Equipment Commonly Used in Veterinary Renal Replacement Therapy

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- Dialysis machine • Monitor • Water treatment system
- Intermittent hemodialysis
- Continuous renal replacement therapy

INTERMITTENT HEMODIALYSIS MACHINES

There are several basic types of dialysis machines. In general, dialysis machines are designed to be used either for intermittent hemodialysis (IHD) or for continuous renal replacement therapy (CRRT), although “hybrid” machines, which are able to perform both types of therapies, have recently become available. Intermittent hemodialysis machines can be also used to provide sustained low-efficiency dialysis (SLED) treatments in addition to highly efficient intermittent treatments. Specific details of operation vary among machines (eg, minimum and maximum ranges for blood or dialysate flow and dialysate component concentrations); general ranges of commonly available machines are listed and illustrated here.

In the United States, most veterinary units performing intermittent hemodialysis use either Gambro (Phoenix or CentrySystem 3 models) (**Figs. 1** and **2**) or Fresenius machines (**Fig. 3**). The Gambro machines have a cartridge system for the extracorporeal circuit that includes all of the necessary tubing. The dialyzer is separate. The snap-in cartridge simplifies machine set-up, but limits tubing choices. The Fresenius machines incorporate several tubing components that are selected separately during machine set-up. This arrangement provides more flexibility with tubing size, volume, and manufacturers, but lacks the simplicity of the Gambro cartridge. There are several other types of dialysis machines that are approved for use in Europe or Canada but not in the United States. Many of these machines have the capability of on-line

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Fig. 1. Gambro Phoenix Intermittent Hemodialysis machine.

hemodiafiltration, which means they can provide large volumes of solutions to infuse into the patient as replacement fluid, in addition to producing large volumes of dialysate.

Regardless of the model or manufacturer, all modern IHD machines have certain common characteristics. First, they all contain a display screen, which may be a touch screen on newer models. This screen displays the current dialysis treatment mode, all options available in that mode, treatment parameters, alarm conditions, and any necessary instructions. During the dialysis treatment, the screen also displays treatment status (ie, time left, amount of fluid removed, catheter pressures, and so forth).

IHD machines house a dialysate proportioning system. This system takes incoming purified water and mixes it with the appropriate amount of electrolyte and bicarbonate concentrates to create dialysate at a rate of 300 to 800 mL/min. The electrolyte solution is a highly concentrated salt solution containing sodium, chloride, glucose, and other components as desired (potassium, calcium, magnesium). The machine operator sets the desired sodium concentration of the dialysate (within the limits of the

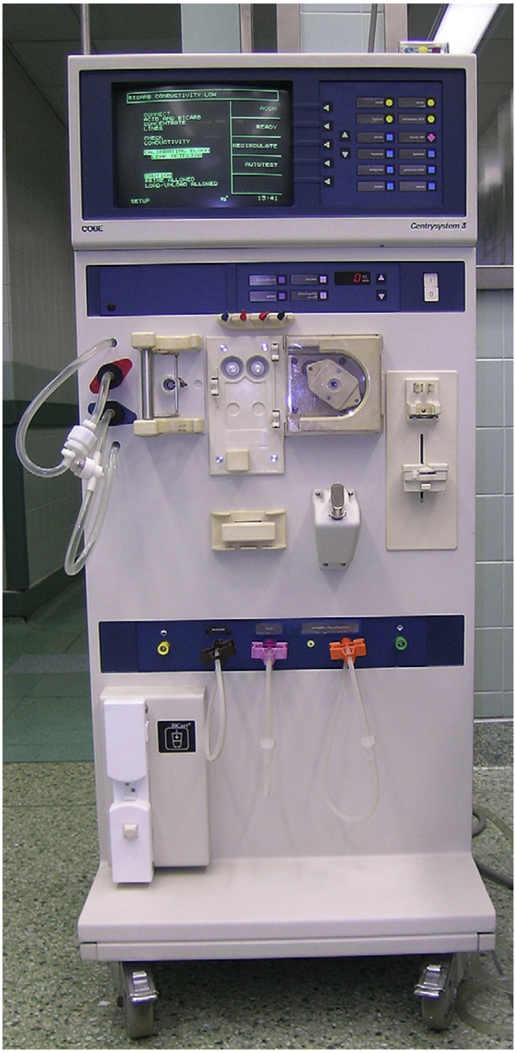

Fig. 2. Gambro CenturySystem3 Intermittent Hemodialysis machine.

machine of between 130 and 155 mEq/L) based on patient parameters. The sodium concentration can be readily adjusted to avoid large or rapid changes in the patient's serum sodium concentration, thus avoiding dramatic fluid shifts. Sodium profiling is a feature of most machines that allows the dialysate sodium concentration to automatically adjust throughout the treatment to match a preset pattern. The dialysate sodium may be set slightly higher than the patient's serum concentration at the start of the treatment and gradually decrease to normal over the course of the treatment. This profile enhances diffusion of sodium into the patient early in the course of treatment when urea removal is most rapid, and helps maintain a stable patient osmolality. This process decreases the risk of cerebral edema and the related neurologic symptoms known as dialysis disequilibrium syndrome. The sodium concentration is lowered by the end of the treatment to avoid loading the patient with sodium, which

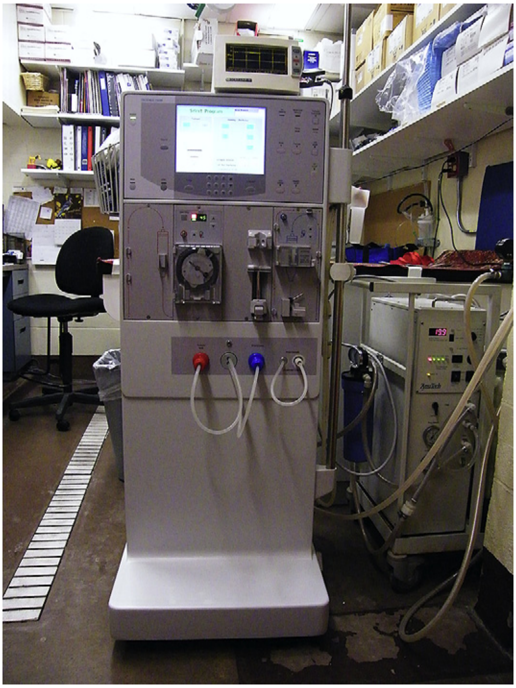

Fig. 3. Fresenius 2008H Intermitttent Hemodialysis machine. (*Courtesy of* Mary Anna Labato, Tufts University, North Grafton, MA.)

can enhance thirst and water retention in the interdialysis interval.[1] The concentration of other dialysate components will be proportional to the sodium concentration and cannot be individually adjusted. However, different salt solutions can be used, such as potassium-free or calcium-free solutions.

Bicarbonate is incorporated separately because bicarbonate and calcium from the electrolyte concentrate are incompatible in a concentrated form without inducing precipitation, thus allowing the bicarbonate concentration to be adjusted independently from sodium concentration, generally within the range of 25 to 40 mEq/L. To combat metabolic acidosis that is commonly present, the dialysate bicarbonate concentration is usually higher than that of the patient, allowing diffusion of bicarbonate from the dialysate into the patient. The typical dialysate bicarbonate concentration used in people (35 mEq/L) leads to panting in dogs; a slightly lower concentration (30 mEq/L) is typically used in veterinary hemodialysis. If acidosis is severe, a high dialysate bicarbonate concentration may cause paradoxic central nervous system acidosis and dialysis disequilibrium syndrome.

An alternative method of producing dialysate involves mixing the salt and buffer solutions with water in a large bulk tank, where it is stored until being piped to the individual dialysis machines in the unit. Every patient in the unit would use the same dialysate composition. This method is rarely used in veterinary medicine.

Each machine has a blood pump to draw blood from the catheter and return it to the patient. The blood pump speed ranges from 10 to 600 mL/min in most machines. The vast majority of patients are heparinized to prevent blood clotting in the extracorporeal circuit, so all modern dialysis machines have a built-in syringe pump for heparin administration.

In addition to removing uremic toxins, one of the main goals of dialysis is to control the patient's fluid volume. To this end, dialysis machines are able to remove fluid from the blood via a process called ultrafiltration. A vacuum is applied to the outgoing dialysate flow to create hydrostatic pressure. The result is that pressure within the straw-like semipermeable membrane in which the blood is traveling is positive in relation to the dialysate. The pressure forces fluid out of the blood and into the dialysate. The volume of fluid to be removed is programmed by the technician, and the dialysis machine will then automatically set the removal rate based on the intended duration of the treatment. Ultrafiltration rates vary from 0 to 4 kg/h (4 L/h). In older machines, the smallest increment of fluid removal is 100 mL/h, which can be excessive for small patients. As a safety feature of some new machines, such as the Gambro Phoenix, some degree of ultrafiltration must be used to maintain a positive pressure gradient across the entire dialyzer. The ultrafiltration prevents any back leakage of dialysate into the bloodstream, thus decreasing risk to the patient in the event the dialysate has any bacterial contamination. If this degree of fluid removal (100 mL/h) is not desired in a smaller patient, intravenous fluid administration may be necessary to avoid causing hypovolemia. Dialysate sodium concentration can also be profiled in such a way to maximize fluid removal from the patient, following osmotic gradients.

Some newer machines can be set to remove fluid at variable rates during the dialysis treatment. A common profile involves a faster rate of fluid removal at the beginning of the treatment, when the extra fluid is readily accessible in the bloodstream, and a slower rate toward the end, to account for a slower transfer from the interstitium to the bloodstream as the patient nears the optimal fluid status.[1] In intermittent hemodialysis, with its high dialysate flow rate, ultrafiltration contributes relatively little to the overall solute clearance.[2]

Most newer dialysis machines also incorporate ionic dialysance measurement. Dialysance is a measure of solute mass transfer from blood to dialysate. The collective dialysance of small molecular weight ions is considered equivalent to the urea dialysance. For conventional single-pass hemodialysis circuits, urea dialysance is equal to urea clearance. By programmed alterations in dialysate conductivity and measurement of conductivity at the dialysate inlet and outlet, the dialysis machine can calculate the dialyzer ionic dialysance and thus urea clearance. Repeated measurements are made throughout the treatment, allowing calculation of urea clearance over time (Kt) for each dialysis treatment. By entering the patient weight and volume of distribution, the machine will calculate the dialysis adequacy (Kt/V) throughout the dialysis treatment.[3]

Because of the difficulties associated with maintaining an adequately functioning vascular access, most dialysis machines can be programmed for blood removal and return through a single lumen of a catheter, referred to as single-needle dialysis. Such dialysis involves a discontinuous flow of blood, therefore single-needle dialysis is less efficient than standard dialysis.

A therapeutic plasma exchange cartridge can be used to separate plasma from the cellular blood components. Thus, plasma can be removed from the patient and replaced with a colloid solution while preserving the patient's red cells, white cells, and platelets. Therapeutic plasma exchange may be helpful in the treatment of autoimmune disease such as myasthenia gravis, as the offending antibodies are discarded. A charcoal hemoperfusion cartridge can be placed in the extracorporeal circuit to allow treatment of certain toxicities.

It is essential for patient safety that the dialysate is proportioned consistently and accurately to the technician's specifications. To that end, the machines have many built-in sensors and alarms to ensure patient safety. There are sensors that monitor pressure changes in the extracorporeal circuit, air in the return line, blood leaks in the dialyzer, or other unsafe conditions. Sensors constantly monitor dialysate composition and temperature. The machine does not monitor specific dialysate components; rather, the system monitors total electrical conductivity, which is dependent on solute concentration. If any unsafe or potentially unsafe conditions are detected in the dialysate, its flow is diverted from the dialyzer while blood continues to circulate; this minimizes the likelihood of clotting while the dialysate error is corrected. If blood path conditions are potentially compromised, as indicated by excessively high or low pressures in the circuit, the blood pump stops and the blood lines are automatically clamped to prevent further removal of blood from the patient or unsafe return of patient's blood. On-screen instructions notify the operator of the specific alarm, which must be remedied to restart the treatment. In extreme situations, the machine will require the operator to perform an emergency stop treatment procedure. Despite the myriad safeguards and in many cases, duplicate monitors installed in the machine, technician error can still occur. Only personnel specifically trained to use and troubleshoot the specific machine should perform IHD treatments.

Machine maintenance involves routine internal cleaning and intermittent machine calibration. At the end of each treatment day, the technician may be required to put the machine in a rinse cycle to flush bicarbonate out of the tubing to avoid precipitation. A cleaning cycle involving bleach removes any protein deposits from the dialysate tubing. Some of the newer machines automatically perform these cleaning steps without technician input. Weekly disinfection should be part of the dialysis unit routine. Chemical disinfection can be performed using a variety of cleaners. A blend of peroxyacetic acid and hydrogen peroxide (Actril; Minntech, Minneapolis, MN, USA) is popular. The cleaning solution is distributed throughout the internal tubing of the machine via the acid and bicarbonate ports and is allowed to dwell for several minutes to hours. In many units, the disinfect cycle is started at the end of the day, so the dwell period occurs overnight. There is a mandatory rinse cycle afterwards, and the technician should then check that no residual disinfectant is in the dialysate (generally using a simple dipstick test). Some machines can also perform a heat disinfect cycle, which heats water in the tubing for several hours to destroy any bacterial contaminants. In machines that are capable of both chemical and heat disinfection, alternating weekly is recommended.

Water Treatment System

A well-maintained water treatment system is essential to provide a safe hemodialysis treatment. The patient is exposed to roughly 20 gallons (76 L) of water in an average dialysis treatment, so even trace amounts of impurities can have detrimental effects.[4–6] Water treatment systems vary in size and water output, from a small portable unit that fits on the back of a dialysis machine to an entire room full of equipment that provides water for up to 30 dialysis machines (**Fig. 4**), but they all have certain common features. A typical system contains a hot and cold water mixing valve, a sediment filter (to remove debris), an ion exchange tank (to remove calcium and magnesium), carbon tanks (to remove organic components), and a reverse osmosis or deionization filter (to remove any remaining contaminants and ions). Daily monitoring of the product water is required to ensure patient safety. The technician performing the hemodialysis treatment generally performs this task. The water treatment system is so essential to performing a safe hemodialysis treatment that it

Fig. 4. Example of a water treatment system.

is highly recommended to have a backup system that can be placed in-line almost immediately.

Newer dialysis machines are capable of producing "ultrapure" dialysate. The dialysate made from purified water is filtered through a special membrane before it is passed into the dialyzer. Water and electrolytes are able to pass through the membrane, but any bacterial contaminants are excluded. The ultrapure dialysate is then delivered to the dialyzer that contains the patient's blood. Ultrapure dialysate is thought to decrease systemic inflammation that can occur when patients are exposed to small amounts of endotoxins present in dialysate; however, this has not yet been proved.[7]

On every day that dialysis is performed, the water treatment system needs to be checked to ensure proper performance. Inadequate water treatment can expose the patient to harmful contaminants in the water. The specific testing necessary depends on the unit. In addition to daily monitoring, scheduled weekly or biweekly cultures of water and dialysate should be performed for surveillance of bacterial contamination, and water samples should be analyzed biannually for chemical composition to ensure safe levels of various other compounds (heavy metals, nitrates, and so forth).

CONTINUOUS RENAL REPLACEMENT THERAPY MACHINES

Most veterinarians in the United States who offer CRRT use one of the Gambro machines, either the older Prisma (**Fig. 5**), or the newer PrismaFlex (**Fig. 6**). Although the basic premise of clearance across a semipermeable membrane housed in a dialyzer is the same with intermittent and continuous dialysis, the machines used have several key features that differ. The Gambro CRRT machines, like the IHD machines, use a dialyzer (frequently referred to as a hemofilter) and tubing incorporated into a cartridge system that easily snaps onto the machine for easy set-up.

CRRT involves a much slower dialysate flow rate than IHD. Rather than having the CRRT machine create dialysate from purified water and an electrolyte concentrate, CRRT uses prepared sterile dialysate, which is prepackaged in bags similar to intravenous fluids. Several formulations are available with different components or concentrations, such as potassium-free or calcium-free, to allow prescriptions to be tailored to the individual patient's needs. The sodium concentration cannot be varied during treatment as it can with IHD. It is possible to modify intravenous fluid solutions to

Fig. 5. Gambro Prisma CRRT machine.

function as dialysate, although this introduces more chances for formulation errors and bacterial contamination. The Prisma machine dialysate flow rate varies from 0 to 2500 mL/h in 50-mL increments; the PrismaFlex can deliver up to 8000 mL/h.

While both IHD and CRRT use diffusive and convective clearance, CRRT uses convective clearance to a greater degree than IHD. The fluid removal rate to control overhydration is prescribed based on the patient's volume status and the excess fluid is removed by ultrafiltration. Ultrafiltration rates range from 0 to 1000 mL/h in 10-mL increments with the Prisma, and up to 2000 mL/h with the PrismaFlex. While both IHD and CRRT use diffusive and convective clearance, CRRT uses convective clearance to a greater degree than IHD. By employing additional fluid removal, plasma fluid and small to moderately sized molecules (eg, urea) are drawn out of the blood and discarded, a process called convective clearance. This fluid is then replaced with

Fig. 6. Gambro PrismaFlex CRRT machine. (*Courtesy of* Mary Anna Labato, Tufts University, North Grafton, MA.)

a balanced electrolyte solution. The dialysis technician sets the replacement fluid rate; the CRRT machine then simultaneously removes fluid from the patient via the effluent pump and replaces the same volume of fluid via the replacement fluid pump. Replacement fluid rates range from 0 to 4500 mL/h in 100-mL increments for the Prisma, and up to 8000 mL/h with the PrismaFlex. The dialysis technician sets the replacement fluid rate; the CRRT machine then simultaneously removes fluid from the patient via the effluent pump and replaces the same volume of fluid via the replacement fluid pump. Replacement fluid rates range from 0 to 4500 mL/h in 100-mL increments for the Prisma, and up to 8000 mL/h with the PrismaFlex.

The Gambro Prisma and PrismaFlex systems determine these various fluid rates by weight. The bags of dialysate, replacement fluid, and effluent (the combined spent dialysate and ultrafiltrate from patient fluid removal and fluid used for convective clearance) are placed on scales built into the machine. Excessive motion of the machine will cause the bags to sway, interfering with accurate weight measurement and thus causing a machine alarm until the problem is corrected. The total rate of effluent production that is possible with the Prisma machine is 5500 mL/h, compared with 10 L/h with the PrismaFlex.

Because CRRT is intended to be provided over a longer treatment period (ie, 24 hours a day compared with 4–5 hours a day for IHD), a slower blood flow rate is generally selected. In addition, clearance with CRRT is influenced more by effluent rate than by blood flow rate, making a rapid blood flow rate unnecessary in most cases. The

Prisma machine can provide a blood flow rate from 10 to 180 mL/min in 5-mL increments. The PrismaFlex machine provides a blood flow rate from 10 to 450 mL/min in 10-mL increments.

Both the Prisma and PrismaFlex have an incorporated syringe pump to allow infusion of heparin. The PrismaFlex has an additional pump system to allow infusion of an additional fluid if desired. Attachments to externally warm the bloodlines are available for both machines.

Because the CRRT machines do not prepare dialysate, there is no need for internal conductivity meters. At the end of treatment, all of the fluid bags and blood lines are discarded, so there is no need for disinfecting or cleaning cycles for CRRT machines. The scales should be calibrated by the dialysis technician on a scheduled basis.

Therapeutic plasma exchange cartridges are available for the Prisma and PrismaFlex. Charcoal hemoperfusion cartridges are available for the PrismaFlex.

ANCILLARY EQUIPMENT

Patients undergoing IHD require a significant amount of monitoring in the course of a treatment. One device specifically used during hemodialysis treatments is the Crit-Line in-line hematocrit monitor (CLM III TQA; Hema Metrics, Kaysville, UT, USA). This monitor measures real-time hematocrit, venous oxygen saturation, and percent change in blood volume (**Fig. 7**). A sterile, disposable Crit-Line blood chamber is placed in the patient's extracorporeal circuit during priming (**Fig. 8**). This chamber fills with the patient's blood during treatment, and an optical sensor placed on the chamber reads the hematocrit of the blood as it flows through the chamber and detects changes instantaneously. While it is useful to know the patient's hematocrit throughout the treatment, the real value of this is the ability to concurrently appreciate changes in the patient's intravascular volume. Presuming there is no ongoing bleeding or transfusion, any changes in hematocrit reflect changes in intravascular volume. A rapid decrease in intravascular volume (10% per hour) from an excessively rapid ultrafiltration rate may precipitate symptomatic hypotension.

The Crit-Line also monitors the oxygen saturation (SvO_2) of the blood in the extracorporeal circuit, which is considered mixed venous blood. SvO_2 is the balance between oxygen delivery and oxygen consumption (metabolic rate). Mixed venous oxygen saturation is affected by cardiac output, blood pressure, oxygenation, and hemoglobin. An SvO_2 of more than 70% is considered normal, however, many patients with values around 50% show no noticeable ill effects during IHD treatments.[8] A significant decrease in SvO_2 may be an indicator of an impending hypotensive episode. The ability to see changes in blood volume and predict a hypotensive

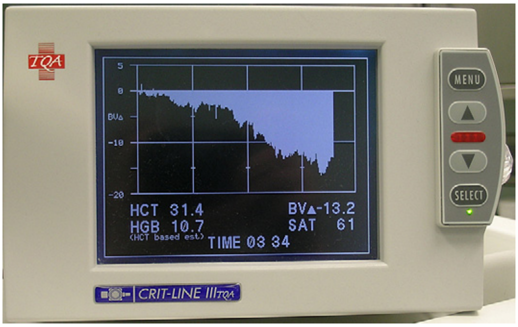

Fig. 7. Crit-Line Blood Volume Monitor.

Fig. 8. A Crit-Line blood chamber (*left*) and the Crit-Line sensor (*right*) that is attached to the blood chamber to detect hemoglobin and oxygen saturation.

episode is important because it is sometimes necessary to remove large volumes of extra fluid from a patient. The Crit-Line monitor has become a valuable tool in helping to assess how quickly and how much fluid can safely be removed.

The Crit-Line monitor can be used to measure access recirculation in dialysis catheters by sequential injections of a small volume of saline into the extracorporeal circuit.[9] Access recirculation is the reuptake of blood into the arterial lumen that has just been returned through the venous lumen (ie, reuptake of clean blood). Recirculation will decrease the efficiency of the dialysis treatment, so it is important that it be monitored. An increase in the measured amount of recirculation over several treatments is also an indication that the access is beginning to fail, so early detection will help guide intervention. An additional function of the Crit-Line monitor in human hemodialysis patients is to measure access recirculation in arteriovenous fistulas and grafts. In veterinary medicine, catheters are used almost exclusively for vascular access, so this function of the machine is not used.

Another method of monitoring for access recirculation is the Transonics Flow Monitor (Transonics Systems, Ithaca, NY, USA). These machines measure access recirculation in all types of hemodialysis vascular access, and they seem to have a greater sensitivity and more accuracy than the Crit-Line device.[10] The Transonics device can also be used to measure actual, in-line blood flow through the dialysis circuit. At lower blood pump speeds the blood flow should equal the blood pump speed, and therefore the Transonics machine acts as a calibration device. At higher blood pump speeds the actual blood flow will be less than the blood pump speed, therefore knowing the actual blood flow allows for more accurate prediction of the dialysis treatment efficacy. Some of the newer hemodialysis machines have built-in sensors to measure actual blood flow.

Blood pressure monitors are a very important monitoring tool in hemodialysis. Renal failure patients often have blood pressure abnormalities before institution of dialytic therapy. Dialysis itself involves removing anywhere from 47 to 150 mL of blood from the patient just to fill the extracorporeal circuit, which can lead to a noticeable drop in blood pressure at the start of treatment. Anuric and oliguric patients are often overhydrated and require fluid removal during a dialysis treatment. A fluid removal rate in excess of the rate of intravascular refilling from the interstitium can cause hypotension, therefore blood pressure must be monitored. Noninvasive blood pressure monitors are most commonly used. For cats and small dogs, an Ultrasonic Doppler Monitor (Parks Medical Electronics, Inc, Aloha, OR, USA) works very well. Oscillometric monitors are used on medium- to large-sized patients because they measure diastolic and mean blood pressures. These monitors can also be set to cycle on a regular basis, usually every 15 minutes. In a dialysis unit, it is essential to have access to one blood pressure machine for each dialysis machine because every patient on dialysis will require frequent blood pressure monitoring.

When patients undergo IHD, their blood is removed from their bodies and run through an extracorporeal circuit. The blood is exposed to foreign material that may activate the clotting cascade. Therefore, anticoagulant therapy is often required during a dialysis treatment, and equipment is necessary for monitoring the level of anticoagulation. The most common anticoagulant used in veterinary IHD is unfractionated heparin. Previously, the most practical method of measuring the level of anticoagulation was to measure activated clotting time (ACT), generally accomplished using an ACT II monitor (Medtronic, Minneapolis, MN, USA; **Fig. 9**). The sample required is fresh whole blood, and sampling is done anywhere from 15 to 60 minutes apart, so it is essential to have at least one dedicated ACT machine for the dialysis unit. If newer cage-side anticoagulation monitors are validated for measuring partial thromboplastin time on whole blood, they may supplant ACT measurement.

Another method of anticoagulation is regional anticoagulation with citrate. Citrate is infused into the patient's blood as it enters the extracorporeal circuit, and chelates calcium in the blood rendering it incapable of clotting. To prevent the patient from becoming hypocalcemic, calcium is restored as an infusion. Citrate is not used as often in IHD as in continuous therapies, but it may be useful in certain patients. When using citrate regional anticoagulation, the level of anticoagulation is assessed by measuring the ionized calcium concentration in the extracorporeal circuit. The patient's ionized calcium is also measured to ensure proper infusion rates. Once in the body, citrate is converted into bicarbonate; therefore, a chemistry analyzer capable of measuring both ionized calcium and pH becomes essential. Most specialty veterinary practices will have at least one in-house analyzer that runs ionized calcium, so it might not be absolutely necessary to install a separate one in the dialysis unit. However, this increases the personnel needs because then a second person must be available at times to take the blood sample to the machine to run the ionized calcium. Handheld analyzers, such as the iStat (Abaxis, Union City, CA, USA), are convenient because they can be moved to the dialysis treatment area when necessary, and they are a quick method of performing the needed assays (**Fig. 10**).

Even with a handheld chemistry analyzer, it is useful to have a tabletop analyzer. The level of azotemia is evaluated often in hemodialysis patients, and it useful to evaluate individual blood urea nitrogen and creatinine concentrations. Tabletop analyzers

Fig. 9. ACT II monitor to measure activated clotting time.

Fig. 10. iStat Handheld chemistry monitor.

usually offer more flexibility in choosing exactly which chemistries to run, as opposed to handheld monitors that run only predetermined panels.

One additional piece of equipment that should not be overlooked is a heat source. Patients undergoing IHD tend to be hypothermic due to their azotemia and hypotension. These patients tend to lose some heat in the blood tubing because their blood is exposed to room air. The temperature of the dialysate can be adjusted so that the patient's blood can be warmed (or cooled) as it passes through the dialyzer, but because IHD machines are manufactured solely for human use, the temperature range is such that animal blood is often cooled even at the highest temperature setting. Circulating water heating pads provide some heat, but to combat the cooling effects of the dialysate, the patient needs to be surrounded by heat. A second pad could be placed over the patient, or a heat lamp could be placed on the patient. A method that has proven effective in the authors' unit is to use a hot air machine (Bair Hugger, Augustine Medical, Eden Prairie, MN, USA) to create a microenvironment that is much warmer than the surrounding room (**Fig. 11**). As with anesthetized patients, small and obtunded patients undergoing IHD can lose a significant amount of body heat if not properly monitored.

Fig. 11. Bair Hugger warm air heater.

Bioimpedance analyzers are used in human medicine to measure total body fat and water. The distribution of water is of importance when trying to remove fluid from a hemodialysis patient. Extra water can only be removed from the vascular space, so an overhydrated patient can become hypotensive if the extra water is not distributed appropriately. Patients can also become hypotensive if too much water is removed from the entire body and they become dehydrated. Bioimpedance analyzers help the clinician determine if a patient is becoming hypotensive because the vascular space is not refilling or because the patient truly is no longer overhydrated. These analyzers are expensive and are not manufactured for veterinary patients, so their use in veterinary hemodialysis is still being studied.

SUMMARY

There are several different machines available for the performance of renal replacement therapy in veterinary medicine. Extracorporeal renal replacement therapies (IHD and CRRT) involve dedicated personnel who are familiar with the operations and maintenance of the equipment. The availability of such equipment has resulted in the ability to treat both acute kidney injury and chronic kidney disease.

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