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CE **Article #3 (1.5 contact hours)**
Refereed Peer Review

Hemodialysis in Dogs and Cats

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KEY FACTS

- Volume overload caused by oliguria can be effectively treated with ultrafiltration.
- Ethylene glycol can be removed efficiently by hemodialysis, thereby averting renal failure if treated promptly after ingestion.
- Hemodialysis can be used in patients weighing 2.5 kg or more.
- Patients in which other treatments have failed may respond to hemodialysis.

ABSTRACT: Hemodialysis treats renal failure by removing uremic toxins. This is accomplished by diffusion down a concentration gradient across a semipermeable membrane that is housed in the dialyzer. Electrolyte concentrations can be normalized, and fluid can be removed by ultrafiltration. Vascular access is usually through a dedicated, double-lumen hemodialysis catheter placed in the jugular vein. Specialized equipment (i.e., dialysis machine, monitoring equipment) and technical assistance are required. Hemodialysis is appropriate for dogs and cats with acute renal failure unresponsive to medical management, unremitting chronic renal failure, and certain toxicoses as well as before renal transplantation surgery. Outcome can be favorable for patients in which other treatments have failed.

Renal failure is a well-recognized problem in dogs and cats. Many treatment options are available, and selection depends on a variety of factors, including severity of illness and client preferences. However, traditional management has limitations in severe renal failure, whether from acute oliguric disease or end-stage chronic renal failure. In those situations, advanced renal therapies, such as dialysis and transplant, may improve longevity and quality of life. As more hemodialysis units are established, opportunities for referral are improved. Principles of hemodialysis and crucial issues that must be considered when deciding whether to institute hemodialysis for a patient are reviewed here.

INDICATIONS FOR HEMODIALYSIS

Hemodialysis can be used to treat acute renal failure, chronic renal failure, and certain toxicities.[1] Acute renal failure is the most common indication for hemodialysis in veterinary patients.[2–4] Anuric patients generally die within 5 days if urine production cannot be reestablished, but repair of the kidneys (if possible) may take weeks to months, depending on the cause and degree of renal failure.[5] Hemodialysis bridges this gap by supporting the patient and allowing time for the kidneys to heal. Hemodialysis does not cause the kidneys to repair themselves; it provides vital excretory functions during the repair stage. Hemodialysis can be used for any cause of acute renal failure, including leptospirosis, ethylene glycol intoxication, and acute bacterial pyelonephritis. The ideal patient for acute hemodialysis should have a potentially reversible renal disease and weigh 2.5 kg or more. Because of frequent monitoring and handling, a tractable patient is preferred.

Indications for acute hemodialysis include renal failure unresponsive to medical

Indications for Hemodialysis

Acute Renal Failure

- Uncontrolled biochemical or clinical manifestations of uremia
- Life-threatening electrolyte disturbances: hyperkalemia, hyponatremia, hypernatremia
- Life-threatening fluid overload: pulmonary edema, congestive heart failure, systemic hypertension
- Severe or refractory azotemia (BUN level >100 mg/dl; creatinine level >10 mg/dl) that is unresponsive to aggressive medical management for 12 to 24 hours

Chronic Renal Failure

- Refractory uremia (BUN level >100 mg/dl; creatinine level >8 mg/dl)
- Intractable clinical signs related to uremia
- Preoperative stabilization for renal transplantation

Acute Poisoning/Drug Overdose

- Antifreeze poisoning
- NSAIDs
- Barbiturates

management, overhydration, or ingestion of a dialyzable toxin. Hemodialysis is usually reserved for cases in which traditional medical management has proven ineffective or the amount of renal damage is severe enough that medical management is likely to fail. Before considering hemodialysis, certain aspects of medical management should be addressed. The patient should be adequately hydrated. If urine output is unknown or diminished, rehydration should be achieved over 4 to 6 hours unless the patient's cardiovascular status cannot tolerate rapid fluid administration. If hypotension is present, it should be corrected so that systolic blood pressure is sufficient to perfuse the kidneys (greater than 80 mm Hg, systolic). If these interventions do not induce urine flow, diuretics can be used. Furosemide is the most potent diuretic commonly used; if an initial dose (2.2 mg/kg IV) does not increase urine output in 20 to 30 minutes, the dose can be doubled or tripled (to a maximum of 8.8 mg/kg IV). If anuria or oliguria persists after appropriate therapy, hemodialysis is indicated.

Hyperkalemia is an immediately life-threatening complication of oliguric renal failure; it can also occur in some cases of polyuric or nonoliguric renal failure. By altering electrical conduction in the heart, hyperkalemia leads to bradycardia, which can progress to atrial stand-

Table 1. Hemodialysis Equipment and Supplies

Product	*Trade Name*	*Manufacturer*
11.5-Fr temporary hemodialysis catheter	Hemocath	MedComp, Inc., Harleysville, PA
5.5- or 7-Fr double-lumen catheter		Arrow International, Inc., Reading, PA
Oval permanent hemodialysis catheter	PermCath®	Quinton Instrument Co., Seattle, WA
8-Fr pediatric hemodialysis catheter	Pediatric Hemocath	MedComp, Inc.
Dialysis machine	Centurysystem 3 2008H	Cobe Laboratories, Inc., Lakewood, CO Fresenius, Inc., Walnut Creek, CA
Extracorporeal blood circuit		
Low volume		Cobe Laboratories, Inc.
Neonatal		Cobe Laboratories, Inc.
Dialyzers	100HG, 500HG Polyflux 17S F3, F4	Cobe Laboratories, Inc. Cobe Laboratories, Inc. Fresenius, Inc.
Inline hematocrit monitor	Crit-Line III™	HemaMetrics, Kaysville, UT
Automated coagulation monitor	ACT II	Hemotec, Englewood, CO
4-Methylpyrazole	Antizol-Vet®	Orphan Medical, Inc., Minnetonka, MN
Dextran	6% Gentran 70®	Baxter Healthcare Corp., Deerfield, IL
Oxyhemoglobin	Oxyglobin®	Biopure Corp., Cambridge, MA

still. Emergency therapies (i.e., calcium, insulin, dextrose, bicarbonate) may provide rapid relief (onset in 10 to 30 minutes) but are not long-term cures. Unless urine output is established over the next several hours, the plasma–potassium concentration will become elevated again. Hemodialysis and peritoneal dialysis are the only methods of rapidly removing potassium from the body in cases of anuric or oliguric renal failure.

Oliguric or anuric patients receiving fluid therapy or enteral fluids are prone to overhydration, which may manifest in many ways. Limb edema, intermandibular edema, chemosis, and ascites are common but not life threatening. Pulmonary edema and pleural effusion are serious complications of overhydration. Pleural effusion can be managed by thoracocentesis. Pulmonary edema in an oliguric patient is not responsive to furosemide. Effective treatment involves fluid removal with ultrafiltration during hemodialysis. In patients with massive overhydration, ultrafiltration to control pulmonary edema is needed more urgently than is uremic toxin removal.

Hemodialysis is also indicated for severe uremia (blood urea nitrogen [BUN] level greater than 100 mg/dl; creatinine level greater than 10 mg/dl) that is not responsive after 24 hours of medical management. Patients that are producing urine but not effectively clearing uremic toxins can benefit from hemodialysis. Controlling azotemia, acid–base imbalances, and electrolyte disturbances can decrease patient morbidity and clinical manifestations of uremia, including anorexia, lethargy, and vomiting.

Certain toxins, such as ethylene glycol, can be removed by the dialysis membrane. The efficiency with which hemodialysis removes a toxin partly depends on the size of the molecule (smaller particles are removed more easily) and the degree of protein binding (highly protein-bound molecules are more difficult to remove). Hemodialysis has been used for a variety of toxicities in humans, including salicylates, alcohols and ethylene glycol, lithium, barbiturates, and theophylline.[6] Hemodialysis can avert renal failure with early removal (within 6 hours of ingestion) of ethylene glycol in a single treatment (4-methylpyrazole is also highly effective in this early period in dogs). After the onset of metabolism of ethylene glycol to glycolic acid, hemodialysis can remove any remaining ethylene glycol and its metabolites in addition to addressing renal failure.

Because returning normal renal function is not possible with chronic renal failure, hemodialysis is used as an ongoing therapy to improve the quality and quantity of life. While renal transplant would be preferable in many ways, it is not always feasible. Many cats with chronic renal failure are excluded from consideration for transplantation due to concurrent illness or infection, and canine transplantation currently has limited availability. In these patients, hemodialysis may be the only option aside from euthanasia. Managing uremia in these patients improves appetite, decreases vomiting, and increases activity level.

Perioperative hemodialysis for transplantation patients is showing promise in improving outcome and

reducing complications. If the creatinine level cannot be reduced to less than 8 mg/dl by fluid diuresis, one to three preoperative dialysis treatments can help control azotemia and fluid balance. Incidence of posttransplantation neurologic complications is reduced in cats with a pretransplantation creatinine level less than 8 mg/dl.[7] In cases of delayed graft function or ureteral obstruction after surgery, hemodialysis can support a patient until renal function improves.

If any of these indications for acute hemodialysis are present, early referral for hemodialysis could decrease patient morbidity by instituting effective therapy to limit damage from uremia, its treatment, or the ingested toxin. In cases of chronic renal failure, evaluation by the hemodialysis team before hemodialysis is necessary is strongly recommended. The short-term morbidity for humans with chronic renal failure who start dialytic therapy on an emergency basis is much worse than those started in a controlled fashion.[8]

HEMODIALYSIS PROCEDURES

Vascular Access

Because hemodialysis involves cleansing the blood, reliable vascular access is necessary. Catheters placed in the jugular vein are used for this purpose. Temporary access can be achieved in medium to large dogs using an 11.5-Fr, double-lumen, temporary hemodialysis catheter (Table 1). The catheter can be placed percutaneously with local anesthesia in a mildly sedated dog and can remain functional for 2 to 6 weeks. For cats, a percutaneously placed 5.5- or 7-Fr, double-lumen catheter can be used for temporary access. Blood flow rate through a 5.5-Fr catheter is extremely limited (5 to 10 ml/min), making it suitable for only the first one or two treatments. A 7-Fr catheter can provide better, but still limited, blood flow rates. Temporary catheters are advantageous when a patient is too unstable to anesthetize, rapid access is desired, or only a few treatments are anticipated; however, they do not provide the rapid blood flow (up to 20 ml/kg/min) needed to allow maximal toxin removal in a 4- to 5-hour treatment period.

For more efficient treatment or for therapy extending longer than a few weeks, a permanent catheter is used. This catheter is surgically placed with a portion of it tunneled subcutaneously to decrease the risk of bacteremia from skin exit-site infections (Figure 1). These catheters are made of a soft, silicone material that is minimally thrombogenic. In medium to large dogs, an oval catheter (approximately 15 Fr) is used most often; for cats and small dogs, an 8-Fr pediatric catheter is used. These catheters can remain in place for 1 to 2 years.

All catheters intended for hemodialysis are handled in an aseptic fashion at all times and should not be used for blood sampling or administering fluids or medications. Heparin (1000 U/ml) is instilled to fill the lumen of the catheter and left in place between treatments to prevent catheter occlusion.

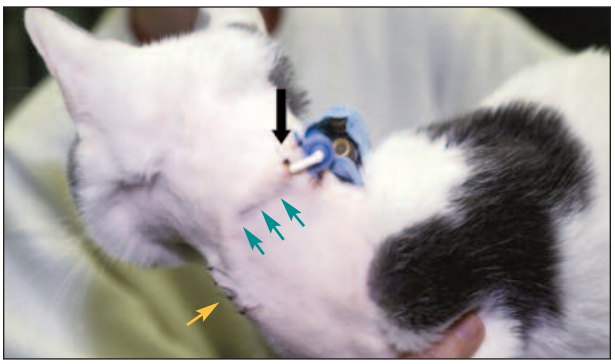

Figure 1—A permanent hemodialysis catheter in place. It exits dorsally *(black arrow)* and is tunneled subcutaneously *(green arrows)*. Sutures are visible over the site where the catheter enters the jugular vein *(gold arrow)*.

In humans, arteriovenous fistulas are the primary method for vascular access. They are surgically created by anastomosing an artery to a vein and require 1 to 2 months to endothelialize before use. Although they have not been used clinically in veterinary patients, a successful model has been created.[9]

Dialysis Machine

The dialysis machine formulates and delivers the dialysate and circulates the blood. Dialysate is the fluid circulated through the dialyzer, surrounding and bathing the hollow fibers containing the blood. It is similar to plasma water, but without the plasma proteins, and is produced by the dialysis machine by mixing an electrolyte solution with purified water to create a fluid with concentrations of sodium, chloride, calcium, magnesium, potassium, dextrose, and bicarbonate that approximate normal plasma concentrations. A separate water-treatment system is necessary to ultrapurify the water (usually by a process of filtration and either deionization or reverse osmosis) to remove trace amounts of impurities. Because a patient's blood is exposed to 120 to 150 L of dialysate per treatment, even minute amounts of impurities could accumulate to toxic levels if the water is not purified sufficiently. The dialysis machine controls and monitors multiple dialysate parameters, including composition, temperature, and pressure, and can divert dialysate flow away from the blood interface if a parameter does not meet specifications.

Blood Path

The dialysis machine also circulates the blood

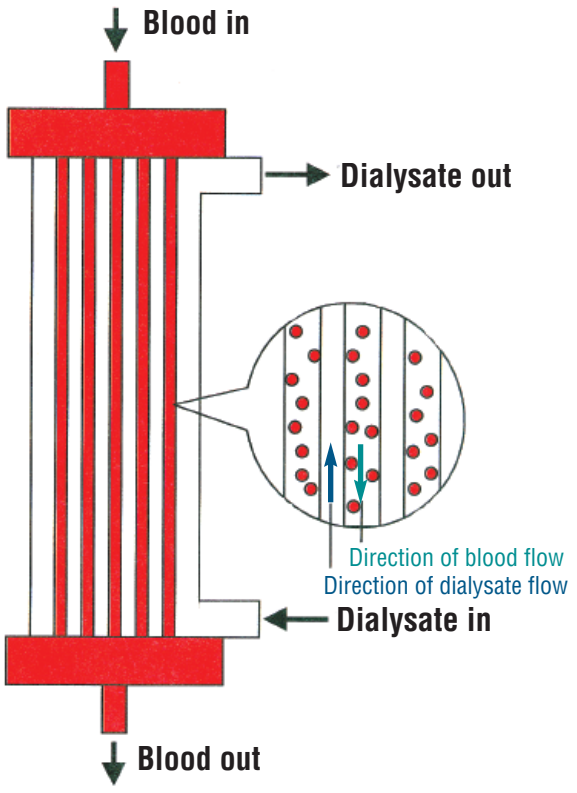

Figure 2—Diagram of a hollow-fiber dialyzer.

through the extracorporeal circuit—the disposable tubing that carries blood from one port of the patient's catheter to the dialyzer—and returns it to the patient via the other catheter port. The volume of blood contained in the extracorporeal circuit is 40 ml for the neonatal circuit and 75 ml for the pediatric circuit used with the Cobe Centurysystem 3 Dialysis Delivery System (Cobe Laboratories). The dialysis machine has pressure monitors that can detect occlusion in the extracorporeal circuit or disconnection from the catheter, triggering an automatic clamp of the blood path until the condition is remedied. There are also air traps and detectors in the blood path to prevent air embolism as well as a filter to catch any thrombi that may form.

Dialyzer

The dialyzer (also known as the "artificial kidney") contains a semipermeable membrane that is usually arranged as thousands of hollow fibers. The blood flows through the center of the fibers, and uremic wastes diffuse through the membrane into the fluid (dialysate) surrounding the fibers (Figure 2). The membrane contains pores that allow diffusion of water and small molecules, but proteins and cells remain in the blood compartment. Dialyzers vary in size and membrane composition. Larger dialyzers have a larger membrane surface area, allowing more dialysis per unit of time, but require a larger volume of blood. Membrane type is generally divided into cellulosic types and synthetic types. Cellulosic membranes are generally less expensive but generate a greater inflammatory response than synthetic membranes. Synthetic membranes are more inert and tend to have larger pores, allowing better clearance of mid-sized molecules. Cellulosic dialyzers (e.g., 100HG, 500HG [Cobe Laboratories]) are commonly used for veterinary patients, but synthetic dialyzers are becoming more widely used. In humans, cleaning and reusing a synthetic dialyzer for up to 50 dialysis treatments in the same patient is common practice. Reuse is not practiced with veterinary patients because of safety concerns and labor costs; each dialyzer is discarded after a single use.

PRINCIPLES OF HEMODIALYSIS

Dialysis works by diffusing molecules across a semipermeable membrane from an area of high concentration to an area of low concentration. By this method, high concentrations of uremic toxins (e.g., urea, creatinine, phosphates) can be removed from the blood to the dialysate, which has a zero concentration of these substances. Because diffusion is based on the concentration gradient, a high concentration of bicarbonate in the dialysate causes diffusion into the blood, thereby combating metabolic acidosis. Because they diffuse more readily, smaller molecules are removed more efficiently than larger molecules. Small molecular-weight toxins or drugs that are not extensively protein bound can also be removed via dialysis. The flow of dialysate is usually directed opposite to the blood flow direction. Blood entering the top of the dialyzer has a high concentration of uremic toxins; by the time the blood exits the dialyzer at the bottom, substantial amounts of uremic molecules have been removed, thereby lowering their concentration in the blood. The dialysate enters the dialyzer at the bottom. Dialysate initially has a zero concentration of uremic toxins but accumulates increasing amounts of toxins from the blood by the time it exits the top of the dialyzer. Because diffusion depends on the difference between concentrations in each compartment, this countercurrent flow pattern maximizes the concentration gradient throughout the dialyzer. In addition, a potassium-free dialysate can be used to enhance potassium removal if needed.

Fluid can also be removed from the patient if volume overload is present; this process is called *ultrafiltration*. In peritoneal dialysis, fluid is removed by creating an osmotic gradient using dextrose. A hydrostatic pressure gradient is employed in hemodialysis by placing a vac-

uum on the outgoing dialysate port. The higher hydrostatic pressure in the blood compartment of the dialyzer compared with the lower pressure dialysate compartment drives plasma water into the dialysate compartment, thus removing fluid from the patient. Fluid retention without uremia (i.e., diuretic-resistant congestive heart failure) has been treated by this method in humans.[10]

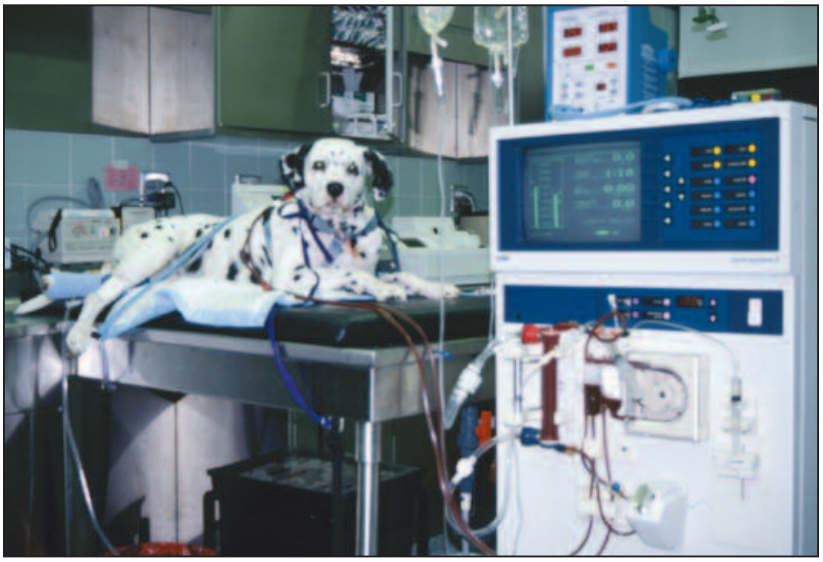

Figure 3—A dog receiving dialysis treatment is minimally restrained via a harness tethered to the table.

HEMODIALYSIS PRESCRIPTION

The dialysis prescription, which includes such parameters as desired length of treatment, blood flow rate, dialysate flow rate, dialysate parameters, and ultrafiltration volume, is tailored to the needs of the individual patient. In general, the first two to three dialysis treatments are abbreviated to allow the patient to gradually adapt to the changes induced by the procedure. The goal of the first treatment is to decrease the BUN level by 25% to 33%. This is accomplished with 1.5 to 2 hours of dialysis at a blood flow rate of 5 ml/kg/min. In patients with severe uremia, the direction of dialysate flow through the dialyzer can be reversed, diminishing the concentration gradient and decreasing efficiency, to avoid causing dialysis disequilibrium. The second treatment is longer, usually 3 hours, and requires a blood flow rate of 10 ml/kg/min. The urea reduction is typically around 50% for this treatment. By the third or fourth treatment, a patient is usually stable enough for a standard treatment, which is 4 hours in cats and 5 hours in dogs. Blood flow is usually 15 to 20 ml/kg/min, up to a maximum of 500 ml/min in dogs and 125 ml/min in cats. This will reduce the urea by greater than 95% of the starting concentration and exposes up to 50 times the entire blood volume to the dialyzer in one treatment.

Once the initial few dialysis treatments have normalized the BUN level and fluid status of the patient, treatments are performed three times a week until renal function recovers in the case of acute renal failure or indefinitely in the case of chronic renal failure. As function improves with acute renal failure, twice-weekly treatments may suffice. The BUN level typically increases to less than 100 mg/dl between treatments and decreases to less than 5 mg/dl at the end of the treatment. Sedation is not needed during dialysis. Dogs are restrained using a harness loosely tethered to the treatment table (Figure 3); cats are usually content to sit quietly in a heated box or carrier.

The amount of urea removed is more directly related to the amount of blood exposed to the dialyzer membrane than it is to the length of dialysis treatment.[11] In patients at high risk for complications relating to rapid solute removal, including small patients (especially cats) and those with severe uremia (BUN level greater than 150 mg/dl), using a slower blood flow rate for a longer period of time will remove the desired amount of urea while minimizing complications.[12] In many cats, a blood flow rate of 5 ml/min for 6 to 18 hours has been used without complications.

If occlusion of one lumen of the dual-lumen catheter prevents adequate blood flow or if only a single-lumen catheter is available, a single-needle mode can be used. In this mode, dialysis can proceed through a single lumen with the use of a Y connector and intermittent blood flow. This is a less efficient method than continuous flow (double-needle mode) but provides an alternative to immediate catheter replacement or discontinuing dialysis.

To prevent clotting in the extracorporeal circuit, heparin is administered as an intravenous bolus immediately before treatment and continued as a constant-rate infusion during therapy. The dose is adjusted to achieve a target activated clotting time (ACT) of 1.5 to 2 times the normal value. ACT is routinely measured before and during each treatment in order to guide heparin therapy.

Parameters routinely monitored before and after each dialysis treatment include body weight, temperature, packed-cell volume, BUN, and creatinine concentrations. Blood pressure, heart rate, and ACT are monitored repeatedly during each treatment. Other parameters (e.g., respiratory rate, oxygen saturation, blood

volume changes) are monitored as needed based on the individual patient and equipment availability.

INTRADIALYTIC MANAGEMENT

Between dialysis treatments, medical management is based on the patient's condition. Intravenous fluids, histamine blockers, antibiotics, diuretics, antihypertensives, and other treatments are used on a case-by-case basis. Because dialysis patients are critically ill, around-the-clock monitoring is needed initially. As dialysis stabilizes the patient, less intensive monitoring is required, and some patients can be sent home (with the dialysis catheter bandaged in place) to continue thrice-weekly outpatient hemodialysis treatments. Outpatient medications (e.g., antihypertensives, phosphate binders, erythropoietin, iron supplements) are prescribed as needed.

Anemia is common in uremic patients on hemodialysis. This may be due to uremic gastrointestinal bleeding, blood sampling, blood loss in the extracorporeal circuit during the hemodialysis procedure (about 5 ml/treatment), and/or a preexisting anemia associated with chronic renal failure. Substituting small volumes of Oxyglobin® (Biopure) for dextran when priming the extracorporeal circuit can help improve oxygen-carrying capacity. Blood transfusions and/or erythropoietin therapy are frequently required.

Nutritional support is usually necessary initially due to anorexia associated with acute renal failure. A nasogastric tube can be used, or a percutaneous endoscopic gastrostomy tube can be placed if gastric ulceration is not severe. If vomiting cannot be controlled pharmacologically, parenteral nutrition may be indicated. The fluid burden associated with both enteral and parenteral nutritional support may require additional ultrafiltration in the anuric or oliguric patient. As the uremia is controlled, appetite usually improves.

COMPLICATIONS

Because hemodialysis is a technically complex procedure performed on critically ill patients, there are a number of potential complications (e.g., hypotension, dialysis disequilibrium, respiratory dysfunction, hemorrhage, thrombosis) that may be due to the hemodialysis procedure itself or underlying uremia.

There are a variety of causes for hypotension during hemodialysis. Because 60 to 200 ml of blood (up to 30% of blood volume) is removed from a patient at the start of each treatment as the extracorporeal circuit is filled, a decrease in blood pressure is anticipated, especially in smaller patients. The removed blood is simultaneously replaced by an equal volume of either 0.9% saline (in medium to large dogs) or 3% dextran (in cats and small dogs) in an effort to maintain adequate blood pressure. Exposure of the blood to certain types of dialysis membranes can induce an inflammatory reaction, leading to hypotension. Also, an aggressive rate of fluid removal via ultrafiltration can remove fluid from the vascular space faster than it can refill from the interstitial space, leading to hypotension.

Continuous monitoring of blood volume during hemodialysis can predict hypotensive episodes induced by rapid ultrafiltration. An optical sensor placed on the blood path measures the hematocrit. In the absence of blood transfusion or loss during treatment, changes in hematocrit are a reflection of changes in plasma water volume. Evaluating the rate of change can allow for intervention (e.g., temporarily slowing or stopping ultrafiltration, administering fluids) before patient complications occur.[13]

Dialysis disequilibrium syndrome is caused by rapid, dialysis-induced changes in the composition of the blood. The pathogenesis of this condition may involve removal of urea from the blood compartment more rapidly than urea can diffuse from the intracellular compartment into the blood. The resultant osmotic gradient causes intracellular swelling, and clinical signs are related to cerebral edema. An alternate theory incriminates rapid correction of metabolic acidosis by the bicarbonate in the dialysate, leading to paradoxical central nervous system acidosis.[12] Signs may include

Hemodialysis Units

Animal Medical Center
510 E. 62nd Street
New York, NY 10021
Phone: 212-838-8100

Companion Animal Hemodialysis Unit
Veterinary Medical Teaching Hospital
University of California, Davis
Davis, CA 95616
Phone: 530-752-1393

VCA Veterinary Referral Associates, Inc.
15021 Dufief Mill Road
Gaithersburg, MD 20878
Phone: 301-340-3224

Tufts University
School of Veterinary Medicine
200 Westboro Road
North Grafton, MA 01536
Phone: 508-839-5395

San Diego Hemodialysis Unit
University of California Veterinary Medical Center
6525 Calle del Nido
Rancho Santa Fe, CA 92067
Phone: 858-759-7235

agitation, disorientation, seizure, coma, or death. Treatment includes correcting the osmotic gradient with infusion of mannitol and slowing or stopping the hemodialysis session. Prevention is achieved by slow correction of uremia in the first few treatments and prophylactic mannitol administration in high-risk patients. Patients with uremic and hypertensive encephalopathies may show the same signs.

Respiratory dysfunction in hemodialysis patients has many precipitating factors. Pulmonary edema and pleural effusion are common in oliguric patients. Hemodialysis can be used to correct these conditions, although massive pleural effusion is managed more effectively by thoracocentesis. Uremic pneumonitis may result in mild to severe respiratory impairment but can improve with hemodialysis.[14] Exposure of the blood to the dialyzer membrane, particularly the cellulosic membranes, activates complement, causing sludging of neutrophils and platelets in the pulmonary capillaries, thereby impairing oxygen diffusion. Although these changes reverse within hours of starting hemodialysis, the impairment may cause clinically significant dyspnea in a patient with preexisting pulmonary dysfunction. Pulmonary thromboembolism originating from the hemodialysis catheter can cause severe respiratory compromise.

Despite careful attention to anticoagulation, hemorrhage is a potential complication of hemodialysis. Bleeding at the surgical site of catheter placement or from gastrointestinal ulcers may require blood transfusion. Catastrophic events can occur secondary to pulmonary or cerebral hemorrhage.

Although silicone hemodialysis catheters are not as thrombogenic as those made from other materials, any intravascular implantation carries a risk of thrombosis. In veterinary patients, thrombi that adhere to the tip of the catheter and extend into the right atrium are not uncommon if catheters are in place for more than 3 weeks. These thrombi tend to adhere to the wall of the atrium and may become endothelialized; however, they can result in pulmonary thromboembolism. If thrombi form around the catheter in the vena cava, facial edema may develop. Low doses of aspirin are usually administered to decrease platelet activation and thus minimize thrombus formation.

Technical complications (e.g., air embolism, hemolysis from improper dialysate preparation, blood leak from ruptured dialyzer fibers or housing) are rarely encountered with current machines.

OUTCOME

The survival rate of dogs with acute renal failure without hemodialysis is about 38% to 44%.[15,16] Hemodialysis is targeted at the more severely affected acute renal failure patients, and the 35% to 50% survival rate of dialysis patients represents animals that were very likely to die if not dialyzed.[1,12] Certain patients may have even better results: 60% of cats with acute renal failure[11] and 86% of dogs with leptospirosis[17] reportedly survive without the need for ongoing hemodialysis. Survivors may have complete resolution of renal dysfunction or may be left with residual damage that requires ongoing therapy for chronic renal failure. Experience with hemodialysis for chronic renal failure is still very limited, but long-term survival (longer than 1 year) can be achieved.[12] Hemodialysis can be used for stabilization before renal transplantation in cats that otherwise would not be transplantation candidates (e.g., cats with ethylene glycol toxicity or decompensated chronic renal failure).

Hemodialysis is an effective but expensive therapy for renal failure. The cost varies from institution to institution. In general, management of a reversible episode of renal failure lasting up to 4 weeks might cost as much as $6000 to $15,000. Long-term hemodialysis lasting for a year may exceed $60,000.

CONCLUSION

Hemodialysis is an effective method of treating renal failure. It provides the opportunity to give more support to a patient than traditional medical management. Hemodialysis can control life-threatening uremic complications and thus allow time for renal recovery. The need for specialized equipment currently limits availability; therefore, prompt referral to a hemodialysis center is warranted in selected cases. As with any technically complex procedure in critically ill patients, there are a number of potential complications. The overall survival rate is about 50%, which represents patients that probably would have died of renal failure without intervention.

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ARTICLE #3 CE TEST

The article you have read qualifies for 1.5 contact hours of Continuing Education Credit from the Auburn University College of Veterinary Medicine. *Choose the best answer* to each of the following questions; then mark your answers on the postage-paid envelope inserted in *Compendium.*

1. A patient in which hemodialysis would be appropriate could have any of the following conditions except
   a. oliguric acute renal failure.
   b. end-stage chronic renal failure unresponsive to medical management.
   c. ethylene glycol toxicity.
   d. the need for a renal transplant and a creatinine level greater than 8 mg/dl.
   e. compensated chronic renal failure before anesthesia for dentistry.

2. Indications for hemodialysis include any of the following except
   a. hyperkalemia.
   b. pulmonary edema due to volume overload.
   c. oliguria/anuria.
   d. acute antifreeze ingestion without renal failure.
   e. peripheral edema.

3. Temporary hemodialysis catheters have all of the following advantages over permanent catheters except
   a. rapid placement.
   b. no need for anesthesia.
   c. rapid blood flow.
   d. no need for invasive surgery.
   e. smaller size allowing easier placement.

4. Dialysis machines perform which of the following functions?
   a. purify water
   b. produce dialysate
   c. monitor patient blood pressure
   d. sterilize dialyzer between treatments
   e. monitor ACT

5. Standard dialysate contains normal serum concentrations of all of the following except
   a. sodium.
   b. potassium.
   c. albumin.
   d. calcium.
   e. magnesium.

6. Dialyzer characteristics vary based on all of the following parameters except
   a. membrane composition.
   b. pore size.
   c. surface area.
   d. ability to induce inflammation.
   e. provision of semipermeable membrane.

7. During hemodialysis, ultrafiltration removes
   a. fluid by hydrostatic forces.
   b. fluid by osmotic forces.
   c. molecules by hydrostatic forces.
   d. molecules by osmotic forces.
   e. plasma proteins.

8. In a standard 4- to 5-hour hemodialysis treatment, BUN concentration can be reduced by what percentage of the starting concentration?
   a. 25%
   b. 33%
   c. 50%
   d. 75%
   e. more than 95%

9. In a very small hemodialysis patient (approximately 2.5 kg), what volume of blood is removed during treatment?
   a. 3%
   b. 8%
   c. 15%
   d. 30%
   e. 45%

10. Hemodialysis causes respiratory dysfunction by creating
    a. uremic pneumonitis.
    b. pulmonary edema.
    c. complement activation and sludging of blood.
    d. pleural effusion.
    e. ascites and increased abdominal pressure.