the valves opening and closing is synchronized. One chamber is filling with used dialysate, pushing fresh dialysate to the dialyzer. At the same time, the other chamber is filling with fresh dialysate, pushing the used dialysate to the drain.

One pump moves the proportioned dialysate to the balance chambers. A second pump pulls dialysate from the dialyzer and pushes it to the balance chambers. This keeps a constant flow through the dialyzer. The movement of dialysate to and from the dialyzer takes place in a closed loop. The volume of dialysate entering and exiting the dialyzer is the same, because the volume entering one side of the balance chamber displaces the same amount on the other side. So, the flow to and from the dialyzer is balanced.

Another main component in the system is the ultrafiltration pump (UF pump) or the fluid removal pump. Its function is to remove fluid from the closed loop. This results in fluid removal from the patient through the dialyzer membrane. Most UF pumps are diaphragm or piston type, and are most often placed in the used dialysate flow path. The pumps work with a stroking movement that removes a small, fixed amount of fluid on each stroke (about 1 cc or less). The removal of fluid from the closed loop creates a negative pressure in the loop. Therefore, pressure is negative in the dialysate compartment of the dialyzer, relative to the blood compartment pressure. This creates the pressure gradient that is needed for UF. When the UF pump is off, there is no pressure difference between the blood and dialysate—and no fluid is removed.

As the pump removes fluid from the closed loop, the same amount is replaced, moving across the dialyzer membrane into the loop. This allows the machine to precisely remove the right amount of fluid from the patient. You or the nurse will determine the total amount of fluid that should be removed and use the machine controls to enter it along with the duration of the treatment in hours. The machine’s computer will calculate the UFR, which decides the rate at which the UF pump will run.

Other important components in the system are used to perform control, monitoring, and safety functions. Pressure sensors serve functions such as controlling pump speeds, preventing overpressurization, calculating TMP, and detecting leaks within the system. Air separation chambers remove any air coming out of the dialyzer. (This will occur when priming a new [dry] dialyzer.) Any air in the system could result in incorrect fluid removal. The air separation chamber maintains a level of fluid while releasing air out the top that is routed to the drain.
Flow Control

Another type of UF system is the flow control system (see Figure 10). This system has flow sensors on the inlet and the outlet side of the dialyzer to control dialysate flow through the dialyzer. Inlet and outlet flow pumps are set so the flow measured at the inlet and outlet flow sensors is equal. This flow balance is the key to the system's accuracy and ensures that the only fluid removed from the patient is that which is removed by the UF pump.¹⁹

This UF control system uses a postdialyzer UF pump that removes fluid at the UFR calculated by the machine’s computer. The speed of the pump is equal to the UFR. It is determined by the time needed to fill a small chamber of a known volume (UF burette). There are high- and low-level sensors in the UF burette that signal a valve to open and close. When the UF burette becomes full, the valve opens and a pump empties it by forcing air into the top and the contents to the drain. When it has emptied, the valve closes and the UF burette begins to fill again.¹⁹ This occurs repeatedly throughout the treatment. The outlet flow sensor does not measure the fluid removed by the UF pump. Flow control UF systems may also use pressure sensors and air separation chambers in the same way that volumetric systems do.

EXTRACORPOREAL CIRCUIT

The extracorporeal circuit carries blood from the patient's access to the dialyzer and back to the access. It is the second major subsystem of the hemodialysis delivery system. The extracorporeal circuit includes the arterial and
venous blood tubing, blood pump, heparin pump, dialyzer, venous line clamp, blood flow monitors, pressure monitors, and air monitors (see Figure 11). We will cover each part next.

**Components and Monitoring**

### Blood tubing

During hemodialysis, blood from the patient's vascular access (arterial needle) flows to the dialyzer. Blood flows back to the patient's access (venous needle) through blood tubing, or “lines” (see Figure 12). The inner diameter of the blood tubing is small. Only a small amount—about 100–250 mL—of blood is outside the patient's body at any time.

There are two parts of the blood tubing: arterial and venous. The arterial segment is most often color-coded red; the venous segment is most often color-coded blue. Bloodlines are smooth on the inside to reduce clotting and air bubbles. Many manufacturers offer custom-made blood tubing for various types of equipment and patients.

Each set of blood tubing has different, specialized parts. The order in which those parts are installed in the delivery system varies with the system's design, prescribed treatment, and the monitoring desired. Parts of blood tubing include:

- **Patient connectors:** A tip, or Luer-Lok® connector, at the end of the arterial and venous blood tubing segments connects the tubing to the patient's needles or catheter ports.

- **Dialyzer connectors:** Luer-Lok connectors at the other end of the blood tubing segments connect the tubing to the dialyzer. The arterial blood tubing segment connects to the arterial end of the dialyzer. The venous blood tubing segment connects to the venous end of the dialyzer.

- **Drip chamber/bubble trap:** The drip chamber checks arterial or venous pressure in the blood circuit. It uses a monitoring line with transducer protectors (see page 109), and collects or “traps” any air that accidentally gets into the extracorporeal circuit. The drip chamber can also keep blood clots in the extracorporeal circuit from reaching the patient, by using a very fine mesh screen. This type of drip chamber is placed on the venous blood tubing segment, after the dialyzer and before the patient's access.

- **Blood pump segment:** The blood pump segment is a durable, pliable, larger diameter part of the arterial blood tubing. It is threaded through the blood pump roller.
**Heparin infusion line:** During dialysis, heparin (a blood thinning drug) may be given to the patient through a very small diameter tube that extends out of the blood tubing. The heparin infusion line is most often placed on the arterial blood tubing segment just before the dialyzer.

**Saline infusion line:** This line allows saline to be given to the patient during dialysis. It is most often placed on the arterial blood tubing segment just before the blood pump, so saline can be pulled into the circuit. If the saline infusion line is not clamped correctly, too much fluid or air can enter the extracorporeal circuit.

**Transducer protectors**

A transducer is a mechanical device inside the machine that converts air pressure into an electronic signal. This signal is used to display venous pressure, arterial pressure, and TMP. Moisture would damage the transducer. Transducer protectors are a barrier between blood in the tubing and the transducer in the machine. They connect to the machine's venous and/or arterial ports via a small tubing segment on top of the drip chamber. Transducer port lines have a small line clamp in the middle. The transducer protector connects to the end of these lines and is the link between the machine and the blood tubing set (drip chambers).

Transducer protectors use membranes with a nominal pore size of 0.2 microns that are hydrophobic when wetted, to keep fluid from passing through. If these filters get wet, they prevent air flow. Wetted or clamped transducer protectors cause pressure reading errors. A wet or clamped venous transducer protector will also cause TMP problems, since TMP is partly venous pressure. A loose or damaged transducer protector on a pre-pump arterial drip chamber port could allow air into the bloodline circuit.

In May, 1999, the federal Food and Drug Administration (FDA) put out a safety alert on cross-contamination from wet transducer protectors. In April 2001, the Centers for Disease Control and Prevention (CDC) made recommendations. These require centers to change wet transducer protectors right away and inspect the machine side of the protector for contamination or wetting. If a fluid...
breakthrough is found on the removed transducer protector, the machine’s internal transducer protector (a back-up) must be inspected by a qualified technician. You may be required to disinfect the machine’s transducer protector port and replace the internal transducer protector before the next treatment can begin.23

**Blood pump/blood flow rate**
The blood pump (see Figure 13) moves blood from the patient’s arterial needle through the blood tubing, to the dialyzer, and then back to the patient through the venous needle. Most often, the type of blood pump used is a roller pump. This pump uses a motor that turns a roller head. Speed of the roller head determines blood flow rate, which is set by the staff person.

The blood pump segment of the blood tubing is threaded between the rollers and the pump head. The rollers turn, blocking the tubing and pushing blood out of the segment. After the roller has passed, the segment resumes its shape and blood is drawn in to refill the pump segment. In this way, blood is pulled into and pushed out of the segment at the same time.

By changing the roller speed, blood flow through the extracorporeal circuit can be set according to the prescription. Blood flow rates can be varied between 0 mL/min and 600 mL/min.

Some machines count blood pump turns and calculate the number of liters processed in a treatment. Knowing the number of liters prescribed to be processed allows calculation of the blood flow rate: divide liters processed by minutes of treatment. This value can be used as a quality assurance tool; it should equal the blood flow rate shown on the machine. For an effective treatment, the blood flow rate must be accurate and reflect the doctor’s prescription. The staff member must verify that the rate on the readout is correct.

Pump occlusion is the amount of space between the rollers and the pump housing. The blood pump rollers must press against the blood pump segment hard enough to pull and push the blood through the extracorporeal circuit. If the rollers are too tight, the blood pump segment may crack or red blood cells may be destroyed. If the rollers are too loose, blood may escape out the back of the segment, reducing blood flow below the prescribed level. Modern rollers use springs to create occlusion, so the pump segment must be inserted properly. Pulling down the ends of the pump segment in the housing will compress the

---

**Figure 13:**
**Blood pump**

The blood pump segment of the tubing is stronger and thicker to withstand the pressure of the pump.

Step one – Blood enters the pump

Step two – Blood is pushed along by the rollers

Step three – A constant blood flow rate is created
springs and cause the wrong occlusion. This will also reduce blood flow by decreasing the amount of pump segment in the blood pump.

It has to be realized that the blood flow measured by the number of pump revolutions assumes a stable blood volume pushed with each revolution. A high negative pressure flattens the tubing in the roller pump and decreases its volume. The blood flow indicated by the dialysis blood roller pump is always greater than the delivered blood flow, and this difference is in turn conditioned by the negative pressure induced by the blood roller pump in the arterial bloodline.

Pump occlusion must be checked periodically and adjusted per the manufacturer’s instructions. The occlusion should also be checked when the tubing size or manufacturer changes.

In case of emergency, all blood pumps have a way to allow hand cranking. Most often, the pump will have a handle, either with the pump head or one that can be inserted into the pump, which can be used to crank the pump. The pump head should be hand cranked just fast enough to keep the venous pressure at the pre-alarm level.

**Extracorporeal pressure monitors**

Pressure in the extracorporeal circuit depends on blood flow rate and resistance to the flow. Resistance occurs in nearly every part of the extracorporeal circuit: access needles or catheters, blood tubing, and the dialyzer. The blood pump is used to overcome this resistance. Pressures are displayed in millimeters of mercury (mmHg) on a gauge, meter, or screen. Depending on the equipment, pressure can be read at several sites.

Extracorporeal pressure monitoring is needed to calculate TMP and ensure patient safety. In some systems, pressure monitors have upper and lower limits that can be set. In others, they have a preset range within which staff can choose a midpoint.

When pressure exceeds the high or low setting, the system will trigger audible and visual alarms, stop the blood pump, and clamp the venous line. **You must check the extracorporeal blood pressure alarm to ensure that it works properly before each treatment.**

A pre-pump or post-pump drip chamber may be placed on the arterial bloodline. A monitoring line or pressure gauge connection at each drip chamber is used to check arterial and/or venous pressure in the extracorporeal circuit (see Figure 14).
The pressures described below may be monitored, depending on the dialysate delivery system used:

- **Arterial pressure** is pressure from the patient’s access to the blood pump. It is also called pre-pump pressure. When a blood pump is used with a fistula or graft, arterial pressure will usually be less than zero, or negative. Resistance from the vascular access and the pulling of the blood pump creates this negative pressure.

- **Predialyzer pressure** is pressure between the blood pump and the dialyzer, also called post-pump pressure, predialyzer pressure, or post-pump arterial pressure. Pressure in this segment of the blood tubing is greater than zero, or positive. Predialyzer pressure is monitored to detect clotting in the dialyzer. **Suspect clotting if there is a large pressure differential on each side of the dialyzer.**

- **Venous pressure** is pressure from the monitoring site to the venous return. This pressure is often called postdialyzer pressure. Pressure in this segment is positive.

### Table 4: Pressure Alarm Triggers

<table>
<thead>
<tr>
<th>LOW ALARM</th>
<th>HIGH ALARM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arterial pressure (negative) (pre-pump)</strong></td>
<td></td>
</tr>
<tr>
<td>• Blockage of arterial blood flow from the vascular access</td>
<td>• A bloodline separation (if the upper limit is set below zero)</td>
</tr>
<tr>
<td>• Compression or kinking of the arterial bloodline</td>
<td>• A leak between the patient and the monitoring site</td>
</tr>
<tr>
<td>• Wrong position or infiltration of the arterial needle</td>
<td>• A decrease in the blood pump speed</td>
</tr>
<tr>
<td>• Blood pump set at a rate higher than the vascular access can supply</td>
<td>• Infusion of saline or medications</td>
</tr>
<tr>
<td>• Hypotension</td>
<td></td>
</tr>
<tr>
<td>• Vasocostriction (tightening of the patient’s blood vessels)</td>
<td></td>
</tr>
<tr>
<td>• Poorly working central catheter</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Predialyzer pressure (positive) (post-pump)</strong></td>
</tr>
<tr>
<td>• A bloodline separation or leak between the monitoring point and the dialyzer, or at the needle</td>
<td>• A clotted dialyzer</td>
</tr>
<tr>
<td>• Occlusion in the blood tubing between the blood pump segment and the monitoring site</td>
<td>• Poor placement or infiltration of the venous needle or catheter</td>
</tr>
<tr>
<td>• A kink in the blood tubing anywhere from the patient to the monitoring site</td>
<td>• A rise in the blood flow rate</td>
</tr>
<tr>
<td>• Poor blood flow or drop in blood flow rate</td>
<td>• A kink in the blood tubing from the dialyzer back to the monitoring site</td>
</tr>
<tr>
<td></td>
<td><strong>Venous pressure (positive)</strong></td>
</tr>
<tr>
<td>• Separation of blood tubing from the venous needle or catheter</td>
<td>• A blockage in the blood tubing between the monitoring site and the venous needle</td>
</tr>
<tr>
<td>• Drop in blood flow rate</td>
<td>• Poor position or infiltration of the venous needle</td>
</tr>
<tr>
<td>• Blockage in the blood tubing before the monitoring site</td>
<td>• Poorly working central catheter</td>
</tr>
<tr>
<td>• A severely clotted dialyzer</td>
<td>• Clotting access</td>
</tr>
</tbody>
</table>
Common causes of high and low pressure alarms for arterial pressure, predialyzer pressure, and venous pressure are shown in Table 4.25

**Air detectors**

Air can cause death if it gets into the patient’s bloodstream. Air/foam detectors continuously check the blood in the venous tubing segment for air and foam (see Figure 15). The system may check for air at the venous drip chamber or at the blood tubing just below it.

Air detectors are ultrasonic devices that check for changes in a sound wave sent through a cross-section of the blood path. Sound travels faster through air than liquid. Therefore, any air in the blood will raise the speed at which the sound wave passes through the blood, setting off an alarm. An air detector’s alarm sensitivity limits are most often preset by the manufacturer, but can be calibrated by qualified technicians.

When the air detector senses air, it will trigger audible and visual alarms, stop the blood pump, and clamp the venous blood tubing to keep air from getting into the patient’s bloodstream.

**You must check the air detector to be sure it is working properly before each treatment, following the manufacturer’s instructions.** The air detector must always be used during the dialysis treatment and venous line clamps engaged with the tubing segment.

**Heparin system**

When the patient’s blood touches the artificial materials of the lines and dialyzer, it tends to clot. Heparin, an anti-clotting drug, or anticoagulant, is used to prevent clotting in the extracorporeal blood circuit.

Some centers give heparin intermittently (on and off) during dialysis; a prescribed amount is injected into the arterial bloodline at prescribed times. Also, heparin can be given by bolus (the full prescribed amount is given all at once just before the treatment.)

Other centers give heparin by continuous infusion (a prescribed rate throughout the treatment.) A syringe filled with heparin, a heparin infusion line (see Figure 16), and an infusion pump are used and the pump slowly injects heparin into the extracorporeal circuit.
For most patients, heparin is stopped before the end of the treatment so blood clotting can go back to normal. A continuous infusion heparin pump has four parts:

1. A syringe holder
2. A piston to drive the plunger of the syringe
3. An electric motor to drive the plunger forward and infuse heparin from the syringe
4. A way to set the prescribed infusion rate

Heparin pumps have variable speeds that can be set to the physician’s prescription.

Heparin is infused into the heparin line on the arterial blood tubing before the dialyzer. Most heparin lines are placed after the blood pump segment. This helps avoid negative pressure at the part of the blood circuit that could otherwise draw air into the extracorporeal circuit through the heparin line.

SORBENT DIALYSIS

Sorbent dialysis can be used for acute, home, and chronic dialysis treatments. A sorbent dialysis system (see Figure 17) needs no water treatment system. It does not contain water and concentrate proportioning pumps. Instead, premixed chemicals are added to 6 L of tap water. The water and chemicals are cycled through a sorbent regenerative cartridge to purify the dialysate. Then the dialysate is

![Sorbent dialysis system](image-url)
collected in a disposable bag in the device and circulated to the dialyzer.

Used dialysate is then cycled through the cartridge, where it is chemically converted back into fresh dialysate and returned to the storage bag. The sorbent cartridge also removes all calcium, magnesium, and potassium from the used dialysate, since their concentrations were altered by passage through the dialyzer. These electrolytes are added back into the regenerated dialysate in the prescribed amounts by an infusion system. The patient’s ultrafiltrate is also converted into dialysate by passage through the cartridge. Each increase in the total volume of dialysate is a direct reflection of total UF and is continuously displayed.

The sorbent cartridge has four chemical layers. Besides regenerating dialysate, the layers serve as a water treatment system; they purify the 6 L of dialysate made with tap water. The sorbent cartridge also serves as a continuous dialysate disinfection system, keeping bacteria and endotoxin levels below 1 cfu/mL and 0.5 EU/mL, respectively.

Depending on which cartridge is used, the system can do short (3–5 hour) treatments at dialysate flow rates up to 400 mL/min, or long, slow (5–8 hour) treatments at dialysate flows between 200–300 mL/min. Since using the sorbent cartridge means no continuous water source, floor drain, or water treatment system are needed, sorbent systems can be used anywhere that an electrical outlet (or suitable generator) is present.

Conclusion

As you have read in this module, the delivery system plays a key role in monitoring dialysis. During each treatment, the machinery checks almost every aspect of the patient’s care except one: you.

The dialysis staff person is the most important monitor of all to keep patients safe. Alarms are of no use if someone forgets to turn them on or to check them against an independent meter.

The patient can be in great danger if a staff person hooks up the wrong dialysate to the machine. It is vital to recall that dialyzers and delivery systems are not just machines, and dialysate is not just salty water. They are precise parts of a medical treatment that can help patients with kidney failure lead full and active lives. Your attention to detail and skill at finding and troubleshooting problems will make all the difference in patients’ outcomes. Your job is to help them by staying alert at all times and by learning all you can about the equipment and procedures at your center.
FORMULA FOR DIALYZER SOLUTE CLEARANCE

\[ K = \frac{C_{Bi} - C_{Bo}}{C_{Bi}} \times Q_b \]

Where:

- \( K \) is clearance
- \( C_{Bi} \) (concentration at the blood inlet) is the concentration of “x” solute in the blood entering the dialyzer (arterial sample)
- \( C_{Bo} \) (concentration at the blood outlet) is the concentration of “x” solute in the blood leaving the dialyzer (venous sample)
- \( Q_b \) is blood flow rate in mL/min

For example, imagine that you wanted to calculate the clearance of urea in a patient for whom:

- \( C_{Bi} = 82 \) mg/dL (arterial BUN sample)
- \( C_{Bo} = 8 \) mg/dL (venous BUN sample)
- \( Q_b = 350 \) mL/min

Step 1:

\[ \frac{(82-8)}{82} \times 350 \]

Step 2:

\[ \frac{74}{82} \times 350 \]

Step 3:

\[ 0.9 \times 350 = 316 \text{ mL/min} \]

Therefore, during each minute of dialysis, 316 mL of this patient’s blood has been cleared of urea.
References


