

Principles of Continuous Renal Replacement Therapy

Self-Learning Packet

2005

This self-learning packet is approved for 2 contact hours for the following professionals:

- 1. Registered Nurses**

*** This packet should not be used after 3/31/2007.**



Table of Contents

Purpose	4
Objectives	4
Instructions	4
Introduction	5
The Multidisciplinary Team	5
Continuous vs. Intermittent Renal Replacement Therapy	5
Indications for CRRT	7
Contraindications for CRRT	7
Principles of Renal Replacement Therapy	7
Renal Replacement Therapy.....	7
Semipermeable Membranes	8
Ultrafiltration.....	8
Convection.....	9
Adsorption	9
Diffusion.....	9
Vascular Access and the Extracorporeal Circuit	10
Fluids Used in CRRT	11
Dialysate	11
Replacement Fluids	12
Anticoagulation & CRRT	14
Heparin	14
Prostacyclin	15
Citrate.....	15
No Anticoagulation	15
Types of CRRT Therapy	16
Slow Continuous Ultrafiltration (SCUF)	17
Continuous Veno-venous Hemofiltration (CVVH)	18
Continuous Veno-venous Hemodialysis (CVVHD).....	19

Continuous Veno-venous Hemodiafiltration (CVVHDF)	20
Complications of CRRT	21
Bleeding	21
Hypothermia	22
Electrolyte Imbalances	22
Acid-Base Imbalances	23
Infection.....	23
Appropriate Dosing of Medications.....	23
Nursing Assessment of the CRRT Patient.....	24
Psychosocial Assessment.....	24
Cardiovascular System	24
Pulmonary System.....	26
Neurological System	26
Gastrointestinal System.....	27
Renal System	27
Troubleshooting.....	28
Access Pressure Alarms.....	28
Return Pressure Alarms.....	28
Filter Pressures	28
Blood Leak Detectors	28
Air In Line.....	29
Fluid and Effluent Pump Alarms	29
Conclusion	29
Appendix.....	30
Glossary	32
Post Test.....	33
References.....	39

Purpose

The purpose of this self learning packet is to educate critical care registered nurses regarding the basic principles of continuous renal replacement therapy and to satisfy the continuing education requirements of Orlando Regional Healthcare employees.

Orlando Regional Healthcare is an Approved Provider of continuing nursing education by Florida Board of Nursing (Provider No. FBN 2459) and the North Carolina Nurses Association, an accredited approver by the American Nurses Credentialing Center's Commission on Accreditation (AP 085).

Objectives

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

1. Identify indications and contraindications for CRRT and compare CRRT to intermittent dialysis therapy.
2. Discuss the importance of a multidisciplinary team approach to managing patients on CRRT.
3. Define diffusion, convection and ultrafiltration and describe their role in blood purification.
4. Describe the function of the semi-permeable membrane in blood purification.
5. Describe the vascular access and extracorporeal circuit used for CRRT.
6. Discuss the use of replacement fluids and dialysates in CRRT.
7. Compare and contrast the four treatment modalities available when using CRRT.
8. Describe medical and nursing management during initiation and maintenance of CRRT.
9. Discuss options for anticoagulation during CRRT therapy.
10. Discuss potential complications of CRRT.
11. Discuss essential components of nursing care for patients receiving CRRT.

Instructions

In order to receive 2 contact hours, you must:

- complete the posttest at the end of this packet
- submit the posttest to Education & Development with your payment
- achieve an 84% on the posttest

Be sure to complete all the information at the top of the answer sheet. You will be notified if you do not pass, and you will be asked to retake the posttest.

Introduction

Traditional intermittent hemodialysis often causes hemodynamic instability in the critically ill. Continuous renal replacement therapy (CRRT) was developed in the 1980s in an effort to provide artificial kidney support to patients who could not tolerate traditional hemodialysis. The earliest forms of CRRT used arterial and venous access and depended on the patient's mean arterial pressure to push blood through the filter. This technique was rarely successful for patients in shock – those who needed the continuous therapy the most. In response to this shortcoming, the current techniques of veno-venous CRRT were developed. Most CRRT delivered today uses veno-venous access and an external blood pump to maintain adequate flow through the filter.

As CRRT techniques have become more effective, its use has increased dramatically. In Australia 90% of patients in an ICU with acute renal failure receive CRRT, in Europe about 50%, and numbers in the United States continue to rise. As the frequency of CRRT increases, critical care nurses find themselves managing therapies that were previously managed by dialysis nurses. This packet addresses the fundamental vocabulary and concepts of CRRT. It also reviews the medical and nursing care priorities specific to these patients. Throughout the packet you will encounter words in italics. These words are defined in the glossary at the end of the packet.

The Multidisciplinary Team

The success of CRRT depends upon the presence of a cohesive, well-educated, multidisciplinary team. The team is usually led by a nephrologist or intensivist, and comprised of at least one member of each of the following professions: critical care nurse, dialysis nurse, clinical pharmacist, dietician, clinical laboratory, and consulting physicians. CRRT is a complex therapy that purifies the blood. Because the blood comes into contact with every organ system, CRRT will affect every organ system in some way. Without a cohesive multidisciplinary approach, professionals often end up working at cross-purposes leading to less than ideal outcomes.

Continuous vs. Intermittent Renal Replacement Therapy

Intermittent renal replacement therapy includes traditional dialysis and ultrafiltration therapies. Intermittent therapies are performed every two to three days and last about three to four hours per treatment. During treatment large amounts of fluids, electrolytes and toxins are removed. In hemodynamically stable patients this type of therapy can cause significant hypotension.

Critically ill patients requiring renal replacement therapies cannot tolerate rapid fluid and electrolyte shifts without significant hemodynamic compromise. Even if these hypotensive episodes are brief, they may result in further damage to the kidney. Multiple hypotensive episodes have been shown to slow recovery from acute renal failure in the critically ill.

The critically ill patient is also susceptible to protein calorie malnutrition due to the marked catabolism that accompanies critical illness. Multiple studies have shown that the maintenance of a positive protein balance improves outcome in the critically ill. In order to provide adequate protein to these patients, large amounts of fluids and protein must be administered, either

enterally or parenterally. Intermittent hemodialysis (IHD) requires that patients' protein and fluid intake be limited between treatments to prevent toxic levels of nitrogen and fluid overload.

Many critically ill patients also require large amounts of fluid for various reasons. Often the need for these fluids is sudden, requiring unplanned additional IHD treatments.

CRRT addresses the needs of the critically ill patient with renal dysfunction and/or fluid volume excess by providing slow, continuous removal of toxins and fluids. By removing fluids continuously over a 24 hour period, CRRT mimics the native kidney. Hemodynamic stability is improved, and multiple hypotensive episodes are significantly reduced. Because there is no buildup of toxins and fluids, patients receiving CRRT can receive as much protein and fluid as needed to achieve optimal nutrition. CRRT also allows the freedom to administer large-volume infusions whenever needed, because the therapy can be titrated to achieve specific hemodynamic goals. At this time there is no scientific evidence showing improved mortality with the use of CRRT vs. IHD. There are several researchers actively involved in collection of outcomes data.

	CRRT	IHD
Continuous	Y	N
Rapid change in electrolytes, pH, and fluid balance	N	Y
Need to reduce dosage of renally cleared drugs	Dependent on mode of therapy	Y
Need to adjust administration times of renally cleared drugs	N	Y
Need to limit protein, potassium & fluid intake	N	Y
pH and electrolyte shifts after therapy	N	Y

Indications for CRRT

CRRT is indicated in any patient who meets criteria for hemodialysis therapy but cannot tolerate intermittent dialysis due to hemodynamic instability. CRRT is better tolerated by hemodynamically unstable patients because fluid volume, electrolytes and pH are adjusted slowly and steadily over a 24 hour period rather than a 3 – 4 hour period. This pattern more closely mimics the native kidney and prevents abrupt shifts in fluid, electrolyte and acid-base balance.

Hemodynamically unstable patients with the following diagnoses may be candidates for CRRT:

- fluid overload
- acute renal failure
- chronic renal failure
- life-threatening electrolyte imbalance
- major burns with compromised renal function
- drug overdose

There is no clear consensus on when CRRT should be started, though most experts tend to favor earlier starts over later ones.

Contraindications for CRRT

Contraindications to CRRT include:

- Advance directives indicating the patient does not desire dialysis, or that the patient does not desire life-sustaining therapy
- Patient or family refusal of therapy
- Inability to establish vascular access

Principles of Renal Replacement Therapy

Renal Replacement Therapy

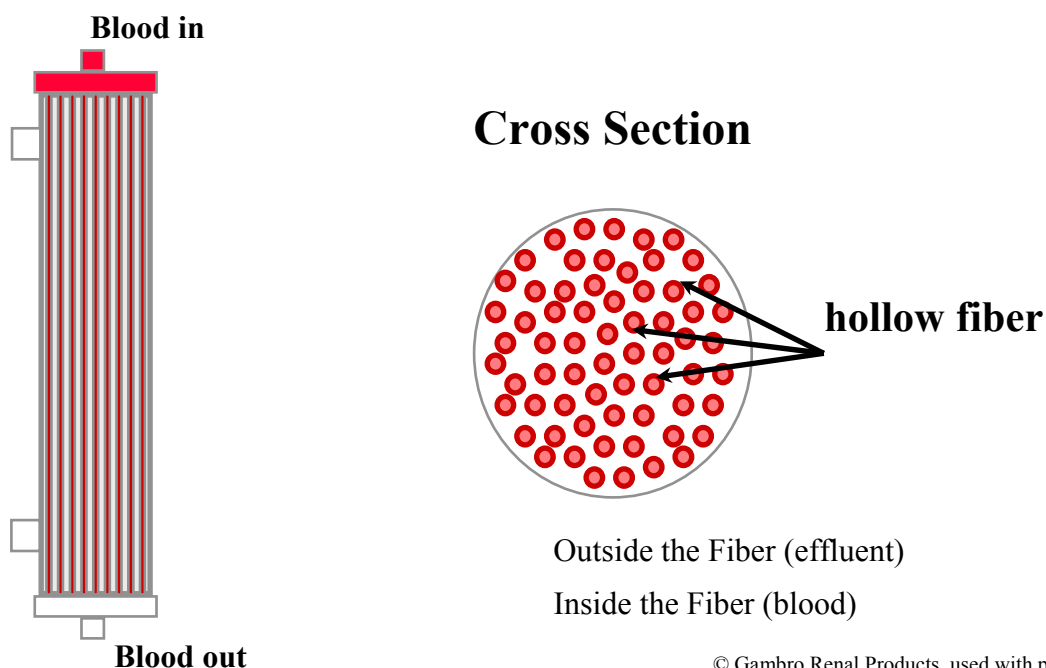
Renal replacement therapy is any treatment modality that seeks to replace the excretory function of the kidney. Renal replacement always uses a *semi-permeable membrane* to achieve blood purification. It can be intermittent or continuous, and can involve any of 4 major transport mechanisms: *diffusion*, *convection*, *adsorption* and *ultrafiltration*. The focus of this packet is continuous renal replacement therapies.

Semipermeable Membranes

Semipermeable membranes are the basis of all blood purification therapies. They allow water and some *solutes* to pass through the membrane, while cellular components and other *solutes* remain behind. The water and solutes that pass through the membrane are called *ultrafiltrate*. The membrane and its housing are referred to as the *filter*.

There are two types of membranes used in renal replacement therapy, cellulose and synthetic. Synthetic membranes allow clearance of larger molecules and are the primary type used in CRRT.

Filters are changed when they become contaminated, clogged or clotted, and when institutional policies dictate they be changed. Check your hospital's policy to determine when you must change the CRRT filter. With anticoagulation techniques filters can stay patent longer than they remain safe to use.



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Ultrafiltration

Ultrafiltration refers to the passage of water through a membrane under a pressure gradient. To better understand ultrafiltration, think of a drip coffee maker. The paper filter is the membrane through which the water drips under gravity pressure. The coffee grounds remain on one side of the filter, while the coffee (the ultrafiltrate) drips into the pot. Pressures that drive ultrafiltration can be positive, that is the pressure pushes fluid through the filter. They can also be negative, there may be suction applied that pulls the fluid to the other side of the filter. The rate of ultrafiltration will depend upon the pressures applied to the filter and on the rate at which the blood passes through the filter. Higher pressures and faster flows increase the rate of ultrafiltration. Lower pressures and slower flows decrease the rate of ultrafiltration.



Convection

Convection is the movement of *solutes* through a membrane by the force of water. *Convection* is sometimes called “solvent drag”. Think back to the coffee maker example. When the water drips through that filter it doesn’t come out the other side as pure water, does it? It carries along with it flavor molecules, caffeine and other substances that make it coffee. How do those molecules get to the other side of the filter? *Convection*. The water pulls the molecules along with it as it flows through the membrane.

Convection is able to move very large molecules if the flow of water through the membrane is fast enough. In CRRT this property is maximized by using *replacement fluids*. *Replacement fluids* are crystalloid fluids administered at a fast rate just before or just after the blood enters the filter. The increased fluid flow rate across the filter allows more molecules to be carried through to the other side. To better understand this phenomenon, think of a quiet stream as compared to a raging river. The stream could never shift a boulder, but the powerful raging river could easily drag a boulder downstream. So it is with *convection*; the faster the flow through the membrane, the larger the molecules that can be transported



Low flow High flow
 Low convection High convection

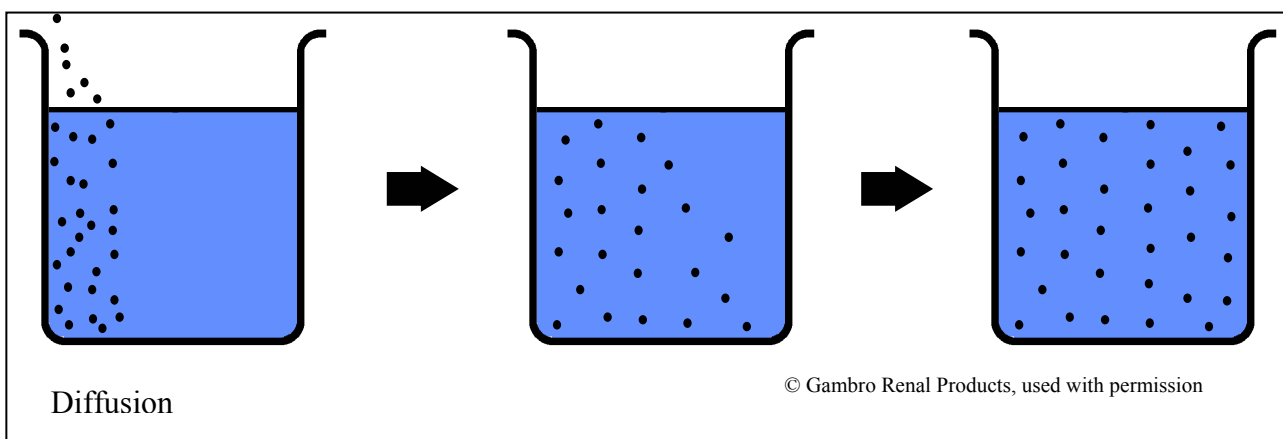


Adsorption

Adsorption is the removal of solutes from the blood because they cling to the membrane. Think of an air filter. As the air passes through it, impurities cling to the filter itself. Eventually the impurities will clog the filter and it will need to be changed. The same is true in blood purification. High levels of *adsorption* can cause filters to clog and become ineffective

Diffusion

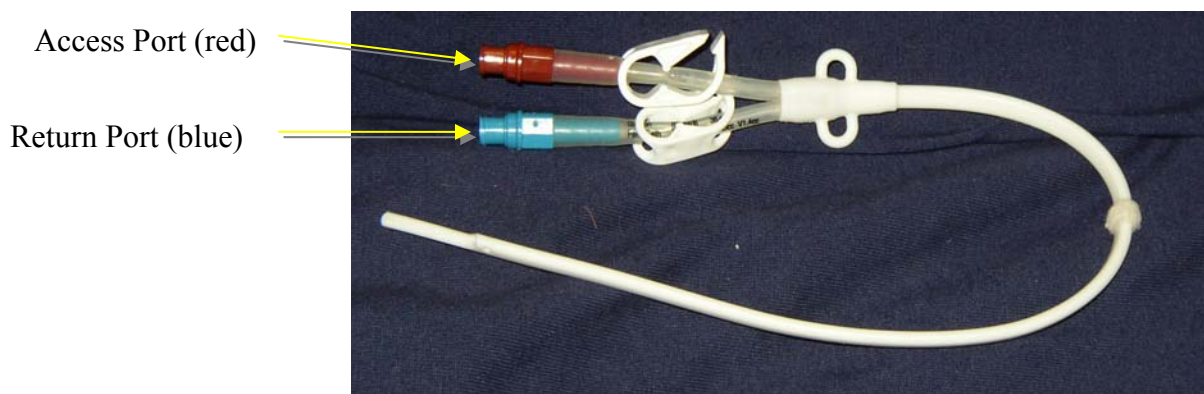
Diffusion is the movement of a solute across a membrane via a concentration gradient. For *diffusion* to occur, another fluid must flow on the opposite side of the membrane. In blood purification this fluid is called *dialysate*. When solutes diffuse across a membrane they always shift from an area of higher concentration to an area of lower concentration until the *solute* concentration on both sides of the membrane is equal. To understand diffusion, think of adding drops of food coloring to a bathtub. Initially the coloring appears as a dense cloud, but over time the coloring spreads (diffuses) evenly throughout the water.



Vascular Access and the Extracorporeal Circuit

There are two options for vascular access for CRRT, *venovenous* and *arteriovenous*. Venovenous access is by far the most commonly used in the modern ICU.

Venovenous access is generally achieved with the use of a large-bore (11.5 – 13.5 French) dual lumen dialysis catheter placed in a large central vein. Only one puncture is required. The patient's blood will be removed from one lumen of the catheter, directed through the pump, and returned through the other lumen. By convention blood is usually removed through the red port and returned through the blue port. Common sites for venous access include the internal jugular, subclavian and femoral veins. The site is selected by the physician in the same manner as for any central venous access device. **The CRRT access must not be located close to other vascular access used for infusion of drugs or nutrition.** If it is, the infused substance will be sucked into the access port and filtered before returning to the patient's bloodstream. Any substance that is dialyzable will be removed as it passes through the filter



Dual-lumen Temporary Dialysis Catheter

Venovenous access requires the use of a blood pump in conjunction with the dialysis filter and tubing. Use of the pump provides reliable, adjustable blood flow through the filter. The constant blood flow provided by the pump lessens the risk that the filter will clot. The adjustability allowed by using a pump means that the flow rates can be fine tuned to suit the needs of the patient. The pump also alarms if the system clots, becomes disconnected, or if an air bubble is detected in the blood line.

There are many manufacturers who produce blood pumps for CRRT. Throughout this packet we will use the Gambro PRISMA™ as an example. Your institution may use a different device. The principles of therapy do not change, but specifics of operation may be different than what you see depicted in this packet. Refer to the documentation provided with the device you use for specific operation instructions.



Gambro Prisma

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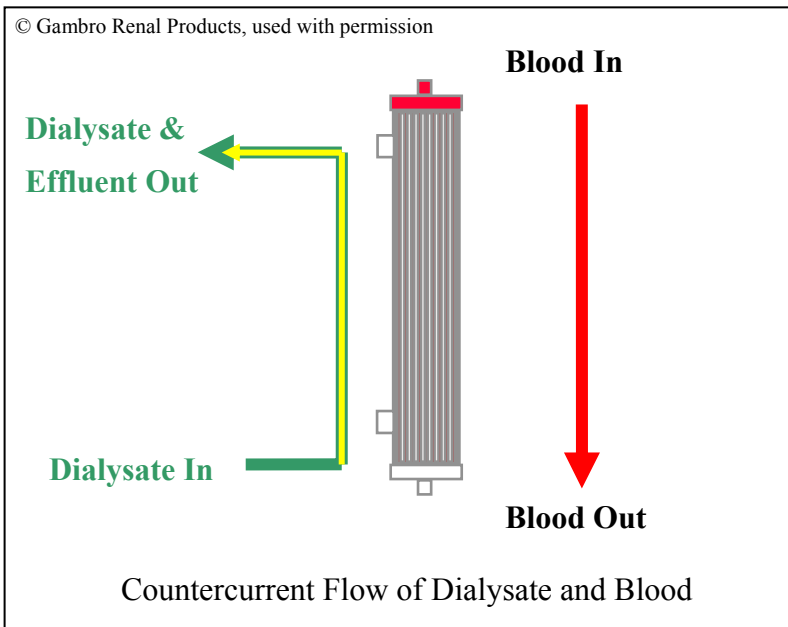
Arteriovenous access was the first method of access for CRRT. It may still be used in facilities that do not have access to a blood pump. To perform CRRT in this way, two punctures are required, one in an artery for blood removal and one in a vein for blood return. The “pump” is provided by the difference between the patient’s mean arterial pressure (MAP) and the venous pressure. Because critically ill patients often do not have a high MAP, it is important to remove as much resistance from the circuit as possible. Because of this, large short catheters, short blood lines and short filters are used. Despite these attempts to increase efficiency, arteriovenous access tends to fail at a very high rate. The patient is also exposed to the additional risk of the large-bore arterial access, and the lack of alarms on a system of this type. Most practitioners now believe that the risks of this form of CRRT outweigh the benefits for the majority of patients.

Fluids Used in CRRT

Dialysate

Dialysate is any fluid used on the opposite side of the filter from the blood during blood purification. As with traditional hemodialysis therapy, the dialysate is run on the opposite side of the filter, counter-current to the flow of the patient’s blood. The countercurrent flow allows a greater diffusion gradient across the entire membrane, increasing the effectiveness of solute removal.

Dialysate is a *crystalloid* solution containing various amounts of electrolytes, glucose, buffers and other solutes. The most common concentrations of these solutes are equal to normal plasma levels. The concentration of solutes will be ordered by the physician based on the needs of the patient.



Clinical Application

If a patient has hyperkalemia that causes life-threatening symptoms, physiologic levels of potassium in the dialysate will not produce a change in the plasma quickly enough. In addition to other measures to reduce the potassium, the physician may order a custom dialysate with a low concentration of potassium.

Safe administration of such therapy requires that the potassium be monitored frequently. When the patient's potassium level approaches normal, the dialysate potassium concentration must be increased to physiologic levels. If the low-potassium dialysate is continued, the patient's plasma will equilibrate with the dialysate and cause hypokalemia.

Typical *dialysate* flow rates are between 600 – 1800 mL/hour. There are several options for dialysate in CRRT:

- Commercially prepared pre-mixed dialysates (Normocarb, Prismaate).
- Commercially prepared peritoneal dialysate (Dianeal). Peritoneal dialysates contain high concentrations of glucose. When using this type of dialysate close monitoring of the patient's blood glucose and appropriate insulin coverage is essential.
- Custom dialysate compounded by the pharmacy.
- Commercially prepared dialysates with additives.

Caution: some dialysates are incompatible with certain additives. Consult your clinical pharmacist before requesting that anything be added to a bag of dialysate.

Clinical Application

Dialysate solutions containing bicarbonate have low compatibility with calcium. If calcium is added to a bag containing bicarbonate, a chemical reaction could occur that produces calcium carbonate, which could precipitate out of solution and clog the filter.

You may be more familiar with the common name for calcium carbonate – limestone!

Calcium can be added to bicarbonate-containing solutions in limited amounts; calcium concentrations of less than 2.5 mEq/L usually do not result in precipitation.

Replacement Fluids

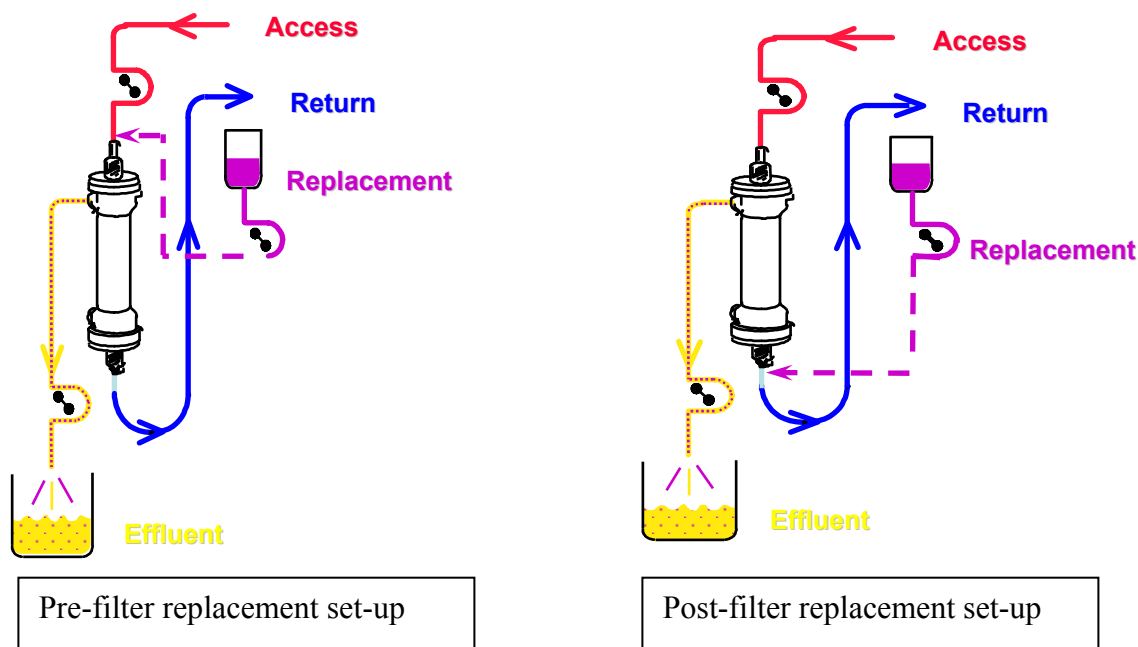
As stated earlier, *replacement fluids* are used to increase the amount of convective solute removal in CRRT. It is very important to understand that despite their name, **replacement fluids do not replace anything**. Many professionals new to CRRT mistakenly believe that if replacement fluids are added to the therapy, fluid removal rates are decreased or eliminated. This is not the case. Fluid removal rates are calculated independently of *replacement fluid* rates.

The most common replacement fluid is 0.9% Normal Saline. Other crystalloid solutions may also be used as replacement fluid. Sometimes an additive will be added to the *replacement fluid* bag to aid in correction of electrolyte or acid-base balance. An additive incompatible with the *dialysate* solution can sometimes be safely added to the *replacement fluid*. As with additives to dialysate, consult with the clinical pharmacist before adding anything to a bag of *replacement fluid*.

Clinical Application

Replacement fluids must be chosen carefully if Citrate anticoagulation is being used. If calcium is present in the replacement fluid it will neutralize the Citrate before it can do its job of keeping the filter free of clots.

The decision to infuse *replacement fluids* before or after the filter is made by the physician. *Replacement fluids* administered pre-filter reduce filter clotting and can be administered at faster rates (driving higher *convection*) than fluids administered post-filter. The downside of pre-filter replacement fluids is that they invalidate post-filter lab draws; the lab results will show the composition of the *replacement fluid* rather than that of the *effluent*. Some physicians use labs drawn in this way to gauge the efficiency of the filter, and thus prefer post-filter administration of replacement fluids. Follow the physician's orders when setting up *replacement fluids*.



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Typical *replacement fluid* rates are 1000 – 2000 mL/hour. Rates slower than this are not effective for convective solute removal.

Anticoagulation & CRRT

Anticoagulation is needed in CRRT because the clotting cascades are activated when the blood touches the non-endothelial surfaces of the tubing and filter. CRRT can be run without anticoagulation, but filters last much longer if some form of anticoagulation is used. Advantages of longer filter life include reduced time off therapy, reduced nursing time for filter changes, and reduced cost. Any form of anticoagulation has its risks; when considering anticoagulation the guiding principle is “Losing the filter is better than losing the patient.” (Bellomo & Ronco). The physician must consider the relative risks of anticoagulation and choose the safest option for the patient. Options for anticoagulation include Heparin, Prostacyclin, Citrate, and no anticoagulation. Direct thrombin inhibitors are also being investigated for use in CRRT.

Heparin

Most medical professionals caring for CRRT patients are well-acquainted with Heparin. It is a common parenteral anticoagulant that works by inhibiting clot formation. When used for anticoagulation in CRRT, Heparin can be used in several ways. Regardless of how it is administered, Heparin carries with it the risk of Heparin-induced thrombocytopenia and thrombosis (HITT). Platelet counts must be monitored, and HITT should be suspected if the platelet count drops by more than 50% from the patient’s baseline after Heparin therapy is begun. If HITT is suspected, all forms of Heparin must be discontinued immediately. Further discussion of HITT is beyond the scope of this packet.

- **Low-dose pre-filter unfractionated Heparin:** any dose less than 5 units/kg/hour. This dose is common in many institutions and is reported to have minimal effect on the activated partial thromboplastin time (aPTT). The Heparin may be administered using a pump integrated into the CRRT machine, or via a separate volumetric pump. There are no controlled studies to confirm efficacy or safety.
- **Medium-dose pre-filter unfractionated Heparin:** a dose between 8-10 units/kg/hour. This dose reportedly mildly elevates the aPTT and can be used for patients with minimal risk of bleeding. The Heparin may be administered using a pump integrated into the CRRT machine, or via a separate volumetric pump. There are no controlled studies to confirm efficacy or safety.
- **Systemic unfractionated Heparin** is administered intravenously and titrated to achieve an activated partial thromboplastin time (aPTT) ordered by the physician. The Heparin is usually administered using a separate volumetric infusion pump. This dose is typically reserved for patients who have another indication for Heparinization, such as deep vein thrombosis or cardiac valve replacement.
- **Regional unfractionated Heparin:** a pre-filter dose of 1500 units/hour of Heparin combined with administration of Protamine post-filter at a dose of 10-12 mg/hour. This approach is monitored with the aPTT, keeping the patient’s aPTT as close to normal as possible. Protamine can have serious side effects in some patients, including hypotension, cardiovascular collapse and acute pulmonary hypertension. The Heparin is administered via a separate volumetric pump, as is the Protamine. There is some scientific evidence supporting this approach.

- **Low-molecular-weight Heparins (LMWH):** These agents can be used to prolong filter life. They have not been shown superior to unfractionated Heparin for this use, but they are less likely to cause complications such as Heparin-induced thrombocytopenia (HITT). Even though LMWH are less likely to cause HITT, they are contraindicated for patients who have developed HITT because of cross-reactivity. LMWH are administered subcutaneously. Anticoagulation is monitored with Factor Xa levels which may not be readily available in all hospitals, and Protamine results in only partial reversal of LMWH.

Prostacyclin

Prostacyclin is a very effective platelet antagonist and there is evidence to show that it can prolong filter life. It is unclear whether Prostacyclin is superior to Heparin in this regard. Because Prostacyclin is extremely expensive and can induce hypotension, it is rarely used.

Citrate

Regional anticoagulation of the filter can be achieved through the use of Citrate. Citrate inhibits clotting by binding Calcium, a key cofactor in many steps of the clotting cascade. Citrate is infused pre-filter using a volumetric infusion pump. A Calcium Chloride infusion is administered to the patient to replace the Calcium bound by the citrate. Anticoagulation is monitored using ionized calcium levels. Used in this way, Citrate is comparable to Heparin in maintaining filter patency. Use of Citrate eliminates the risk of HITT, and does not cause systemic anticoagulation. Adverse events associated with citrate occur at about half the rate of those seen with unfractionated Heparin. Risks include hypocalcemia and metabolic alkalosis. Citrate is available as Trisodium Citrate (TSC) and ACD-A Citrate. Both types have been used successfully in Citrate protocols. When Citrate anticoagulation is used, dialysate and replacement fluids must be calcium free.

Clinical Application

When checking ionized calcium levels to regulate citrate anticoagulation, take great care to label specimens accurately. If the patient's serum level is mislabeled as the post-filter sample, the citrate will be titrated in the wrong direction.

Consult with your clinical laboratory to determine the safest way to handle these specimens.

No Anticoagulation

Many critically ill patients are at increased risk of bleeding. In these patients anticoagulation may not be needed to achieve adequate filter life, and avoiding anticoagulation is safer for the patient. The following types of patients probably do not require anticoagulation:

- Platelet count < 50,000/mm³
- INR > 2.0
- aPTT > 60 seconds
- actively bleeding or with an active bleeding episode in the last 24 hours
- severe hepatic dysfunction or recent liver transplantation

- within 24 hours post cardiopulmonary bypass or extra-corporeal membrane oxygenation (ECMO)

A trial of CRRT without anticoagulation may be tried if there is concern about the risk of bleeding for these or other reasons.

Types of CRRT Therapy

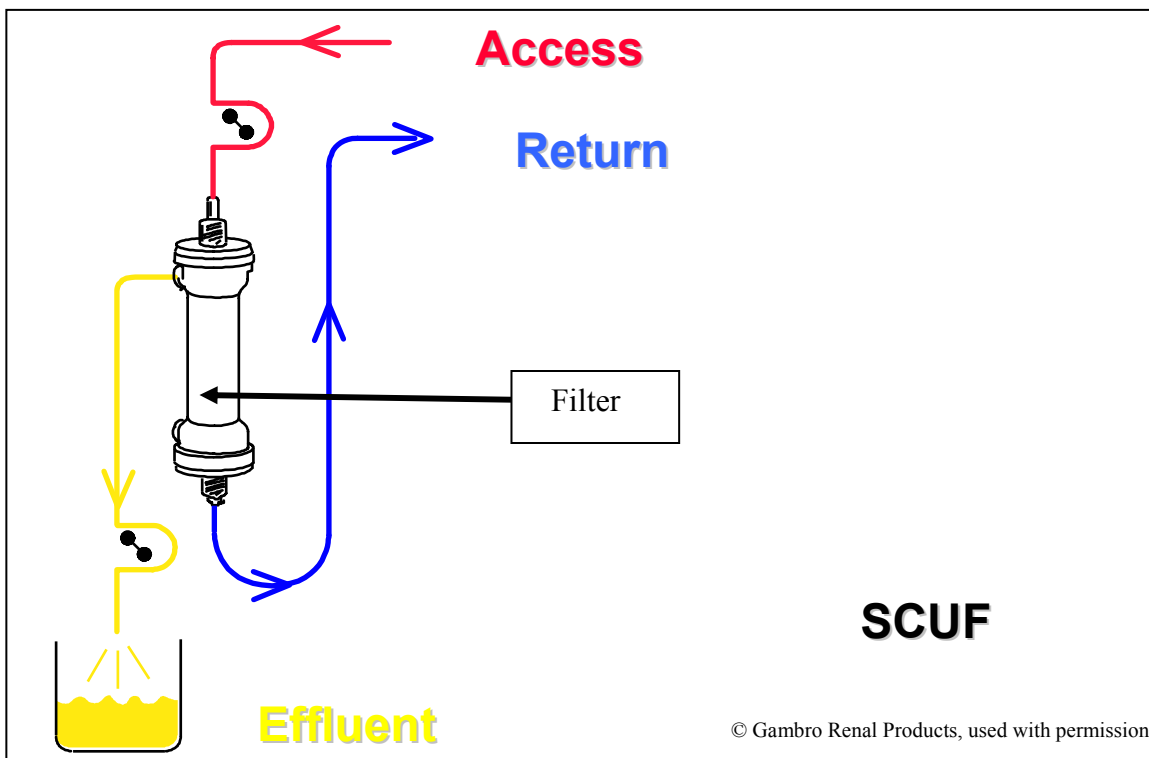
CRRT encompasses several therapeutic modalities:

- Slow Continuous Ultrafiltration (SCUF)
- Continuous VenoVenous Hemofiltration (CVVH)
- Continuous VenoVenous HemoDialysis (CVVHD)
- Continuous VenoVenous HemoDiaFiltration (CVVHDF)

Each of these modalities is dealt with individually in the section that follows. All CRRT machines have the capability to perform any of these therapies with the proper set-up. Which therapy is chosen depends on the needs of the patient and the preferences of the physician ordering the therapy.

Slow Continuous Ultrafiltration (SCUF)

To perform SCUF, the patient is placed on the CRRT machine and the blood is run through the filter. No *dialysate* or *replacement fluid* is used. The primary indication for SCUF is fluid overload without uremia or significant electrolyte imbalance.

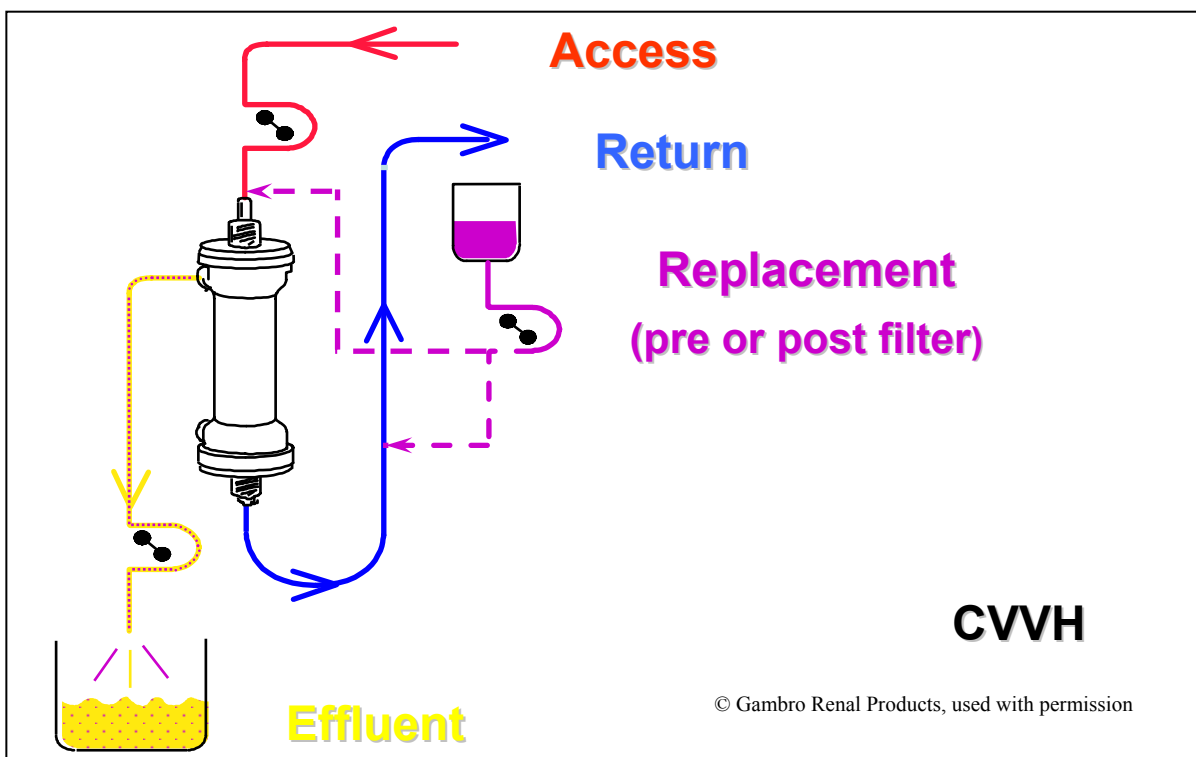


SCUF therapy primarily removes water from the bloodstream. The main mechanism of water transport is *ultrafiltration*. Other solutes are carried off in small amounts, but usually not enough to be clinically significant. When performing SCUF, the amount of fluid in the *effluent* bag is the same as the amount removed from the patient.

Fluid can be removed at a rate of up to 2 L/hour using SCUF, but this defeats the purpose of continuous therapy. Fluid removal rates are typically closer to 100 mL/hour.

Continuous Venovenous Hemofiltration (CVVH)

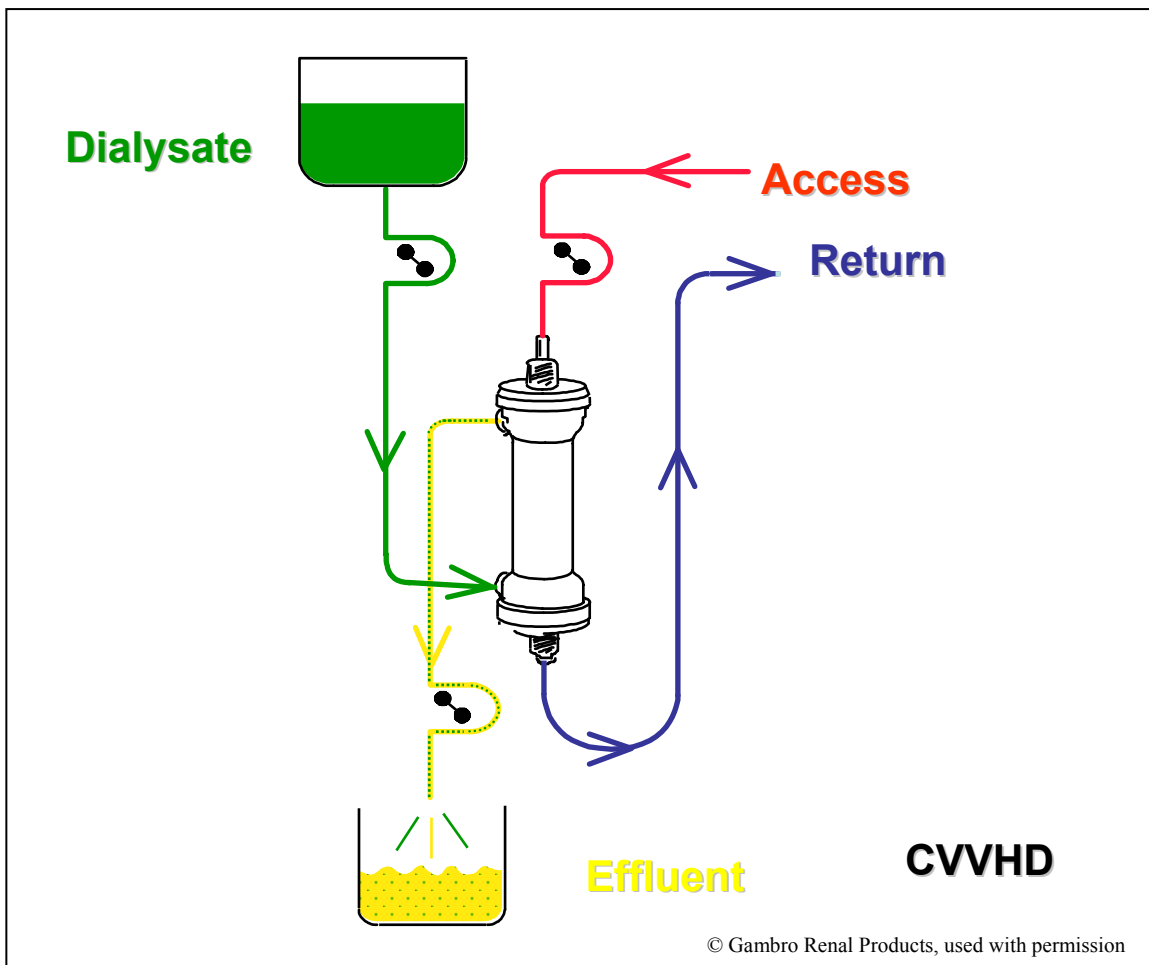
To perform CVVH, the patient is placed on the CRRT machine and blood is run through the filter with a *replacement fluid* added either before or after the filter. No dialysate is used. CVVH can be an extremely effective method of solute removal and is indicated for uremia or severe pH or electrolyte imbalance with or without fluid overload. Because CVVH removes solutes via *convection*, it is particularly good at removal of large molecules. Many theories exist regarding the removal of pro-inflammatory mediators by CVVH. Investigators are working to find out if removal of these mediators can improve outcome for patients with sepsis and systemic inflammatory response syndrome (SIRS). To date, there is no definitive data that supports the use of CVVH for these patients in the absence of other indications.



One major advantage of CVVH is that solutes can be removed in large quantities while easily maintaining a net zero or even a positive fluid balance in the patient. This flexibility makes CVVH an ideal therapy for patients who have severe renal impairment combined with a need to maintain or increase fluid volume status. When performing CVVH, the amount of fluid in the *effluent* bag is equal to the amount of fluid removed from the patient plus the volume of *replacement fluids* administered.

Continuous Venovenous Hemodialysis (CVVHD)

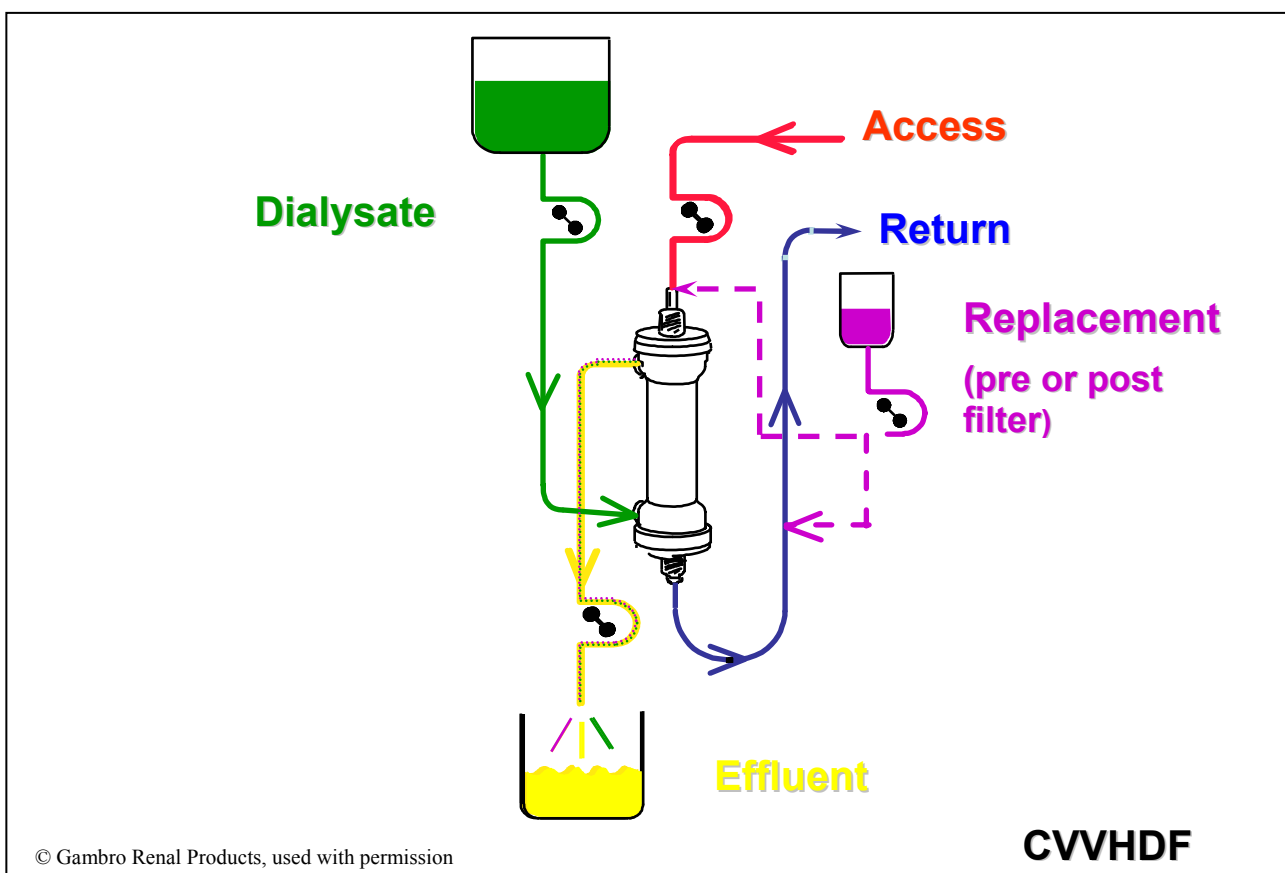
To perform CVVHD, the patient is placed on the CRRT machine and *dialysate* is run on the opposite side of the filter, no *replacement fluid* is used. CVVHD is very similar to traditional hemodialysis, and is effective for removal of small to medium sized molecules. Solute removal occurs primarily due to *diffusion*, and *dialysate* can be tailored to promote *diffusion* of specific molecules. While CVVHD can be configured to allow a positive or zero fluid balance, it is more difficult than with CVVH because the rate of solute removal is dependent upon the rate of fluid removal from the patient.



When performing CVVHD the amount of fluid in the *effluent* bag is equal to the amount of fluid removed from the patient plus the *dialysate*.

Continuous Venovenous Hemodiafiltration (CVVHDF)

To perform CVVHDF the patient is placed on the CRRT machine with *dialysate* running on the opposite side of the filter and *replacement fluid* either before or after the filter. CVVHDF is the most flexible of all the therapies, and combines the benefits of diffusion and convection for solute removal. The use of replacement fluid allows adequate solute removal even with zero or positive net fluid balance for the patient. The replacement fluid rates and dialysate rates are similar to those described for CVVHD and CVVH. In CVVHDF the amount of fluid in the effluent bag equals the fluid removed from the patient plus the dialysate and the replacement fluid.



Complications of CRRT

CRRT is a complex invasive therapy and can cause complications. The most common complications encountered include bleeding, infection, fluid & electrolyte imbalances, hypothermia, and hemodynamic instability.

Bleeding

Bleeding complications related to CRRT can be local or systemic. Local bleeding can occur at the vascular access site and may or may not be visible. Visible bleeding includes external bleeding, hematoma and ecchymosis. The site should be monitored hourly for these changes. Vascular access sites can also bleed in areas that are not visible. Subclavian and femoral lines in particular may cause internal bleeding that is not immediately apparent. Monitor the hemoglobin and hematocrit for decreases that may indicate hidden bleeding.

Inadvertent disconnection of the CRRT blood circuit could lead to significant blood loss. Modern CRRT machines are equipped with alarms and cutoff switches to minimize this risk. **Never disable these safety alarms.** Watch for low access pressure alarms and low return pressure alarms, as they could indicate a disconnection. Keep the lines and connections on top of the linens if possible so any disconnect can be rapidly recognized and corrected. Use Luer-lock type connectors for all connections and make sure any unused ports are capped with sterile dead-end connectors.

Generalized bleeding complications can occur as a side effect of anticoagulation or as a result of critical illness itself. Monitor the platelet count for thrombocytopenia. Monitor the patient and lab data for signs of disseminated intravascular coagulation (DIC).

Lab Abnormalities That May Indicate an Increased Risk of Bleeding	
PT, PTT, aPTT	Elevated
Fibrinogen, Platelet Count	Decreased
Bleeding Time	Elevated

Check all skin surfaces for petechiae and ecchymosis, and monitor wounds and punctures for oozing. Keep in mind that not all bleeding can be seen. Bleeding that is not visible externally is called occult bleeding, and signs and symptoms can be subtle and diverse.

Hypotension is usually a late sign of bleeding. If sudden hypotension occurs, consider the possibility that the return lumen may have slipped out of the vessel. Though rare, this event results in the patient's blood volume being pumped into the extravascular space. All symptoms of hypovolemia will be noted. Other symptoms are dependent on the location of the return catheter.

Signs & Symptoms of Occult Bleeding

- Lab Studies
 - Decreased RBC, hemoglobin and hematocrit; the decrease may not be seen until fluid volume is replaced
- Hemodynamics
 - tachycardia, signs of low preload, unstable blood pressure (late), narrowing pulse pressure, decreased SvO₂
- GI Bleeding
 - Hematemesis, coffee-ground emesis, melena, hematochezia
- Intracranial bleeding
 - Decreased LOC, headache, nuchal rigidity, pupil changes (late)

Hypothermia

Patients receiving CRRT are at risk for hypothermia because the blood is circulated outside the body (extracorporeal circulation) and exposed to room-temperature fluids. Patient body temperature should be kept over 36 degrees Centigrade to maintain adequate hemodynamics and effective hemostasis. Monitor the body temperature at least every two hours, and implement treatment for hypothermia as appropriate.

There are several techniques available to treat hypothermia; you may not have all options available where you work. The simplest intervention is to keep the patient as covered as possible and to keep the ambient room temperature warm. Blanket type warmers use warm air or water to warm the patient. Some CRRT machines have blood warmers integrated into them or available as an extra attachment. Inline fluid and blood warmers are also available so that fluids can be warmed prior to administration. Use the method supported by your hospital's protocols.

Caution: Do not warm fluids containing bicarbonate. Warming causes the bicarbonate to come out of solution as carbon dioxide bubbles.

Electrolyte Imbalances

Most patients who are receiving CRRT have baseline electrolyte abnormalities. These derangements are not complications of therapy. Sometimes though, CRRT results in over-correction of an imbalance, and these abnormalities are considered complications of therapy. Be especially vigilant for over-correction of electrolytes when non-physiologic solutions are used as dialysate or replacement fluids, or when electrolytes are added to these fluids.

Glucose rich peritoneal dialysate fluids used for CRRT can cause hyperglycemia. If blood sugars become very high electrolyte balance can also be affected. Although all electrolytes can be affected, keep a close watch on potassium levels because potassium is carried into the cell with glucose.

Most CRRT protocols call for monitoring of electrolytes every 4 to 6 hours during the first 24 hours of therapy and whenever dialysate or replacement fluids are changed. After the electrolyte levels become stable and there are no changes to the fluid prescriptions the

frequency of lab testing can be safely reduced. The exact frequency used will depend on your hospital's protocols and physician preferences.

Acid-Base Imbalances

CRRT complications that result in acid-base abnormalities usually result from over-correction of metabolic acidosis. If bicarbonate is used at greater than physiologic levels large pH shifts can occur. The pH must be trended so that fluid prescriptions can be adjusted to more physiologic solutions as the pH approaches normal. Most critical care references recommend that metabolic acidosis not be treated with bicarbonate until the pH is less than 7.1. Remember that CRRT effectively treats metabolic acidosis related to renal failure, not acidosis related to inadequate tissue perfusion or respiratory acidosis.

Electrolyte balance and pH balance are closely linked, so monitor electrolytes closely as pH is corrected. Plan to monitor the pH at the same frequency as electrolytes are monitored, at least initially.

Infection

CRRT is an invasive process that increases infection risk. Patients receiving CRRT are already vulnerable to infection due to their renal failure, critical illness, and other invasive lines and procedures. These patients must be monitored closely for signs and symptoms of infection so treatment can be instituted rapidly should infection occur. Infections caused by CRRT may be local to the vascular access site or systemic (septicemia).

When CRRT is in progress fever may be masked due to the cooling effect of extracorporeal circulation. Monitor for other signs of infection such as elevated white blood cell count, increased numbers of immature white blood cells, and local symptoms like redness, swelling and purulent drainage.

All connections and vascular access sites must be handled with meticulous aseptic technique to prevent infection. Standard nursing interventions to reduce infection risk also apply to CRRT patients. These techniques include, but are not limited to, handwashing, aggressive pulmonary hygiene, meticulous and frequent oral care, as much mobility as hemodynamics will allow, frequent position changes, and meticulous skin care.

Appropriate Dosing of Medications

Patients receiving CVVH, CVVHD and CVVHDF therapies clear most renally excreted drugs as efficiently as patients with normal renal function. Do not reduce drug dosages for renal function while the therapy is in place unless drug levels or patient response indicate. After initiation of CRRT drug levels may need to be drawn to ensure adequate plasma concentrations. This is especially true of antibiotics and anticonvulsants. Consult with the clinical pharmacist to determine optimal drug doses for these patients.

Critically ill patients often receive multiple continuous infusions. Be prepared that any renally cleared infusions may need to be titrated upward when CRRT is begun. Likewise, they may need to be titrated down if CRRT is discontinued.

Special care must be taken when discontinuing CRRT. To be certain that drugs do not build to toxic levels vigilant monitoring and consultation with the clinical pharmacist are essential. Patients may or may not require dose adjustments after discontinuation of CRRT depending on the degree of renal function present when the therapy is discontinued.

Nursing Assessment of the CRRT Patient

CRRT is a blood purification therapy. Because the blood comes into contact with every organ system, every system will be affected by CRRT in some way. Frequent head-to-toe assessment is needed to evaluate effectiveness and detect complications of CRRT. Prior to initiation of therapy a full assessment should be documented. The changes observed due to CRRT are typically related to the effects of uremia, fluid balance, electrolyte balance, and pH balance on the various organ systems.

Psychosocial Assessment

The most important psychosocial assessment for the patient receiving CRRT should take place before the therapy is ever begun. The patient or family must be asked if the therapy is what the patient wants. Many patients who are candidates for CRRT are unable to speak for themselves. Advance directives, if present, are then used to guide the decision whether CRRT should be begun. If no advance directive is present the healthcare surrogate or other legal representative is approached to determine what the patient would want.

CRRT is a supportive therapy that replaces excretory renal function. It is considered a life-sustaining therapy for certain patients. Discontinuation of CRRT in a patient who has not regained renal function and who will not tolerate intermittent dialysis treatment may be considered withdrawal of life support. Patients or their families need to be aware of this, and have an opportunity to discuss the situation and available treatment options with the physician(s) and other members of the team. Consult with the risk management department if you are unsure of a particular situation.

The multidisciplinary team must clearly communicate to the patient and family that CRRT is supportive in nature. It does not cure any underlying disease process, and it is not a miracle in machine form. CRRT “buys time” for other treatment modalities to work by allowing clearance of toxins, improved nutrition and fluid balance, and improved hemodynamic stability. Set realistic expectations and reinforce them frequently.

Teach the family the importance of not touching the CRRT machine and how to safely move around the room and the patient. Also teach them through actions and words that all alarms are promptly and appropriately acted upon. The presence of the nurse will help alleviate many of the fears families have. Critical care nurses tend to be frightened of CRRT at first. Imagine how much more anxiety patients and their families experience.

Cardiovascular System

Assessment and monitoring of the cardiovascular system for the patient receiving CRRT should include vital signs, indicators of hemodynamic status, and cardiac rhythm. The heart rate (HR) and blood pressure (BP) must be monitored at least hourly during the first several hours of therapy, once the patient is stable follow your hospital’s guidelines. As for any critically ill patient, the trends of HR and BP are far more important than any single measurement in isolation.

The nurse should collaborate with the physician(s) to determine individualized hemodynamic goals for each patient. As fluid, electrolyte and pH imbalances are gradually corrected, hemodynamics should optimize and HR and BP should stabilize. Fluid balance goals are generally geared toward measures of preload and related to cardiac output.

Assessment of Preload

Preload measures that may be used to gauge the effectiveness of CRRT include:

- Physical assessment findings of volume status including jugular vein distension, skin turgor, and moistness of mucous membranes.
- Central Venous Pressure (CVP).
- Pulmonary artery occlusion pressure (PAOP) also called wedge or pulmonary capillary wedge pressure (PCWP).
- Right ventricular end-diastolic volume index (RVEDVI); a measurement available from volumetric pulmonary artery catheters.

Assessment of Cardiac Output

Cardiac output is best assessed using indicators of tissue perfusion. Common assessments include:

- Physical assessment findings of tissue perfusion including level of consciousness, capillary refill, and end-organ function. The normally sensitive indicator of urine output is not a valid measure in these patients due to impaired renal function and the presence of CRRT.
- Cardiac index (CI).
- Right ventricular ejection fraction (RVEF).
- Mixed venous oxygen saturation (SvO₂)
- Serial lactate and/or anion gap levels.

Rhythm disturbances may be related to either fluid balance problems or electrolyte and acid-base balance problems. Pay particularly close attention to potassium, calcium and magnesium levels if ventricular or atrial dysrhythmias are present. Tachycardia can be related to dehydration or fluid overload and must be investigated if it is new or worsens.

If CRRT is doing its job, cardiovascular assessment findings should begin to normalize over time. Remember that CRRT is not a rapid fix. Expect to see a gradual trend toward improved findings over a period of 12 to 24 hours.

Pulmonary System

Assessment changes in the pulmonary system relate to the effects of CRRT on pulmonary edema and acid-base balance. The changes will evolve slowly over time. CRRT is not an effective treatment for respiratory acidosis, metabolic acidosis related to tissue hypoperfusion, or pulmonary edema related to capillary leak or hypoproteinemia.

Pulmonary Assessment of Fluid Overload

Assessment findings that may indicate improvement of fluid overload include:

- Decrease in adventitious lung sounds, particularly crackles.
- Reduced appearance of pulmonary congestion on chest x-ray.
- Reduced tachypnea, related to improved pulmonary compliance and reduced work of breathing.
- Improved oxygen saturation and/or decreased requirement for supplemental oxygen.
- In mechanically ventilated patients, look for decreased peak-inspiratory pressures, reduced need for oxygen and lower positive end-expiratory pressure (PEEP) requirements.
- In patients with pulmonary artery catheters, look for decreased PA pressures and a lower pulmonary vascular resistance (PVR).

Pulmonary Assessment of Metabolic Acidosis

Pulmonary assessment findings that may indicate improvement of metabolic acidosis:

- Decrease in respiratory rate and depth.
- ABG changes including:
 - Increased pH, bicarbonate and PaCO₂.
 - Decreased base deficit.

Neurological System

Monitor the neurologic status of the patient at least hourly for changes in level of consciousness, seizure activity, and neuromuscular function appropriate to the patient's diagnosis and coexisting conditions. Improvements in pH balance, electrolyte balance and uremia should produce slow improvement. Pay particularly close attention to sodium balance in patients with cerebral edema.

Gastrointestinal System

As with the other organ systems, changes in the GI system will relate to uremia, pH and electrolyte balance, and fluid volume status. Patients receiving CRRT do not require limitations on intake of fluids, protein or electrolytes. Nutrition should be provided based on metabolic requirements without limitations based on renal function. Unless there is a contraindication, enteral feeding is preferred. Consultation with the clinical dietician familiar with CRRT helps ensure that patients receive adequate nutrition.

Renal System

The excretory function of the renal system is replaced by CRRT. Expect to see signs of uremia slowly resolve as blood purification progresses. Electrolyte imbalances caused by renal failure should also slowly resolve. Watch for over-correction of electrolyte imbalances if non-physiologic dialysates are used.

Signs and Symptoms of Uremia

- Decreased attention span, lethargy, peripheral neuropathy
- Nausea, vomiting, stomatitis, gastritis, constipation, carbohydrate intolerance
- Weight loss, muscle wasting
- Itching, dry skin, ecchymosis, edema
- Pericarditis, friction rubs
- Platelet dysfunction, anemia, decreased immune response
- Hyperkalemia, hyponatremia, hypocalcemia, hyperphosphatemia
- Pleuritis, pulmonary edema

Accurate intake and output (I&O) measurement is essential for these patients. Record I&O hourly according to your hospital's protocols. The nurse must know what I&O calculations are performed by the CRRT equipment and which must be calculated manually. If fluids are added or subtracted more than once the totals will be inaccurate and could result in harm to the patient.

The Gambro Prisma™ calculates a total fluid removal that accounts for total ultrafiltrate, dialysate and replacement fluids. The nurse uses only the total fluid removal number in calculation of the I&O. The CRRT machine cannot account for IV fluids that are run separately from it, nor can it account for enteral intake, drains, GI losses or insensible losses. In simple terms if it doesn't run through the machine it must be calculated separately.

Review the manuals provided with the machine you use to determine how to accurately calculate I&O on your patient.

Troubleshooting

Although there are many brands of CRRT equipment available, some aspects of troubleshooting are universal. These universal aspects are covered here. Always consult your equipment's user manuals for specific information.

Access Pressure Alarms

The access pressure is normally negative. Excessive negative pressure usually indicates an occlusion somewhere in the access limb of the blood circuit. Check all stopcocks for proper position and trace the tubing looking for kinks. Check the vascular access site for poor position of the catheter or swelling at the site. If no problems are apparent externally, there may be a kink or occlusion internally. Position the patient to minimize flexion near the insertion site and consider aspirating and manually flushing the access (red) port of the catheter.

Return Pressure Alarms

The return pressure is normally positive. Low return pressures may indicate disconnection; check all return tubing for tight connections. Low return pressures are frequently encountered when patients are laterally rotated due to orthostatic changes in venous pressure. Alarms that occur due to position changes will resolve within a minute or two.

Return pressures that are too high are seen with occlusions. Check all stopcocks for proper position and trace the tubing looking for kinks. Check the vascular access site for poor position of the catheter or swelling at the site. If no problems are apparent externally, there may be a kink or occlusion internally. Position the patient to minimize flexion near the insertion site and consider aspirating and manually flushing the return (blue) port of the catheter.

Filter Pressures

Filter pressure alarms usually only sound when the filter is clogged or clotted. Trending of the filter pressures is helpful for prediction of clotting or clogging, however. Make a note of the initial filter pressures each time a new filter is placed. Filter pressure usually remains stable through therapy. A sudden increase in the pressure usually indicates that the filter will fail within the next few hours. Be prepared to change the filter soon.

Blood Leak Detectors

CRRT machines detect broken filaments in the filter by looking for the presence of blood in the effluent. The detectors used for this purpose may alarm if there is myoglobin or large amounts of bilirubin in the effluent as well. If the blood leak detector alarms, most references suggest sending a sample of effluent to the lab to be tested for red blood cells. If red blood cells are found, there is a leak in the filter and the filter must be changed. If there are no red blood cells, the alarm is a false positive, and therapy may be safely continued with the physician's approval. Continuing therapy while ignoring the false positive does increase the risk that a blood leak could occur and go undetected later.

Air In Line

The bubble detector in the CRRT machine is designed to stop the blood pump if air is detected in the line. If the air in line detector alarms, inspect all tubing carefully for the presence of bubbles. If large bubbles are found, follow your hospital's policy to either re-prime or change the filter set. If no bubbles are visible, microbubbles may be present. Follow the instructions provided with your equipment to clear microbubbles from the system.

The best way to deal with air in the line is to prevent it. Make sure that all air is cleared from the system during priming, keep all connections tightly joined and use Luer-lock type connectors.

Fluid and Effluent Pump Alarms

The fluid and effluent pumps alarm when a bag is empty (for fluids) or full (for effluent). Alarms will also sound if a clamp is left closed or a bag is improperly spiked. Change bags according to the manufacturer's instructions. On the Gambro Prisma™, changing a bag before the Prisma instructs you to will cause all volume calculations to be inaccurate. Check your user's manual for instructions for the machine you use.

Conclusion

CRRT can replace excretory renal function with a minimum of hemodynamic instability in critically ill patients. CRRT allows for optimal alimentation and administration of fluids and medications that would be limited if intermittent therapies were used. Optimal outcomes are dependent upon a well-educated and cohesive multidisciplinary team.

The critical care nurse is an integral part of the multidisciplinary team, responsible for administering CRRT and assessing the patient's response to therapy. The nurse is also a key communicator in the process, ensuring that all members of the team are informed of assessment findings. This packet has provided you with a starting point for managing patients with CRRT. Further references can be found in the references section of the packet.

Appendix

Electrolyte	Normal Value	Signs & Symptoms of Abnormal High	Signs & Symptoms of Abnormal Low
Ionized Calcium	4.65-5.28 mg/dL	<p>Neuromuscular: fatigue, lethargy, muscle weakness, confusion, coma, personality changes</p> <p>GI: Anorexia, nausea & vomiting, constipation</p> <p>Renal: polyuria, dehydration, flank & thigh pain associated with renal calculi</p> <p>Skeletal: bone pain, metastatic calcifications</p> <p>ECG: prolonged PR and QRS intervals, shortened QT interval</p>	<p>Neuromuscular: irritability, muscle and abdominal cramps, tetany, seizures</p> <p>Respiratory: labored shallow breathing, wheezes, bronchospasm</p> <p>Cardiovascular: decreased myocardial contractility</p> <p>GI: abdominal distension, constipation or diarrhea</p> <p>Hematologic: bleeding, bruising</p> <p>ECG: dysrhythmias, long flattened ST segment and elevated T waves</p>
Magnesium	1.6-2.6 mEq/L	<p>Neuromuscular: muscle weakness, fatigue, lethargy to coma, loss of deep tendon reflexes, seizures</p> <p>Respiratory: depressed respirations to apnea</p> <p>Cardiovascular: bradycardia, hypotension, cardiac arrest</p> <p>ECG: bradycardia, prolonged PR, prolonged ARS and peaked T waves</p>	<p>Neuromuscular: muscle weakness, tremors, ataxia, dizziness, lethargy, confusion, coma</p> <p>GI: anorexia, nausea</p> <p>ECG: dysrhythmias, small P waves, small and slightly widened QRS complexes, flattened T waves</p>
Phosphorus	2.5-4.5 mg/dL	<p>Neuromuscular: muscle cramps, seizures, joint pain (symptoms primarily related to hypocalcemia)</p>	<p>Neuromuscular: muscle weakness, fatigue, confusion</p> <p>Respiratory: dyspnea</p> <p>Cardiovascular: cardiac failure, tachycardia</p> <p>GI: anorexia</p>
Potassium	3.5-5.0 mEq/L	<p>Neuromuscular: lethargy & weakness progressing to flaccid paralysis and extremity numbness</p> <p>GI: abdominal cramping, diarrhea</p> <p>ECG: (in order of appearance) tall tented T waves, widened QRS, prolonged PR interval, flattened P waves, asystole</p>	<p>Neuromuscular: drowsiness, weakness progressing to paraparesis, muscle tenderness, muscle cramps</p> <p>GI: nausea, vomiting and constipation (paralytic ileus)</p> <p>ECG: Dysrhythmias, ST depression, flat or inverted T wave, U waves</p>

Electrolyte	Normal Value	Signs & Symptoms of Abnormal High	Signs & Symptoms of Abnormal Low
Sodium	135-145 mEq/L	<p>Associated with volume excess: excessive weight gain and possible SOB</p> <p>Associated with volume deficit: thirst, fever, dry mucous membranes</p> <p>Neuromuscular: restlessness, irritability, lethargy, confusion progressing to coma, twitching and seizures, muscle weakness</p> <p>GI: anorexia</p> <p>Integument: dry flushed skin, edematous tongue, pitting edema</p>	<p>Associated with volume excess: edema & muscle weakness</p> <p>Associated with volume deficit: thirst and muscle weakness</p> <p>Neuromuscular: malaise, confusion progressing to coma, headache.</p> <p>GI: abdominal cramps, nausea</p>

Typical Flow Rates in CRRT Using the Gambro Prisma™

Dialysate flow rate	1 – 3 L/hour
Replacement fluid flow rate	1 – 3 L/hour
Blood flow rate	80 – 120 mL/min
Effluent rate (set automatically by Prisma)	Equal to fluid removal rate + replacement fluid rate + dialysate rate

Glossary

Arteriovenous: referring to vascular access, when blood is removed from an artery and returned to a vein.

Cardiac output: the amount of blood pumped by the heart in one minute.

Convection: solute transport across a membrane together with a solvent (usually water) in response to a pressure gradient across the membrane.

CRRT: continuous renal replacement therapy.

Crystalloid: fluid composed of water and one or more dissolved salts (e.g. saline, lactated Ringers).

CVVH: continuous venovenous hemofiltration.

CVVHD: continuous venovenous hemodialysis.

CVVHDF: continuous venovenous hemodiafiltration.

Dialysate: solution administered into the compartment of the hemofilter opposite the blood to achieve diffusive solute clearance.

Diffusion: solute transport from a compartment with high concentration to a compartment with low concentration.

Effluent: the fluid that drains out of the hemofilter; a combination of plasma water, removed solutes, spent dialysate and replacement fluid volume. Effluent volume is only equal to fluid removal volume in SCUF.

Fluid balance: net amount of fluid gained or lost by the patient in a given period of time. Negative fluid balance occurs when losses are greater than gains and positive fluid balance results when gains are greater than losses.

IHD: intermittent hemodialysis.

Preload: the amount of blood in the ventricle just prior to systolic ejection.

Replacement fluids: fluids administered into the blood compartment to drive convective solute losses. All replacement fluid volume is removed during CRRT.

SCUF: slow continuous ultrafiltration.

Semipermeable membrane: a barrier, either cellulose or synthetic, that allows water, electrolytes and other molecules to pass through while cellular components and larger molecules are held on one side.

Solute: a substance dissolved in water or plasma (e.g. sodium chloride).

Ultrafiltrate: plasma water and solutes that pass through the semipermeable membrane.

Ultrafiltration: transport of water across a membrane by a pressure gradient. In hemofiltration, the process by which plasma water and filterable solutes are separated from whole blood.

Venovenous: taken from a vein and returned to a vein



Education & Development Answer Sheet

Complete all lines and PLEASE PRINT

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First Name _____

If employee, Department Name & Number _____

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Education & Development, MP 14
1414 Kuhl Ave.
Orlando, FL 32806
- Achieve an 84% on the posttest. (You will be notified if you do not pass and will be asked to retake the posttest.)

Post Test

Directions: Do NOT write on this test. Complete this test using the bubble sheet provided.

1. The multidisciplinary team that manages CRRT is usually composed of a nephrologist or intensivist, a critical care nurse, dialysis nurse and
 - A. Pharmacist, consulting MD, dietician and clinical laboratory
 - B. Pharmacist and physical therapist
 - C. Consulting MD, clinical laboratory and social worker
 - D. No other members

2. CRRT is a preferred blood purification therapy for hemodynamically unstable patients because it:
 - A. Achieves blood purification faster
 - B. Causes less hypotension
 - C. Removes larger volumes of fluid
 - D. Is a non-invasive therapy

3. One advantage of CRRT vs. traditional intermittent dialysis therapy is that CRRT:
 - A. Requires strictly limited protein intake
 - B. Allows complete nutritional support
 - C. Removes toxins intermittently
 - D. Eliminates the need for large-volume infusions

4. Central venous access for venovenous CRRT must be placed away from other central venous access devices because:
 - A. The two devices could become tangled with one another
 - B. Two access devices in close proximity increase infection risk
 - C. Medications administered through the other device would be rapidly filtered out
 - D. Two access devices in close proximity increase bleeding risk

Match the following four terms to their definitions (labeled A, B, C and D below):

5. _____ Ultrafiltration
 6. _____ Diffusion
 7. _____ Convection
 8. _____ Adsorption
- A. Movement of solutes by the force of water flow. Also called solvent drag.
 - B. Removal of solutes by the adherence of the solute to the membrane
 - C. Movement of water by a positive pressure such as gravity or via a negative pressure applied to the opposite side of the membrane
 - D. Movement of solutes from an area of high concentration to an area of lower concentration

Match the therapy to the types of fluids it uses (labeled A, B, C and D below):

9. _____ SCUF
 10. _____ CVVH
 11. _____ CVVHD
 12. _____ CVVHDF
- A. Uses dialysate only
 - B. Uses replacement fluid only
 - C. Uses both dialysate and replacement fluid
 - D. No dialysate or replacement fluid are used
13. Select the best candidate for CRRT
- A. Chronic renal failure patient; unable to establish vascular access
 - B. Trauma patient with acute renal failure and septic shock
 - C. Chronic dialysis patient with stable hemodynamics
 - D. Acute renal failure patient with advance directive stating no dialysis
14. The patient receiving CRRT is at risk for hypothermia related to:
- A. Metabolic suppression
 - B. Extracorporeal circulation of blood
 - C. Large volumes of room temperature fluids
 - D. B and C

15. Select the statement that is true regarding CRRT
- A. CRRT can only be used for chronic dialysis patients
 - B. CRRT should only be used if the potassium is greater than 6.0 mg/dL
 - C. CRRT is used for hemodynamically unstable patients with renal failure
 - D. CRRT is a simple, low-risk therapy
16. Within the dialysis filter:
- A. Blood and dialysate mix freely
 - B. The blood is separated from the dialysate by the semipermeable membrane
 - C. Cellular blood components cross the membrane easily
 - D. Molecules such as electrolytes and cytokines are not able to cross the membrane
17. The purpose of using replacement fluids is:
- A. To eliminate fluid losses
 - B. To drive convective solute losses
 - C. To replace electrolytes
 - D. To restore lost fluids
18. Mrs. T is receiving CRRT for acute renal failure associated with septic shock. The nephrologist has ordered a custom dialysate with a very low concentration of potassium to help correct her serum potassium of 6.0 mg/dL. Safe administration of this non-physiologic dialysate requires
- A. Monitoring of the serum potassium every hour
 - B. Calling for a change in the dialysate formula order when the serum potassium approaches normal
 - C. Use of Citrate anticoagulation rather than Heparin
 - D. Decreasing the frequency of serum potassium measurement
19. The cardiologist has written an order to add 40 mEq of KCl to the dialysate. Before requesting that the KCl be added to the bag the nurse should:
- A. Check the serum potassium
 - B. Remove any replacement fluids that are hanging
 - C. Ask the lab to recheck the last serum potassium level
 - D. Consult with the nephrologist and clinical pharmacist

20. Risks associated with Heparin anticoagulation include:
- A. Hypocalcemia
 - B. Deep vein thrombosis
 - C. HITT
 - D. Hypotension
21. The effectiveness of Citrate anticoagulation is assessed by:
- A. aPTT levels
 - B. Serum Citrate levels
 - C. Platelet count
 - D. Ionized calcium levels
22. Your patient has returned from the operating room after a coronary artery revascularization and aortic valve replacement. In the OR the patient received 5 liters of fluids and blood products. The patient is now exhibiting signs of fluid overload and hemodynamic instability. The patient's BUN and creatinine are both normal, and the UOP is 45 cc/hour. CRRT is ordered for fluid management. The most appropriate treatment modality for this patient would be
- A. SCUF
 - B. CVVHD
 - C. CVVHDF
 - D. CVVH
23. The CRRT modality that is best able to remove large molecules like cytokines is:
- A. CVVHD
 - B. SCUF
 - C. CVVH
 - D. IHD
24. Safety measures to limit the likelihood of blood loss in CRRT include:
- A. Continuous cardiac monitoring
 - B. Turning all alarms on the CRRT machine to the lowest volume
 - C. Keeping tubing visible and capping all open ports with dead-end connectors
 - D. Use of Citrate anticoagulation

25. Which type of fluids cannot be warmed?
- A. Solutions containing Glucose
 - B. Solutions containing Citrate
 - C. Solutions containing Sodium Chloride
 - D. Solutions containing Bicarbonate
26. Your patient has just been started on CVVHDF therapy. The patient is septic and has been receiving multiple renally cleared antibiotics. You anticipate:
- A. Decreasing the doses of all antibiotics by half due to hemoconcentration
 - B. Increasing the doses of all antibiotics because they will dialyze out
 - C. Checking antibiotic peak and trough levels to determine appropriate doses
 - D. Discontinuing all antibiotics because CVVHDF will cure the sepsis
27. Select the statement that is most appropriate regarding input and output (I&O) calculations in patients receiving CRRT
- A. All I&O calculations are performed by the CRRT machine
 - B. The nurse must always manually calculate dialysate and replacement fluid use
 - C. I&O is not necessary for these patients
 - D. The nurse must be aware of which calculations are performed by the CRRT equipment
28. Preload measures are used to assess the adequacy of fluid volume in patients receiving CRRT. Which set of measures most accurately reflects preload?
- A. CVP, RVEDVI and PAOP (wedge) pressure
 - B. PA pressure and systemic vascular resistance
 - C. Cardiac output and heart rate
 - D. Mixed venous oxygen and lactate level
29. If the patient is responding well to CRRT, the nurse expects the hemodynamic parameters to:
- A. Fluctuate widely from hour to hour
 - B. Rapidly shift toward normal values
 - C. Slowly shift toward normal values
 - D. Get worse before they get better

References

- Angus, D. C., Griffin, M., Johnson, J. P., Kellum, J. A., LeBlanc, M., Linde-Zwirble, W. T., & Ramakrishnan, N. (2002). Continuous versus intermittent renal replacement therapy: a meta-analysis. *Intensive Care Medicine*, 28, 29-37.
- Baldwin, I., Bellomo, R., Golper, T., & Ronco, C. (2002). *Atlas of Hemofiltration*. London: W.B. Saunders Company.
- Bellomo, R., & Ronco, C. (2001). Dialysis: Continuous versus Intermittent Renal Replacement Therapy in the Treatment of Acute Renal Failure. In *Acute Renal Failure: A Companion to Brenner & Rector's The Kidney* (pp. 497-506). Philadelphia: W. B. Saunders Company.
- Bellomo, R., Ricci, Z., & Ronco, C. (2001). Continuous renal replacement therapy in critically ill patients. *Nephrology, Dialysis, Transplantation*, 16, 67-72.
- Burr, R., Greenberg, A., Gupta, B., Lesko, J. M., Palevsky, P. M., & Ramesh-Prasad, G. V. (2000). Factors affecting filter clotting in continuous renal replacement therapy: results of a randomized, controlled trial. *Clinical Nephrology*, 53, 55-60.
- Canulla, M. V., Caruso, D. M., Foster, K. N., Gilbert, E. A., Gilbert, R. W., & Nelson, M. L. (2002). Development of a continuous renal replacement program in critically ill patients. *The American Journal of Surgery*, 184, 526-32.
- Druml, W. (1999). Metabolic aspects of continuous renal replacement therapies. *Kidney International*, 56, S-56-S-61.
- Finn, W. F. (2001). Recovery from Acute Renal Failure. In *Acute Renal Failure: A Companion to Benner's & Rector's The Kidney* (pp. 425-446). Philadelphia: W. B. Saunders Company.

Self-Learning Packet Evaluation

Name of Packet: _____ **Date:** _____

Employee Non-Employee

Your position?

RN LPN Respiratory Radiology
 Lab Social Work Rehab Clin Tech

Other: _____

If RN/LPN, which specialty area?

Med/Surg Adult Critical Care OR/Surgery ED
 Peds Peds Critical Care OB/GYN L&D
 Neonatal Behavioral Health Cardiology Oncology

Other: _____

Please take a few moments to answer the following questions by marking the appropriate boxes.

Strongly Agree Agree Neutral Disagree Strongly Disagree



- | | |
|--|--|
| 1) The content provided was beneficial. | <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> |
| 2) The packet met its stated objectives. | <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> |
| 3) The packet was easy to read. | <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> |
| 4) The posttest reflected the content of the packet. | <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> |
| 5) The course was: | <input type="checkbox"/> Mandatory
<input type="checkbox"/> Optional |

Please answer the following questions:

How long did this packet take you to complete? _____

What have you learned that you will apply in your work? _____

What was the best part of the packet? _____

What would you suggest be done differently? _____

Additional Comments:

Thank you for your input.

Please return this evaluation to **Education & Development**, either in person or by mail:
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