Veterinary Dialysis Handbook

Extracorporeal Renal Replacement Therapies: Intermittent Hemodialysis and Continuous Renal Replacement Therapy

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Introduction

This handbook is intended to help guide you through treating a patient with an extracorporeal blood purification technique. Most of these patients will have renal disease, but the technique can be used to treat certain toxicities and other conditions. It is written specifically for The Animal Medical Center, and includes practices and details that are specific to AMC, but I have tried to include other information for completeness.

In addition to guidelines on treating the patient, this handbook will also serve as a guide for the database program used to record patient data.

This handbook is not intended to be the only resource you use, and does not cover many of the components of RRT that are necessary to understand to provide the optimal care of our patients. The bibliography at the end of the handbook points out some excellent references on these topics. The author of this handbook presupposes the reader is using this handbook only as a memory aid, after suitable study of the source material and hands-on training.

This handbook is not intended to replace standard daily consultation with the nephrologist about case management.

Acknowledgements

A large part of the content of this handbook has been taken from a chapter to be published in a Nephrology and Urology of Small Animals (eds: Polzin D, Bartges J, 2010). I could not have done all this without the efforts of the entire AMC dialysis team.

Disclaimer

You should not attempt to set up and use the Phoenix or CentrySystem 3 intermittent hemodialysis machine unless you have specifically been trained in their operation. This information is provided here for those trained technicians to have all of the procedural information in one convenient manual.
Chapter 1  Does This Patient Have Renal Failure?

If you are a doctor and you are unable to answer this question without the aid of this handbook, you are not qualified to perform any form of ERRT. Put the book down and call for help.

However, since I intend for this handbook to be useful to the entire healthcare team, of which doctors are only one small segment, allow me to elaborate on renal function. The kidneys serve many roles in the body. It is one of the main organs for eliminating wastes from the body, by filtering the waste products (which include by-products of normal metabolism, substances ingested in food or drink, drugs, and other toxins) from the blood stream and concentrating them in the urine for elimination. The kidneys are also critical in maintaining homeostasis, by controlling water balance, electrolytes, and acid-base status. The kidneys provide the main long-term control of blood pressure. The kidneys also produce a number of hormones, including erythropoietin, calcitriol, renin, and others.

The most common way of measuring renal function involves measuring blood creatinine and urea concentrations. There are hundreds of other substances that are present in elevated concentrations in renal failure. BUN and creatinine are convenient to measure because they are present in easily measured concentrations, although neither is highly toxic on its own. Renal function must be less than 25% of normal before BUN and creatinine are elevated. BUN can be affected by diet, GI bleeding, and dehydration, whereas creatinine is less affected by non-renal issues.

Measurement of the glomerular filtration rate is a more accurate measure of renal function compared to BUN or creatinine. With severe renal failure (such as that requiring RRT), creatinine is a sufficient measure, and GFR measurements are not commonly performed.

Urine production is necessary for renal function, but the presence of urine does not equate to normal renal function. Although going from anuric (no urine production) or oliguric (decreased urine production) to non-oliguric is a sign of some degree of renal recovery, it does not automatically mean that renal function will return to normal. In many patients, once they start making urine, they will progress to polyuria (large urine volume), and gradually the BUN and creatinine will return to normal if the kidneys recover. Some patients are making a large volume of urine, but not excreting the uremic toxins as they should, and need dialysis despite the urine production.

Dialysis, whether intracorporeal (peritoneal) or extracorporeal (IHD or CRRT) replaces the excretory functions, and helps maintain fluid, acid-base, and electrolyte homeostasis. It does not replace the hormonal functions of the kidney.

Figure 1-1. Relationship between GFR and serum creatinine
Chapter 2  Does This Patient Need RRT?

Acute Kidney Injury

Acute Kidney Injury (AKI) ranges from mild injury that is not discernable with commonly available tests to fulminant anuria. Although RRT may be started in humans after a known renal insult (such as radiocontrast administration) prior to the onset of azotemia, in veterinary medicine, almost all patients treated with RRT for AKI are azotemic. The level of azotemia may be mild, however.

Urine Volume

Urine volume may be decreased or absent due to prerenal causes (appropriate water conservation) or post-renal causes (obstruction, leaks). Both should be corrected prior to considering RRT. Pre-renal azotemia may occur not only from dehydration, but also from poor renal perfusion. Systolic blood pressure should be above 80 mmHg, or mean arterial pressure above 60 mmHg, to ensure adequate renal perfusion.

If the decrease in urine volume is due to intrinsic renal failure, appropriate medical management should be used, including ensuring adequate volume expansion. If the patient appears hydrated, an IV dose of fluid equal to 5% of body weight should be given for undetectable dehydration. Diuretics have not been shown to improve outcome, but there is speculation that patients that can respond to diuretics by increasing urine output have less severe renal damage. Previously, it was standard procedure to treat with at least one diuretic before determining if a veterinary patient should be treated with RRT, but it is not an obligation. Mannitol and/or furosemide are commonly used; IV diltiazem is rarely used, and dopamine is not useful for oliguria. The role of fenoldopam is yet to be determined.

If optimizing volume status and blood pressure (and potentially the use of diuretics) do not cause adequate urine production, RRT may be helpful. In addition to absolute anuria (urine output < 0.08 ml/kg/hr) or oliguria (< 0.5 ml/kg/hr), relative oliguria is a potential reason for RRT. Relative oliguria is a condition in which urine output is ≥ 0.5 ml/kg/hr, but does not increase in response to volume loading. Continued fluid diuresis in this setting will lead to volume overload. RRT is also appropriate with polyuria, if azotemia or other signs of uremia do not improve.

The determination of urine output can generally be made within a few hours of admission. If adequate urine production is not established, RRT should be started before further sequelae appear.

Volume Overload

Life-threatening volume overload can develop in oligoanuric patients or in patients with a relative oliguria. Pulmonary edema can develop in overhydrated patients. In the absence of urine production, the body has very limited methods of removing excess pulmonary water. Although venodilators may decrease the respiratory compromise modestly, this is not an adequate therapeutic maneuver. RRT would be indicated in that setting. Pleural effusion is more effectively treated with thoracocentesis, but can be partially controlled with RRT. Other manifestations of volume overload that are not life-threatening, such as peripheral edema, are relative indications for RRT, but close control of volume status in the patient with relative oliguria may allow resolution without RRT.

Hyperkalemia

Anuric or oliguric patients, patients with severe renal impairment, and patients receiving overly aggressive potassium supplementation are at risk of hyperkalemia. Emergency treatment (i.e., insulin,
dextrose, bicarbonate, calcium, albuterol) will provide temporary relief. If urine production cannot be established, RRT is indicated.

**Azotemia**
Progressive azotemia or azotemia that does not resolve is an indication for RRT. Urine output in patients with AKI can range from anuric to massively polyuric. In cases with non-oliguric or polyuric renal failure (urine output ≥ 2 ml/kg/hr), azotemia may still fail to improve or may even progress. In those settings, RRT is indicated to prevent or control uremic symptoms. Although the underlying etiology and potential for rapid reversal play a role in the decision to start RRT, in general, rapid progression over 6-12 hours would prompt RRT, as would failure to improve over 24 hours.

**Patient Considerations**
RRT involves prolonged and intimate contact with the patient. It would be unsafe for both the patient and technician to treat an aggressive patient with RRT. Repositioning of the catheter and/or patient for continuous blood flow is frequently necessary, and the inability to handle the patient can lead to catastrophic clotting of the extracorporeal circuit. Sedation for 4-5 hours daily for IHD or 24 hrs/day for CRRT is likely counterproductive to recovery, but has been used in select cases.

**Patient Size**
Suitable patients should weigh at least 2.5 kg. The smallest volume of extracorporeal circuit is 45 ml with CRRT (using the now discontinued M10 and the older Prisma model machine) and 70 ml with IHD. Treatment of a patient smaller than 2.5 kg would require priming the circuit with blood from the blood bank. There are only limited situations in which I would treat a patient smaller than 2.5 kg.

**Patient Blood Pressure**
Because of the volume of the extracorporeal circuit, starting RRT will cause a decrease in blood pressure. If that pressure is marginal to begin with, that decrease may precipitate a fatal crisis. Peritoneal dialysis would be the choice if systolic blood pressure cannot be maintained at 80 mmHg or above with or without pressor agents.

<table>
<thead>
<tr>
<th><strong>Box 2-1. Indications for RRT</strong></th>
<th><strong>Box 2-2. Patient Characteristics</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadequate urine production</td>
<td>≥ 2.5 kg</td>
</tr>
<tr>
<td>Life-threatening pulmonary edema</td>
<td>systolic BP ≥ 80 mmHg</td>
</tr>
<tr>
<td>Hyperkalemia</td>
<td>tractable</td>
</tr>
<tr>
<td>Progressive/unremitting azotemia</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2-1. Algorithm to help determine if ERRT is indicated
Figure 2-2. Algorithm to determine if ERRT is indicated, including diuretics for oliguria
Chronic Kidney Disease

The decision to start chronic dialysis is entirely different than the decision to start acute RRT. However, it is not uncommon for patients with end-stage CKD to present in an acute uremic crisis, without prior consultation with the nephrologist. In this setting, RRT decisions frequently need to be made rapidly due to the unstable condition of the patient, and treatment progresses similar to treatment for AKI until the crisis is stabilized.

Indications for controlled initiation of chronic dialysis center on failure of medical management to control uremic symptoms, which include vomiting, nausea, anorexia, weakness, etc. If anorexia is essentially the only sign, placement of a feeding tube may control malnutrition with much less invasiveness than dialysis. Patients with a creatinine of < 5 mg/dl are unlikely to have sufficient benefit from chronic dialysis to make it worth pursuing.
Chapter 3  What Form of RRT Is Best for This Patient?

Terminology
Renal replacement therapies (RRT) include dialysis and transplantation. Dialytic therapies include peritoneal dialysis, an intracorporeal technique, and extracorporeal renal replacement therapies (ERRT), which include intermittent and continuous hemodialysis. The principles of intermittent and continuous therapies are the same, but there are practical differences between the techniques. In this handbook, the term dialysis is used to indicate peritoneal dialysis (PD), intermittent hemodialysis (IHD) and continuous renal replacement therapy (CRRT), and the term extracorporeal renal replacement therapy (ERRT) is used to include intermittent and continuous hemodialysis therapies. Additionally, we commonly use a hybrid form, which we call prolonged intermittent renal replacement therapy, or PIRRT. This is essentially the same as sustained low efficiency dialysis (SLED).

ERRT
IHD and CRRT are closely related techniques, and one is not superior to the other. They each have different strengths and weaknesses, however, which we want to utilize since we have both therapies available.

In general, IHD is faster and more efficient at clearing small solutes, such as urea, potassium, and some toxins like ethylene glycol. If rapid metabolic control is desired, IHD is superior. If removal of a large amount of uremic toxics in a short period of time is desired, IHD is superior.

In the initial treatment of AKI, rapid urea clearance may not be desired. Rapid shifts of potentially osmotically active agents (i.e., urea, sodium) can lead to dialysis disequilibrium syndrome (DDS). Urea can be an effective osmole when high concentrations are cleared quickly with IHD and there is insufficient time to equilibrate. In severely azotemic patients or small patients with moderate azotemia, PIRRT or CRRT has theoretical advantages to decrease the risk of DDS, because uremic toxin removal is more gradual. If the patient is massively volume overloaded, it may be difficult to remove the surplus fluid in a short period of time without inducing hypotension; PIRRT or CRRT would be advantageous in that setting. In people, CRRT was preferred over IHD in hemodynamically unstable patients, but recent evidence has failed to show superiority of one modality over another.

Another factor in deciding between IHD and CRRT involves availability of personnel. There is a limited pool of people trained for IHD, and if they are not available, we can use PIRRT or CRRT until IHD is available. On the other hand, because CRRT involves full-time monitoring 24 hours a day, if IHD is available and appropriate, it is far more cost and labor efficient.

It is my anticipation that CRRT will be used for up to 72 hours, by which point I am hopeful that the majority of patients will be stable enough to transition to IHD, thus alleviating the demands of 24 hour nursing care.

Peritoneal Dialysis
Peritoneal dialysis is another option that we can offer. For AKI, it will require 24 hour nursing (and cost about the same as CRRT). Because of complications associated with PD (catheter occlusion, difficulty in controlling fluid balance, inefficient control of uremia), it is unlikely that PD would be preferred over CRRT or IHD except in certain situations. One of those includes uroabdomen, in which a peritoneal catheter will be placed and maintained anyway. In most of those situations, the azotemia will resolve simply by draining the urine from the abdomen, but I would not be opposed to a few dialysate exchanges if the azotemia is slow to resolve.
The most likely reason for us to choose PD would be a patient that is too hemodynamically unstable even for CRRT. In that setting, it would be prudent to counsel the owner about the high probability of a poor outcome despite a high cost. PD might be an acceptable option for the extraordinarily small patient (< 2 kg).

Renal Transplantation

The outcome of renal transplantation in cats is quite remarkable (80% perioperative survival, over 60% 6 month survival, and about 40% 3 year survival), but it takes about 2-4 weeks to schedule the surgery. Lifelong medication is necessary with transplantation, so I would always give a cat at least 4 weeks to recover from an acute insult before deciding to transplant. The exception to that is with a severe nephrotoxic insult, with slim hope of recovery of renal function. In cats with CKD and acute decompensation, ERRT can be used both to sustain the cat and to diminish uremia while planning the transplant surgery. In some cases, we will perform 2-4 dialysis treatments immediately prior to transplant to decrease anesthetic and perioperative risk, but those cases are generally very tightly coordinated between the transplant surgeon and dialysis nephrologist directly (i.e., call me before you admit that case to the hospital!)

Because of the immunosuppression associated with transplantation, hypervigilance in regards to infection control is mandatory in any patient undergoing ERRT or PD that may be a transplant candidate. This is especially important in regards to dialysis or other IV catheter placement. Because of the high rate of PD catheter infection, PD prior to transplantation is discouraged, as is urinary catheter placement.

There are no facilities that routinely offer canine renal transplantation.

Ureteral Obstruction

Ureteral obstruction is a common cause for acute uremic syndrome in cats. ERRT is one method of controlling uremia to stabilize the cat for further diagnostics and surgery. Another option is placement of a percutaneous nephropyleostomy tube. Theoretically, this can be placed with a short anesthesia and ultrasound or fluoroscopic guidance, but it is more likely to require an open abdominal approach. The renal pelvis must be dilated to at least 1 cm, which corresponds to about grade 3-4 (extending to or past the corticomedullary junction) in cats. If the azotemia is purely post-renal, the azotemia should resolve in short order, making ERRT unnecessary in those cases. However, some of those cases have suffered intrinsic renal failure as a result of the obstruction, in which case, ERRT may be indicated. Our IR team is not likely to place a nephrostomy tube, because placing a subcutaneous ureteral bypass (SUB) takes only marginally more surgery time, and avoids the need for a second surgery a few days later for the definitive procedure. Some hospitals routinely perform emergency surgery on unstable cases in preference to RRT, even when RRT is available.
Chapter 4  What Does The Primary Veterinarian and Pet Owner Need To Know?

Undertaking RRT is a big commitment for the owner and the health care team. On the surface, withholding optimal medical care (i.e. RRT) for a patient with severe acute renal failure may seem unethical, but embarking on a major medical course with unrealistic expectations will lead only to disappointment for all involved parties.

The survival rate for dogs and cats with AKI treated with dialysis is approximately 50%. This statistic includes patients who survive the initial insult, but are later euthanized due to failure to recover adequate renal function for discontinuation of dialysis. Etiology of AKI has a large impact on outcome. RRT patients with obstructive and infectious etiologies may have as high as a 90% probability of survival, whereas some patients with toxic etiologies (particularly ethylene glycol or lily intoxication) have only a 20% chance of survival. The impact of etiology on outcome should not be overstated, as even in the toxic category of AKI, prognosis varies; 100% of RRT patients with AKI secondary to raisin ingestion have survived (statistic obtained from the Animal Medical Center’s database).

It is important to understand that this survival rate may appear dismal, but is actually quite similar to the survival rates achieved in human medicine. The silver lining is that our patients’ prognoses are likely to improve substantially when treatment can be initiated early in the course of illness, prior to the onset of severe uremic complications. Therefore, it is essential to inform owners who are interested in pursuing RRT that the earlier treatment can be initiated, the higher likelihood of a positive outcome.

Some patients will show definite signs of recovery within a week, and we expect the majority of patients to show renal recovery within 3-4 weeks. The client should be committed emotionally and financially to at least 2 weeks of therapy. If there are no signs of renal recovery after 2 to 3 weeks of treatment, the likelihood of sufficient recovery to allow for eventual discontinuation of RRT fades. Many patients will not look noticeably improved after their first 1 to 2 treatments, despite normalization of acid-base and electrolyte abnormalities but by day 3 to 5 of treatment, we expect a noticeable improvement in clinical status. In the few hours immediately after a RRT treatment, patients may appear weak and/or sedated, due to acute intravascular volume shifts associated with the rapid return of blood from the extracorporeal circuit.

Complications of treatment include adverse cardiac and respiratory events associated with anesthesia for catheter placement, bleeding due to systemic administration of anticoagulant during each RRT treatment, thrombosis of the vena cava due to the indwelling dialysis catheter, dialysis disequilibrium syndrome (neurologic sequela associated with the first few treatments in cases of severe azotemia), hypotension, failure of renal recovery, and sudden death. Additional risks of which the owner must be informed include those associated with the administration of human erythropoiesis stimulating agents (necessary in most cases of RRT, both acute and chronic), and respiratory complications associated with the underlying disease (acute lung injury or acute respiratory distress syndrome, pulmonary thromboembolism, pulmonary edema and pleural effusion in cases of oligoanuria). It is important that the owner not be overwhelmed by the number and severity of complications associated with RRT as this therapy is usually undertaken as a life-saving measure, and the potential complications that accompany withholding treatment are much more likely to result in an undesirable outcome.
Most patients will be hospitalized for a minimum of 1 to 2 weeks. However, once the patient is stabilized, outpatient RRT can be performed, provided the owner is able to transport the patient to the dialysis facility 3 days a week, and the patient can remain at the facility for the majority of the day. If there are no signs of improvement after 4 weeks, it may be prudent to discuss revising expectations for renal recovery and transitioning to chronic RRT. For many owners, chronic RRT is not an option, due to financial, logistical, and emotional limitations. For situations in which there is a perceived potential for renal recovery and 3 to 4 weeks have passed from the time of the initial renal insult, a kidney biopsy (evaluated by a nephropathologist) may provide additional prognostic insight.

Any form of RRT is going to be intensive and, therefore, expensive. Costs of RRT exceed $3,000 within the first 24 hours and hospital costs (including RRT) are approximately $10,000 to $12,000 during the first week. The overall estimate for RRT is approximately $20,000 for the first 2 weeks. The costs associated with the subsequent weeks of treatment are highly dependent on whether the patient is treated on an inpatient or outpatient basis and whether the patient is experiencing any complications of AKI that cannot be controlled with RRT.
Methods of Clearance

Diffusion
Diffusion is defined as the movement of particles from an area of higher concentration to an area of lower concentration. Particles in solution have kinetic energy causing movement, and smaller particles tend to have more movement than larger particles. If two identical solutions are separated by a membrane that is permeable to a substance, individual particles may cross the membrane in either direction, and although the individual particle on either side of the membrane may change, there is no net change in the concentration of particles. If, however, the concentration on one side is lower, there will be net diffusion from the higher concentration to the lower concentration. Over time, the two solutions will equilibrate to the same concentration on both sides. The higher the concentration gradient between the two sides, the faster the rate of diffusion. With dialytic therapies (including extracorporeal and peritoneal), the solution on one side of the membrane is the blood, and dialysate is the solution on the other side of the membrane. By constant replenishment of the dialysate, a large concentration gradient is maintained and equilibrium is never reached, so diffusive clearance continues. Extracorporeal therapies have a constant dialysate flow, although the rate of dialysate flow generally varies dramatically between intermittent and continuous therapies. Extremely fast dialysate flow rates maximize diffusive clearance, and flow rates of 300-800 ml/min are typical with intermittent hemodialysis (usually 500 ml/min). Continuous therapies in a diffusive clearance mode typically use lower dialysate flow rates (1.5 to 133 ml/min). Peritoneal dialysis involves instillation of a discrete volume of dialysate that is periodically removed and replaced with fresh dialysate. During the dwell time, diffusion occurs. Equilibrium may be reached with longer dwell times, but short dwell times (1-2 hours) used in treating acute renal failure do not allow equilibrium to be reached. Because the majority of diffusion occurs when the concentration gradient is highest, frequent exchanges increase the overall uremic toxin removal.

Ultrafiltration
Although we are composed of approximately 60% water and could not live without it, water can be considered a “uremic toxin” that needs to be removed in the oliguric renal failure patient. Diuretics may be ineffective in this patient population, leaving ultrafiltration (UF) as the only effective means of removing fluid. As opposed to diffusion, in which a concentration gradient causes solute movement, ultrafiltration involves a hydrostatic pressure gradient to cause water movement. By creating negative pressure on the side opposite the blood compartment, water is “pulled” out of the blood. The water removed in this fashion is termed ultrafiltrate in IHD and is part of the effluent in CRRT. Different dialyzers have different hydraulic permeability characteristics, termed the coefficient of ultrafiltration (KUF). KUF is the number of milliliters of fluid transferred across the membrane per hour when 1 mmHg of transmembrane pressure is applied. With a higher KUF, less of a pressure gradient is needed to remove fluid. With machines used today, the transmembrane pressure is automatically controlled by the dialysis machine to achieve the desired fluid removal in the time specified. With peritoneal dialysis, ultrafiltration is achieved using an osmotic gradient (created by adding dextrose to the dialysate) instead of a hydrostatic pressure gradient.
**Convection**

Convective clearance removes solutes by removing the water in which they are dissolved, a process that is also called solute drag. Middle molecules (compounds with a molecular weight of 500 to 5000 daltons) are more efficiently cleared with convection compared to diffusion, whereas diffusion is a very efficient method of removing small molecules (e.g., urea, creatinine, sodium). The term hemofiltration indicates using convective clearance for uremic toxin removal, whereas the term hemodialysis indicates using diffusive clearance. When ultrafiltration is used for net fluid removal, convective clearance will occur. If a larger degree of convective clearance is desired, the ultrafiltration rate can be increased dramatically (up to 35 ml/kg/hr or higher), with administration of intravenous fluids (replacement fluid) to avoid volume depletion.

**Absorption**

Certain substances, like cytokines, will bind to the dialyzer membrane, and thus can be removed from the circulation. The adsorptive capacity of the dialysis membrane is limited, with saturation occurring after about 30 minutes to 2 hours, making this an ineffective method of removal. Charcoal and other hemoperfusion techniques are better suited for significant adsorption.

**Overview of Adequacy**

Prescribing the dialysis dose requires an ability to predict the adequacy of treatment. The most commonly used measure of clearance in veterinary hemodialysis is the urea reduction ratio (URR), which can be calculated by the formula: \( \frac{\text{pre-treatment BUN} - \text{post-treatment BUN}}{\text{pre-treatment BUN}} \). The most commonly used measure of dialysis dose in humans is \( \text{Kt/V} \), a dimensionless unit of measurement that incorporates the dialyzer clearance, time on dialysis, and volume of distribution. The adequacy of dialysis is discussed more fully in Chapter 16 Adequacy.

\[
\text{URR} = \frac{(\text{BUN pre} - \text{BUN post})}{\text{BUN pre}}
\]

*Equation 5-1. Urea Reduction Ratio*
Chapter 6  What Vascular Access Should I Use?

“The better the access, the more restful your night. Put in the largest access you can manage.”

“Temporary” vs “Permanent” Catheters
Temporary catheters should more precisely be called non-tunnelled, non-cuffed catheters. Depending on type, a temporary catheter may function for up to 4 weeks. In most cases, a temporary catheter will be the appropriate choice, unless there is suspicion of pre-existing CKD and the owners are interested in chronic dialysis if needed. Temporary catheters are placed via Seldinger technique (see below). Because this catheter may need to remain in place for weeks, strict attention to aseptic technique during placement is mandatory. These catheters are generally placed in a clean procedure room with restricted traffic. Caps and masks should be worn by all involved in the procedure. A large barrier drape and sterile gloves are mandatory. Because of the “springiness” of the guidewire, a surgical gown is recommended to decrease the risk of contaminating the guidewire during placement. Permanent catheters generally have a Dacron cuff that is placed in a subcutaneous pocket (cuffed tunneled catheter). These catheters are generally placed with a surgical technique. Ideally, this catheter would be placed in an operating room under fluoroscopic guidance.

![Figure 6-1](image)

In the correct configuration, blood enters the catheter through the proximal lumen and is returned via the distal lumen (Panel A). If the direction of flow is reversed (Panel B), blood returning via the proximal lumen is likely to be recirculated by reuptake at the distal lumen.

Catheter Size.
Poulselle’s Law: $Q_b \propto \frac{(k \times \Delta P \times D^4)}{L \times V}$, where $Q_b$ is blood flow, $k$ is a proportionality constant, $\Delta P$ is the pressure drop, $D$ is catheter diameter, $L$ is catheter length, and $V$ is blood viscosity.

Flow is proportional to the catheter diameter raised to the 4th power, and inversely proportional to length. Thus, very small changes in diameter cause large changes in flow. Because of greater resistance in a longer catheter, the shortest feasible catheter should be chosen.

<table>
<thead>
<tr>
<th>Equation 6-1. Poulselle’s Law</th>
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<tbody>
<tr>
<td>$Q_b \propto \frac{(k \times \Delta P \times D^4)}{L \times V}$</td>
</tr>
</tbody>
</table>
Table 6-1. Common ERRT catheter specifications and approximate blood flow rates*

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Type</th>
<th>Lumens</th>
<th>French Size</th>
<th>Length (cm)</th>
<th>Max Qb (ml/min)</th>
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</thead>
<tbody>
<tr>
<td>†Intracath through the needle</td>
<td>Noncuffed</td>
<td>1</td>
<td>19 ga</td>
<td>30.5</td>
<td>20</td>
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<tr>
<td>†Arrow, 22 ga lumen</td>
<td>Noncuffed</td>
<td>3</td>
<td>5.5</td>
<td>8</td>
<td>30</td>
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<tr>
<td>†Arrow, 20 ga lumen</td>
<td>Noncuffed</td>
<td>3</td>
<td>5.5</td>
<td>8</td>
<td>50</td>
</tr>
<tr>
<td>†Arrow, 22 ga lumen</td>
<td>Noncuffed</td>
<td>3</td>
<td>5.5</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>†Arrow, 20 ga lumen</td>
<td>Noncuffed</td>
<td>3</td>
<td>5.5</td>
<td>13</td>
<td>40</td>
</tr>
<tr>
<td>†Arrow</td>
<td>Noncuffed</td>
<td>2</td>
<td>7</td>
<td>16</td>
<td>55†</td>
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<td>2</td>
<td>7</td>
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<td>2</td>
<td>8</td>
<td>16</td>
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<td>9</td>
<td>15</td>
<td>80‡</td>
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<td>Noncuffed</td>
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<td>11.5</td>
<td>20</td>
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</tr>
<tr>
<td>MedComp</td>
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*Maximum blood flows determined in vitro using canine packed red blood cell solution (29% packed cell volume). Arterial chamber pressure maintained at -250 mmHg or higher. Maximum blood flow rates in vivo may be lower.
‡Maximum blood flow determined in vivo.
†Not designed for dialysis.

Catheter Location

The jugular vein is essentially the only choice that will provide adequate blood flow. The catheter should be able to provide rapid blood flow from both ports. If fluoroscopy is not used during placement, a post-procedure radiograph should be taken. With intermittent hemodialysis, this radiograph is generally taken after the first dialysis treatment, for efficiency sake, but since CRRT may last for days, please have the radiograph taken prior to starting treatment. The tip of the catheter is typically positioned at the junction of the cranial vena cava and right atrium. In some cases, the catheter is placed through the right atrium with the tip resting in the caudal vena cava.

Figure 6-2. Appropriate positioning of hemodialysis catheter, with the distal tip of the catheter positioned at the junction of the cranial vena cava and the right atrium
Sedation/Anesthesia for Catheter Placement

If you are placing a non-tunneled catheter, you may not need sedation. In other situations, some degree of sedation is necessary. For large compliant (or severely depressed) dogs, I might use only a local lidocaine block. For smaller animals or any time I suspect I will need to cut down to the vessel, I frequently use a short acting anesthetic like propofol, but general anesthesia is not necessary. When placing a tunneled catheter, general anesthesia is required. If an esophagostomy tube is being placed, of course general anesthesia with intubation is required.

Figure 6-3. Permanent (tunneled, cuffed) catheter in place. Skin exit site indicated by straight arrow. The catheter is tunneled under the skin (arrowheads), and the point of insertion into the jugular vein is indicated by the curved arrow.

Accessing the Catheter

The dialysis catheter should be handled in an aseptic fashion at all times. See Box 6-3 for instructions on accessing the catheter for dialysis treatments or changing the catheter locking solution. The catheter lock should be changed at least every 3-4 days if dialysis is not being performed. The catheter should not be used for other purposes.
### Box 6-1. Seldinger Technique for Non-tunneled Catheter Placement

- Clip a wide area, including dorsal cervical area.
- Position pet for catheter placement. We usually place the pet in dorsal recumbency with the legs pulled back, which allows preparation of both sides simultaneously, but typically requires generally anesthesia to control patient movement. Lateral recumbency with the front legs pulled back and a bolster (i.e., stack of paper towels) under the neck to expose the jugular vein is also acceptable, and may obviate the need for anesthesia.
- Perform a surgical scrub of the area.
- Place steridrape over site (helps to dry site with sterile gauze first). Extend the coverage with 4 quadrant drapes.
- Fill both lumens of the catheter with heparinized saline (500 units in 250 ml saline, usually in a bowl, although steriley drawn from a bag is tedious but acceptable). Wet the outside of the catheter.
- Prepare the guidewire by retracting the J wire part back into the introducer segment.
- Use an 11 blade to nick the skin over the venipuncture site. Place the introducer needle into the jugular vein. Some prefer placing a small catheter (i.e., Jelco, comes with most catheter kits) into the vessel. Some kits come with a Raullerson bulb. If you choose to use it, place the small plastic bulb on the needle and squeeze it to evacuate the air prior to inserting it under the skin. Once the needle is in the vessel, let go of the bulb and the vacuum will draw blood into the bulb without spilling on your fingers. This was designed to decrease risk of contagious diseases in human procedures.
- If you can’t hit the vessel with the needle, you may need to do a cut down. You may want to put silk or umbilical tape under the vessel to help mobilize, stabilize, and provide hemostasis (in case of mishap).
- With either method, once there is flashback of blood, advance the guidewire through the needle or introducer catheter into the vessel. Frequently you will need to have the front legs moved cranially to allow the wire to cross over the clavicle. Watch the EKG – if you see artifacts, the wire may be “tickling” the myocardium.
- Remove the needle, but be careful not to let the guidewire back out. Apply pressure to avoid excessive bleeding.
- Pass the smaller dilator down the guidewire. Be careful that you do not contaminate the guidewire or allow it to back out. Advance the dilator with a push and twist motion. Hold it as close to parallel to the vessel as possible (i.e., lay the dilator flat against the body). The dilator should go at least halfway.
- Remove the dilator, applying pressure to decrease blood loss, and pass the larger dilator (if present) in the same way.
- Remove the dilator and pass the catheter down the guidewire. Be careful to keep hold of the guidewire and don’t let it advance into the patient as the catheter is advanced.
- Once the catheter is in place, remove the guidewire.
- Check each lumen of the catheter for free flow of blood. Flush with heparinized saline when catheter placement is optimal.
- If a cutdown was needed, close the SQ, then the skin. The method of securing the catheter to the skin varies with model. If a large amount of catheter is outside the body, drape it in a gentle curve over the dorsal cervical region and suture there as well as near the skin exit site.
- Wrap the catheter sufficiently to travel to radiology and back without dislodging.
Box 6-2. Surgical Placement of a Tunneled Cuffed “Permanent” Catheter

“Permanent” catheter placement should ideally occur in an operating room with fluoroscopic guidance, with full barrier precautions (large drape, gown, gloves, cap, mask, etc.)

With the patient under general anesthesia in left lateral recumbency, clip a wide area over the right jugular vein from the angle of the mandible to beyond the thoracic inlet, and from the dorsal midline to past the ventral midline. Pull the pet’s front legs back and secure them to provide optimal exposure of the jugular vein. A rolled towel under the neck helps with positioning. Sterilely prepare the area. Place 250 cc of sterile saline in the bowl and add 500 units of heparin (0.5 cc).

After the drapes have been positioned, make a skin incision over the jugular vein as close to the thoracic inlet as possible. Dissect down to the jugular vein and isolate it with moistened umbilical tape in dogs, with silk in cats. Use the umbilical tape to free some of the fascia off of the vein for a distance of about 2.5 cm. Ligate any tributaries that may be entering the jugular vein in this segment. Preplace (but do not tie) silk ligatures at the most proximal and distal ends of the exposed vessel. Carefully clear all of the fascia off of the vessel, using fine forceps without teeth. Any fascia left on the vessel decreases its expandability and makes it more difficult to pass the catheter. Excessive handling of the vessel can promote vasospasms that make passing the catheter much more difficult. Once the vessel is adequately exposed and cleaned, have an assistant place ¼ to ½ cc of lidocaine on the vessel to decrease vasospasm.

Have an assistant open the catheter pack, being careful to not let the injection caps fall out. Fill both lumens with heparinized saline and close the clamps. To determine where to make the exit site, set the tip of the catheter at the level of the right atrium (roughly at the point of the elbow) and determine where the cuff will lie. The catheter needs to fall in a gentle arch toward the dorsal aspect of the neck, with the ports facing more toward the back of the animal. After determining the exit site, set the catheter aside and make a stab incision in the skin. If necessary, use hemostats to get through the subcutaneous layer. Use the tunneling device to make a subcutaneous tunnel for the catheter. Initially, direct the device toward the head to the angle of the mandible, then direct it back to exit it the skin incision at the jugular vein. Attach the catheter to the device and pull the catheter through the tunnel.

To place the catheter in the vessel, gently grasp the vein with the thumb forceps. Holding an #11 blade almost parallel to the vessel, insert the tip of the blade into the vessel and gently pull the blade up to make a very small incision into the vessel. Have the assistant control hemostasis with the umbilical tape or silk ligatures. Place the tip of the catheter into the lumen of the vessel. At the point where the arterial port starts, the catheter will have to be turned to allow this area to fit into the incision without snagging. The vessel can now be grasped with a moistened gauze sponge at the distal end. Pass the catheter into the vessel with gently steady movements to the predetermined level. In cats particularly, passing the catheter may be a slow process. Once the catheter is in position, check blood flows by aspirating each port with a 12 cc syringe. There should no resistance to flow and no stopping or “stickiness.” If the catheter does not flow well, reposition it and check again. Use intraoperative fluoroscopy to confirm positioning. (If for some reason excellent flows cannot be obtained simultaneously for both ports, make sure the arterial side works well.) Ligate the proximal jugular vein with the preplaced suture. Ligate the distal vein over the catheter to prevent backflow. Tie this suture snugly, but do not compress the lumen of the catheter.

Close the incision in two layers. Close the exit site stab incision with one suture. Suture each port to the skin separately. If the catheter is not to be used immediately, fill each lumen with the exact filling volume of 500-5000 units/ml heparin or 4% citrate, or your standard catheter locking solution. Bandage the catheter in place.
**Box 6-3. Dialysis Catheter Care**

- Unwrap catheter bandage by cutting bandage on opposite side of neck from where catheter is—be VERY careful not to cut catheter. Avoid cutting the esophagostomy tube, if present.
- Clean area around catheter exit site and between catheter and skin
- Assess catheter exit site for redness, swelling, odor, or discharge, and assess subcutaneous tunnel for signs of infection or excess bruising
- Remove vetwrap and the tape that is on the clamps
- Place a sterile barrier around catheter to prevent ports from touching fur or skin
- Exam gloves and a mask should be worn from here until you begin wrapping the catheter again
- Perform a surgical-type scrub on both ports, extending from the clamps to the tops of the injection ports
- Spray ports with dilute nolvasan or betadine
- Place another sterile barrier around catheter
- Have two squares of STERILE gauze within reach, as well as all syringes that are needed
- Open arterial/proximal port by removing injection cap
- Wipe port opening with sterile gauze
- Withdraw the exact volume (the exact volume for each side is printed on the catheter) of the lumen and discard—this is the citrate lock, so you must NEVER flush the catheter first
- Flush lumen with 6 cc fresh (mixed within 24 hrs) heparinized saline or normal saline
- Repeat this procedure on the venous/distal side
- Replace the citrate locks by injecting the exact volume of each lumen
- Replace injection cap—we always use a new injection cap even when just changing the citrate lock
- At this point, you can remove your gloves and mask
- Tape both clamps shut to ensure they do not pop open inadvertently
- Place a piece of vetwrap around both ports to keep ports clean if bandage becomes wet or soiled
- Place a gauze square with triple antibiotic ointment over the catheter exit site
- Wrap catheter with cast padding, kling, then vetwrap—the trick here is to wrap tightly enough that the bandage stays in place, but not too tightly
- Place a strip of porous white tape around both ends of bandage to anchor it to skin and prevent slipping—this is especially important for active animals
- Place a final piece of tape with the words DO NOT CUT/DO NOT USE on the outside of the wrap
Chapter 7  Prescription

General Comments
The treatment prescription is rather fluid and may need to be adjusted in response to changes in
the patient. Although the overall goal of hemodialysis is to control uremic symptoms, the specific goals
of an individual treatment vary based on the situation. The components of a dialysis prescription
include modality (i.e., intermittent vs continuous), schedule (i.e., daily vs alternate day), intensity (i.e.,
amount of blood processed in IHD or therapy fluid volume/rate with CRRT), dialyzer type and size,
dialysate composition, and UF rate.

Dialyzer
Considerations for selecting a dialyzer (also called hemofilter) include membrane type and size.
Substituted cellulosic membranes (i.e., hemophan, used in the Cobe HG series of dialyzers) have
excellent small molecule clearance (< 500 d) but limited middle molecule (500-5000 d) clearance. They
are more likely to induce complement activation. We no longer carry these dialyzers.

Synthetic membranes have better middle molecule clearance compared to cellulosic
membranes, and are less likely to induce as much of a biologic reaction. Commonly used materials
include polysulfone and AN69. Dialyzers may be characterized as high flux, meaning they have a
membrane with a large pore size, allowing clearance of middle molecules and water. High efficiency
dialyzers have a large surface area and efficient urea and other small molecule clearance. Dialyzers for
CRRT and IHD are not interchangeable (at least, not with the machines commonly used in USA).

The size of the dialyzer may be measured in surface area or priming volume. Table 7-1 lists
characteristics of commonly used dialyzers. The choice of dialyzer size depends on desired clearance and
patient size. Although pediatric hemodialysis recommendations include limiting the total volume of the
extracorporeal circuit and dialyzer to less than 10% of the infant’s blood volume, this guideline may be
impractical in veterinary dialysis (Table 7-2). If the extracorporeal volume constitutes a large percentage
of the blood volume (i.e., > 20%), use of a colloidal solution to prime the circuit is recommended instead
of saline.

Dialyzers for CRRT
The dialyzer and extracorporeal tubing are integrated into one unit for use with the Prisma or
PrismaFlex machines. The Prisma and PrismaFlex units are not interchangeable. All options available in
the USA have the same membrane (AN-69). The M-10, the smallest available set for the Prisma, has
been discontinued, although we still have a few sets stockpiled. While the small priming volume is
desirable for cats with very small blood volume, the risk of clotting is high, and the amount of uremic
toxin clearance is low/slow. Some units eschewed use of this set for these practical reasons, even
before it was discontinued. Prisma sets are designed for either pre-filter or post-filter replacement fluid,
but not both. PrismaFlex sets can be configured for either pre- or post-filter replacement via the
PrismaFlex machine.

The NxStage machine has tubing and dialyzer sets that are integrated into one piece, called the
cartridge express (CAR-500, or the deluxe version, CAR-505), which use a cartridges with a
polyethersulfone membrane. You can also get the tubing without the hemofilter, allowing you at attach
the hemofilter of your choice.
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</table>
Measurements performed in vitro at Qb = 200 ml/min, Qd = 500 ml/min, UF = 0, except where otherwise noted.

‡Qb = 100 ml/min  *Qb = 150 ml/min  †UF = 13 ml/min  ¶Qd = 2 L/hr (33 ml/min)  #Qd = 4 L/hr (67 ml/min)  ◊Discontinued

Polyamix™ = Polyarylethersulfone, Polyvinylpyrrolidone and Polyamide  △Qd = 1 L/hr, Qb = 20 ml/min, UF = 1 ml/min

With some dialysis machines, various tubing configurations are available, allowing flexibility with tubing volume. The Gambro CentrySystem 3 and Phoenix machines have specific tubing sets. The tubing volume for the neonatal set is 40 ml, and the volume for the pediatric set is 75 ml. The volume of the dialyzer is added to this volume to determine the total extracorporeal circuit volume. With the Gambro Prisma and PrismaFlex, the tubing and dialyzer are one integrated set. With the NxStage, the CAR-500 tubing has a priming volume of 80 ml; the CAR-125 low volume tubing has a volume of 55 ml.
Dialyzers for IHD

For the first 1 to 3 treatments, when slower clearance is desired, choose a slightly smaller dialyzer than generally recommended. In a standard treatment, the largest feasible dialyzer is preferred.

Table 7-2. Recommended Extracorporeal Volumes for ERRT in Dogs and Cats (adapted from Cowgill 2008 ARTS)

<table>
<thead>
<tr>
<th>Species</th>
<th>Body Weight</th>
<th>Dialyzer Volume</th>
<th>Total Extracorporeal Volume</th>
<th>% Blood Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cats, Dogs</td>
<td>&lt; 6 kg</td>
<td>&lt; 20 ml*</td>
<td>&lt; 60 ml</td>
<td>13-40%</td>
</tr>
<tr>
<td>Cats</td>
<td>&gt; 6 kg</td>
<td>&lt; 30 ml</td>
<td>&lt; 70 ml</td>
<td>&lt; 23%</td>
</tr>
<tr>
<td>Dogs</td>
<td>6-12 kg</td>
<td>&lt; 45 ml</td>
<td>&lt; 90 ml</td>
<td>9-19%</td>
</tr>
<tr>
<td>Dogs</td>
<td>12-20 kg</td>
<td>&lt; 80 ml</td>
<td>100-160 ml</td>
<td>6-17%</td>
</tr>
<tr>
<td>Dogs</td>
<td>20-30 kg</td>
<td>&lt; 120 ml</td>
<td>150-200 ml</td>
<td>6-13%</td>
</tr>
<tr>
<td>Dogs</td>
<td>≥ 30 kg</td>
<td>&gt; 80 ml</td>
<td>150-250 ml</td>
<td>6-10%</td>
</tr>
</tbody>
</table>

*The smallest dialyzer available in the USA is 28 ml (as of Jan 2014).

Priming Solution

During machine set-up, the dialyzer and extracorporeal circuit are filled with a priming solution that will be infused into the patient as the blood is being withdrawn. This volume helps avoid a precipitous decrease in effective circulating volume that would cause hypotension.

Normal saline

The priming solution is usually normal saline in medium to large dogs.

Hetastarch

In small animals, in which the total extracorporeal circuit volume represents a greater proportion of the blood volume, a colloid solution is used instead of saline. In the past, we routinely used Dextran 70 6% diluted with an equal volume of saline, to provide colloid support without risking excessive volume overload. As Dextran 70 is no longer available, we now use hetastarch diluted 50% with saline, and may switch to VetStarch or other colloids as they become popular.

Oxyglobin

In rare situations, diluted oxyglobin (1 part oxyglobin to 3 parts saline) has been used as a priming solution. In addition to colloid support, this provides some oxygen-carrying capacity. If it becomes commercially available again, we will likely use this as a priming solution in small cats.

Blood priming

In the past, blood priming has not been used commonly in veterinary medicine for intermittent hemodialysis for various practical reasons, including limited availability of blood for daily treatments and concern about transfusion reaction due to the rapid infusion rate. However, in recent years, more experience has been gained, without obvious transfusion reactions despite rapid infusion, and anecdotally seems to lead to better hemodynamic stability. With CRRT, theoretically the same circuit
can be used for 3 days, potentially reducing some of the mentioned concerns, although practically a single circuit is unlikely to be maintained for that long.

Blood priming an AN-69 membrane (i.e., all PrismaFlex and Prisma filters available in USA) leads to bradykinin release. This reaction is exquisitely pH sensitive, and stored blood tends to be highly acidic. Because angiotensin converting enzyme degrades bradykinin, ACE inhibitors can worsen this reaction, which is characterized by bronchospasm, vomiting, and hypotension. Other complications associated with blood priming in our clinical experience are clotting in circuit shortly after starting treatment.

There are 3 main methods of blood priming.

1. Recirculation. After priming the system with blood (reconstituted pRBCs – use saline or HES as needed, unless whole blood is available and indicated), connect the access and return lines to each other (see note), set the blood pump to 50-100 ml/min, replacement fluid to 1000 ml/hr, and dialysate to 2000 ml/hr. Run the circuit for 15-30 minutes and then attach to the patient. We have not worked out anticoagulation in this period. The ACD-A in the blood will dialyze out, theoretically creating a risk of clotting. If you are using heparin, I would consider giving the heparin prime to the banked blood.
   a. When connecting the access and return lines, a connector is available in the CRRT toolkit (recycled from the IHD sets), but this is not recommended for this indication. You will likely get flow alarms (access too positive, return too negative) because blood is being pushed into the access and sucked from the return. You can use a stopcock, but you will have the same issues with the connector. To overcome this, you may need to insert a reservoir, such as the empty blood bag, on one end of the 3 way stopcock, to dissipate the pressure problems.

2. Buffer the blood. After mixing the blood according to the following recipe, connect the access line to the blood bag, and connect the return line to a drain bag (such as the empty saline bag used to prime the circuit). Start dialysis, and when the blood has reached the end of the return line (or the blood bag has emptied), stop the blood pump and connect the access line to the access port of the patient’s catheter and the return line to the return port of the patient’s catheter. By buffering the blood with bicarbonate, the dialyzer reaction is minimized, and the blood can be directly infused into the patient. The recipe is:
   a. 50 mL pRBC
   b. 50 mL 5% albumin or saline
   c. 30 mEq sodium bicarbonate (30 ml of 1 mEq/L)
   d. 250 mg 3% calcium chloride (8.3 ml of 10% CaCl)
   e. 100 units heparin (0.1 ml of 1000 u/ml)

3. “Baby Buffer” Bleed-on method. Attach the access line to the patient’s catheter but leave the return line attached to the prime collection bag. Start the blood pump, which will draw blood from the patient while dumping the prime solution into the prime bag. When the blood is close to the end of the line, stop the blood pump and attach to the return port of the catheter. Simultaneously with starting the extracorporeal circulation, transfuse an equal volume of blood (i.e., 30 ml pRBC diluted to 90 ml with saline and/or HES for cat blood; 45 ml pRBC + saline for dog blood) through a separate catheter over 15 minutes. With this method, the patient’s body buffers the acidic transfused blood before it eventually reaches the membrane. This is the most common method I have used.
CRRT

CRRT has multiple modes of use. All are continuous (C) therapies, and all are veno-venous (VV), meaning that a blood pump is used to withdraw venous blood from a venous catheter and return the cleansed blood to the venous circulation. Arteriovenous (AV) therapies used an arterial catheter to withdraw blood (under the power of the heart as the pump) and returned the blood through a venous catheter, but this technique is no longer used.

CVVH – Continuous venovenous hemofiltration (Figure 7-1 A and B). This mode uses exclusively convective clearance without dialysate for diffusive clearance. Fluid is removed from the patient via hydrostatic forces (ultrafiltration). Because the rate of ultrafiltration exceeds the need for net fluid removal from the patient, replacement fluid is administered to avoid volume depletion.

CVVHD – Continuous venovenous hemodialysis (Figure 7-1 C). This mode uses exclusively diffusive clearance without any extra ultrafiltration and replacement fluid for convective clearance.

CVVHDF – Continuous venovenous hemodiafiltration (Figure 7-1 D). This mode combines diffusive clearance (using dialysate) and convective clearance (using ultrafiltration and replacement fluid).

SCUF – Slow continuous ultrafiltration (Figure 7-2). This mode uses solely convective clearance via ultrafiltration, but replacement fluid is not administered, as the goal of SCUF is mainly fluid removal. This technique is used in non-renal applications (such as diuretic resistant congestive heart failure).

Programs differ in standard mode of CRRT. Some use predominantly CVVH, others CVVHDF, few use CVVHD. Treatments relying exclusively on convective clearance (CVVH) may have more dialyzer thrombosis (due to hemoconcentration of blood as it passes through the dialyzer). Pre-dialyzer fluid replacement decreases this risk, but dilutes the blood entering the dialyzer and therefore decreases efficiency of uremic toxin removal. With the Prisma cartridges, either pre-filter or post-filter fluid replacement sets are available, but as the sets are pre-configured, this parameter cannot be changed. With the newer machine, Prisma-Flex, the site of fluid replacement can be varied by the operator. Addition of diffusive clearance (dialysate) provides clearance without changing the risk for thrombosis.
Figure 7-1. A. CVVH, pre-filter replacement; B. CVVH, post-filter replacement; C. CVVHD; D. CVVHDF

Figure 7-2. SCUF
Intensity of Treatment

The intensity of treatment is same as the dose of dialysis. It is based on both the rate of clearance and the duration of clearance. Intermittent hemodialysis machines, such as the Phoenix (and C3, among others), have very high dialysate flow rates (typically 300-800 ml/min, or about 30 L in an hour), compared to blood flow rates of about 10-400 ml/min. The dialysate is not saturated with uremic toxins in one pass through the dialyzer due to the high volume and fast flow rate. At very slow blood flow rates, the blood may be completely cleared of all uremic waste in one pass through the dialyzer. At higher blood flow rates, there may not be time for complete clearance in once pass, but the faster flow overcomes the decrease in efficiency (Table 7-3). The more blood processed through the dialyzer, the more clearance.

Table 7-3. Sample Clearances with Blood Flow Limited Clearance (IHD)

<table>
<thead>
<tr>
<th>Qb (ml/min)</th>
<th>Clearance*</th>
<th>Urea entering (mg/dL)</th>
<th>Urea exiting (mg/dL)</th>
<th>Clearance (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>95%</td>
<td>100</td>
<td>5</td>
<td>48</td>
</tr>
<tr>
<td>300</td>
<td>75%</td>
<td>100</td>
<td>25</td>
<td>225</td>
</tr>
</tbody>
</table>

*theoretical. Not intended to portray real values.

With therapies delivered by CRRT type machines (PrismaFlex, Prisma, etc.), the effluent rate (total therapy fluid plus net patient fluid removal) ranges from 0 to 5500 ml/hr (Prisma) to 10 L/hr (PrismaFlex), although blood flow rates may be similar to those with IHD (10-180 ml/min with M60, 10-450 ml/min with M100). With convective clearance, every ml of effluent is completely saturated with uremic solutes. With diffusive clearance, as long as the blood flow is at least 3 times faster than the therapy fluid rate, the dialysate will be completely saturated. If the dialysate flow rate is too fast, there is not enough time for it to equilibrate, and the dialysate is not completely saturated (Table 7-4). The more therapy fluid (effluent) processed, the more clearance.

Table 7-4. Sample Clearances with Therapy Fluid Limited Clearance (CRRT)

<table>
<thead>
<tr>
<th>Qb (ml/min)</th>
<th>Effluent Rate (ml/hr)</th>
<th>Clearance*</th>
<th>BUN (mg/dL)</th>
<th>Effluent urea (mg/dL)</th>
<th>Clearance (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1000</td>
<td>100%</td>
<td>100</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>300</td>
<td>6000</td>
<td>100%</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>300</td>
<td>8000</td>
<td>80%</td>
<td>100</td>
<td>80</td>
<td>106</td>
</tr>
</tbody>
</table>

*theoretical. Not intended to portray real values.

CRRT

There are multiple valid ways of determining CRRT dose which all yield similar results. The first point to make, however, is that the contribution of convective and diffusive clearance is roughly equal ml for ml. For example, 1000 ml/hr of replacement fluid = 500 ml/hr replacement fluid + 500 ml/hr dialysate = 1000 ml/hr dialysate. I generally choose to divide the total dose approximately equally between diffusive and convective clearance.

Method 1: 2000 ml/1.73 m2/hr (total of replacement fluid + dialysate)
Method 2: 35 ml/kg/hr (total of replacement fluid + dialysate)
Method 3: Qb = 3-5 ml/kg/min; UF rate 20% of Qb (CVVH)
Blood flow rate with CRRT

Increasing the blood flow rate will have no beneficial effect on convective clearance, but does decrease the likelihood of dialyzer thrombosis (which leads to a decrease in clearance or necessitates discontinuing therapy to replace the dialyzer). The ultrafiltration rate should not exceed 25% of the blood flow rate, or the degree of hemoconcentration in the dialyzer will be too great. With dialysate flow in these ranges, dialysate is likely to be saturated in one pass, and increasing blood flow rate will only add modestly to clearance.

IHD

In therapies that depend on diffusive clearance and have high dialysate flow rates (IHD and SLED), blood flow is the primary determinant of small solute clearance (i.e., urea, potassium). The volume of blood that needs to be processed through the dialysis machine (measured in L/kg) to effect a certain percentage of clearance (measured as urea reduction ratio, see Chapter 16 Dialysis Adequacy) can be predicted from empirical data (Figures 7-3 and 7-4). To avoid dialysis disequilibrium syndrome during the first few treatments, the recommended amount of clearance may be limited during a single treatment when azotemia is severe or the patient is small. The risk of dialysis disequilibrium syndrome is decreased when solutes are gradually removed slowly. Consult Table 7-3 for recommended URR and rates of clearance. After selecting the URR, the duration of treatment and desired blood flow to accomplish the treatment goal can be calculated.

Table 7-5. Treatment Intensity Prescription Guidelines (adapted from Cowgill 2008 ARTS)

1st Treatment

<table>
<thead>
<tr>
<th>BUN</th>
<th>URR</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 200 mg/dl</td>
<td>URR &lt; 0.5 @ no greater than 0.1 URR per hour</td>
</tr>
<tr>
<td>200-300 mg/dl</td>
<td>URR 0.3 to 0.5 @ no greater than 0.1 URR per hour</td>
</tr>
<tr>
<td>&gt; 300 mg/dl</td>
<td>URR ≤ 0.3 @ no greater than 0.05-0.07 URR per hour</td>
</tr>
</tbody>
</table>

2nd Treatment

<table>
<thead>
<tr>
<th>BUN</th>
<th>URR</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 200 mg/dl</td>
<td>URR 0.6 to 0.7 @ 0.01-0.15 URR per hour</td>
</tr>
<tr>
<td>200-300 mg/dl</td>
<td>URR 0.4 to 0.6 @ 0.10-0.12 URR per hour</td>
</tr>
<tr>
<td>&gt; 300 mg/dl</td>
<td>URR ≤ 0.4 URR @ no greater than 0.05-0.1 URR per hour</td>
</tr>
</tbody>
</table>

3rd and Subsequent Treatments

<table>
<thead>
<tr>
<th>BUN</th>
<th>URR</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 150 mg/dl</td>
<td>URR &gt; 0.8 @ &gt; 0.15 URR per hour</td>
</tr>
<tr>
<td>150-300 mg/dl</td>
<td>URR 0.5 to 0.6 @ 0.10-0.15 URR per hour</td>
</tr>
<tr>
<td>&gt; 300 mg/dl</td>
<td>URR 0.5 to 0.6 @ &lt; 0.1 URR per hour</td>
</tr>
</tbody>
</table>
Figure 7-3. Urea reduction ratio for dogs treated with intermittent hemodialysis

Figure 7-4. Urea reduction ratio for cats treated with intermittent hemodialysis
PIRRT

With prolonged intermittent therapies provided by a CRRT-type machine, doses based on CRRT generally will not provide adequate clearance in shorter time frames than 24 hours. Using the premise that every ml of effluent is completely saturated, clearing a volume of effluent equal to the urea volume of distribution (60% of body weight), one might predict good clearance, but it will not be complete. Clearance from different compartments will vary, based on factors such as perfusion of that compartment, and ability of urea and other solutes to diffuse out of the intracellular space. Limited preliminary data suggests that 1 L/kg will provide a URR of over 80% (Figure 7-5).

SLED

Sustained low efficiency dialysis is a method of using the IHD machine for treating small, severely azotemic, or hemodynamically unstable patients. It can be thought of as a compromise between IHD and CRRT. See Table 7-3 for treatment recommendations. Convective clearance can be added to increase removal of middle molecule weight solutes, but prescription guidelines have not been established. In one report, convective clearance at 1 L/1.73 m2/hr was used (Berbece).

Figure 7-5. Relationship of L of Therapy fluid (effluent) per kg on urea reduction ratio in 36 PIRRT treatments
Dialysate Composition

CRRT

The composition of dialysate is similar to the composition of plasma water. Several different commercially prepared formulations are available, or dialysate can be improvised from available intravenous fluid solutions.

Sodium

The sodium concentration should be within the normal physiologic range. Preprogrammed gradual alterations in dialysate sodium concentration (sodium profiling) is not possible with CRRT as it is with IHD.

Potassium

If the patient is severely hyperkalemic, dialysate that contains no potassium or a low potassium concentration is recommended initially. Once the patient serum potassium concentration is normalized, dialysate should be switched to one containing potassium (or potassium should be added to the dialysate or replacement fluid) to avoid hypokalemia.

Calcium

A calcium free dialysate should be used with citrate anticoagulation, to avoid clotting in the dialyzer.

Buffer

Dialysate generally is formulated to contain a higher than normal bicarbonate concentration, to combat the metabolic acidosis commonly encountered with renal failure. Bicarbonate is the best buffer; lactate can be used if liver function is normal. Acetate can cause hemodynamic instability in large amounts with IHD; the possibility of this with CRRT is unexplored. Because citrate is metabolized to bicarbonate, metabolic alkalosis can occur if standard dialysate bicarbonate concentrations (30-35 mEq/L) are used with citrate anticoagulation; switching to a dialysate solution with a slightly lower bicarbonate concentration is advised after the first 24 hours in that setting.

Glucose

Some dialysate solutions contain physiologic levels of glucose, to avoid causing hypoglycemia.

Table 7-6. Examples of prepared dialysate solutions and alternatives

<table>
<thead>
<tr>
<th></th>
<th>Prismasate</th>
<th>Prisma</th>
<th>LRS</th>
<th>P'lyte</th>
<th>Saline</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>BK0/3.5</td>
<td>B22GK4/0</td>
<td>BGK4/2.5</td>
<td>BGK2/0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na⁺</td>
<td>140</td>
<td>140</td>
<td>140</td>
<td>140</td>
<td>130</td>
<td>140</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>109.5</td>
<td>120.5</td>
<td>113</td>
<td>108</td>
<td>109</td>
<td>103</td>
</tr>
<tr>
<td>K⁺</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Bicarb</td>
<td>32</td>
<td>22</td>
<td>32</td>
<td>32</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lactate</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>28⁺</td>
<td>A</td>
</tr>
<tr>
<td>Dextrose</td>
<td>0</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ca⁺⁺</td>
<td>3.5</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Mg⁺⁺</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

*No calcium if using citrate
⁺⁺Use Bicarb instead of lactate if liver disease
A= Acetate (47 mEq/L)
P'lyte = Plasmalyte
IHD

Sodium

With IHD, the sodium concentration can be readily adjusted to avoid large or rapid changes in the patient’s serum sodium concentration. 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 at the start of the treatment and gradually decreased 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, thus decreasing the risk of dialysis disequilibrium syndrome. The sodium concentration is lowered by the end of the treatment to avoid loading the patient with sodium, which can enhance thirst and water retention in the interdialysis interval. Because the dialysis machine proportions the dialysate concentrate based on the sodium concentration, individual adjustments of other dialysate components are not possible, but can be made by using different concentrates.

Potassium

Dialysate typically contains approximately 3 mEq/L of potassium, but potassium free dialysate is available for use in hyperkalemic patients.

Calcium

Several concentrations of dialysate calcium are available, including calcium free dialysate, used with some citrate anticoagulation protocols (see Chapter 8 Anticoagulation). Various magnesium concentrations are available also.

Bicarbonate

Bicarbonate is incorporated separately and can be adjusted independently from sodium concentration. To combat metabolic acidosis that is commonly present, the dialysate bicarbonate concentration is usually higher than the patient’s, 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 CNS acidosis and dialysis disequilibrium syndrome.

Flow Rate

CRRT

Dialysate flow rates in CRRT are generally between 0 and 133 ml/min. With CRRT, dialysate is saturated with one pass through the dialyzer, and faster dialysate flow rates have a substantial effect on clearance. The dialysate flow rate is an important determinant of treatment intensity in CRRT. See discussion above.

IHD

Although most intermittent dialysis treatments use a dialysate flow rate of 500 ml/min, the dialysate flow rate is adjustable from 300-800 ml/min. With IHD, clearance depends more on blood flow rate than on dialysate flow rate. At a slow blood flow rate and rapid dialysate flow rate, blood leaving the dialyzer may be completely cleared of a solute. With a fast blood flow rate and the same dialysate flow rate, the blood spends less time in the dialyzer and a lower percentage of the solute is extracted. For example, at a blood flow rate of 20 ml/min, blood entering the dialyzer with a urea concentration of 100 mg/dl has a 0 mg/dl concentration when leaving the dialyzer. At a blood flow rate of 200 ml/min, blood entering the dialyzer with a urea concentration of 100 mg/dl has a 30 mg/dl concentration when
leaving. In the first example, 20 ml/min of blood are completely cleared of urea, whereas in the second example, 140 ml/min of blood are completely cleared. Thus, despite the decrease in efficiency from 100% to 70% clearance in one pass, there is an overall greater clearance with a higher blood flow rate. Increasing the dialysate flow rate from 500 ml/min to 800 ml/min will increase the clearance by 5-10%, if the blood flow rate is already at very high rate (> 350 ml/min). A lower dialysate flow rate (i.e. 300 ml/min) will modestly decrease clearance.

**Dialysate Flow Direction**

In most IHD treatments, dialysate flows from the bottom of the dialyzer to the top, while blood flows in the opposite direction, to maximize the concentration gradient across the length of the dialyzer. By reversing the dialysate connectors, dialysate can flow in a concurrent direction instead of countercurrent, thus decreasing efficiency by about 10%, which may be indicated in the first 1 to 3 treatments. Dialysate flow direction cannot be changed with CRRT, and while dialysate flows in an opposite direction to blood in CRRT, the blood generally enters at the bottom of the dialyzer in CRRT, vs entering at the top in IHD.

**Dialysate Temperature**

**CRRT**

Substantial loss of heat can occur through the blood tubing. The Prisma/PrismaFlex has two optional methods of combating this heat loss. One involves adding a length of tubing to the extracorporeal circuit that is routed through a special heater (PrismaTherm), thus increasing the volume of blood required. The other involves a heated sleeve that fits around the blood tubing or dialysate tubing (PrismaFlo). We have the PrismaFlo. We also have heating pads for the animal’s cage. Hot water gloves placed on the return line (before we acquired the PrismaFlo) was a moderately effective method of decreasing heat loss.

**IHD**

With IHD, dialysate is warmed by the dialysis machine. Blood leaving the dialyzer is in thermic equilibrium with the dialysate. Higher patient temperatures promote vasodilation of the skin and periphery, which may cause cardiovascular instability and intradialytic hypotension. A dialysate temperature slightly (2° C) below body temperature promotes mild patient cooling and vasoconstriction to the periphery, and decreases the risk of intradialytic hypotension. Because basal temperatures of dogs and cats are higher than that for humans, dialysate temperature settings available with currently used machines are typically slightly below normal for veterinary patients.

**Dialysate Additives**

**Phosphate**

**IHD**

When dialysis is used for nonrenal indications, such as removal of a toxin, hypophosphatemia can develop as a result of rapid clearance of phosphorus. Although phosphorous concentration may rebound shortly after the dialysis treatment, there is a risk of hemolysis with severe hypophosphatemia (serum phosphorus < 1.0 mg/dl). Addition of phosphate to the dialysate may prevent this from occurring. Addition of 16 ml of a neutral sodium phosphate (Fleet Enema, Fleet Brand Pharmaceuticals, C.B. Fleet Company, Inc., Lynchburg, VA) per liter of dialysate concentrate produces a dialysate concentration of approximately 2 mg/dl.
Ultrafiltration

The desired volume of ultrafiltration depends on the patient’s hydration status. Some patients may be 10 to 25% overhydrated, in the most severe cases.

\[
\text{\% overhydration} \times \text{kg body weight} \times 10 = \text{ml fluid to remove}
\]

CRRT

The rate of fluid removal will depend on the specific clinical circumstances. An advantage of CRRT is excess fluid can be removed gradually leading to better hemodynamic stability compared to rapid short bursts of intensive fluid removal (as with IHD). Another advantage is the ability to continually remove fluid as medications/nutritional supplements are administered. If respiratory compromise is present from fluid overload, a more rapid fluid removal plan is prudent (i.e., within 4-6 hours, or as rapidly as possible). Otherwise, removing the excess fluid can generally be accomplished within 24 hours.

IHD

The rate of fluid removal should not exceed 20 ml/kg/hr. More rapid fluid removal may cause intradialytic hypotension. With excessive fluid overload, it may not be possible to remove all of the fluid in a single dialysis treatment, and SLED, CRRT, or isolated ultrafiltration should be considered if the patient is compromised by the fluid overload. 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 towards the end, to account for a slower transfer from the interstitium to bloodstream and thus to dialyzer as the patient nears the optimal fluid status. In intermittent hemodialysis, with its high dialysate flow rate, the addition of ultrafiltration for convective clearance contributes relatively little to the overall solute clearance.

Replacement Fluid

CVVH and CVVHDF rely exclusively or partially, respectively, on convective clearance. Because the convective clearance goals will exceed the need for ultrafiltration, replacement fluid is provided to prevent volume depletion. For example, if the desired convective clearance rate is 300 ml/hr and the desired net fluid removal for volume overload is 100 ml/hr, an extra 200 ml/hr of fluid can be ultrafiltered and replaced with replacement fluid.

Setting the replacement fluid pump rate on the PrismaFlex or Prisma machine causes two things to simultaneously happen. The amount of ultrafiltration is automatically increased by the rate of the replacement fluid pump, and replacement fluid is infused into the circuit at an equal rate. Using the example above, if the ultrafiltration pump is set at 100 ml/hr and you then set the replacement fluid pump at 200 ml/hr, a total of 300 ml/hr of fluid will be removed from the patient via the effluent pump, and 200 ml/hr of fluid will be infused into the patient (via the replacement fluid pump). The I and O screen (ins and outs), also called the status screen, will indicate the various fluid rates.

Replacement fluid can be any crystalloid fluid. Although PrismaSate, a commercially prepared dialysate solution, is not labeled for use as an intravenous fluid, many human CRRT units use it as the replacement fluid. PrismaSol is essentially PrismaSate packaged under a different name with FDA approval for IV administration. We do not carry any of the PrismaSol solutions; we use PrismaSate for replacement fluid.
Pre or Post-Filter Replacement

With the Prismaflex, the replacement fluid can be delivered before or after the filter, based on operating parameters set on the screen. With the Prisma, each set is configured to either pre or post-filter replacement and this is not modifiable. Pre-filter replacement decreases the efficiency of therapy; post-filter replacement increases the risk of clotting in the filter.

Figure 7-6. Status Screen for Prismaflex
Reading the screen. The left side of the screen shows the current flow settings. The middle of the screen shows the ins-and-outs data for the specified time (default is an hour monitoring period, with 41 of those minutes already elapsed. The volume of each component used during that time period is shown. The chart below indicates the pressure drop from the blood inflow to the blood outflow over time (an increasing pressure generally indicates clotting), and the transmembrane pressure. The various pressure are show in the upper left both numerically and visually. The buttons along the bottom navigate to various other screens.
### Status Screen from Prisma Machine

The current mode is highlighted on the top of the screen. There are three boxes of information. The one on the left is the current pump settings. The middle box gives ins and outs data of how much of each solution has been used and how much fluid has been removed from the patient. The default is to give information for the current hour. Elapsed time means how much of the current hour has elapsed. Since it is 11:49 am on this screen, 49 minutes of the current hour have elapsed. It is possible to see data from a different time period by touching the Treatment History button. The box on the right includes current pressure measurements.

<table>
<thead>
<tr>
<th>Current Flow Rates</th>
<th>I/O Data</th>
<th>Current Pressures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood: 100 ml/min</td>
<td>Elapsed: 49 of 60 min</td>
<td>Access: -111 mmHg</td>
</tr>
<tr>
<td>Replace: 210 ml/hr</td>
<td>Replacement</td>
<td>Filter: -23 mmHg</td>
</tr>
<tr>
<td>Dialysate: 550 ml/hr</td>
<td>Sol. Input: 72 ml</td>
<td>Effluent: -63 mmHg</td>
</tr>
<tr>
<td>Pt Removal: 360 ml/hr</td>
<td>Dialysate Used: 188 ml</td>
<td>Return: -37 mmHg</td>
</tr>
<tr>
<td>Anticoag: Continuous 0.0 ml/hr</td>
<td>Effluent: 376 ml</td>
<td>TMP: 31 mmHg</td>
</tr>
<tr>
<td></td>
<td>Actual Pt.</td>
<td>ΔP Filt: 10 mmHg</td>
</tr>
<tr>
<td></td>
<td>Fluid Removed: 116 ml</td>
<td></td>
</tr>
</tbody>
</table>

Next intervention in approx: 0 hr 25 min
Due to: Dialysate bag empty

---

### Prisma Pumps

The blood pump is removing (and returning) blood through the extracorporeal circuit. The dialysate pump determines the dialysate flow. The replacement pump infuses fluid into the extracorporeal circuit for convective clearance. The effluent pump removes the dialysate, replacement volume, and ultrafiltration from the patient.

### PrismaFlex Pumps

In addition to the pumps found on the Prisma, this machine has an additional pump that delivers fluid to the access blood line near the catheter connection.
Setting the pump rates (See also Figure 7-10).

There are 5 pumps integrated into the Prisma machine.
Blood pump
Dialysate pump
Effluent pump
Replacement fluid pump
Heparin pump

In addition to these 5, we will need two separate IV fluid pumps to administer the citrate and the calcium, and more pumps if other medications are being given (i.e., TPN, constant drug infusions, etc.).

To determine how to set the pumps, follow these easy instructions!
Blood pump: See prescription guidelines for maximum blood flow rate. Take about 30 minutes to get to the target speed.

Dialysate pump: Use prescription to determine overall amount of clearance desired, then divide that amount into diffusive clearance (dialysate) and convective clearance. A general rule of thumb for our practice is to divide approximately equally. Set the dialysate rate on the pump.

Effluent pump: Ultrafiltration is used to remove fluid from the patient, including excess fluid accumulation in the patient (overhydration) and medications/nutrition that are being administered (including citrate and calcium). Calculate the rate of ultrafiltration to address overhydration

\[
\text{UF for overhydration (___\% overhydration x ___kg body wt x 10) ÷ ___ hr = _________ml/hr}
\]

Citrate rate
Calcium rate
Other medications/nutrition rate
Total

Set the UF pump to the rate needed to remove the fluid overload plus ongoing administration (sum of rates listed above).

Replacement Fluid Pump: In order to achieve sufficient convective clearance, it may be necessary to remove more fluid than accounted for in the UF pump calculations above. In that situation, the replacement fluid pump is used to accomplish two things: extra fluid removal with replacement of that exact volume by replacement fluid. The total amount of fluid removed from the patient is the sum of the fluid removal pump and replacement fluid pump. Using the dose prescribed (see discussion above in dialysate section), subtract the UF rate from the total desired convective clearance rate. If the UF rate is higher than the desired convective clearance rate, the replacement fluid rate will be zero. If the UF rate is less than the desired convective clearance rate, the replacement fluid rate will be the difference between the desired convective clearance rate and the UF rate.
Example 1.
5 kg cat, 200 BUN, 10% overhydrated
Qb = 2 ml/kg/min = 10 ml/min
Desired clearance = 25 ml/kg/hr (Method 2) = 125 ml/hr. If we divided this equally between dialysate and convective clearance, each would be set at 62.5 ml/hr. However, dialysate can be set only in 50 ml increments, so we will set the dialysate flow rate at 100 ml/hr
Qd = 100 ml/hr Desired convective clearance 25 ml/hr (100 + 25 = 125 ml/hr)
Citrate: 1.5X Qb. 1.5 x 10 ml/min = 15 ml/hr citrate rate (note Qb in ml/min but citrate in ml/hr)
Calcium: 0.4 x citrate rate = 15 x 0.4 = 6 ml/hr calcium
Desired fluid removal = 500 ml over 25 hrs = 20 ml/hr
UF rate = 15 + 6 + 20 = 41 ml/hr, which exceeds the desired convective clearance rate. Thus, the replacement fluid rate is set at zero.

Example 2.
25 kg dog, 125 BUN, normal hydration status
Qb = 5 ml/kg/min = 125 ml/min
Desired clearance = 25 ml/kg/hr (Method 2) = 625 ml/hr, split approximately equally between diffusive and convective clearance.
Qd = 300 ml/hr
Desired convective clearance = 325 ml/hr
Citrate: 1.5 X Qb = 190 ml/hr
Calcium: 0.4 x citrate = 75 ml/hr
Desired fluid removal – none, as patient is hydrated and not receiving any medications or nutrition (!)
Replacement fluid rate = 325 – 190 – 75 = 60 ml/hr. This means an additional 60 ml/hr will be removed from the patient and automatically replaced with the fluid hanging on the replacement fluid pump.
Fluid removal pump rate = 190 + 75 = 265 ml/hr

Example 3.
12 kg dog, 166 BUN, 5% overhydrated
Qb = 4 ml/kg/min = 50 ml/min
Desired clearance = 2000 ml/1.73m2/hr = 600 ml/hr. I want to divide this equally between diffusive (dialysate) and convective (UF) clearance.
Qd = 300 ml/hr
Citrate = 1.5X Qb = 75 ml/hr
Calcium = 0.4 x citrate = 30 ml/hr
Desired fluid removal = 600 ml over 24 hours = 25 ml/hr
UF rate = 25 + 75 + 30 = 130 ml/hr
Replacement fluid rate = 300 – 130 = 170 ml/hr
Figure 7-10. Example of Enter Flow Settings screen on Prismaflex CRRT machine

SET FLOW RATES

1. Press the name of the flow rate to be changed
2. Select next flow rate or press status to enter new values

Figure 7-11. Example of Set Flow Rates screen on Prisma CRRT machine
Single Needle Dialysis

If only one vascular access lumen is available, either because a single lumen catheter was placed or because one lumen of a double lumen catheter is nonfunctional, IHD can be performed in what is termed single needle mode. A Y-connector is attached to the single lumen so that both the access ("arterial") and return ("venous") extracorporeal tubing segments can be attached. The return side is automatically clamped while the blood pump draws blood from the access side into the dialyzer. Blood already in the dialyzer is displaced into a reservoir placed in the extracorporeal circuit on the return side (after the dialyzer but before the clamp). The access side is then clamped and the return side is unclamped, allowing the dialyzed blood to be returned to the patient, and the cycle is repeated. Single needle dialysis is far less efficient than double needle, as less than half of the dialysis time is spent withdrawing blood. There is also a decrease in efficiency due to recirculation of the returned blood in the catheter that is withdrawn on the next cycle. By maintaining a fast blood flow rate and a higher stroke volume (amount of blood removed in each cycle), the effect of recirculation is decreased, but in many situations, a fast blood flow rate is limited by the type and condition of the functional lumen of the catheter. A single needle mode is not available with CRRT or with the Phoenix. Thus, functionally, this mode is limited to the C3 and C3 Plus machines, which have been phased out by the company.
Chapter 8  Anticoagulation

Coagulation is a big problem when blood is taken out of its natural environment of endothelial lined blood vessels. Clotting in the dialyzer decreases clearance. Clotting in the tubing can cause the treatment to be stopped, and the volume of blood in the circuit may not be able to be returned to the patient. In the tubing, it seems that the Critline chamber is the first area likely to develop clots, followed by the filter in the venous chamber (Phoenix machines, adult and pediatric sets, but not the low volume neonatal set), then the injection ports. A variety of methods of anticoagulation can be used for extracorporeal therapies. Unfractionated heparin, administered either as a continuous infusion or intermittent boluses, is simple and effective, but increases the risk of patient bleeding, as the patient is systemically anticoagulated. It generally should be avoided in patients with pre-existing coagulopathy or in patients that recently have had or will have surgery. Regional citrate with calcium infusion is more complicated to use, but prevents dialyzer clotting more effectively than heparin. Citrate is relatively contraindicated in patients with liver failure. During treatments with no anticoagulation, with intermittent saline flushing of the dialyzer, the treatment frequently must be stopped due to clotting within a few hours. Other anticoagulant options are available, but are not in widespread use.

Heparin

Heparin is usually administered as a loading dose followed by a constant infusion. The infusion is adjusted to maintain clotting times within a specified range. Additional boluses of heparin may be needed if the clotting time is far below the target range. Activated clotting time was the most commonly used measure, due to availability of automated equipment early in the history of dialysis. The Medronics ACT II machine was the most commonly used device. Normal for that machine is about 100 seconds. For most ERRT treatments, the target range is 160-200 seconds (1.6-2 times normal). If there are concerns about systemic heparinization, a tighter range, generally 150-180 seconds may be prescribed.

We have switched to using PTT instead of ACT. We use the Idexx Coag Dx machine (available in dialysis, ICU, and the mini-lab on the 2nd floor across from radiology). We DO NOT use the standard cartridges that require citrated blood. We have a supply of cartridges for use with whole blood (with no anticoagulation), that are stored in the dialysis fridge on the 3rd floor. Request the PTT through Cornerstone (PVL code Dialysis Monitoring), then load the cartridge. It takes a few seconds to warm up, then you have 5 minutes to draw the blood sample. The sample needs to be run within seconds of acquisition. Normal values for this machine are 59-87 seconds in dogs and 66-123 seconds in cats. In general, the PTT seems to change proportionately less than the ACT did, but the target ranges are fairly close.

All of our machines have an integrated syringe pump for heparin administration. Each machine is calibrated for a specific size and brand of syringe. Using the wrong size or brand of syringe will cause sometimes dramatic differences in the intended and delivered dose of heparin.

CRRT

Heparin is used in about half of human (and some veterinarian) CRRT units.

Practical points: The lowest heparin infusion rate on the Prisma is 0.5 ml/hour, and changes in increments of 0.1 ml/hr. For animals that may need smaller amounts of heparin, or if precise control is desired, dilute the heparin. For a cat or small dog, dilute the heparin to 50-100 u/ml.
Practical points: The lowest heparin infusion rate on the PrismaFlex is 0.5 ml/hour for the M60 and M100 when using a 20ml syringe, and changes in increments of 0.1 ml/hr. If using a larger syringe, the lowest rate can be as high as 2ml/hr. The factory default setting is for a 50ml syringe. For animals that may need smaller amounts of heparin, or if precise control is desired, dilute the heparin. For a cat or small dog, dilute the heparin to 50-100 u/ml.

Heparin Prime: 25 u/kg, repeat if ACT < 180 sec
Heparin CRI: Start 10-20 u/kg/hr

<table>
<thead>
<tr>
<th>ACT (sec)</th>
<th>PTT (sec)</th>
<th>Adjustment</th>
<th>Pump calibrated to 20 cc BD syringe at AMC for Prisma</th>
<th>Pump calibrated to 20 cc BD syringe at AMC for Prismaflex</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;150</td>
<td>&lt;150</td>
<td>&lt;120 Bolus 15 u/kg &amp; incr CRI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150-180</td>
<td>150-180</td>
<td>120-150 Incr by 1 u/kg/hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180-200</td>
<td>180-200</td>
<td>150-180 No change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;200</td>
<td>&gt;200</td>
<td>&gt;180 Decr by 1 u/kg/hr</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IHD

Heparin is the most commonly used method of anticoagulation in IHD. Most IHD machines can be programmed to discontinue the heparin infusion at a set time prior to the end of the treatment (commonly 30 minutes) to allow the effects of heparin to partially dissipate before the patient leaves the unit.

<table>
<thead>
<tr>
<th>Pre-treatment ACT or PTT (sec)</th>
<th>Heparin bolus (u/kg)</th>
<th>Pump calibrated to 12 cc Monoject syringe at AMC for Phoenix</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;120</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>120-160</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>&gt;160</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Body Weight</th>
<th>Heparin Rate (U/hr)</th>
<th>Practical Points: The Phoenix can infuse in 0.1 ml/hr increments, with the lowest starting dose of 0.5 ml/hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cats, Dogs</td>
<td>&lt;6 kg</td>
<td>50-100</td>
<td></td>
</tr>
<tr>
<td>Cats</td>
<td>&gt;6 kg</td>
<td>50-100</td>
<td></td>
</tr>
<tr>
<td>Dogs</td>
<td>6-12 kg</td>
<td>100-300</td>
<td></td>
</tr>
<tr>
<td>Dogs</td>
<td>12-20 kg</td>
<td>400-600</td>
<td></td>
</tr>
<tr>
<td>Dogs</td>
<td>20-30 kg</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Dogs</td>
<td>&gt;30 kg</td>
<td>1000</td>
<td></td>
</tr>
</tbody>
</table>
If clotting in the venous chamber is noted, or if the TMP (transmembrane pressure) or Delta P (pressure drop across the dialyzer) are increasing, which indicates clotting in the dialyzer, adding a little bit of heparin to the venous side may be helpful. A constant infusion of 5-10 units/kg/hour into the venous drip chamber may overcome those problems, or using a Y-piece from the heparin syringe to the arterial and venous chambers.

Regional Citrate Anticoagulation

General Principles

Calcium is an important factor in multiple steps of the coagulation cascade. Citrate binds to calcium, preventing activation of coagulation. With regional citrate, citrate is infused into the extracorporeal circuit as the blood is being withdrawn from the body, and anticoagulates the blood in the extracorporeal circuit. Calcium is infused into the patient (generally through a separate catheter) to prevent hypocalcemia. Some portion of the citrate and bound calcium is removed in the effluent (dialysate and ultrafiltration). Any citrate (and the calcium bound to it) not removed in the dialyzer circulates to the liver where each citrate molecule is metabolized to 3 molecules of bicarbonate and the calcium is released.

![Image of citrate and calcium placement]

**Figure 8.1.** Typical citrate and calcium placement

Citrate Protocol

With the PrismaFlex, the pre-blood pump is a convenient place to hang the citrate for administration. With the Prisma, you will need a separate fluid infusion pump to administer the citrate,
as the heparin infusion pump incorporated into the Prisma machine will not be able to provide the flow rates necessary. The citrate line can be attached to the heparin infusion line (leaving the heparin syringe pump empty, and the heparin infusion rate set at 0).

Citrate is available in several concentrations. The following recommendations are based on 3.2% Sodium Citrate (anticoagulant citrate dextrose A, ACD-A).

- The citrate infusion rate (in ml/hr) should be around 1.5 times blood flow rate in ml/min (Example: if Qb = 100 ml/min, start citrate at 150-200 ml/hr). Start at 3X blood flow rate for first 30 minutes.
- Titrate the citrate infusion to maintain extracorporeal iCa++ 0.25 to 0.45 mmol/L

**Table 8-4. Citrate Infusion Recommendations**

<table>
<thead>
<tr>
<th>Post filter iCa++ (mmol/L)</th>
<th>Citrate Infusion Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.25</td>
<td>Decrease rate by 3 ml/hr</td>
</tr>
<tr>
<td>0.25-0.35</td>
<td>5 ml/hr</td>
</tr>
<tr>
<td>0.36-0.45</td>
<td>10 ml/hr</td>
</tr>
<tr>
<td>&gt;0.45</td>
<td>Notify Dr. if citrate infusion &gt;200 ml/hr</td>
</tr>
</tbody>
</table>

**Calcium Protocol**

Calcium chloride will cause sloughing if given perivascularly; make sure that the catheter used for infusion is in a central vein and has not dislodged.

**Practical Point:** With the multiple calcium recalls, the supply and form of calcium is variable. Calcium gluconate (which is not irritating if given SQ), does not have the same concentration of elemental calcium as calcium chloride.

- Make a 0.8% calcium chloride solution (2 gm CaCl2 in 250 ml 0.9% saline). Calcium chloride is available in the CRRT toolkit.
- Administer the calcium chloride infusion at 0.4 times the citrate infusion rate.
- Titrate the calcium infusion rate to maintain patient iCa++ at 1.1-1.3 mmol/L.
- Use calcium free dialysate.

**Table 8-5. Calcium Infusion Recommendations**

<table>
<thead>
<tr>
<th>Patient iCa++ (mmol/L)</th>
<th>Calcium Infusion Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;1.3</td>
<td>Decrease rate by 3 ml/hr</td>
</tr>
<tr>
<td>1.1-1.3</td>
<td>5 ml/hr</td>
</tr>
<tr>
<td>0.9-1.1</td>
<td>10 ml/hr</td>
</tr>
<tr>
<td>&gt;0.9</td>
<td>20 ml/hr</td>
</tr>
<tr>
<td></td>
<td>Notify Dr. if calcium infusion &gt; 200 ml/hr</td>
</tr>
</tbody>
</table>
No Anticoagulation

In some settings, systemic anticoagulation should be avoided, including patients with pre-existing critical bleeding (i.e., pulmonary hemorrhage, CNS hemorrhage), or within 24 hours of surgery or invasive procedures (e.g., renal biopsy, feeding tube placement). Regional citrate anticoagulation may be an alternative to systemic heparinization, but if liver failure is also present, citrate is relatively contraindicated.

CRRT

Without anticoagulation, expect the dialyzer to clot and need to be replaced frequently. Some human units routinely avoid anticoagulation and replace the dialyzer 2 to 3 times a day when it clots.

IHD

Intermittent hemodialysis can be performed without anticoagulation. A fast blood flow rate should be used to decrease thrombosis. Every 30 minutes, the dialyzer is flushed with 100-200 ml saline to disrupt any thrombi that are forming, and to visually assess the amount of clotting present. The ultrafiltration rate is adjusted to remove this fluid administration. In my experience, even with these modifications, thrombosis is severe enough to require discontinuation of treatment between 1 and 1.5 hours of treatment, unless the patient has a severe coagulopathy (i.e., full-blown DIC).

Other Anticoagulation Strategies

Other anticoagulants have been investigated in human dialysis fields, but there is no veterinary experience as yet. Low molecular weight heparin can be effective, and is preferred by some for people at high risk of bleeding, but is not considered cost-effective in the average patient.
Chapter 9  Machine Preparation

CRRT

Machine set-up takes about 15 minutes in experienced hands and only slightly longer in inexperienced hands. The machine is not supposed to be set up until immediately before the patient is ready to connect.

Prismaflex Setup

The Prismaflex machine will guide you through set up by on-screen instructions. Those instructions will not be recreated here. For each step on the screen, you can touch the circle to the left to mark it as done as you complete each step. The image of the machine on the right of the screen will change to highlight the area involved.

Prisma Setup

The Prisma machine itself will guide you through set up by on-screen instructions. These instructions are basically a recap of those instructions. While the control unit is in Setup mode, appropriate alarms are enabled and the yellow status light is illuminated.

- Choose a New Patient or Same Patient.
- If New Patient is chosen the control unit deletes the treatment history data of the last treatment. You will also be asked to confirm that this is a new patient. Press CONTINUE to do so. If Same Patient is chosen the control unit retains the treatment history data of the last treatment, retains the last chosen therapy and all its setting values. Press the CANCEL key if you want to change the therapy. Dialysate and/or replacement solution bags in use can remain in use until empty.
- Now you will be asked to set excess patient fluid loss or gain limit. You cannot lose or gain less than 130ml within 3 hrs. Press CONFIRM to save your setting.
- Choose the therapy desired based on the prescription (CVVH, CVVHD, CVVHDF, or SCUF).
- CVVHDF is the most versatile therapy, and is generally the therapy chosen. After the dialyzer is loaded, you cannot go back and change the therapy type.
- Attach crit-line chamber to bottom of filter; unscrew the red line from bottom—you will have to pull the line free from behind the filter—then screw the crit-line between red line and bottom of filter.
- Hold the filter vertically, and snap the cartridge into the carrier.
- Route replacement and dialysate lines
- Attach the 4 pressure pods.
- Press effluent line into BLD from bottom up; secure line in tubing guides. Hang effluent bag (yellow scale hook).
- Route access line. Hang prime collection bag (left corner).
- Insert return line into air detector and return line clamp.
- Press LOAD. When LOAD is pressed, the pumps begin turning, the set is drawn inward, and the pump segment of the set are threaded into the pump raceways.
- You will now be in the PREPARE SOLUTIONS screen
- Check that all 4 pump segments are loaded into pump raceways. If not, press UNLOAD and try again.
- Prepare priming, anticoagulant, replacement, and dialysate solutions. Hang 1 liter of priming solution (right corner). Saline is the typical prime solution. It can be refreshed later in the process.
• Connect anticoagulant line to anticoagulant syringe. Install syringe in pump.
• If using citrate anticoagulation, fill anticoagulant syringe with saline.
• Hang replacement solution (purple scale); hang dialysate (green scale).
• Press CONTINUE.
• The screen now says CONNECT LINES TO SOLUTIONS
• Connect return line (blue) to priming solution bag (use spike or luer connector).
• Connect effluent line (yellow) to effluent bag if required. Check for secure preconnection of access line (red) to prime collection bag.
• Connect replacement solution line (purple) to replacement solution bag (use spike or luer connector).
• Connect dialysate line (green) to dialysate bag (use spike or luer connector).
• If patient is not going to be ready to start treatment within 10 minutes leave machine in this screen. If patient will be ready continue to next step.
• Unclamp any clamped lines. Press PRIME to start automatic priming.
• The screen will say “Priming, please wait “
• During priming: do not connect or disconnect anything. Observe set closely for leaks; if they cannot be fixed, do not use set.
• When priming is complete, inspect all lines for air.
• If there is no air in the set, and no more priming is necessary, press CONTINUE.
• If more priming is needed, press and hold MANUAL PRIME until all air is out. If total reprime is needed, press REPRIME. Press CONTINUE when ready.
• The screen will say “Prime Test, please wait“ Wait for screen to say PRIME TEST PASSED.
• The machine will ask you to verify the correct sequence of a set of numbers. If the numbers are correct, press CONTINUE.
• IF THE NUMBERS ARE INCORRECT. TURN OFF THE MACHINE AND CALL SERVICE.
• If you need to refresh with Hetastarch or other solution hang the solution on the right corner replacing the nearly empty one-liter bag of saline. Clamp return line (blue), pull spike from saline bag and use the spike to connect to new bag. Unclamp return line (blue) and then press and hold down the Manual Prime key. Refresh volume should be twice the priming volume of the set.
• Press CONTINUE when ready.
• The screen will say SET FLOW RATES. Press the name of the flow rate you want changed. Press the up and down arrow to change the rates according to the prescription. If using citrate anticoagulation, set anticoagulant flow rate to zero.
• When all flow rates are set press CONTINUE.
• Machine will say “Connect Patient”.
• Clamp the following: prime collection bag, access line (red), return line (blue).
• Disconnect access line from collection bag: connect to red-coded luer lock or proximal lumen on catheter.
• Disconnect return line from priming solution bag: connect to blue-coded luer or distal lumen on catheter.
• Clamp all unused lines. Verify correct setup.
• Wrap catheter connections with Nolvasan soaked gauze
• Attach patient lines to patient’s harness or leg for safety
• Press START to begin treatment.
Setup Procedure for NxStage

The NxStage has detailed setup instructions on screen, with step-by-step instructions and pictures and diagrams to help you. Those will not be repeated here. A few key details:

- If the OneView computer screen is not on, press the very tiny reset button on the back of the cycler near the cycler on/off switch. If you cannot locate it, you can unplug and replug in the unit, which will turn on the machine. Select either New Patient or Current Patient. Touch SIMPLE to get to the set-up instructions.
- The buttons on the cycler interface are purposefully difficult to press. There should be a sound when you have actually pressed the button.

IHD

We have 3 intermittent hemodialysis machines available: one CentrySystem 3 machines (C3) and two Phoenix machines. The Phoenix is a newer model than the C3, and has more software features, including the ability to measure Kt/V by ionic dialysance. Certain features of the Phoenix are less well suited for small patients. Because the C3 is no longer supported by the company, we are slowly migrating to using the Phoenix exclusively. We will likely retire the C3 by April 2014.

IHD Disclaimer:
You should not attempt to set up and use the CentrySystem 3 or Phoenix intermittent hemodialysis machine unless you have specifically been trained in their operation. This information is provided here for those trained technicians to have all of the procedural information in one convenient manual.

The Gambro Phoenix: the ABC’s

This section will provide familiarity with the layout of the Gambro Phoenix intermittent hemodialysis machine and its parts, buttons, and accessories. The picture below shows the most important components of the Phoenix: the acid container, the bicarbonate source, and the cartridge (A, B, C). These are the first three components that must be connected to the machine during set up.

![Figure 9-1. Parts of the Phoenix machine](image)
1. Acid concentrate

This is the concentrated dialysate. It is mixed with ultra-pure water to make a dialysate that approximates the physiologic composition of plasma water. Even though this concentration, when reconstituted is in contact with the patient’s blood, the acidity and osmolality of the concentrate is so extreme that no organisms could possibly survive in this jug. Therefore, the acid concentrate does not need to be kept sterile. Please do not spit in it, though.

2. Extracorporeal circuit

This disposable accessory is the circuit that conducts blood from the patient’s dialysis catheter, through the machine and dialyzer and back to the patient. The circuit, along with the dialyzer (which is the red, blood filled tube on the left side of the dialysis machine), are used once then discarded.

3. Bi-Cart: bicarbonate source

Remember when I wrote that the acid concentrate is really acidic? Well, it would not be ideal to expose this concentrate (even after it is diluted) to the patient’s blood until it is buffered with a base to bring the solution’s pH down to a more physiologic range. The Bi-Cart provides more than enough bicarbonate to accomplish this. The Bi-Cart is separate from the acid concentrate because: (1) the bicarbonate ions will form solid precipitates with the acid ions if they dwell in solution together for too long; (2) the bicarbonate is a great medium for bacterial growth—therefore, the Bi-Carts are sterilized and are only used for 1 to 2 treatments; (3) separating the bicarbonate from the acid allows us to titrate the amount of bicarbonate separately from the amount of acid concentrate to which we expose the patient.

4. Blood pump

5. Drip chambers (arterial/access and venous/return)

6. Air/blood detector

7. Venous return clamp

8. Waste handling option (WHO) port

9. Heparin infusion pump

Figure 9-2. Additional parts of the Phoenix machine
4. Blood pump

This pump uses peristaltic action to propel blood from the arterial/access port of the dialysis catheter, through the extracorporeal circuit and back to the patient via the venous/return catheter port. Blood pump speeds range from 2.5 to 500 ml/min, depending on the machine settings.

5. Drip chambers (arterial/access and venous/return)

The drip chambers are 2 adjacent reservoirs of blood (1 reservoir is upstream of the dialyzer and the other is immediately downstream of the dialyzer). These chambers serve multiple purposes:

-They have ports for infusions of medications (e.g. heparin, citrate, mannitol, anti-emetics, sedation, etc.). Keep in mind, however, that if you infuse a substance in the arterial/access port, unless it is very large, it is likely to be removed by the dialyzer. So, all medications with the exceptions of anticoagulants (heparin, citrate) should be given through the venous/return drip chamber.

Each chamber has a pressure sensor that quantifies the amount of pressure on each side of the blood pump. The arterial/access pressure transducer almost always has a negative pressure reading, because it is quantifying how much negative pressure must be generated by the blood pump to aspirate blood from the arterial/access port of the catheter at the programmed blood flow speed. When the pressure is too negative, an alarm sounds and the pump stops until the pressure has been returned to within an acceptable range. The venous/return pressure transducer is almost always generates a positive measurement of pressure, because it is quantifying how much pressure the blood pump is generating to push the blood through the dialyzer and back to the patient through the venous/return port of the catheter. So, pulling blood = negative pressure and pushing blood = positive pressure. More on the pressure transducers later…

There is an air/blood interface in each of the drip chambers that allows any air bubbles that form from turbulent flow or that are dislodged from the dialyzer to rise from the blood and escape into the air (think bubbles fizzing up from a glass of beer…or soda for those that don’t partake). Hopefully, all air is trapped within these “bubble traps” because air elsewhere in the circuit can predispose to clotting. And if the air bubbles move to the dialyzer, they are just taking up space in there…that space could be used for dialyzing!! Air bubbles that are returned to the patient can cause air emboli in the lungs…which I guess is bad.

6. Air/blood detector and 7. Venous return clamp

The air/blood detector initially alarms when it first detects blood in the extracorporeal circuit. In the beginning of the treatment, as blood is initially removed from the patient and the priming solution (either a crystalloid or colloid is returned to the patient, the venous/return section of the extracorporeal circuit fills with blood. The initial alarm indicates that blood has been detected in the return line, thus blood has filled the dialyzer. This is the machine’s way of giving you the go-ahead to turn on the dialysate flow. This component also detects when there is air in the venous return line. Theoretically, air should be removed from the extracorporeal circuit in the bubble trap above the air/blood detector (see the section on the “drip chambers” above), but occasionally, especially with fast or turbulent blood flow (or when you royally screw things up). When the air/blood detector senses air, the venous/return clamp (#7) clamps the venous/return line and will not allow blood flow through the extracorporeal circuit and back to the patient, until the air bubbles have been removed from the circuit. Explicit instructions for removing air bubbles are available elsewhere in this tutorial.

8. Waste handling option (WHO) port

When the top of this little port is opened, there is a small drainage hole that has negative pressure to suck waste down the drain. This port is used during priming of the extracorporeal circuit; it
provides a cleaner, smoother option than during priming of the extracorporeal circuit. There are special WHO adapters that are attached to the end of the blood lines on the cartridge portion of the extracorporeal circuit. These allow for maintenance of sterility of the blood line attachments while the blood lines are hooked up to the dirty WHO port. SAVE THESE ADAPTERS AFTER USE! There will be a little container in the dialysis room labeled “USED WHO ADAPTERS;” put the used WHO adapters in this container. We re-sterilize and re-use these for various procedures such as blood primes.

9. **Heparin infusion pump**

No mystery here...the heparin infusion pump infuses heparin. You can program the rate of infusion (ml/hr), when the infusion starts, when it stops, whether you want a constant rate infusion or intermittent boluses, etc. The heparin infusion line enters the extracorporeal circuit immediately downstream of the blood pump.

10. **Hansen connectors**

These hoses/connectors transport dialysate from the Phoenix to the dialyzer (blue connector; bottom) and from the dialyzer back to the Phoenix (red connector; top) to be flushed down the drain. These connectors must snap into place, both on the dialyzer during treatment and the machine after treatment. If they are not snapped into place, there will be a flood of dialysate in the dialysis room or the machine will make lots of loud, annoying alarm sounds...or both. You’ll notice that the Hansen connectors conduct dialysate in a countercurrent direction to the blood...can you think of any reason this might be helpful?

11. **Dialyzer**

I saved the best for last...the dialyzer. This is the artificial kidney. This tiny little tube attached to this giant machine is where all the dialysis (a.k.a. magic) happens. The dialyzer is composed of an outer, plastic jacket and inner hollow fibers. Blood flows through the inside of the hollow fibers (there are as many as 20,000 fibers in each dialyzer), which are made of a semi-permeable membrane, and
dialysate flows around the hollow fibers, bathing the fibers. Uremic toxins are removed from the blood and swept away in the dialysate via a phenomenon called diffusion (more on diffusion later).

**Setup Procedure for the Phoenix**

Set-up check list: Blood cartridge, dialyzer, 2x 500ml bags of NaCl, 10X either 6mls (med-large dog), or 3mls (cat/small dog) of hep/saline flushes, 3X 6cc syringes, 1x 12cc hep/saline syringe, Crit-line adaptor.

- Turn on RO pump and do all daily water tests
- Turn on water to machine
- Turn on machine
- Do your ABC’s:
  - Connect Acid Concentrate (White wand on back of machine to white connector)
  - Attach BiCart (keep caps as can last 48hrs if capped on both ends and kept in refrigerator)
- Load blood cartridge
  - Open door of blood pump segment
  - Place arterial patient line in arterial clamp
  - Place venous patient line into air/blood detector and venous clamp by opening clamp, seating tubing, and closing clamp.
  - Clamp heparin line into green clamp (do not attach heparin syringe at this time)
  - Clamp arterial saline infusion lines in the two red clamps (with no syringes or saline attached)
  - Clamp venous saline infusion line in blue clamp and attach 6cc syringe
  - Close door on blood pump segment
- On right side of machine press Setup key when using the pediatric blood cartridge or LWLV Setup key when using the neonatal blood cartridge
- While waiting for Prime key:
  - Make up a 500cc bag of heparinized saline using 1cc heparin and connect a 10 gtt/ml administration set
  - Load 12cc heparin syringe into pump on machine by using arrow keys to move the syringe pump mechanism to full open position, snap the syringe in place and then using the opposite arrow key to seat the mechanism against the end of the plunger. Snap the holding mechanism closed and attach to heparin line.
  - Attach crit-line chamber to arterial end of dialyzer
  - When Prime key appears on right side of machine:
    - Load dialyzer onto machine
    - Attach arterial blood line to dialyzer
    - Attach venous patient line to hep/saline bag
    - When machine opens venous line clamp, open administration set and gravity prime venous side of the blood cartridge (with the hep/saline). Be prepared to clamp the venous blood line.
    - When hep/saline reaches venous chamber and begins to spill over the lip, aspirate with 6cc syringe to raise saline level above lip
    - When hep/saline reaches the blue cap, clamp the line and connect it to venous end of dialyzer; then unclamp line
    - Open WHO port and check integrity (there should be no visible fluid)
    - Insert arterial patient line into WHO port
    - Open clamp on heparin line (green clamp)
• Connect Hansen connectors to dialyzer (depending on settings on machine, may need to wait for prompt to connect, after dialysate preparation is complete).
• Press Prime, then Prime w/o UF
• As the dialyzer fills with hep/saline, hit it with the pleximeter to jar air bubbles loose
• As hep/saline gets to arterial chamber, open one red clamp until saline rises to desired level, then immediately close clamp
• Gently hit area of venous chamber filter to knock all air bubbles from filter, and then continue to tap bubbles free from dialyzer fibers and blood cartridge lines
• Blood pump will stop automatically--if priming is not complete, follow instructions on machine

After Priming is complete
• When prime is complete, the blood pump will stop. Clamp arterial and venous patient lines, saline administration set, and heparin line clamp
• Connect saline administration set to arterial saline line with priming connector and open red clamp and fluid administration set
• Connect arterial and venous patient lines using priming connector on venous line and unclamp both lines--cover connection with nolvasan soaked gauze
• Discard priming connector in WHO port and close door
• Check that saline line is open, the clamp is open to saline, the clamps to venous and arterial patient lines are open and patient lines are connected and protected.
• Machine will automatically prime dialysate side of dialyzer when dialysate preparation is complete.
• When Recirculate button appears, continue to next steps (recirculate button will not appear until dialysate prep is complete)
• Press Recirculate button
• Allow recirculation to complete (15 min.) and use this time to tap all remaining air bubbles out of dialyzer, both chambers, and off of filter and all connections and injection ports
• During this time, set all dialysis treatment parameters—make sure to activate profiling before programming sodium profile. Activate profiling curve if you are using UF profiling.

Setting Treatment Parameters
• Go to the Home screen by pressing the tab at the lower left corner of the screen (the tab with the red dot)
• If using the blood pressure cuff on the Phoenix, press BPM tab, then select BPM ON at the right
• Press the SET button
• The parameters that can be programmed appear in different rectangles; select the parameter to be changed by touching it
• The parameter can then be adjusted using the “+” or “-” buttons just below the SET button
• When the desired value appears, press the backward arrow button below the SET button to confirm; this is the equivalent of pressing “enter” on a computer
• When all parameters are set, press the SET button again to get out of “set” mode, then press the Home tab
• Next press the Kt/V tab at the bottom of the screen to adjust settings for the Diascan program; then press the SET button
• If you choose not to use Diascan, touch the DIASCAN rectangle, then select the NO rectangle, and confirm by pressing the back arrow button
• If you are using Diascan, select each parameter, set it and confirm it as described for the blood pressure programming
• NOTE: you must select and confirm both the DRY WEIGHT and VOL OF DISTRIB parameters in order to get Kt/V readings, even if you don’t change the value of the parameter
• When finished with Diascan settings, press SET to come out of this screen, then press Home
Next press the PROFILE tab at the bottom of the screen

On the right you’ll see an ACTIVATE CONDUCT. CURVE button and/or an ACTIVATE UF RATE CURVE button; you must activate each one by touching the button or set the program to CONSTANT if you are not going to use the program

If you do not know what each program does and do not know how to turn it off, you need a little more training before using this machine!

After activating, press the SET button

At the bottom left will be a TREATMENT TIME button if either one of the programs is activated; press it and program the amount of time you plan to treat by using the “+” and “-” buttons just below the SET button

Confirm the treatment time by pressing the back arrow button below the SET button

Touch the UF and/or CON tabs to set the profiling parameters; each parameter can be changed as described above by selecting the parameter, adjusting it, and then confirming it

When all parameters are set, press the SET button again to get out of Set mode; then press HOME

Select the HEPARIN tab at the bottom of the screen to set heparin infusion parameters

The syringe type to be used is written at the top of the screen, and the infusion modes are on the right; the syringe type must be set prior to SETUP, but the mode of infusion can be chosen now

Select the preferred mode of infusion (we usually do LINEAR, which is equivalent to CRI)

Press SET to set parameters, regardless of mode; set and confirm parameters as described previously

When parameters are set, press the SET button again, then the HOME tab

From the Home screen, press SET in order to program the final parameters

If neither of the programs in the PROFILE tab are activated, then there will be a rectangle for TREATMENT TIME, TARGET LOSS and UFR (ultrafiltration rate) at the top of the screen and one for CONDUCTIVITY just below UFR; one or more rectangles may be absent if either program is activated

All four of the above parameters must be set in order to start the treatment; parameters are set and confirmed as described above

Any of the other parameters in this screen can also be adjusted, although we generally don’t adjust them

Press the SET button to get back to the Home screen; a rectangle that says Pt. CONNECT should appear on the right near the bottom of the screen when the RECIRC TIME has counted down to 00:00; if not, one or more of the parameters may not have been set and confirmed (this is one of the trickier aspects of this particular machine)

When recirculation is complete, continue to next steps

Refresh after recirculation

Press Pt Connect , then confirm, and allow blood pump to stop

Clamp arterial saline infusion line and saline administration set

Clamp arterial and venous patient lines and disconnect, keeping priming connector attached to venous line

Insert venous line into WHO port

Connect arterial patient line to saline or Hetastarch administration set; use priming connector on saline administration set if using saline, or use new priming connector if using Hetastarch

Open clamps on arterial and venous lines, and on administration set

Press blood pump on/off and increase pump speed to 150ml/min

Refresh with proper amount and type of fluid

- Neonatal-- Half strength colloid solution (such as Hetastarch, Voluven, or Vetstarch
- Pediatric-- 0.9% Saline
• Volume should be twice the priming volume of the dialyzer and tubing combination being used—see list of volumes at end of section
• Stop blood pump.
• Clamp arterial and venous patient lines, and fluid administration set
• If priming with saline, leave as is until ready to connect to patient, but for no more than 5 minutes—you can skip the next section
• **If refreshing with a colloid, or waiting longer than 5 minutes to connect patient, perform the following steps, otherwise skip to “When patient is properly prepared…”**
  • Connect arterial and venous patient lines to each other as if in recirculation
  • Connect saline administration set into saline infusion line, unclamp the line and the red clamp
  • Close WHO port
  • Press Changes
  • Press Dialyzer Prime and confirm
  • Unclamp arterial and venous patient lines
  • Press Prime w/o UF
  • Press Bypass
  • Increase prime volume so that Hétrastarch can continue to recirculate until patient is ready to be connected
  • When ready to connect patient, decrease prime volume to the number of liters already primed—this will end the prime mode
  • The Pt Connect key should appear again—press this, and blood pump will stop
  • Clamp arterial and venous patient lines, and red clamp on saline infusion line
• **When patient is properly prepared, continue to next steps**
• Connect the arterial patient line to the arterial/proximal lumen of the patient’s catheter—unclamp line
• Connect the venous patient line to the venous/distal lumen of the patient’s catheter—unclamp line
• Wrap catheter connections with Nolvasan soaked gauze
• Unclamp both lumens of dialysis catheter
• Turn on blood pump
• When blood reaches the air detector, the machine will alarm and say blood has been detected. At this point, press Dialysis to start dialysis treatment. Override the alarm, and start blood pump again. Increase or decrease to desired blood pump speed.
• Open green heparin clamp
• Record start time

**Setup Procedure for Centrysystem 3**
• Turn on water treatment system and do all daily water tests
• Turn on water to machine
• Turn on machine
• Hook up acid concentrate and BiCart column
• Prime BiCart column twice
• Press Autotest
• Set dialysis treatment parameters
• Make up a 500 cc bag of heparinized saline using 1 cc heparin (1000 u) and connect a 10 gtt/ml administration set

*Do not hook up acid concentrate or BiCart during Autotest*
• Load 12cc syringe with desired concentration of heparin into pump on machine (1000 u/ml for large dogs, 500 u/ml for smaller animals)
• Attach crit-line chamber to arterial end of dialyzer
• Press Load/Unload
• Load dialyzer and blood cartridge onto machine. Do not place any lines into holder or clamps except for the venous patient line into the air detector
• Once blood cartridge is loaded and blood pump cover is closed:
  • Clamp heparin infusion line into black clamp and attach line to heparin syringe
  • Clamp arterial saline infusion lines into red clamps
  • Clamp venous saline infusion line into blue clamp and attach a 6cc syringe to the line
  • Connect arterial dialyzer line to red end of dialyzer
  • Put venous patient line into venous clamp and attach to heparinized saline administration set
  • Put arterial patient line into arterial clamp and insert priming connector into WHO port
  • Press Prime button to put machine in prime mode
  • Open black clamp, prime heparin line by going to the heparin screen and selecting Heparin Prime, then close black clamp
  • Open administration set and gravity prime venous side of the blood cartridge
  • When saline reaches venous chamber and begins to spill over the lip, aspirate with 6cc syringe to raise saline level above lip
  • When saline reaches the blue cap, clamp the line and connect it to blue end of dialyzer; then unclamp line
• When Autotest is complete, proceed to next steps
• Press Bypass and connect the Hanson connectors to the dialyzer
• Turn blood pump on (it should move clockwise)
• As the dialyzer fills with saline, hit it with the pleximeter to jar air bubbles loose
• When dialyzer is filled with saline, press Bypass (light should go out) and continue to hit dialyzer
• As saline gets to arterial chamber, open one red clamp until saline rises to desired level, then immediately close clamp
• Gently hit area of venous chamber filter to knock all air bubbles from filter, and then continue to tap bubbles free from dialyzer fibers and blood cartridge lines
• Blood pump will stop automatically--if priming is not complete, restart blood pump and allow prime to continue until complete
• When prime is complete, clamp arterial and venous patient lines and saline administration set
• Connect saline administration set to arterial saline line with priming connector and open red clamp and administration set
• Connect arterial and venous patient lines and unclamp both lines--cover connection with nolvasan soaked gauze
• Cover priming connector in WHO port so as to keep sterile using 3 cc syringe
• Press Prime button to take machine out of prime if necessary
• Turn blood pump on and increase speed to 500
• Select Recirculate
• Perform venous pressure high test during recirculation--while pressure limits are open and saline administration set is open to arterial chamber, clamp venous patient line; verify that machine gives a venous pressure high alarm
• Allow recirculation to complete (15 min.) and use this time to tap all remaining air bubbles out of dialyzer, both chambers, and off of venous chamber filter and all connections and injection ports
• When recirculation is complete, continue to next steps
• Clamp arterial saline infusion line and saline administration set
- Neonatal—turn off blood pump
- Pediatric—decrease speed to 200, then turn off blood pump
- Clamp arterial and venous patient lines and disconnect, keeping priming connector attached to arterial line
- Connect venous line to priming connector in WHO port
- Connect arterial line to saline or Hetastarch administration set
- Open clamps on arterial and venous lines, and on administration set
- Press resume
- Refresh with proper amount and type of fluid
- Neonatal—3% Hetastarch
- Pediatric—0.9% Saline
- Volume should be twice the priming volume of the dialyzer and tubing combination being used—see list of volumes in appendix or Table 7-1
- Stop blood pump
- Clamp arterial and venous patient lines, and administration set
- Connect arterial and venous lines and cover again with nolvasan soaked gauze
- Leave priming connector uncapped in WHO port to test port function. There should be no liquid backed up into connector after 5 minutes, otherwise WHO port is not functioning properly. After 5 minutes, remove connector from WHO port.
- Connect a 0.9% saline bag to arterial saline infusion line and open administration set but keep red clamp closed
- Unclamp arterial and venous patient lines
- Press resume and set blood pump speed between 350 and 400
- Use pleximeter to tap any remaining air bubbles from dialyzer and lines
- Press Ready
- Press Alarm Test
- Select A for all tests
- Watch to see that the machine passes all tests
- When alarm test is complete, reduce speed to 80 ml/min
- The machine is now ready to hook to patient
- We leave the screen with the Pass/Fail option at the bottom as a way for others to know that the disposables have been refreshed and the alarm test has been completed
- When patient is properly prepared, continue to next steps
- Turn blood pump off
- Clamp arterial and venous patient lines
- Connect the arterial patient line to the arterial/proximal lumen of the patient’s catheter—unclamp line
- Connect the venous patient line to the venous/distal lumen of the patient’s catheter—unclamp line
- Wrap catheter connections with Nolvasan soaked gauze
- Attach patient lines to patient’s harness or leg for safety
- Unclamp both lumens of dialysis catheter
- Turn on blood pump
- When blood reaches the dialyzer, press Dialyze and record start time
- Unclamp heparin infusion line
Water Treatment System Daily Use and Monitoring

Water purity is a vitally important, often overlooked aspect of maintaining a hemodialysis unit. Exposure of patients to impure dialysis water can result in disastrous consequences. There are several modalities and devices available for cleaning water and, because no single method is adequate for production of dialysis-quality water on a large scale, a combination of methods are generally employed. In our unit, we use multiple filters with varying sized pores for removal particulate matter from the water, activated carbon filters (ACFs) for removal of chlorine and chloramines, and a reverse osmosis (RO) device for removal of inorganic and organic solutes, including microorganisms and endotoxin. These devices, along with additional portions of the treatment system that are in place to optimize performance of the RO device, will be discussed in detail, by the order in which the water travels. Devices that may be present in other configurations of water treatment systems will be discussed at the end of this section.

Temperature Blending Valve (TBV)

Water treatment systems, particularly RO devices, operate most efficiently at particular water temperatures (most commonly 77 degrees Fahrenheit). In order to achieve this optimal temperature, a water heater is attached to a valve that allows addition of heated feed water to the original feed water source. The thermometer on the heating valve utilizes spring-loaded technology. It is important that the temperature be kept within the desired range (within 2 to 3 degrees of 77) as exposure of the water treatment equipment to a wide range of temperatures can damage the water treatment equipment.

Booster Pump (BP)

Booster pumps are used to maintain a minimum water pressure and flow throughout the water treatment system at all times. The BP is controlled by a drop in either water pressure or water flow, which initiates the action of the pump, returning water pressure and flow to a predetermined level (above a set point).

Depth Filter #1 (DF1)

Depth filter #1 is a multi-media filter located after the booster pump. Due to the large pore size (5 microns) of DFI, it primarily functions to remove large particulate matter (e.g. silica and clay particles) from the water. Removal of these particles preserves the downstream devices by preventing fouling of ACFs and RO membranes.

Activated Carbon Filters (ACFs)

Chlorines and the combination of chlorine and ammonia (chloramines) are oxidative chemicals added to municipal water systems as bactericidal agents. These agents provide control of bacterial growth at low costs. Effective removal of chlorine and chloramine from feed water is essential to obtaining acceptable water quality for dialysis because exposure of blood to these chemicals results in oxidation of hemoglobin, formation of Heinz bodies, and extravascular hemolysis. In severe cases of chlorine/chloramine exposure intravascular hemolysis may also occur. The consequence of a single exposure to chlorines or chloramines can be disastrous. Therefore, fail-proof measures must be in place to prevent exposure.

Reverse osmosis and deionization devices (discussed later) do not effectively remove chlorine or chloramines, so an additional device consisting of a tank filled with granulated activated charcoal or carbon (GAC) must be used. Two tanks are placed in series within the path of water flow, before water reaches the RO device. The first tank, the primary carbon tank or the "worker," removes nearly all of the...
chlorine and chloramine chemicals and the second tank, the "polisher", removes the remainder. The microporous structure of the GAC permits adsorption of organic matter, such as chlorine and chloramines, thus removing these substances from the feed water. Over time, the GAC in the "worker" tank becomes saturated with organic water and the "polisher" tank must remove a larger amount of chlorine and chloramines. The two tanks are situated in series to prevent escape of chlorine and chloramines into the product water, once the "worker" tank becomes saturated. To detect saturation of the "worker" tank, a water sample is taken at a valve (Sp2) situated where the water leaves the "worker" tank, prior to entering the "polisher" tank. The chlorine content of the water is tested to verify that chlorine and chloramines have been sufficiently removed from the water. If the test results show an inappropriately high amount chlorine leaving the "worker" tank, a second sample should be taken immediately after the water leaves the "polisher" tank (Sp3). If the water leaving the "polisher" tank has sufficiently low chlorine content, you may proceed with dialysis. However, the water treatment vendor must be contacted immediately to replace the "worker" tank as soon as possible (usually, the "polisher" tank replaces the "worker" tank, and a new "polisher" tank is provided). If an inappropriately high amount of chlorine is detected leaving the "polisher" tank, you CANNOT use product water from the treatment system for dialysis, and the water treatment vendor must be contacted immediately to replace both GAC tanks.

**Total Chlorine Test Instructions:**
1. Be sure that the water system has been in operation for at least 15 to 20 minutes prior to testing the chlorine content—it is essential that all stagnant water is flushed through the tank prior to testing
2. Using the valve (Sp2) located between the two carbon tanks, pour 25ml of water in the mixing glass bottle, up to the white line
3. Open the chlorine reagent powder and add the contents to the mixing bottle
4. Gently agitate the mixture, then allow it to sit for 5 minutes
5. Place the viewing adapter in the color comparator opening
6. Fill the clear, plastic tube labeled H2O to the line with water from the valve (Sp2) located between the two carbon tanks, and place it on the left side in the comparator
7. Fill the other tube labeled Cl- with the solution prepared in the mixing glass bottle sample and place it on the right side in the comparator
8. Orient the comparator with the tube tops pointing to a window or light source
9. Rotate the disc to obtain a color match.
10. Read the chlorine concentration from the scale window, divide the result by 5
11. The acceptable range is less than 0.1 ppm

**Depth Filter #2 (DF2)**

The GAC particles can release particles, called "fines" which can foul the RO membrane. Therefore, an additional 5 micron multi-media filter is located within the housing of the RO device to prevent contact of the "fines" with the RO membrane. This filter has the same pore size as DF1, but has a smaller surface area.

**Water Softener**

Water softeners are utilized to protect and prolong the life of the RO membrane. While there are economical advantages to the use of water softeners, they are major sites of microorganism growth and a reservoir for downstream seeding of the water treatment system. Our water treatment system
does not utilize a water softener. However, typical devices consist of resin beads fixed with sodium ions. Water passes around these beads, cations, such as calcium, magnesium, iron, and manganese, are exchanged with sodium. An adjacent brine tank is necessary as a source of salt to regenerate the resin beads. Water softeners usually have timers that are set to regenerate the resin beads; these timers should be set such that regeneration does not occur when a patient is being treated.

Water hardness is monitored in grains per gallon (GPG) or ppm. AAMI recommends a limit of 1 GPG or 17.2 ppm. To convert GPG to ppm, divide by 0.058. Additional monitoring includes measurement of the change in pressure before and after the water softener. The device may require back flushing if the pressure drop is greater then 10 PSI. Chlorine may also cause the resin to deteriorate, which can also cause a drop in pressure. The salt level in the brine tank should be monitored, as well. The water should always be above the salt, and one should be certain that the salt at the top of the water level has not solidified, making visualization of the true salt level difficult.

**Reverse Osmosis Machine**

The reverse osmosis machine is a critical part of the water treatment system. The RO membrane is a highly selective membrane that allows only water to pass through. Bacteria, endotoxins, sodium, other electrolytes and elements are rejected. Hydrostatic pressure is placed on the incoming water to force it through the membrane to be delivered to the dialysis machines. Because the RO membrane is one of the most expensive components of the system, the multimedia filters are important to remove as much particulate matter as possible to avoid fouling the membrane.

**Deionization Tanks**

Deionization tanks are not part of our current system. With our old system, we had DI tanks available for emergency use in case the RO pump failed. The resin in deionization tanks bind cations such as sodium and release H⁺ and they bind anions such as chloride and release OH⁻. The H⁺ and OH⁻ combine into H₂O.
Chapter 10  Patient Preparation

Once the catheter is in place and the machine is set up, get the patient. Immediately before starting ERRT, re-evaluate the patient. If the blood pressure is less than 80 mmHg, start a pressor agent before starting ERRT. If you cannot maintain the blood pressure above 80 mmHg, consider peritoneal dialysis instead of ERRT. If the PCV is less than 20% in dogs or 18% in cats, decide whether you need to transfuse in advance or have cross-matched and blood-type compatible blood on hand.

<table>
<thead>
<tr>
<th>Box 10.1</th>
<th>Pre-dialysis patient parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td></td>
</tr>
<tr>
<td>Blood pressure – Sys/Dias (MAP)</td>
<td></td>
</tr>
<tr>
<td>Heart Rate</td>
<td></td>
</tr>
<tr>
<td>Respiratory Rate</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
</tr>
<tr>
<td>O2 Saturation</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Box 10-2</th>
<th>Pre-Dialysis Laboratory Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUN</td>
<td>Sodium</td>
</tr>
<tr>
<td>Creatinine</td>
<td>Chloride</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Potassium</td>
</tr>
<tr>
<td>Albumin</td>
<td>PCV</td>
</tr>
<tr>
<td>ACT or iCa++</td>
<td>Total Solids</td>
</tr>
</tbody>
</table>

Put on a harness (dogs) and tie the dog loosely to the table (if dialyzing on a table, not in a cage). Remove the bandage covering the catheter. Scrub the catheter (see section on catheter care), wearing a surgical mask and exam gloves.

Draw any pretreatment blood samples needed. If using heparin as the anticoagulant, wait for the ACT or PTT results to determine heparin priming dose. After administering the heparin prime, connect the blood tubing. Wrap the connection in a nolvasan soaked gauze. Tape the tubing to the harness (dogs) or front leg (cats). Double check the prescription parameters, dialysate, and replacement fluid composition.

When ready to start, unclamp the catheter lumens and blood lines. Start the blood pump on the lowest setting. Gradually, over the first 15-30 minutes, increase the blood pump speed to the target speed.
Chapter 11 Monitoring

A quick assessment of the patient immediately prior to starting CRRT or IHD should be performed, as patients that require these procedures are frequently critically ill and may become unstable in a short period of time. In addition to monitoring prior to starting, several parameters need to be monitored throughout the duration of the treatment. This chapter covers the parameters that are routinely measured; additional parameters may need to be assessed in individual patients.

Blood Pressure

Blood pressure may decrease for a variety of reasons, including acute decrease in effective circulating volume associated with filling the extracorporeal circuit, inflammatory reactions associated with exposure of blood to the dialysis membrane, rapid ultrafiltration, excessive ultrafiltration, bleeding from excessive anticoagulation or uremic thrombocytopathy, and the underlying disease process.

The frequency of monitoring blood pressure depends on the circumstances, and certainly patients with unstable or marginal blood pressure measurements or those developing clinical signs of hypotension should be monitored frequently.

General Guidelines

CRRT: 15, 30, and 60 minutes after starting treatment, then hourly thereafter.
IHD: 15 minutes after starting treatment, and every 30 minutes thereafter.

Coagulation

Heparin

Currently, we use the partial thromboplastin time (PTT) to monitor heparin anticoagulation. Assess the PTT prior to starting treatment, and use this value to determine the initial heparin dose. Check the PTT 30 minutes after starting, and adjust the heparin infusion as necessary (see Tables 8-1 and 8-3 in Chapter 8 Anticoagulation). If the PTT is in the target range and no dose adjustments are needed, check the PTT every hour during IHD. With CRRT, check the PTT at 30 minutes, 1 hour, and then every 4-6 hours thereafter. Always check the PTT 30 minutes after any dose adjustment. If whole blood PTT cartridges are not available, we may still have some activated clotting time (ACT) cartridges around, which can be used with the ACT II machine in dialysis.

Citrate

If you are using regional citrate, you can measure either PTT, ACT or the ionized calcium, with ionized calcium being preferred. See Tables 8-4 and 8-5 in Chapter 8 Anticoagulation for target ranges for the extracorporeal circuit and patient. Check calcium parameters at 1 hour, then every 4 hours for the first 12 hours, every 6 hours for the next 24 hours, and if all is stable, every 12 hours until therapy is discontinued.

Blood Volume

The CritLine monitors hemoglobin and mixed venous oxygen saturation via an optical sensor that attaches to cartridge that can be placed in the blood line. Presuming there is no ongoing bleeding or transfusion, any changes in hemoglobin content reflect changes in intravascular volume. A rapid decrease in intravascular volume, generally considered to be more than a 10% decrease in an hour, may precipitate symptomatic hypotension.
Mixed Venous Oxygen Saturation

The CritLine also monitors the oxygen saturation of the blood in the extracorporeal circuit, which is considered mixed venous blood. SvO2 is the balance between oxygen delivery and oxygen consumption (metabolic rate). Mixed venous oxygen saturation is impacted by cardiac output, blood pressure, oxygenation, and hemoglobin. A SvO2 over 70% is considered normal, however, I have had many patients with values around 50% without any noticeable ill effects during intermittent hemodialysis treatments. Whether patients can sustain that over the much longer time course of CRRT is unknown to me.

Box 11-1. Downloading Data from Crit-line to the Computer

- Turn on Crit-line machine if off. If a treatment has just finished, go to the menu and select “setup/stop”, and then again “stop”.
- Attach cable/phone line labeled “crit-line” from the computer hard drive in diaysis to the port labeled “serial/nurse” on the back of the Crit-line machine.
- Use the “Crit line Reporter” icon on the dialysis computer screen to open the program.
- Enter patient name and ID number. Also enter any other information you want.
- Click the button “Get Data”. Downloading of data will now occur.
- Save the report.
- At this time, you can clear the data from the Crit-line machine by selecting “clear memory”.


Figure 11-1. Algorithm for assessing disorders of tissue oxygenation
Biochemical parameters

During CRRT, a renal panel consisting of BUN, creatinine, phosphorus, albumin, sodium, chloride, and potassium is assessed prior to treatment, at 6 hours, 12 hours, and 24 hours during the first day. A renal panel will likely be performed every 12 hours on days 2 and 3 of treatment. Additionally, a BUN and/or creatinine will be measured after any major changes in the CRRT prescription.

Before and after each intermittent hemodialysis treatment, a renal panel (BUN, creatinine, phosphorus, albumin, sodium, chloride, and potassium) is assessed.

In dogs, we send the renal to Idexx, because the Catalyst frequently gives us erroneous results for creatinine if the patient is icteric. If immediate results are needed, there is a Catalyst machine in dialysis and in the mini-lab on the 2nd floor. Heparinized plasma or serum can be used. Generally, 0.5 ml whole blood will provide sufficient plasma. If any parameters are above the detection limits of the machine (BUN > 130 mg/dl; creatinine > 13.6 mg/dl; phosphorus > 16 mg/dl), be sure to use the dilution feature on the Catalyst. If a full chemistry panel is desired to monitor other parameters, of course it can substitute for the renal panel.

Hematocrit

The PCV should be checked immediately prior to starting therapy and at the conclusion of each IHD treatment. Anemia is common in patients with renal failure, and PCV can drop precipitously in actively bleeding patients. Starting the extracorporeal circuit in a patient with low or marginal anemia may induce a crisis of tissue oxygenation, and transfusion prior to starting treatment may be necessary.

If the CritLine monitor is being used, the hematocrit will be continually monitored during treatment. If not, monitor the PCV every 6-12 hours during CRRT and SLED treatments.

Weight

Patients should be weighed before and after each IHD treatment. For small CRRT patients, body weight every 6 hours is one aspect of monitoring fluid status. Larger patients should be weighed at least once a day. More frequently would be ideal, but may be impractical. The patient may be temporarily disconnected from the machine to be transported to the scale, or the machine may be taken to the scale (with a battery back-up). Be prepared for blood flow alarms as the patient is moved, and for dialysate and replacement fluid error messages due to movement of the machine.

Transmembrane Pressure

Transmembrane pressure (TMP) is a measure of the pressure gradient from the blood side to the dialysate side. The higher the transmembrane pressure, the more ultrafiltration that can be achieved per unit time. Mathematically, the coefficient of ultrafiltration (KUF) is the number of ml of fluid that can be removed per hour for each 1 mmHg of transmembrane pressure.

\[ \text{Equation 11-1} \]

\[
\text{UF (ml) = KUF x TMP (mmHg) x Dialysis Time (hr)}
\]

All of our machines have precise volumetric ultrafiltration control, which means that the machine automatically calculates the required TMP to remove the desired amount of fluid, and monitoring/adjustment of the TMP to control UF is not required. However, changes in TMP may indicate thrombosis in the dialyzer, which decreases the efficiency of clearance. The TMP alarm limits can be set by the operator, so that if the TMP increases, an alarm alerts the operator. A rising TMP may
prompt an increase in anticoagulation, or may prompt a filter change before catastrophic clotting occurs, resulting in significant blood loss for the patient.

Access Pressure

Pressure transducers allow the dialysis machines to monitor pressure in the arterial and venous tubing segments. The arterial access pressure is negative. Poor function of the arterial lumen will cause the access pressure to be excessively negative. Causes of poor function include partial occlusion by thrombosis, kinking, or being lodged against the vessel wall. Venous access pressure is positive. Thrombosis of the catheter (or filter in the venous chamber of the pediatric sized extracorporeal tubing set) or kinking of the catheter will further increase the venous access pressure.

CRRT

The arterial and venous access pressures should be evaluated every hour. Trends in these pressures may allow prediction of thrombosis prior to catastrophic clotting. While it is helpful to record these pressures for quick reference, we can download these measurements (which are recorded every minute) from the PrismaFlex after each treatment.

IHD

In addition to monitoring the access pressures throughout treatment, we routinely record 2 other measures at each dialysis treatment. If the maximum sustained Qb decreases over time, or if the Qb at -200 mmHg decreases, it may indicate impending catheter malfunction. We do not have the software to download this from the Phoenix; you MUST record it in the database manually.

Adequacy

CRRT

The Kt/V should be calculated and subsequently measured every 12 hours also.

IHD

The URR is calculated for each treatment, and Kt/V is measured during each treatment using the Phoenix machine.
Chapter 12  Data Recording

To make data recording and reviewing easier, we have a computerized database for ERRT patients. There is a small MacBook Air and a large MacBook Air available in dialysis for data recording. Additionally, the desktop in dialysis, and Langston’s blue Dell laptop have the necessary software and access. An iPad can be used also, using a free app. The database is based in FileMaker Pro. Specific instructions for that are available separately (click on the User’s Manual button on the Welcome screen). I am trying to get all veterinary dialysis units to use this database, so tell your friends I will give them a copy of the database for free if they will use it.

Figure 12-1. Welcome Screen for Intergalactic Dialysis Database
Figure 12-2. Prescription screen for Intergalactic Dialysis Database
Chapter 13  Complications

Patients with renal failure severe enough to require ERRT are complex patients, and case management is rarely straightforward. In addition to manifestations of uremia that are commonly encountered in uremic patients managed with traditional medical therapies, ERRT patients may have complications directly related to the extracorporeal therapy. The clinician may also encounter long-term complications of uremia that are rarely seen because of limited patient survival time with traditional medical therapy of the end-stage renal failure patient.

Technical Complications

Technical complications due to machine errors or malfunctions are rare because of the number of redundant monitors and alarms built in to modern machines. When they occur, they may range from mild to devastating problems. The number and severity of operator errors are dependent on a variety of factors, including the training and experience of the operator, the work environment, and some patient factors. Complications related to water quality include intoxications and infections.

Hypotension

A decrease in blood pressure is common at the start of ERRT. A variety of reasons contribute to the initial development of hypotension. The volume of the extracorporeal circuit in relationship to the patient’s blood volume can be considerable, up to 35% in smaller cats. Exposure of the blood to a bioincompatible dialyzer membrane can activate the complement and coagulation cascades, releasing several mediators that can cause hypotension, such as C3a, C5a, and kinins.

Signs of hypotension include vomiting and collapse. Hypotension reliably occurs within the first 30 minutes of intermittent renal replacement therapy in cats, and frequently occurs in small dogs, and occasionally in large dogs. The magnitude of decrease in the blood pressure is variable from patient to patient. Most cats are able to autoregulate and return blood pressure to almost baseline values within 30 to 60 minutes of the start of dialysis, but some cats seem unable to autoregulate. The blood pressure will generally return to pre-dialysis values after rinseback. Priming the extracorporeal circuit with a colloid (i.e., half-strength hetastarch) helps mitigate the drop in blood pressure in cats and small dogs, but is not generally necessary for medium to large dogs (in which a saline prime will suffice). With CRRT, priming with blood may be a practical solution.

Rapid ultrafiltration may lead to hypotension, if the rate of removal from the vascular compartment exceeds the capacity for refilling from the interstitial compartment. In general, the ultrafiltration rate should not exceed 20 ml/kg/hr. Although small fluid boluses or hypertonic saline may rapidly correct hypotension, in people, the additional sodium load increases thirst after dialysis, leading to more fluid intake and retention, necessitating a rapid ultrafiltration rate at the next dialysis treatment. Monitoring blood volume (e.g., with a Crit-Line machine) may predict symptomatic hypotension, allowing intervention before hypotension occurs.

Dialysis Disequilibrium Syndrome

Disturbances of the nervous system can be induced by uremia and by its treatment. Disorders caused by dialysis include dialysis disequilibrium and CNS hemorrhage secondary to anticoagulation. Disorders caused by uremia include uremic encephalopathy, peripheral neuropathy, and hypertensive encephalopathy.

Dialysis disequilibrium syndrome (DDS) is a syndrome induced by rapid dialysis in severely azotemic patients. The pathogenesis of this syndrome is poorly characterized, but it results secondary
to the development of cerebral edema. It is most likely to occur during the first few dialysis treatments, when uremia and the associated metabolic derangements are most profound. However, it can occur at any time, even with chronic dialysis. It may be precipitated by a change in the patient’s condition, such as dehydration or worsened uremia. The exact etiology has been difficult to elucidate, but at least 3 theories have been proposed: reverse urea effect, rapid correction of acidosis, and rapid sodium changes.

Urea has a high volume of distribution and it is considered an ineffective osmole, because its wide distribution prevents creation of an osmotic gradient between compartments. Urea is readily removed from the blood by diffusion into dialysate. Redistribution from the intracellular compartment is much slower than the removal from the blood into dialysis, and studies in rats show a decrease in urea transporters in the brain of uremic rats. A relative osmotic gradient is created under these circumstances leading to interstitial and cellular swelling and cerebral edema.

Rapid correction of acidosis with paradoxic CNS acidosis is another suspected cause. Bicarbonate that rapidly diffuses from the dialysate into the bloodstream buffers hydrogen ions, forming H2CO3, which rapidly dissociates into water and carbon dioxide. The blood-brain barrier is highly permeable to carbon dioxide, which diffuses into the brain, where it is converted back to hydrogen and bicarbonate ions. Because these molecules are polar, they are trapped in the CNS, and the increasing hydrogen ion concentration contributes to paradoxic CNS acidosis.

Rapid changes in sodium concentration may also play a role. However, rapid correction of hyponatremia in a severely azotemic patient with large amounts of intracellular urea may not cause central pontine myelinolysis as readily as it would in the nonazotemic patient. The role of formation or clearance of idiogenic osmoles in DDS is unclear.

Clinical signs of DDS include agitation, disorientation, seizures, vomiting, coma, and death. Dogs usually have premonitory signs such as restlessness in a previously quiet dog. Cats, unfortunately, frequently have no noticeable premonitory signs and may rapidly go from appearing normal to a comatose state. DDS may occur at any time during dialysis or up to 24-48 hours after dialysis. Anecdotally, the period immediately after rinseback is a particularly vulnerable time.

Treatment of DDS involves dissipating the osmotic gradient by infusing osmoles into the bloodstream. Mannitol is the most commonly used treatment. The usual dose is ¼ to ½ gm/kg over 10 minutes. Extremely high doses of mannitol (> 4 gm/kg) may cause acute kidney injury (AKI). Hypertonic saline has the same short term effect as mannitol, but creates an undesirable sodium load. Some dialysis machines have the capacity of rapidly increasing the sodium concentration of the dialysate, to cause rapid diffusion of sodium from dialysate into the bloodstream, having the same effect as an IV bolus of hypertonic saline.

Prevention of DDS is clearly desirable. Mannitol may be given prior to development of clinical signs in high risk patients, which includes severely uremic patients (BUN > 150 mg/dl), small patients (< 5 kg), or those with preexisting CNS disease. The dose is administered 30-45 minutes after the start of dialysis for the first one to three treatments.

Sodium profiling, in which the dialysate sodium is initially higher and gradually decreases during the treatment is another preventative measure. Urea removal is greatest early in the treatment, when the concentration is the highest. By essentially adding sodium to the blood during this period, an osmotic balance is maintained, although sodium osmoles are exchanged for urea osmoles. Towards the end of the treatment, when the urea concentration is lower and the risk of disequilibrium is diminishing, the dialysate sodium is lowered, thus removing the sodium load from the patient.

Other preventive measures include decreasing the efficiency of IRRT during the first few treatments. Methods of accomplishing this goal include using slow blood flows, short treatment times, reversing the dialysate lines from countercurrent to concurrent, and by reversing the arterial and
Hemorrhage

Because anticoagulation is necessary during ERRT, a risk of hemorrhage from excessive anticoagulation is present. Mild forms may involve bleeding from the catheter exit site. Internal bleeding, including bleeding from gastric ulceration or massive pulmonary hemorrhage, have been encountered. Discontinuation of the anticoagulant (usually unfractionated heparin), administration of a reversal agent (i.e., protamine for heparin), and red cell or plasma transfusion may be required.

Respiratory Complications

Mild to severe hypoxemia is common during dialysis both in human and animal patients. Some patients come to dialysis with respiratory compromise from pulmonary edema or pleural effusion resulting from volume overload. Pulmonary hemorrhage is common in dogs with leptospirosis. Contact of blood with the dialyzer membrane activates the alternate complement pathway. This causes leukocyte and platelet aggregation in the pulmonary microvasculature that interferes with oxygen diffusion. The effect is maximal within 30 to 60 minutes of the start of dialysis and resolves within 120 minutes after its discontinuation. The Crit-Line monitor acts as a mixed central venous oxygen saturation monitor. Mixed central venous oxygen saturation is dependent on cardiac output, hemoglobin concentration, arterial oxygen saturation, and tissue oxygen utilization, and thus is affected not only by impairment of gas exchange in the lungs but also anemia and hypotension.

Gastrointestinal Complications

Anorexia, nausea, and vomiting are common complications of renal failure but also may be seen at the start of hemodialysis secondary to hypotension and diversion of blood flow from the gastrointestinal tract, biocompatibility reactions to the membrane, or contaminants in the dialysate. Dialysis disequilibrium can also cause centrally mediated nausea and vomiting. Using slow blood flow rates at the start of dialysis treatments with a gradual increase to the prescribed rate minimizes these signs and patient discomfort.

Catheter Thrombosis

Catheter thrombosis may be intraluminal or extraluminal. It can occur at any time, but is uncommon within the first week after catheter placement unless major problems with anticoagulation have occurred. By 1-3 weeks, even with relatively event-free intradialytic anticoagulation, catheter thrombosis becomes common, affecting about 50% of patients. A more complete description of catheter related complications is available in the Vascular Access section. Pulmonary thromboembolism, from platelet aggregation and thrombus formation induced by the catheter, can cause acute onset of mild to severe dyspnea during or between dialysis treatments. Despite the relatively common occurrence of catheter thrombosis, pulmonary thromboembolism appears to be a relatively uncommon problem.
Infection

There are multiple potential sites of infection in the ERRT patient. Uremia decreases the immune function, and indwelling catheters (including vascular and urinary catheters and feeding tubes) are a potential portal of entry for bacteria. The most common bacterium encountered in our unit in dialysis catheter and blood cultures is Staphylococcus. There appears to be a correlation between catheter thrombosis and infection. The most common urine infections are gram negative bacteria (E. coli and Klebsiella).

Edema

Many patients referred for ERRT are volume overloaded, which may manifest in a variety of ways, including pulmonary edema, pleural effusion, ascites, and generalized peripheral edema. Ultrafiltration during ERRT treatment and careful attention to fluid balance can help minimize this problem within the first several days.

Facial, intermandibular, and forelimb edema may occur in dogs over time. This may be an indication of partial cranial vena caval occlusion by the catheter itself or thrombosis or stenosis induced by the catheter. In many dogs, hypoalbuminemia is a concurrent problem, due to ongoing renal albumin loss, loss in the extracorporeal circuit, gastrointestinal loss, and suppressed synthesis due to systemic inflammation.

Malnutrition

Patients dependent on ERRT frequently have gastrointestinal manifestations of uremia including decreased appetite and vomiting, which are partially corrected by therapy. This decreased effective intake in combination with increased energy and protein requirements makes malnutrition common in renal patient. In addition, certain amino acids are lost in the dialysate, including taurine and carnitine. Early and aggressive nutritional support is prudent.

Aluminum toxicity

Aluminum is used in many municipal water treatment plants to clear flocculence as one stage of the water purification process. Municipal water is further processed by the dialysis facility to produce water for dialysate. Trace amounts of aluminum present in the dialysate may be transferred to the patient. Aluminum containing phosphate binders provide an additional and greater source of aluminum. Acute aluminum toxicity can occur if water treatment is inadequate, but it is generally encountered only after long-term exposure with chronic dialysis. Aluminum accumulation can lead to a microcytic hypochromic anemia. Neurologic or neuromuscular signs, including mild weakness, paresis, dullness, obtundation, or coma, are some of the clinical signs associated with aluminum toxicity. Chelation therapy with deferoxamine is used to control aluminum toxicosis, in conjunction with discontinuation of aluminum containing products.

Anemia

With moderate to severe renal disease, erythropoietin production is limited, leading to a slowly progressive anemia. In addition, small amounts of blood loss with each dialysis treatment, combined with any gastrointestinal losses, leads to anemia in almost all dialysis patients. Patients receiving treatment for more than 2-3 weeks generally will require some erythropoiesis stimulating agent (ESA). Darbepoetin (Aranesp) is a recombinant erythropoietin that has more carbohydrate groups than Epogen or Procrit. It appears to be less likely to cause pure red cell aplasia than Epogen or Procrit, and is
dosed less frequently. ERRT patients may have ESA resistance and require higher doses to maintain the hematocrit than non-dialysis dependent patients, because systemic inflammation may render the bone marrow hyporesponsive to ESA.

Bone Disease

Renal secondary hyperparathyroidism occurs in patients with end-stage renal disease. Although pathologic fractures are uncommon in adult dogs and cats with end-stage renal disease, chronic dialysis patients may be at a higher risk because of the longer survival and prolonged bone demineralization. Experience with this condition is limited in veterinary medicine, but new vitamin D derivatives and calcimimetic agents may help prevent or reverse this condition.

Neuropathy

Uremic polyneuropathy is a distal symmetric sensorimotor neuropathy that is probably present in 65% of humans with end stage renal disease on dialysis. It is uncommon in people if the GFR is greater than 10% of normal. “Restless leg syndrome” consists of creeping, crawling, prickling and pruritic sensations deep in the legs that temporarily disappear when the legs are moved. There is also loss of sensation (pain, light touch, vibration, pressure) in the lower leg. Weakness and distal muscle atrophy are common in advanced cases. Motor nerve conduction velocity is decreased. There is axonal degeneration with segmental demyelination. The etiology is still unclear, although involvement of middle molecule uremic toxins is hypothesized, due to improvement with increased hemodialysis. This syndrome has not been evaluated in animals, although dogs with severe CRF have been described as having involuntary muscle twitching or movements. Whether this represents a response to a “restless legs” type syndrome is not known.
Chapter 14  Deciding When To Discontinue ERRT

CRRT
There are two types of decisions for discontinuing CRRT – switching to IHD and stopping ERRT permanently. It may be difficult to determine whether a stable creatinine is due to native renal function or the CRRT procedure. If clinical parameters develop that may indicate improvement (i.e., resolution of anuria, increase in polyuria, return of appetite, etc.), it may be appropriate to decrease the CRRT dose to determine native renal function. Decrease the dose by 25% (i.e., if equal volumes of replacement fluid and dialysate are being used, decrease one of those by 50%). Recheck the BUN in 2 hours. If the BUN remains stable, decrease the dose by an additional 25% and recheck in 2 hours. Continue decreasing, and if the BUN remains stable, stop treatment and return the blood to the patient (if desired).

Transition from CRRT to IHD
The decision to switch from CRRT to IHD is based on hemodynamic stability (and staff availability), not on return of renal function. If the blood pressure is stable (preferably on no pressor agents, or at least on unchanging pressor doses), volume status is optimized, and systemic heparinization is not contraindicated, CRRT can be discontinued and the blood returned to the patient. Because renal function will not have returned by that point, IHD treatments will follow (likely the following day, depending on the time of day and patient characteristics). If a patient is relatively stable and CRRT is discontinued due to circuit clotting or other complications, it may be appropriate to not restart CRRT that night, but plan on starting an IHD treatment the next day.

Intermittent Hemodialysis
There are two types of decisions for discontinuing IHD treatment – stopping the individual treatment, and stopping ERRT permanently. Individual treatment goals are discussed in Chapter 7 and dictate when an individual treatment is complete. The best method is determining the treatment goal based on the amount of blood to process, and using that to guide treatment duration, although treating for a pre-established duration is the alternate method.

Sometimes an anuric patient suddenly becomes polyuric, which may portend renal recovery. The decision of whether to dialyze that day is based on a variety of clinical parameters, including the patient’s overall attitude, the rate of rise or decline in creatinine, potassium concentration, staff availability, and the creatinine (and potentially BUN) value itself, which should be checked prior to starting dialysis if there are strong clinical indicators of recovery. Although there is no absolute creatinine concentration that would dictate dialysis, in general, a creatinine less than 4-5 mg/dl may not necessitate treatment.

If the creatinine value increases only modestly, the interval between IHD treatments can be prolonged. If the creatinine value remains normal, does not increase, or is decreasing spontaneously (without dialysis) for several days, ERRT can be permanently discontinued.
Unscheduled Discontinuation

Machine complications, patient complications that interfere with treatment safety (e.g., bleeding, DDS), or need for procedures (surgery, CT scan, etc.) may necessitate discontinuation of the individual treatment. After the situation is resolved, treatment can be restarted.

Figure 14-1. Pre- and post-dialysis creatinine concentrations in a dog with partial recovery of renal function (5 treatments) ↑ indicates each hemodialysis treatment
Chapter 15 Procedures to Discontinue Treatment

Patient Procedures

During the last 10 minutes or so of the treatment, the patient’s catheter ports should be scrubbed in preparation for disconnection and rinseback. See the catheter care section in the vascular access chapter for details.

Machine Procedures

CRRT

With the Prisma and Prismaflex machines, there are several options for discontinuing treatment, either temporarily or permanently. The machine gives you three options. Change Set involves returning the blood to the patient in order to change the filter and tubing (due to clotting or because the tubing had been used for 72 hours). With this option, all the previous treatment history is retained. End Treatment can be performed with returning the blood to the patient or with discarding the blood. Temporary Disconnection involves returning the blood to the patient but keeping the same filter and tubing. This option is intended to be used for short procedures, such as CT scans or MRI or the like, and it is unlikely that we will use this procedure. Unfortunately, there is not a preset option on the Prisma machine for a temporary disconnection without returning the blood, for very short trips (i.e., radiographs, walk to the scale, etc.). Because this is an option we would like to use, tips on how to accomplish this are included in this section.

The following procedures are described here:
Change Set Procedure (with Blood Returned to Patient), Prisma, Prismaflex
End Treatment Procedure With Blood Returned to Patient, Prisma, Prismaflex
Temporary Disconnection (blood not returned), Prisma, Prismaflex
Temporary Disconnection Procedure With Blood Returned to Patient, Prisma, Prismaflex
Air Rinseback for the Prisma and Prismaflex Machines
Rinseback Procedure for NxStage

Change Set Procedure (with Blood Returned to Patient), Prisma, Prismaflex

- Prepare the catheter by scrubbing the connections to the tubing. Wear a mask and gloves when doing so.
- Hang a bag of saline on the left corner.
- Press STOP.
- Press CHANGE SET.
- Clamp the access (red) line. Disconnect the access (red) line from the patient and connect it to the saline. Wipe opening of proximal lumen with sterile gauze, flush vigorously with saline or heparinized saline, and clamp shut.
- Unclamp access line.
- Return the blood to the patient by pressing and holding down the RETURN BLOOD key to pump the saline through the access line.
- The blood pump will automatically start at 110ml/min, therefore if you desire a slower blood return rate tap the key intermittently to generate a slower average speed. With the Prismaflex, you can adjust the blood return rate.
Blood return should never be done at a quicker blood pump speed than used during treatment. IT IS VERY IMPORTANT TO MONITOR HOW MUCH SALINE YOU USE SO AS NOT TO FLUID OVERLOAD THE PATIENT. The Prismaflex will display the volume of fluid used to return the blood.

When it looks like most of the blood has been returned you are now ready to disconnect the patient from the set.

Press CONTINUE.

Clamp return (blue) line.

Disconnect the return (blue) line from the patient. Wipe opening of distal lumen with sterile gauze, flush vigorously with saline or heparinized saline, and clamp shut.

If the filter is too clotted to do rinseback, instead of pressing the RETURN BLOOD key, press the DISCONNECT key. Clamp all lines in the set, disconnect access and return lines from the catheter, flush the catheter as described above, and continue.

Make sure both lumens are clamped.

If you are not going to restart treatment within 15 minutes, you must place citrate lock in the catheter.

Place new injection caps on both sides of the catheter.

Place a light wrap with cast padding to protect catheter for short term or place full catheter wrap as described in Dialysis Catheter Care (Box 6-3 in vascular access section).

Clamp all unclamped lines on set.

Press UNLOAD.

Remove and discard the set.

Press CONTINUE.

You will now be in the LOAD SET screen. Follow the procedures on the screen to set up a new cartridge.

End Treatment Procedure With Blood Returned to Patient, Prisma, Prismaflex

Prepare the catheter by scrubbing the connections to the tubing. Wear a mask and gloves when doing so.

Hang a bag of saline on the left corner.

Press STOP.

Press END TREATMENT

Clamp the access (red) line. Disconnect the access (red) line from the patient and connect it to the saline. Wipe opening of proximal lumen with sterile gauze, flush vigorously with saline or heparinized saline, and clamp shut.

Unclamp access line.

Return the blood to the patient by pressing and holding down the RETURN BLOOD key to pump the saline through the access line.

The blood pump will automatically start at 110ml/min, therefore if you desire a slower blood return rate with the Prisma, tap the key intermittently to generate a slower average speed. With the Prismaflex, you can adjust the blood return rate.

Blood return should never be done at a quicker blood pump speed than used during treatment.

IT IS VERY IMPORTANT TO MONITOR HOW MUCH SALINE YOU USE SO AS NOT TO FLUID OVERLOAD THE PATIENT. The Prismaflex will display the volume of fluid used to return the blood.

When it looks like most of the blood has been returned you are now ready to disconnect the patient from the set.
Press CONTINUE.
- Clamp return (blue) line.
- Disconnect the return (blue) line from the patient. Wipe opening of distal lumen with sterile gauze, flush vigorously with saline or heparinized saline, and clamp shut.
- If the filter is too clotted to do rinseback, instead of pressing the RETURN BLOOD key, press the DISCONNECT key. Clamp all lines in the set, disconnect access and return lines from the catheter, flush the catheter as described above, and continue.
- Inject the citrate lock into both sides of the catheter (the exact amount is usually written on the catheter, otherwise, see package insert). Make sure both lumens are clamped.
- Place new injection caps on both sides of the catheter.
- You may now remove your gloves and mask.
- Tape the clamps shut so they don’t advertently open. Wrap the catheter as described in Dialysis Catheter Care (Box 6-3 in vascular access section).
- Clamp all unclamped lines on set.
- Press UNLOAD.
- Remove and discard the set.
- Record all necessary parameters in database.
- Turn machine off.
- Wipe down surface of machine with dilute disinfectant. Do not spray any cleaner directly on machine.

Temporary Disconnection Procedure With Blood Returned to Patient, Prisma, Prismaflex

We are unlikely to use this option, but instructions are included here for completeness. This procedure will return the blood and fill the set with saline, which can sit for up to 3 hours without recirculating in the Prisma. See below for instructions on how to disconnect temporarily without returning the blood.

- Prepare the catheter by scrubbing the connections to the tubing. Wear a mask and gloves when doing so.
- Press TEMP DISCON (Prisma) or RECIRC (Prismaflex)
- Disconnect the access (arterial) line from the patient and connect it to a bag of saline. Wipe opening of arterial lumen with sterile gauze and flush with saline or heparinized-saline and clamp shut.
- Return the blood to the patient by pressing START RETURN to pump the saline through the access line.
- If you notice significant clotting after some of the saline has passed through the access line and don’t want to return the remainder of the blood, press CONTINUE, then press UNLOAD when the “TEMP DISCON- Prepare to Prime” screen appears. If you do this, you will have to change the set.
- Disconnect the return line from the patient and connect it to a bag of priming solution. Wipe opening of venous lumen with sterile gauze and flush with saline or heparinized-saline and clamp shut.
- Disconnect the access line from the saline bag and connect it to an empty collection bag.
- Pump priming solution into the blood lines. The control unit automatically returns to the Priming, Please Wait screen in Setup mode.
- When ready to resume treatment and connect patient, press the START key.
• If a patient is not connected to the machine shortly after priming is complete, flush the set with at least 500ml of priming solution (saline with heparin added) before connecting the patient. You will need new priming solution and a new collection bag if you are going to do this.
• Limit the period of time in temporary disconnect to less than 3 to 4 hours. If the patient will be off CRRT for more than 15 minutes, place a citrate lock in the catheter.

Temporary Disconnection (blood not returned), Prisma, Prismaflex

Unfortunately, there is not a preset option for this with the Prisma machine, although there is with the Prismaflex. If the blood is returned to the patient, each stop and restart involves a volume flux of the volume of the extracorporeal circuit at a minimum. For a short disconnection, such as a 15 minute trip to radiology or to the scale, the blood can be circulated in the machine while the patient is absent. The period of time should be limited to less than 3 hours to avoid any risk of the blood becoming contaminated because the blood will be left circulating in the filter and tubing while patient is off and it will not be refrigerated.

Prisma Instructions

• Prepare the catheter by scrubbing the connections to the tubing. Wear a mask and gloves when doing so.
• Press SET FLOW RATES (Prisma). Decrease all flow rate rates except for BLOOD to zero.
• Press STATUS. Record in database current time from the upper left corner of screen.
• Stop citrate and calcium CRI’s. Aspirate respective catheters before flushing with heparinized saline.
• Press STOP. Do not press TEMP DISCON. If you already did, press CANCEL.
• Disconnect the access (red) line from the patient and connect to a sterile priming connector. Wipe opening of proximal lumen with sterile gauze, flush with saline or heparinized saline, and clamp shut.
• Disconnect the return (blue) line from the patient and connect to the access line using a priming connector (provided in the CRRT Toolkit, resterilized from Phoenix sets). Wipe opening of distal lumen with sterile gauze, flush with saline or heparinized saline, and clamp shut. Cover priming connection with Nolvasan soaked gauze.
• Press RESUME.
• Inject the citrate lock into both sides of the catheter (the exact amount is usually written on the catheter, otherwise, see package insert). Make sure both lumens are clamped.
• Place new injection caps on both sides of the catheter.
• You may now remove your gloves and mask.
• Tape the clamps shut so they don’t advertently open. Wrap the catheter as described in Dialysis Catheter Care (box 6-3 in vascular access section).
• When ready to resume treatment unwrap and scrub catheter in preparation for reconnection. Remove citrate locks. If needed refer to dialysis catheter care instructions in the vascular access section.
• Press STOP.
• Clamp access (red) and return (blue) lines. Connect access (red) line to red-coded or proximal lumen of the catheter. Then connect return (blue) line to blue-coded or distal lumen of the catheter.
• Wrap catheter connections with Nolvasan soaked gauze
• Attach patient lines to patient’s harness or leg for safety
• Unclamp both lines and both lumens.
• Press RESUME.
• Press SET FLOW RATES.
• Increase all flow rates to prescribed amounts.
• Press CONTINUE
• Record current time from upper left hand corner of the screen. You will not need to make any adjustments in the volumes of effluent, since those rates were zero during the disconnection, but you will need to account for the time off dialysis when calculating Kt/V.

**Prismaflex Instructions**

- Scrub the catheter connections as described above.
- Set all flow rates to zero except for blood flow.
- Connect a Y-line connector (as used for priming the system at the start of the treatment) to a small (100 ml or less) saline bag (or an empty feline blood transfer bag). Prime both parts of the Y-line connector, and empty most of the saline (leaving 10-15 ml), or inject saline into the transfer bag. This creates a small reservoir to act as the patient, because connecting the access to the return line via a Phoenix priming connector or stopcock will lead to pressure irregularities that will cause the machine to alarm and stop the blood pump. Limiting the saline volume in the bag limits the amount of extra fluid the patient will receive when reconnected. If you use a larger volume in your reservoir, you can increase your ultrafiltration rate to remove that volume once the patient is reconnected.
- Press Stop, then Recirc, then Blood Recirc.
- Connect the access and return lines to the Y-line.
- Press Start Recirc.
- Flush and lock the dialysis catheter lumens.
- When ready to reconnect the patient, scrub the catheter ports again.
- Press Stop and reconnect, then press start.

**Air Rinseback for the Prisma and Prismaflex Machine**

An air rinseback is performed when the patient cannot handle any additional fluid volume. In this case, we return only the blood in the extracorporeal circuit, but do not use any additional saline to help flush the line. The patient receives a net gain of the exact volume of the circuit (i.e., the volume of priming solution in the circuit at the start of the treatment). The typical volume of saline used for rinseback varies, but is generally around 1.5-2 times the circuit volume, or about 40-150 ml additional fluid. The air rinseback procedure eliminates only this additional volume.

An air rinseback should only be performed under careful supervision and by personnel who have been trained in this procedure and are comfortable with performing it under duress. Incorrect performance of this procedure can result in fatal air embolism.

This procedure appears to lead to less complete return of blood compared to a saline rinseback, in the Prisma and Prismaflex systems. It might be wise to pre-emptively ultrafilter the anticipated rinseback volume before the end of treatment, rather than using an air rinseback.

- An air rinseback can be done instead of a saline rinseback when returning blood in either the “Change Set Procedure” or the “End Treatment Procedure”. Refer to those
protocols for details on the entire procedure. Only the deviations from that procedure are discussed here.

- Prepare the patient as described, but when disconnecting arterial patient line, leave it open to the air instead of attaching it to the saline administration set. Flush the catheter as described.
- When you press RETURN BLOOD or START RETURN, the blood will just continue to flow through the cartridge, followed by air. Let this happen.
- Blood will continue to be returned to the patient until the air gets to the air/bubble detector. At this point, the machine will display WARNING: AIR IN BLOOD at the top of the screen.
- Perform the following steps while always keeping a close eye on the air/blood interface in the venous patient line so as not to push air into the patient.
- Clamp the line above the return (blue) line injection port.
- Pull the return (blue) line out of its clamp.
- Using a sterile 12cc syringe 22 ga needle, insert the needle in the blue injection port and flush the blood in the return (blue) line back to the patient. You should be ready to clamp the return line with the other hand as you are doing this.
- When the air is about a centimeter from the end of the venous port of the catheter, stop flushing and clamp the line immediately.
- Clamp the venous lumen of the catheter, disconnect the line, and proceed as described in the saline rinseback protocol.

**Rinseback Procedure for NxStage**

The step-by-step instructions for rinseback are in the End section of SIMPLE. A planned return involves a saline rinseback from the access port, and can be followed by a temporary disconnect with recirculation or at the end of a treatment. Emergency return will not return approximately 20 ml of blood (access line from catheter to saline infusion port).

Air rinseback can be accomplished by turning off the power to the cycler and opening the door. Connect the recirculation connector (hanging on the saline line) to the access line to allow connection of a syringe. Use a syringe to manually push air through the circuit. I suggest you use a stopcock to avoid having to connect and disconnect your syringe, as you will need about 85 ml of air for the low volume set or 200 ml for the regular sets.

**IHD Rinseback for IHD**

**Rinseback Procedure for Phoenix IHD Machine**

- When there are 10 minutes left in the dialysis treatment, prepare the catheter by scrubbing the connections to the tubing as done before treatment.
- Remember to wear gloves and a mask the entire time you are handling the catheter.
- When dialysis time is complete, press Bypass and decrease the blood speed to 50 ml/min (if it was over 50 ml/min). After 30-60 seconds, draw post-dialysis samples from the arterial sampling port in the extracorporeal circuit (the port used for sampling for ACTs).
- When done handling the blood, the following steps should be done as quickly as possible to prevent clotting of blood in the catheter or extracorporeal circuit.
• Press Rinseback on the screen and confirm it; the blood pump will stop on its own
• Clamp the arterial lumen of the catheter and the arterial dialysis line.
• Disconnect the arterial line from the catheter.
• Wipe both openings with STERILE gauze.
• Flush the arterial lumen vigorously with saline or heparinized saline and clamp shut.
  • Use 12cc flush for patients with a pediatric setup
  • Use 6cc flush for patients with a neonatal setup
• Connect the arterial line to a saline line.
• Unclamp the arterial line and the saline line.
• Turn on the blood pump. Blood pump will automatically start at 120ml/min
• Rinseback should never be done at a faster blood pump speed than used during dialysis, so you may need to lower the speed once it is running.  A speed of 120ml/min works best for me when possible.
• As the saline is washing the blood through the lines, use a blue hemoclamp to clamp and unclamp the line in order to help propel the blood forward.
• When the lines are clear of blood (or almost clear, usually I use 100ml to rinse a neonatal set and 150-300ml to rinse a pediatric set) stop the blood pump.  IT IS VERY IMPORTANT TO MONITOR HOW MUCH SALINE YOU USE SO AS NOT TO FLUID OVERLOAD THE PATIENT.
• Clamp the venous dialysis line and the venous lumen of the catheter.
• Disconnect the venous line from the catheter.
• Wipe the opening of the lumen with STERILE gauze, flush the venous lumen vigorously, and clamp the catheter.
  • Use 12cc flush for patients with a pediatric setup
  • Use 6cc flush for patients with a neonatal setup
• The venous line does not need to be covered as it will be thrown away now.
• Inject the citrate or heparin lock into both sides of the catheter (the exact amount is usually written on the catheter, otherwise, see package insert).
• Be sure to clamp both lumens when done.
• Place new injection caps on both sides of the catheter.
• You may now remove your gloves, and mask.
• Tape the clamps shut so they don’t inadvertantly open between treatments.
• Wrap the catheter as described in “Dialysis Catheter Care” (Box 6-3, vascular access section).
• Clean the machine as directed in “Cleaning the Phoenix Dialysis Machine”

Air Rinseback for Phoenix Dialysis Machine

An air rinseback is performed when the patient cannot handle any additional fluid volume. In this case, we return only the blood in the extracorporeal circuit, but do not use any additional saline to help flush the line.

AN AIR RINSEBACK SHOULD ONLY BE PERFORMED UNDER CAREFUL SUPERVISION AND BY PERSONNEL WHO HAVE BEEN TRAINED IN THIS PROCEDURE AND ARE COMFORTABLE WITH PERFORMING IT UNDER DURESS.
INCORRECT PERFORMANCE OF THIS PROCEDURE CAN RESULT IN FATAL AIR EMBOLISM.

• The procedure is very similar to a saline rinseback, so refer to that rinseback procedure for details. Only the deviations from that procedure are discussed here.
• Prepare the patient as described, but when disconnecting arterial patient line, leave it open to the air instead of attaching it to the saline administration set. Flush the catheter as described.
• When you turn the blood pump on, the blood will just continue to flow through the extracorporeal circuit, followed by air. Let this happen.
• Blood will continue to be returned to the patient until the air gets to the air/bubble detector. At this point, the machine will give an “air in blood” alarm.
• Perform the following steps while always keeping a close eye on the air/blood interface in the venous patient line so as not to push air into the patient.
• Clamp the line between the dialyzer and the venous chamber.
• Clamp the venous patient line below the venous clamp.
• Open the blue clamp on the venous chamber saline infusion line.
• Using a syringe, aspirate until the venous pressure is between –50 and –150mmHg.
• Close the blue clamp.
• Press the Override key.
• When the venous clamp releases, pull the venous patient line out of the venous clamp.
• Use the syringe on the saline infusion line connected to the venous chamber to slowly flush the blood in the venous patient line back to the patient. You should be ready to clamp the venous patient line with the other hand as you are doing this.
• When the air is about a centimeter from the end of the venous port of the catheter, stop flushing and clamp the line immediately.
• Clamp the venous lumen of the catheter, disconnect the line, and proceed as described in the saline rinseback protocol.

Rinseback Procedure for CentrySystem 3 IHD Machine

• When there are 10 minutes left in the dialysis treatment, prepare the catheter by scrubbing the connections to the tubing as done before treatment.
• Remember to wear gloves and mask the entire time you are handling the catheter.
• When dialysis time is complete, put the machine in Bypass and decrease the blood speed to 50 ml/min (if it was over 50 ml/min).
• After 30 to 60 seconds, draw post-dialysis samples from the arterial sampling port in the extracorporeal circuit (the port used for sampling for ACTs).
• When done handling the blood samples, the following steps should be done as quickly as possible to prevent clotting of blood in the catheter or extracorporeal circuit.
• Stop the blood pump.
• Clamp the arterial lumen of the catheter and the arterial dialysis line.
• Disconnect the arterial line from the catheter.
• Wipe both openings with STERILE gauze.
• Flush the catheter with saline or heparinized-saline and clamp shut.
  • Use 12 cc flush for patients with a pediatric setup
  • Use 6 cc flush for patients with a neonatal setup
• Connect the arterial line to a saline line.
• Unclamp the arterial line and the saline line.
• Turn on the blood pump.
• Rinseback should never use a faster blood pump speed than was used during the dialysis treatment. A speed of 120ml/min works best for me when possible.
• As the saline is washing the blood through the lines, use a blue hemoclamp to clamp and unclamp the line in order to help propel the blood forward and dislodge cells adhering to the tubing.
• When the lines are clear of blood (or almost clear, usually I use 100ml to rinse a neonatal set and 150-300ml to rinse a pediatric set) stop the blood pump. IT IS VERY IMPORTANT TO MONITOR HOW MUCH SALINE YOU USE SO AS NOT TO OVERHYDRATE THE PATIENT.
• Clamp the venous dialysis line and the venous lumen of the catheter.
• Disconnect the venous line from the catheter.
• Wipe the opening of the catheter with STERILE gauze, flush the lumen vigorously, and clamp the catheter.
  • Use 12 cc flush for patients with a pediatric setup
  • Use 6 cc flush for patients with a neonatal setup
• The venous line does not need to be covered as it will be thrown away now.
• Inject the citrate or heparin lock into both sides of the catheter (the exact amount is usually written on the catheter, otherwise, see package insert).
• Be sure to clamp both lumens when done.
• Place new injection caps on both sides of the catheter.
• You may now remove your gloves.
• Tape the clamps shut so they don’t inadvertently open between treatments.
• Wrap the catheter as described in “Dialysis Catheter Care (Box 6-3, Vascular Access Section)
• Clean the machine as directed in “Cleaning the C3 Dialysis Machines”

Air Rinseback for Centrsysystem 3 Dialysis Machine

An air rinseback is performed when the patient cannot handle any additional fluid volume. In this case, we return only the blood in the extracorporeal circuit, but do not use any additional saline to help flush the line.

AN AIR RINSEBACK SHOULD ONLY BE PERFORMED UNDER CAREFUL SUPERVISION AND BY PERSONNEL WHO HAVE BEEN TRAINED IN THIS PROCEDURE AND ARE COMFORTABLE WITH PERFORMING IT UNDER DURESS.

INCORRECT PERFORMANCE OF THIS PROCEDURE CAN RESULT IN FATAL AIR EMBOLISM.
• The procedure is very similar to a saline rinseback, so refer to that rinseback procedure for details. Only the deviations from that procedure are discussed here.
• Prepare the patient as described, but when disconnecting arterial patient line, leave it open to the air instead of attaching it to the saline administration set. Flush the catheter as described.
• When you turn the blood pump on, the blood will just continue to flow through the extracorporeal circuit, followed by air. Let this happen.
• Blood will continue to be returned to the patient until the air gets to the air/bubble detector. At this point, the machine will give an “air in blood” alarm.
• Perform the following steps while always keeping a close eye on the air/blood interface in the venous patient line so as not to push air into the patient.
• Clamp the line between the bottom of the dialyzer and the venous chamber.
• Go to the “Alarm” screen, and override the air in blood alarm.
• When the venous clamp releases, pull the venous patient line out of the venous clamp.
• Use the syringe on the saline infusion line connected to the venous chamber to slowly flush the blood in the venous patient line back to the patient. You should be ready to
clamp the venous patient line with the other hand as you are doing this.

- When the air is about a centimeter from the end of the venous port of the catheter, stop flushing and clamp the line immediately.
- Clamp the venous lumen of the catheter, disconnect the line, and proceed as described in the saline rinseback protocol.

_Emergency Stop—Phoenix or Centralsystem 3_

Occasionally, the blood in the extracorporeal circuit will clot to such a great extent that you are unable to return the blood by the normal rinseback procedure. This is usually because there is a clot completely occluding the filter in the venous chamber. If this is the case, sometimes you can at least return the blood in the arterial patient line. To do this, follow these steps immediately:

- Perform a quick but thorough emergency scrub of the catheter connections.
- Clamp the venous patient line and venous lumen, and disconnect.
- Flush the lumen vigorously with 6-12cc saline or heparinized saline so that it does not become clotted.
- Attach a bag of saline with administration set to one of the arterial chamber infusion lines. You can use the saline bag usually left attached during the dialysis treatment.
- Open the administration set and the red clamp on the saline infusion line.
- Allow the saline to run into the line, flushing the blood back to the patient.
- Be aware that there are no clamps or sensors along these lines so great care must be taken to prevent an excessive saline bolus or an air embolism. Also do not force blood return as you may inadvertently flush a large clot into the catheter or patient.
- When most of the blood is rinsed back, clamp the arterial patient line and arterial lumen.
- Disconnect the arterial patient line and flush the arterial lumen vigorously with 6-12cc saline or heparinized saline so that it does not become clotted.
- If either catheter lumen appears to be occluded, try flushing with more saline, being careful not to give more volume than the patient can handle. Then consider thrombolytic therapy if this does not work.
- If the catheter is patent, place citrate locks and wrap as described in regular rinseback procedure.
- Unload dialyzer and blood cartridge from machine and clean machine as described in regular rinseback and cleaning procedures.

_Cleaning the Dialysis Machines_

_Cleaning the Phoenix Dialysis Machine_

- After you have completed rinseback, connect the arterial and venous lines using a priming connector; make sure both lines are unclamped.
- Press the Emptying key and confirm.
- Press Autoemptying and confirm.
- Open the venous chamber to the air. A 3 minute descaling procedure will automatically start during autoemptying. Allow this procedure to end before continuing.
- Press Autoemptying when saline is emptied from blood lines and descaling is complete.
- When the machine tells you to, connect the blue dialysate line (Hansen connector) to its port.
- Flip the dialyzer upside down so that the arterial port is on the bottom. The machine will empty the dialysate from the dialyzer.

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The screen will now tell you that the dialyzer is empty and that you can connect the red dialysate line (Hansen connector) to its port. Do that now.

Remove the blood cartridge as well as the Bicart. (Leave BiCart attached if you are going to treat another patient right away). Wipe the Bicart arms before closing.

With the acid still connected to the machine, you can now press Final Rinse on the screen. (This can also be done using vinegar instead of acid concentrate)

Wait for the T1 test procedure in progress to complete, you will then hear 2 loud beeps.

Remove the acid connector from the acid concentrate stick and place it securely in its rinse port.

Clean the acid connector with RO water and replace on back of machine.

You are now ready to clean the machine

Press ADR on the screen.

Press Chem Disinfect on the screen

Press Bleach

The machine will turn off automatically when this cleaning cycle is complete.

*Other Cleaning Procedures*

The Heat Disinfect cycle can be used instead of the Bleach. One or the other should be done at the end of each day that a treatment occurred. A Heat Citric could also be done, but we do not currently have the solution for that.

If the machine is not going to be used for a few days, a bacteriostatic dwell should be used. This can be accomplished by pressing ADR and then Bacteriostatic. When leaving the machine like this, you MUST put a sign on the machine indicating that there is bleach in the machine.

Wipe down outside of the dialysis machine at the end of every day. You can use just a wet paper towel, or towel with a little dilute disinfectant. Do not spray any cleaner directly on machine.

*Procedures for C3 Machine Maintenance*

ACDR stands for Acid Rinse, Clean, Disinfect, and Rinse.

Acid Rinse is rinsing the machine with an acidic solution—we use distilled vinegar because it is inexpensive, but in a pinch, the acid concentrate can be used. This dissolves any precipitate that can form inside the machine’s tubing.

Clean is washing the inside of the machine with bleach. This removes any biological material that may enter the hose post-dialyzer.

Disinfect is using a high level disinfectant to prevent any possible bacterial growth in the hoses in the machines.

Rinse is simply rinsing all the machine’s hoses with pure water.

The dialysis machines should be put through an Acid Rinse cycle any time bicarbonate or acid concentrate has been used. They should be put through a Clean cycle (AFTER the Acid Rinse cycle) any time the machines were used for dialysis. An Acid Rinse cycle must be done first because bleach combined with bicarbonate or acid concentrate will form a sludgy glue-like substance—not so good for the machines. The machines should be disinfected once a week regardless of use. Each of these cycles automatically ends by rinsing out the cleaning agent used, but whenever possible, you can run an extra Rinse cycle.

At the end of each dialysis treatment, remove the dialyzer and extracorporeal circuit from the machine.

Attach each dialysate connector to its respective port, and take the machine out of bypass.
• Remove the BiCart column from its holder, and fold both arms in so that they are completely closed.
• Remove the acid connector from the acid concentrate and place it securely in its rinse port.
• If you don’t see the ACDR option on the screen, select “Setup”.
• Select ACDR
• Select Acid Rinse
• The screen will instruct you to attach the bicarbonate adapter to the acid (vinegar). Then press the arrow that says “press when complete”.
• When you hear a soft beeping, the screen will instruct you to return all adapters to their rinse ports, and again press when complete. The cycle will be done when the clock on the screen counts down to zero and the screen is again in the Setup mode.
• Select ACDR to now run the Clean cycle.
• Select Clean

The screen will instruct you to attach the acetate adapter into the yellow rinse port (the machine uses the symbol that is above the rinse port). Then press the arrow that says “press when complete”.

When you hear a loud double beeping, the screen will instruct you to return all adapters to their rinse ports, and again press when complete. The Clean cycle is now complete.

You can now turn the machine off, and it will be ready to use as soon as you turn it on. If you need to leave as soon as possible after finishing dialysis, the Clean cycle can be done the following day BEFORE the next treatment, but the Acid Rinse cycle must be done soon after use of the machine.

Disinfection should be done once a week. If the machine has just been used, you can substitute the Disinfect cycle for the Acid Rinse cycle immediately following a treatment because the disinfectant is an acidic solution.

Follow the steps above for breaking down the machine after a treatment.

• Select ACDR
• Select Disinfect

The screen will instruct you to attach the bicarbonate adapter to the green rinse port (the machine uses the symbol that is above the rinse port). Then press the arrow that says “press when complete”.

The dwell time for the disinfectant is a couple of hours, so the machine will automatically go into a dwell phase. If you are not going to be around for that long, you can turn the machine off once it is in the dwell phase. In this case, you will rinse the next morning, but you MUST put the “disinfect” sign on the machine overnight so that anyone else will know there is still disinfectant in the machine.

If you don’t turn off the machine, when the Disinfect cycle is complete, you will hear a loud double beeping. The machine will instruct you to return all adapters to their rinse ports, and press when complete.

The Disinfect cycle is now complete.

If you do turn off the machine, it must stay off for at least two hours before turning it back on, but no longer than 48 hours.

To rinse the disinfectant out, turn on the machine.

The machine will sound an alarm and give you the option to Continue.

When you select Continue, the machine will instruct you to return all adapters to their rinse ports, and press when complete. This will put the machine into an automatic Rinse cycle.

When the Rinse cycle is complete, the machine is ready for use (unless you still need to run a Clean cycle).

Wipe down outside of the dialysis machine at the end of every day. You can use just a wet paper towel, or towel with a little dilute disinfectant. Do not spray any cleaner directly on machine.
Chapter 16  Measuring Adequacy of Treatment

A detailed description of dialysis adequacy is available in the 2006 ARTS proceedings. This chapter will cover only a few practical issues of measuring adequacy.

Measures of Adequacy

Urea reduction ratio (URR)

The URR is calculated from blood urea measurements taken before and immediately after dialysis. It is calculated from the formula:

\[
URR = \frac{(BUN_{pre} - BUN_{post})}{BUN_{pre}}
\]

Equation 16-1.

In IHD, URR can be predicted by the volume of blood processed through the dialyzer, presuming standard dialysate flow and no convective clearance (see Figure 7-1 and 7-2, Chapter 7 Prescription). If the actual URR is lower than predicted, there may be substantial clotting of fibers of the dialyzer or substantial catheter recirculation. In limited dialysate procedures (i.e., PIRRT, during use of a dialysate diversion device), URR is predicted by the amount of therapy fluid (dialysate plus convective clearance) and not the volume of blood processed.

Time-averaged urea concentration (TAC)

TAC is not routinely calculated. TAC accounts for the vacillations in urea concentration induced by intermittent hemodialysis by averaging the area under the curve, to provide a measure of the average urea exposure over the week (or measurement interval).

Figure 16.1. Weekly pre- and post-dialysis BUN concentrations. Pre-dialysis BUN is 100-120 mg/dL, but the TAC is 46 mg/dL.
**Kt/V**

The most common measure of dialysis dose in human ERRT is Kt/V, in which K is the clearance of the dialyzer, t is time on dialysis, and V is volume of distribution. Various equations are based on different presumptions about the urea pool and the kinetics of urea movement. The simplest is single pool, in which urea is presumed to diffuse freely and rapidly throughout the entire volume of distribution. The double pool kinetic model presumes differential rates of urea clearance from certain regions (i.e., intracellular space). Kd, the dialyzer clearance, can be measured or estimated. Estimates are provided on the manufacturer’s data sheet for each dialyzer.

**Measuring dialyzer clearance**

Urea is measured in blood entering and leaving the dialyzer, and the clearance is calculated from the formula:

$$K_d = Q_b \times \frac{(\text{BUN}_{\text{in}} - \text{BUN}_{\text{out}})}{\text{BUN}_{\text{in}}}$$

*Equation 16-2.*

Note that the blood flow rate readings from the dialysis machine may vary from the actual blood flow rate.

**Volume of distribution**

The urea volume of distribution is considered to be the same as the total body water, and is generally estimated as 58% of body weight. Alterations in water balance and in lean body mass are common in patients with renal failure. Measurement of body water can be performed with bioimpedance (see dialysis team for machine).

**Methods of Measuring Adequacy**

**CRRT**

Clearance can be estimated with the following formulas.

- **CVVH**, post-dialyzer replacement fluid:
  - UF rate

- **CVVH**, pre-dialyzer replacement fluid:
  - UF rate ÷ [1 + (fluid replacement rate ÷ Qb)]

- **CVVHD**:
  - Dialysate rate

- **CVVHDF**, post-dialyzer replacement fluid:
  - UF rate + dialysate rate

- **CVVHDF**, pre-dialyzer replacement fluid:
  - (UF rate ÷ [1 + (fluid replacement rate ÷ Qb)]) + dialysate rate

All rates (UF, fluid replacement, dialysate) measured in ml/min; urea measurements in mg/dl. When estimating time for CRRT, the average running time is 22 hours per day.

Measuring. The delivered urea clearance can be measured from effluent and pre-dialyzer blood urea concentrations and the ultrafiltration and dialysate flow rates, using the following formulas:
CVVH – Post-dialyzer replacement fluid
\[ K_{\text{DEL}} = \text{Effluent urea} \times \text{Ultrafiltration rate} / \text{Pre-dialyzer BUN} \]

CVVH - Pre-dialyzer replacement fluid
\[ K_{\text{DEL}} = \text{Effluent urea} \times \text{Ultrafiltration rate} / \text{Pre-dialyzer BUN} \]

CVVHD
\[ K_{\text{DEL}} = \text{Effluent urea} \times \text{dialysate rate} / \text{Pre-dialyzer BUN} \]

CVVHDF – Post-dialyzer replacement fluid
\[ K_{\text{DEL}} = \text{Effluent urea} \times (\text{Ultrafiltration rate} + \text{dialysate rate}) / \text{Pre-dialyzer BUN} \]

IHD

**Ionic Dialysance**

Most newer dialysis machines incorporate ionic dialysance measurement. Dialysance is a measure of solute mass transfer from blood to dialysate when the solute is present in both the blood and dialysate. The collective dialysance of small molecular weight ions is considered equivalent to the dialysance of urea. For conventional single pass hemodialysis circuits, urea dialysance becomes 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 the dialyzer urea clearance. Repeated measurements are made throughout the treatment, allowing calculation of Kt for each dialysis treatment. By entering the patient weight and volume of distribution, the machine will calculate the Kt/V throughout the dialysis treatment.

**3 BUN method**

By measuring the BUN before and after dialysis and before the next dialysis treatment, Kt/V can be calculated using urea kinetic modeling software.
Nutritional Management

Malnutrition is a significant concern in the dialysis patient. Acute kidney injury is a highly catabolic disease. Protein restriction, a standard recommendation for patients with chronic kidney disease, may not be appropriate for patients with AKI, because of the high catabolic rate of the patient and because of the loss of amino acids in the dialysate. Recommendations for protein administration have not been established for veterinary ERRT patients. Human pediatric ERRT patients should receive 3-4 gm/kg/day of protein, rather than the normal 1.5 mg/kg/day for patients without AKI. Both enteral and parenteral feeding involves an obligate water load, which many patients cannot excrete due to oliguria or anuria. The administered water can be removed via ultrafiltration, with either intermittent or continuous therapies.

Standard diets for chronic kidney disease may not be appropriate for chronic dialysis patients either. With each dialysis treatment, amino acids are lost into the dialysate, and the protein restriction of renal diets may be insufficient to replenish these losses. Most renal diets are potassium rich, because hypokalemia may occur in the pre-dialysis CKD patient, but these diets induce hyperkalemia in the dialysis patient that has extremely limited renal potassium excretory capability. Supplementation with carnitine and taurine, amino acids that may be lost in the dialysate, is recommended for patients on dialysis for over a month.

Placement of a feeding tube or intravenous catheter for total parenteral nutrition (TPN) can be complicated by systemic heparinization during ERRT. Despite this risk, we routinely place an esophagostomy feeding tube at the time of dialysis catheter placement unless there is a strong contraindication. Patients on CRRT with regional citrate anticoagulation should have no increased risk of hemorrhage beyond that induced by uremic thrombocytopenia or the underlying diseases. If TPN is administered through the CRRT circuit, it should be positioned post dialyzer, to decrease the loss of nutrients into the effluent.

Phosphate supplementation

Phosphorus is removed by ERRT. With aggressive IHD treatments in a non-azotemic patient, or CRRT over time, hypophosphatemia may develop, creating a risk factor for hemolysis. Intravenous phosphate supplementation (for CRRT) or addition of phosphate to the dialysate (for IHD) may be needed.

Drug Dosing

Drugs that are primarily excreted by the kidneys require dose adjustment with advanced renal failure. In general, the loading dose does not need to be adjusted unless the volume of distribution is significantly altered, as with patients with large changes in body water. Extending the dosing interval is useful for drugs with a long half-life. Dose reduction while maintaining the interval between doses generally leads to more constant serum levels. A variety of factors affect removal of drugs by dialysis. Drugs with a molecular weight > 500 daltons are poorly cleared by conventional dialysis, although clearance may be enhanced with synthetic membranes commonly used in veterinary ERRT. Drugs that are highly protein or tissue bound or are highly lipid soluble are not dialyzed to a significant degree due to the high volume of distribution. Drugs that are significantly cleared by dialysis may require
supplemental dosing after the dialysis treatment to maintain therapeutic levels. Drug level monitoring is available for some drugs, but may be impractical in many situations. Tables of recommended dose adjustments in dialysis patients are available. (Aronoff 2005; Johnson 2008; Olyaei and Bennett 2008) With continuous therapies utilizing convective clearance, molecular size and volume of distribution become less limiting than with IHD, but limited pharmacokinetic data is available. Although using specific pharmacokinetic data to adjust dosing is preferred, some suggested guidelines for humans in the absence of necessary data are to presume CRRT is equivalent to a GFR of 10-50 ml/min/1.73 m² (normal GFR for humans is > 90 ml/min/1.73 m²) or to increase the dose of non-toxic drugs by 30% over the drug dose estimated for the degree of renal failure.

Prevention of Catheter Thrombosis

Aspirin has traditionally been administered to veterinary dialysis patients to prevent thrombosis of the dialysis catheter, at antiplatelet doses (0.5 mg/kg q 24 hours in dogs, q 72 hours in cats). The efficacy of this is not proven in people or animals. For CRRT patients, the constant blood flow through the catheter may decrease the risk of thrombosis. I would recommend starting aspirin therapy when the patient transitions from CRRT to IHD.
Chapter 18  Treating Toxicities

Certain toxins can be removed by hemodialysis or a related technique, hemoperfusion. Characteristics of substances that might be removed by dialysis are small molecular weight (< 1500 D), minimal protein binding, and a small volume of distribution. A high flux dialyzer may allow removal of substances up to 20-30,000 D. Hemoperfusion involves placing a charcoal filled cartridge in the extracorporeal circuit. As blood passes through the cartridge, activated charcoal adsorbs the toxin. Charcoal perfusion can remove substantial amounts of substances that are protein bound. Unfortunately, the smallest commercially available hemoperfusion device has a blood priming volume of 150 ml, in addition to the priming volume of the rest of the extracorporeal circuit, and is available for the Phoenix and other intermittent dialysis machines. It is placed in series with the dialyzer, usually before the dialyzer. A charcoal perfusion cartridge that does not contain a dialyzer is available for the Prismaflex in other countries. It is not available in the USA, and we do not have the appropriate software installed on our Prismaflex. For extensively protein bound toxins (> 90%) with a small volume of distribution (< 0.6 l/kg), therapeutic plasmapheresis can be considered (see next chapter), but rarely removes a substantial portion of the toxin.

Remember to prime the perfusion device with dextrose, as the charcoal binds patient glucose. Profound thrombocytopenia is common, but does not seem to cause clinical bleeding. Rebound appears to occur within a day or less, similar to bioincompatability reactions that were seen with hemophage dialyzers in the early days of dialysis.

Specific Instructions for Priming the Adsorba Charcoal Cartridge.

We usually put the charcoal in the circuit in front of the dialyzer. Start with the standard set-up for the Phoenix machine, with the following modifications. Connect the arterial line and CritLine chamber to the inflow side of the Adsorba. Put a connecting tubing segment (preferably with a sampling port) on the inflow (arterial) side of the dialyzer. Hang a 500 ml bag of 5% dextrose (D5W) as the priming solution. Allow the solution to fill the venous line by gravity, then connect to the outflow (venous) side of the dialyzer and start the blood pump in prime mode (in which the pump goes in reverse, filling the circuit from venous to arterial side). When the dialyzer and connecting tubing segment are filled with D5W, connect the tubing to the outflow side of the Adsorba, and position the Adsorba such that the priming solution is flowing from bottom to top. Do not introduce air into the Adsorba. If you stop the blood pump while doing this, you may have to re-engage prime mode when you restart the pump to ensure that the pump is still flowing in reverse. When the D5W bag is empty, follow it with 2 L of heparinized saline (2500 u/L). If the patient is ready to connect, you can continue in priming mode until all of the saline has run through. If the patient is not ready, you can use the 2 L to refresh immediately before connecting the patient. After priming is complete, turn the Adsorba so that the blood will be entering from the bottom, exiting the top, and entering the top of the dialyzer and going to the bottom of the dialyzer. The charcoal binds the dextrose, creating a hypotonic solution, so the D5W must be followed with saline before connecting the patient.

For rinseback, flip the Adsorba again, so that the blood is draining out the bottom for rinseback.

Phosphate supplementation

When IHD is used for nonrenal indications, hypophosphatemia can develop as a result of rapid clearance of phosphorus. Although phosphorous concentration may rebound shortly after the dialysis treatment, there is a risk of hemolysis with severe hypophosphatemia (serum phosphorus < 1.0 mg/dl). Addition of phosphate to the dialysate may prevent this from occurring. Addition of 16 ml of a neutral
sodium phosphate (Fleet Enema) per liter of dialysate concentrate produces a dialysate concentration of approximately 2 mg/dl.

Ethylene Glycol

Ethylene glycol is found in antifreeze and a number of other substances. Ethylene glycol and its more toxic metabolite glycolic acid are both small molecules that are readily removed via IHD. Over 90-95% of the substance can be removed in a single intensive dialysis treatment. IHD is preferred over CRRT if both are rapidly available. Immediate treatment before substantial renal damage has occurred is necessary. Administration of a dose of 4-methylpyraloze (Antizol-Vet) in dogs or ethanol in cats is recommended as soon as ingestion is recognized, to delay metabolism while the patient is being prepared for dialysis. Because ethanol is also readily dialyzable, addition of ethanol to the dialysate can maintain a steady state in the patient. Enough ethanol is added to create a 0.1% ethanol concentration in the dialysate.
**Table 18-1. Substances Removed by Hemodialysis**

<table>
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<tr>
<th>Alcohols</th>
<th>Anticonvulsants</th>
<th>Chelating agents</th>
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<tr>
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<td>Gabapentin</td>
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</tr>
<tr>
<td>Ethylene Glycol</td>
<td>Phenobarbital</td>
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</tr>
<tr>
<td>Methanol</td>
<td>Phenytoin*</td>
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<tr>
<td>Analgesics/anti-inflammatory</td>
<td>Primidone</td>
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<tr>
<td>Acetaminophen</td>
<td>Antifungals</td>
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<tr>
<td>Aspirin</td>
<td>Dapsone</td>
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<tr>
<td>Mesalamine (5-ASA)</td>
<td>Fluconazole</td>
<td></td>
</tr>
<tr>
<td>Morphine*</td>
<td>Flucytosine</td>
<td></td>
</tr>
<tr>
<td>Pentazocine</td>
<td>Antineoplastics</td>
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</tr>
<tr>
<td>Antibacterials</td>
<td>Busulfan</td>
<td>Azathioprine</td>
</tr>
<tr>
<td>Amikacin</td>
<td>Carboplatin</td>
<td>Methyl pred</td>
</tr>
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<td>Amoxicillin (most penicillins)</td>
<td>Cytarabine*</td>
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<td>Cephalexin</td>
<td>Cyclophosphamide</td>
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<tr>
<td>Cefotetan</td>
<td>Fluorouracil (5-FU)</td>
<td>Ascorbic acid</td>
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<tr>
<td>Cefoxitin</td>
<td>Ifosfamide</td>
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<tr>
<td>Ceftriazone</td>
<td>Methotrexate</td>
<td></td>
</tr>
<tr>
<td>Chloramphenicol</td>
<td>Mercaptopurine</td>
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<td>Gentamicin</td>
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<td>Famciclovir</td>
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<td>Valacyclovir</td>
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<tr>
<td>Nitrofurantoin</td>
<td>Zidovudine</td>
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<td>Ofloxacin</td>
<td>Cardiac/vasoactive drugs</td>
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<tr>
<td>Vancomycin*</td>
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*High-flux dialysis only

**Table 18-2. Substances Removed by Charcoal Hemoperfusion**

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<th>NSAIDs</th>
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<td>NSAIDs</td>
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</tr>
<tr>
<td>Barbiturates</td>
<td>Theophylline</td>
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<tr>
<td>Salicylates</td>
<td>Vincristine</td>
</tr>
</tbody>
</table>
Chapter 19  Other Uses of ERRT

Therapeutic Plasmapheresis

Plasmapheresis has limited applications in veterinary medicine as a therapeutic modality. It is indicated for hyperglobulinemia associated with multiple myeloma if clinical signs from hyperglobulinemia are present. Manual methods are tedious. Automated methods include centrifugal separation or membrane filtration. Membrane filtration can be accomplished with IHD or CRRT machines, using a special dialyzer with pores large enough to allow removal of immunoglobulins while restricting cellular elements is needed. As plasma is removed from the patient, the volume removed is replaced with fresh frozen plasma. As a general guideline, one and a half times the patient’s plasma volume would be removed and replaced in the first treatment. A second treatment within 24-72 hours may remove and replace one times the patient plasma volume. On-going treatments (i.e., weekly) have never been attempted in veterinary medicine.

| Diseases For Which Therapeutic Plasmapheresis is Clearly Indicated |
|---|---|
| Myasthenia Gravis | |
| Guillain-Barre Syndrome | |
| Hyperviscosity Syndrome | |
| Cryoglobulinemia | |
| Thrombotic thrombocytopenic purpura | |
| Goodpasture Syndrome | |

| Diseases For Which Therapeutic Plasmapheresis May Be Indicated |
|---|---|
| Systemic lupus erythematosus | |
| Vasculitis | |
| Immune Mediated Hemolytic Anemia | |
| Some Intoxications | |

Diuretic Resistant Congestive Heart Failure

Most cases of CHF respond to diuretics, but SCUF could be used if diuretics are ineffective at clearing the congestion. Blood flow rates can be rather slow, so a smaller catheter can be used.

Sepsis

ERRT removes cytokines and other inflammatory mediators (both pro-inflammatory and anti-inflammatory) from septic patients, but there is insufficient evidence to support ERRT (specifically, CRRT) as a treatment for sepsis in the absence of acute renal failure.

Liver Dialysis

Two machines have been designed to treat liver failure, but veterinary experience is limited. I believe that the University of Florida has used the MARS system (Molecular Adsorbant Recirculating System) that integrates with the Prismaflex system. Charcoal hemoperfusion may remove some toxins retained in liver failure, but there is only limited veterinary experience at this time.
Chapter 20  Peritoneal Dialysis

Discussion of peritoneal dialysis and descriptions of the technique are available elsewhere (Ross, in DiBartola’s Fluid and Acid-Base Disorders). This section presents only a brief overview.

Peritoneal dialysis involves placement of a catheter in the peritoneal cavity. Catheters specially designed for PD are available in a variety of styles. Some are intended for percutaneous placement (similar to chest tube placement) while others are surgically or laparoscopically implanted for long term use. If a specific PD catheter is not available, a variety of other catheters can be used instead, include chest tubes, Jackson-Pratt suction drains, or even a red rubber catheter with additional ports created with a scalpel blade.

Dialysate is infused into the abdomen, allowed to dwell for a period of time to allow diffusion of uremic toxins, then drained and replaced with fresh dialysate. Commercially prepared dialysate is available, but intravenous fluids can be used if specific dialysate is not available. As with ERRT, the dialysate composition is adjusted to suit the needs of the individual patient. Dextrose is added in concentrations ranging from 1.5 to 4.5% to create an osmotic gradient that causes water removal from the patient (ultrafiltration).

Peritoneal dialysis is another option that we can offer. For AKI, it will require 24 hour nursing (and cost about the same as CRRT). Because of complications associated with PD (catheter occlusion, difficulty in controlling fluid balance, inefficient control of uremia), it is unlikely that PD would be preferred over CRRT or IHD except in certain situations. One of those includes uroabdomen, in which a peritoneal catheter will be placed and maintained anyway. In most of those situations, the azotemia will resolve simply by draining the urine from the abdomen, but I would not be opposed to a few dialysate exchanges if the azotemia is slow to resolve.

The most likely reason for us to choose PD would be a patient that is too hemodynamically unstable even for CRRT. In that setting, it would be prudent to counsel the owner about the high probability of a poor outcome despite a high cost. PD might be an acceptable option for the extraordinarily small patient (< 2 kg).
References and Resources

Suggested Reading


Other Resources
www.queenofthenephron.com. This website includes a list of units performing extracorporeal renal replacement therapies and/or renal transplantation.
www.vetcrrt.net. This is the home page of the Veterinary CRRT Society.
http://renalpharmacyconsultants.com/assets/2013dodbooklet.pdf. This website has a pdf file of the Dialysis of Drugs handbook, to help determine if a particular drug is dialyzable.

References
Appendix

Conversion Tables for Weight in Kilograms to Body Surface Area (m²)

The following tables are derived from the equation:
Approximate Surface area in m² = \( \frac{10.1 \times (weight \ in \ grams)^{2/3}}{10000} \)

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<th>CATS Kg m²</th>
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111
# Extracorporeal Renal Replacement Units*

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<td>Tierärztliche Klinik für Kleintiere Norderstedt, Germany</td>
<td>Hospital Veterinario das Laranjeiras Lisboa, Portugal</td>
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<th>Asia/India/Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bombay Veterinary College Mumbai, India</td>
<td>Konkuk University College of Veterinary Medicine Seoul, South Korea</td>
<td>Manhattan Animal Hospital Taipei, Taiwan</td>
<td>National Taiwan Univ. Animal Hospital Taipei, Taiwan</td>
</tr>
<tr>
<td>Kasetsart University Faculty of Veterinary Medicine Bangkok, Thailand</td>
<td>Greencross Vets Ku-Ring-Gai Sydney, Australia</td>
<td>South Tamworth Animal Hospital Tamworth, Australia</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>South/Central America</th>
<th>South/Central America</th>
<th>South/Central America</th>
<th>South/Central America</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canne &amp; Gatto Small Animal Hospital Rio De Janerio, Brazil</td>
<td>Renal Vet Rio de Janeiro Rio de Janeiro, Brazil</td>
<td>Renal Vet Sao Paulo Sao Paulo, Brazil</td>
<td>Renal Vet Salvador Salvador, Brazil</td>
</tr>
</tbody>
</table>

*Unverified information
Outcome prediction models using a scoring system in dogs with AKI managed with hemodialysis

<table>
<thead>
<tr>
<th>Variables</th>
<th>Value</th>
<th>Range</th>
<th>Weighting factor</th>
<th>Patient Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (kg)</td>
<td>&gt;36</td>
<td>27.2-36.0</td>
<td>≤27.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>1.61</td>
<td>2.73</td>
<td></td>
</tr>
<tr>
<td>Red blood cells (*10^6 cells/μl)</td>
<td>&gt;4.93</td>
<td>3.54-4.93</td>
<td>≤3.53</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>1.51</td>
<td>3.61</td>
<td></td>
</tr>
<tr>
<td>Lymphocyte count (cells/μl)</td>
<td>&gt;1000</td>
<td>509-999</td>
<td>≤509</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>1.69</td>
<td>3.44</td>
<td></td>
</tr>
<tr>
<td>Creatinine (mg/dL)</td>
<td>≤13.2</td>
<td>&gt;13.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>2.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosphorous (mg/dL)</td>
<td>≤18.2</td>
<td>&gt;18.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>3.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ionized calcium (mmol/L)</td>
<td>&gt;1.1</td>
<td>0.87-1.1</td>
<td>≤0.86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>1.99</td>
<td>4.16</td>
<td></td>
</tr>
<tr>
<td>Anion gap (mmol/L)</td>
<td>≤18.2</td>
<td>&gt;18.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>2.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Albumin (g/dL)</td>
<td>&gt;1.9</td>
<td>≤1.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>2.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alanine aminotransferase (U/L)</td>
<td>&lt;210</td>
<td>&gt;210</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>2.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urine production (mls/kg/hr)</td>
<td>&gt;1.31</td>
<td>0.1-1.31</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>1.44</td>
<td>5.55</td>
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<tr>
<td>Respiratory system involvement</td>
<td>No</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>2.48</td>
<td></td>
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<tr>
<td>Neurological involvement</td>
<td>No</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>3.76</td>
<td></td>
<td></td>
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<tr>
<td>DIC⊥</td>
<td>No</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When leptospirosis and EG status are known the final predictive score is adjusted as follows:
leptospirosis: -8.46, EG: +2.47, neither: +1.00

The clinical value of each individual patient should be compared to the ranges of each variable to assign a weighting factor for the variable. All weighting factors should be summed to a final predictive score. When leptospirosis and EG status are known an adjustment to the final score is made. The final score is compared to the different cutoff points to predict survival. Dogs with a predictive score below the 20 are expected to survive with 81% sensitivity and 85% specificity.

⊥Disseminated intravascular coagulation.
Outcome prediction models using a scoring system in cats with AKI managed with hemodialysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Patient Value</th>
<th>Range</th>
<th>Weighting Factor</th>
<th>Patient Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (kg)</td>
<td></td>
<td>&gt;5 ≤5</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Total protein (g/dL)</td>
<td></td>
<td>&gt;5 ≤5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>RBC (x 10⁶/uL)</td>
<td></td>
<td>&gt;4.86 ≤4.86</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Body temperature (°F)</td>
<td></td>
<td>&gt;99.35 98-99.35 ≤98</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Ataxia</td>
<td>Yes</td>
<td>No</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Fluid overload</td>
<td>Yes</td>
<td>No</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Respiratory involvement</td>
<td>Yes</td>
<td>No</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Vomiting</td>
<td>Yes</td>
<td>No</td>
<td>-3</td>
<td>1</td>
</tr>
<tr>
<td>EG intoxication</td>
<td>Yes</td>
<td>No</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Lily intoxication</td>
<td>Yes</td>
<td>No</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Ureteral obstruction</td>
<td>Yes</td>
<td>No</td>
<td>-5</td>
<td>1</td>
</tr>
</tbody>
</table>

Model A (without etiology) and Model C (with etiology).

Cutoff 10: Model A - 74% Sen, 75% Spec; Model C - 62% Sen, 88% Spec
Owner Consent for Extracorporeal Renal Replacement Therapy (“Kidney Dialysis” and related therapies)

☐ The goal of kidney dialysis in treating acute kidney failure is to sustain the pet while waiting to see if the kidneys can repair themselves.

☐ The type and schedule of dialysis varies based on the individual patient. Each day we reassess and determine the best plan, based on improvement, worsening, complications, etc.

☐ A common schedule for dialysis is continuous or daily treatments for 3 to 4 days in a row, then alternate day treatments. Some animals are stable enough to go home in-between treatments after the first 2 weeks.

☐ A catheter must be placed to perform dialysis. We generally need some form of sedation or anesthesia to place the catheter, although it is usually short. There is a risk of sedation in patients with severe kidney failure.

☐ There are several risks associated with kidney dialysis, including bleeding, excessive blood clotting, low blood pressure, seizures, coma, and death.

☐ About half of patients treated with dialysis will die, either due to the kidney disease itself, complications in other organs caused by the kidney failure, complications of treatment, or euthanasia. About half of the patients live and do not need dialysis long term, although about half of the survivors do have long term renal damage and may need special diets, medications, and other treatments for kidney disease once they are home.

☐ It generally takes about 3-4 weeks for recovery. If there are no signs of recovery after that time, we may discuss euthanasia, as significant recovery is less likely to occur.

☐ Chronic dialysis is possible if the kidneys do not recover. Treatments are usually 6-7 hours, 3 days a week. Cost can be substantial.

☐ The average cost of intermittent dialysis is around $20-25,000. It is likely that we will spend $2000-3000 within the first 24 hours, and $10,000-12,000 in the first week. Most (but not all) patients are more stable by weeks 2-3, and treatment is not quite as intensive.

☐ If continuous dialysis is used, we will likely spend $4000 in the first 24 hours, and $12-15,000 in the first week, presuming that the pet can be transitioned to intermittent treatment after the first 3 days.
Dialysis Prescription Worksheet

Date_____________________

<table>
<thead>
<tr>
<th>Dialyzer:</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>Revaclear</th>
<th>Revaclear Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tubing:</td>
<td>pediatric</td>
<td>neonatal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prime:</td>
<td>saline</td>
<td>3% HES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prime volume:</td>
<td>_____ ml</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dialysate K+:</td>
<td>3</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Profile:</td>
<td>160-155-150</td>
<td>155-150-145</td>
<td>other (__________)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heparin:</td>
<td>bolus</td>
<td>rate</td>
<td>other (___________________)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heparin concentration/dilution:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target URR:</td>
<td></td>
<td>Target L processed:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time:</td>
<td></td>
<td>Qb:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluid balance:</td>
<td>_____ = [(Fluids supplied ___<em>/hr - Machine UF <strong><strong>/hr) x ___ hrs tx] + Rinseback volume</strong></strong></em>]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rinseback:</td>
<td>air</td>
<td>saline (_____ mls)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other orders:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Doctor____________________________
**CRRT Prescription Worksheet**

**Doctor:**

[Name]

---

**Fill in the blanks or circle your choices. Feel free to make notes about any special circumstances or unusual prescriptions.**

**Date:**

---

**Day of week:** Sun Mon Tues Wed Thur Fri Sat

**Day of Treatment:** [Day 1, Day 2, etc.] **Treatment Number:**

**Patient Weight:** __________ kg

**Patient BUN:** __________ mg/dl  **Creatinine:** __________ mg/dl  **K⁺:** __________ mEq/L

**Catheter:** Noncuffed (temporary) or Cuffed

**Brand:** MedComp  Arrow  Quinton  Other__________

**French Size:** __________ cm  **Length:** __________ cm

**Location:** Right  Left  Jug  Other_______

**Placement:** Seldinger:  Percutaneous  Cutdown

**Surgical:** Tunneled  Not tunneled

**Date Placed:**

---

**Placed by:**

---

**Radiograph confirmation:**

---

**Machine:**

- [ ] PrismaFlex
- [ ] Prisma
- [ ] Phoenix

**CRRT modality:**

- SCUF
- CVVHF
- CVVHD
- CVVHDF
- TPE

**Filter:**

<table>
<thead>
<tr>
<th>Surface area</th>
<th>Priming volume</th>
<th>PrismaFlex</th>
<th>Old Prisma</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6 m²</td>
<td>90 ml</td>
<td>M60</td>
<td>M10</td>
</tr>
<tr>
<td>0.9 m²</td>
<td>150 ml</td>
<td>M100</td>
<td>M100</td>
</tr>
<tr>
<td>0.3 m²</td>
<td>45 ml</td>
<td>M60</td>
<td>M60</td>
</tr>
<tr>
<td>0.6 m²</td>
<td>90 ml</td>
<td>M100</td>
<td>M100</td>
</tr>
<tr>
<td>0.9 m²</td>
<td>107 ml</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Priming Solution**

- Saline  _____% HES  Blood*  Other_______

*If blood prime, which method

- [ ] run machine for 15-30 minutes prior to starting patient
- [ ] add _____ mEq bicarb to blood
- [ ] Baby buffer and bleed on

**Blood Flow Rate (Qb)**

- 2-20 ml/kg/min  
  \[Qb = \text{_______ ml/min}\]

  Start at 1-2 ml/kg/min (lowest is 10 ml/min), increase to desired Qb over 15-30 minutes.
Anticoagulant:  
- Citrate
- Heparin
- None
- Other__________

Avoid citrate if liver dysfunction present

Heparin Orders
- Target ACT:  160-180  160-200  Other__________
- Heparin Prime:  25 u/kg, repeat if ACT < 180 sec  ___________ u
- Heparin CRI:  Start 10-20 u/kg/hr

Citrate Orders
- Sodium citrate  ____________ ml/hr of ACD-A. Record this number on next page.
  - Qb  _____(ml/min) x 1.5 = _____ (put this number on line above)
  - Recommend 1.5 x blood flow rate; titrate to maintain extracorporeal iCa++ at 0.25-0.45 mmol/L
  - Start at 3X blood flow rate for first 30 minutes
- Calcium chloride (8 gm per 1 L 0.9% saline) ____________ml/hr. Record this number on next page.
  - Recommend 0.4 x citrate rate; titrate to maintain patient iCa++ at 1.1-1.3 mmol/L
  - Use calcium free dialysate

Therapy Fluid Choices
- Dialysate ____________  Replacement Fluid ____________
  - □ Pre-filter  □ Post-filter

Dialysate Composition**

<table>
<thead>
<tr>
<th>Prismasate</th>
<th>BK0/3.5</th>
<th>B22GK4/0</th>
<th>BGK4/2.5</th>
<th>BGK2/0</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺</td>
<td>140</td>
<td>140</td>
<td>140</td>
<td>140</td>
<td>mEq/L</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>109.5</td>
<td>120.5</td>
<td>113</td>
<td>108</td>
<td>mEq/L</td>
</tr>
<tr>
<td>K⁺</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>mEq/L</td>
</tr>
<tr>
<td>Bicarb</td>
<td>32</td>
<td>22</td>
<td>32</td>
<td>32</td>
<td>mEq/L</td>
</tr>
<tr>
<td>Lactate</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>mEq/L</td>
</tr>
<tr>
<td>Dextrose</td>
<td>0</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>mg/dl</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>3.5</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>mEq/L</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>1</td>
<td>mEq/L</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*No calcium if using citrate
#Use Bicarb instead of lactate if liver disease
A= Acetate (47 mEq/L)

(you may use same fluid for both dialysate and replacement, or use different fluids)
Patient Fluid Removal Rate (Ultrafiltration)

_____ % overhydrated x _____ kg BW = _____ mL excess

_____ mL removal ÷ _____ hr fluid removal period = _____ mL/hr to achieve dry weight

*Do not exceed 10 ml/kg/hr or 25% of Qb

Net Patient Fluid Removal for overhydration = _____ ml/hr (from above)
Calcium Rate + _____ ml/hr (from page 2)
Volume of medications/nutrition + _____ ml/hr
Fluid Outs (urine, etc) - _____ ml/hr
Total Pt Fluid Removal (set pump to this value) = _____ ml/hr (enter below)

☐ Continuous treatment ☐ Prolonged Intermittent Therapy

Indicate Method of Dose Determination:

Prolonged Intermittent Therapies
☐ Therapy fluid per kg ☐ Eatroff craziness (see database for instructions)

Desired URR (see table) = __________ %
Total Therapy Fluid (from scatterplots) _____ L/kg x _____ kg = _________ L
Treatment Duration = _______ hours
Total Therapy Fluid (Effluent) per hour = _________ ml/hr (enter below)

Or

Continuous Therapies (note: we rarely do true continuous therapy)
☐ 35 ml/kg/hr (target generally ≥ 25 ml/kg/hr) ☐ 2 L/hr per 1.73 m²

Total Therapy Fluid (Effluent) per hour = _________ ml/hr (enter below)

Total Therapy Fluid (Effluent) per hour = _________ ml/hr

Proportion Convective to Diffusive Clearance (*typically 50:50):
Dialysate (Diffusive) Flow Rate (Qd) = _________ ml/hr
Convective Clearance = _________ ml/hr

These two should add up to Total Therapy Fluid per hour

Patient Fluid Removal Rate (from above) = _________ ml/hr
Pre-Blood Pump Rate (i.e. citrate rate) = _________ ml/hr
Replacement Rate = _________ ml/hr

These 3 should add up to Convective Clearance per hour
### Monitoring

As written

With following modifications

#### Patient Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
<th>Time 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>pre</td>
<td></td>
<td></td>
<td>q 6 hr</td>
</tr>
<tr>
<td>Temp</td>
<td>pre</td>
<td></td>
<td></td>
<td>q 1 hr</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>pre</td>
<td>15 min</td>
<td>30 min</td>
<td>q 1 hr</td>
</tr>
<tr>
<td>Heart Rate</td>
<td>pre</td>
<td>15 min</td>
<td>30 min</td>
<td>q 1 hr</td>
</tr>
<tr>
<td>Resp Rate</td>
<td>pre</td>
<td>15 min</td>
<td>30 min</td>
<td>q 1 hr</td>
</tr>
<tr>
<td>Mixed Venous O2 Sat</td>
<td>pre</td>
<td>30 min</td>
<td></td>
<td>q 1 hr</td>
</tr>
<tr>
<td>Arterial O2 Sat</td>
<td>pre</td>
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<td></td>
<td></td>
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#### Laboratory

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
<th>Time 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit and Patient ionized Ca++</td>
<td>1 hr</td>
<td>4 hr</td>
<td></td>
<td>q 4 for 12 hr, then q 6</td>
</tr>
<tr>
<td>Patient total Ca++</td>
<td>pre</td>
<td>4 hr</td>
<td>6 hr</td>
<td>q 12 hr</td>
</tr>
<tr>
<td>Patient BUN/Creat</td>
<td>pre</td>
<td></td>
<td>6 hr</td>
<td>q 12 hr</td>
</tr>
<tr>
<td>Effluent BUN</td>
<td></td>
<td></td>
<td></td>
<td>q 12 hr</td>
</tr>
<tr>
<td>Electrolytes</td>
<td>pre</td>
<td></td>
<td></td>
<td>q 4 for 12 hr, then q 6</td>
</tr>
<tr>
<td>Hematocrit (CritLine)</td>
<td></td>
<td></td>
<td></td>
<td>q 1 hr</td>
</tr>
<tr>
<td>PCV</td>
<td>pre</td>
<td></td>
<td></td>
<td>q 6 hr if no CritLine</td>
</tr>
</tbody>
</table>

#### Machine Rates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
<th>Time 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qb</td>
<td></td>
<td></td>
<td></td>
<td>q 1 hr</td>
</tr>
<tr>
<td>Pt Fluid Removal</td>
<td></td>
<td></td>
<td></td>
<td>q 1 hr</td>
</tr>
<tr>
<td>Replace Solution</td>
<td></td>
<td></td>
<td></td>
<td>q 1 hr</td>
</tr>
<tr>
<td>Dialysate</td>
<td></td>
<td></td>
<td></td>
<td>q 1 hr</td>
</tr>
<tr>
<td>Citrate</td>
<td></td>
<td></td>
<td></td>
<td>q 1 hr</td>
</tr>
<tr>
<td>Calcium</td>
<td></td>
<td></td>
<td></td>
<td>q 1 hr</td>
</tr>
<tr>
<td>Nutrition</td>
<td></td>
<td></td>
<td></td>
<td>q 1 hr</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td>q 1 hr</td>
</tr>
</tbody>
</table>

#### Machine Pressures

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time 1</th>
<th>Time 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access, Filter, Effluent, Return</td>
<td></td>
<td>q 1 hr</td>
</tr>
<tr>
<td>TMP, ΔP Filt</td>
<td></td>
<td>q 1 hr</td>
</tr>
</tbody>
</table>

#### Ins and Outs Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
<th>Time 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replacement Sol Input</td>
<td>q 4 hr</td>
<td></td>
<td>Nutrition</td>
<td>q 4 hr</td>
</tr>
<tr>
<td>Dialysate Used</td>
<td>q 4 hr</td>
<td></td>
<td>Other Ins</td>
<td>q 4 hr</td>
</tr>
<tr>
<td>Effluent</td>
<td>q 4 hr</td>
<td></td>
<td>Urine</td>
<td>q 4 hr</td>
</tr>
<tr>
<td>Actual Pt Fluid Removed</td>
<td>q 4 hr</td>
<td></td>
<td>Vomiting (estimated)</td>
<td>q 4 hr</td>
</tr>
<tr>
<td>Citrate</td>
<td>q 4 hr</td>
<td></td>
<td>Other Outs</td>
<td>q 4 hr</td>
</tr>
<tr>
<td>Calcium</td>
<td>q 4 hr</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Case Number:__________

120