UAB CRRT Primer 2018

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CRRT Primer

Continuous Renal Replacement Therapy (CRRT) is a "catch all" term used for all the continuous modes of renal replacement therapies used in the ICU. The different modes are SCUF (slow continuous ultrafiltration), CVVH (continuous venovenous hemofiltration), CVVHD (continuous venovenous hemodialysis, and CVVHDF (continuous venovenous hemodiafiltration). CRRT was developed for the management of hemodynamically unstable patients with acute kidney injury who cannot tolerate conventional hemodialysis.

Conventional Hemodialysis vs. CRRT

CRRT is better tolerated in hemodynamically unstable patients than conventional hemodialysis due to lower ultrafiltration / effluent rates allowing for slower fluid removal and solute removal per unit time.

Intermittent Hemodialysis	**CRRT (CVVHD or CVVHDF)**
Blood Flow Rate 500 ml/min	Blood Flow Rate 100-200 ml/min
Dialysate Flow Rate 800 ml/min	Dialysate Flow Rate 17-40 ml/min

Indications for CRRT

1. Hemodynamic Instability

CRRT is hemodynamically better tolerated in unstable patients (sepsis, ARDS, GI bleeding, cardiogenic shock, etc.) due to minimal changes in plasma osmolality per unit time.

2. Volume Removal

CRRT allows for easier administration of parenteral nutrition and IV medications by providing slow continuous fluid removal per unit time.

3. Increased Catabolism

CRRT allows for better control of azotemia, electrolytes, and acid-base status in highly catabolic patients (burns, bone marrow transplantation, tumor lysis, rhabdomyolysis, persistent hyperkalemia, persistent acidosis).

4. Increased Intracranial Pressure

CRRT does not increase intracranial pressure, while conventional hemodialysis does. This is beneficial in patients with head trauma or cirrhosis with hepatic encephalopathy.

5. Removal of toxins

CRRT may be beneficial in removing toxins with slow back diffusion from tissue, large volume of distribution, or delayed cell membrane transport (methotrexate, procainimide, etc.)

6. Sepsis?

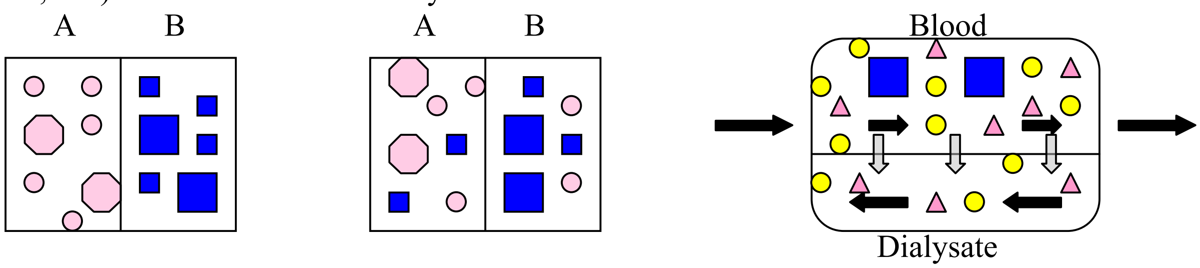
Some studies suggest CRRT removes septic mediators such as TNF, IL-1, etc. This is still controversial and largely not proven.

Disadvantages of CRRT

1. Frequent clotting of filter and access
2. Need for anticoagulation
3. Need for ICU nursing staff
4. Decreased patient mobility
5. Difficulty of drug dosing

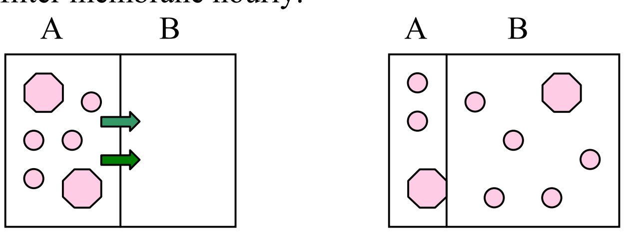
Mechanism of Solute Transport in CRRT

1. **Diffusion** is movement of solutes across a semi-permeable membrane from a higher solute concentration to an area of lower concentration. The diffusion rate depends on the concentration, size, and electrical charge of the solute. The concentration gradient is maintained by running the dialysate (an electrolyte solution with sodium, bicarbonate, chloride, magnesium, calcium, etc.) countercurrent to the blood flow. Diffusion is effective for the removal of small molecular weight solutes less than 500 daltons (BUN, creatinine, potassium, etc.) and is referred to as dialysis.



T = 0 T = Equilibrium

2. **Convection** is the forced movement of solutes along with fluid through a semi-permeable membrane by hydrostatic pressure. When plasma water is pushed through the membrane by a hydrostatic force, it “drags” with it both small molecular weight solutes (BUN, creatinine, etc.) and middle molecular weight solutes (inulin, TNF, IL-1, etc.). The fluid forced through the hemofilter is known as ultrafiltrate (UF). To effectively remove solutes by convection alone, more than 1 L of plasma water needs to be “pushed” or “ultrafiltered” through the hemofilter membrane hourly.

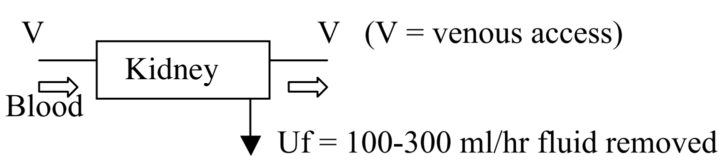


T = 0 T = Later

Nomenclature

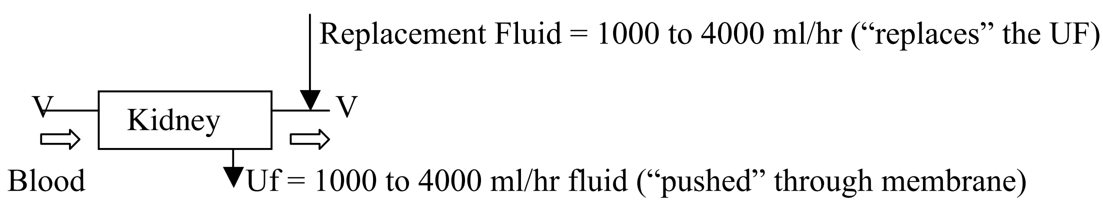
1. **SCUF: Slow Continuous Ultrafiltration**

   This modality is used only to remove fluid from the patient, usually no more than 2-4 L/day (100-300 ml/hr UF). There is minimal clearance of solutes since the amount of plasma water “pushed” through the hemofilter membrane hourly is low and no dialysate is used. This form of therapy has been used for patients with severe CHF who are unresponsive to diuretics and have developed a prerenal azotemia secondary to decreased cardiac output. SCUF is also used for those with anasarca from nephrotic syndrome who are unresponsive to diuretics.

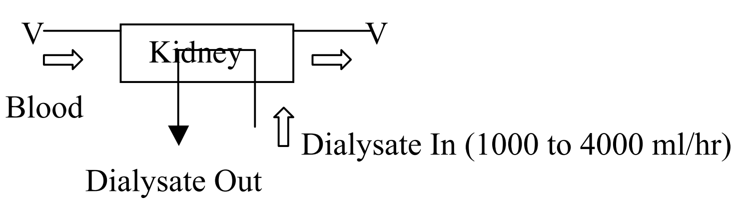


2. **CVVH*: Continuous VenoVenous Hemofiltration**
This modality uses convection to remove solutes. No dialysate is used, and thus no diffusion occurs. Both **small and middle molecular** weight solutes are removed by convection (typically < 10,000 daltons). In order to remove solutes EFFECTIVELY by convection, a large amount of plasma water has to be "pushed" (ultrafiltered) hourly through the hemofilter to have enough force to "drag" with it solutes and then be discarded. Typically, a minimal UF rate of 1 L per hour is used in adults. This means at least 24 L of plasma water is removed and discarded from the patient a day! Since this large amount of fluid and electrolyte removal would result in severe volume and electrolyte depletion, fluid with physiological concentrations of electrolytes is "replaced" back to the patient at a rate determined by what the physician wants the patient's net fluid balance to be. For example, if 1 L of plasma water is removed from the patient per an hour through the hemofilter for the purpose of convective clearance of solutes, and you want the patient to have a fluid balance that is net negative 100 ml/hr, you would "replace" back 900 ml/hr to the patient as replacement fluid.

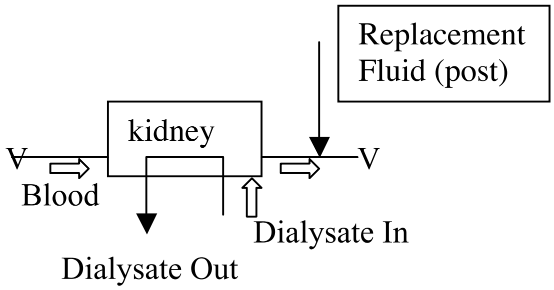
Luckily CRRT devices are automated to make this calculation easier. Bags full of "replacement fluid" that are pre-connected to the CRRT circuit **automatically** replace back the **same** volume of plasma water "pushed" and discarded through the hemofilter. The rate of replacement fluid is determined by the physician and programmed in the device. For instance if you program a replacement fluid rate of 1000 ml/hr, the CRRT device automatically "forces" (or ultrafilters) 1000 ml/hr of plasma water through the hemofilter and "replaces" back to the patient that same volume lost (1000 ml/hr) with an electrolyte solution from the replacement fluid bag, allowing for a net zero fluid balance through the circuit. In other words, the programmed replacement fluid rate is equal to the rate of plasma water removed through the hemofilter. Therefore, for additional plasma water removal for volume status purposes, a Fluid Removal rate is programmed into the device, so extra plasma water can be ultrafiltered through the hemofilter for patient volume control. The typical Fluid Removal Rate for patient volume control is 100 to 300 ml/hr.



3. **CVVHD: Continuous Veno Venous Hemodialysis**
This modality uses diffusion to remove small molecular weight solutes. A dialysate solution runs countercurrent to the blood flow at an initial programmed rate of at least 500-1000 ml/hr Plasma water is also removed through the hemofilter, and the hourly UF rate is determined by the patient's fluid balance status (usually no more than 2-4L/day or 100 to 300 ml/hr). This is not enough to provide solute removal by convection. Therefore, no replacement fluid rate is programmed into the device, only a desired hourly fluid removal rate is programmed.



4. **CVVHDF*: Continuous Veno Venous Hemodiafiltration**
   This modality combines both CVVH (solute removal by convection) and CVVHD (solute removal by diffusion). As a result, typically at least 1 L/hr of plasma water is discarded through the hemofilter and "replaced" back to the patient as replacement fluid, and a dialysate is run at a minimum rate of 1 L/hr countercurrent to the blood flow. This is the modality we use at UAB.



***To prevent hemoconcentration and clotting of the blood as it goes through the hemofilter, replacement fluid is usually infused prior to the hemofilter (pre-filter) rather than after it (post-filter).**

Terminology
Ultrafiltrate is the plasma water pushed through the hemofilter. Low rates of ultrafiltration are used strictly for fluid removal. High rates of ultrafiltration are used for convective loss of solutes.

Replacement fluid is a physiologic electrolyte solution replaced back to the patient when high rates of ultrafiltration are used for convective clearance. It is also known as substitution fluid. Replacement fluid may be replaced pre-filter or post-filter, also referred to as pre-dilution or post-dilution.

Dialysate is an electrolyte solution run countercurrent to the blood to facilitate diffusion of solutes across the hemofilter.

In CVVH, solute removal occurs by convection and fluid removal by ultrafiltration. The total ultrafiltrate is composed of both solutes and plasma water removed (pushed) through the hemofilter. The total ultrafiltration rate is equal to the sum of the replacement fluid rate and fluid removal rate.

In CVVHD, solute removal occurs by diffusion and fluid removal by ultrafiltration. The effluent is composed of spent (discarded) dialysate and ultrafiltrate (used for fluid removal). The total effluent rate is equal to the sum of the dialysate rate and fluid removal rate.

In CVVHDF, solute removal occurs by diffusion and convection, and fluid removal by ultrafiltration. The effluent is composed of spent (discarded) dialysate and the ultrafiltrate. The effluent rate is equal to the sum of the dialysate rate, replacement fluid rate, and fluid removal rate.

Filtration Fraction (FF) is the fraction of plasma water that is removed from blood through the hemofilter. It should be kept below 20–25% to help prevent clotting of the hemofilter. It is calculated as total UF/plasma water: $FF = Q_{totalUF} / Q_P$ where Q_P is [blood flow x (1-hematocrit)].

CRRT dose is the effluent rate per hour divided by the patient weight. It is measured as ml/kg/hr and is a surrogate for urea clearance. The minimal acceptable CRRT dose is 25-30 ml/kg/hr.

Device
The PRISMA FLEX is the machine used for CRRT at UAB. The dialyzer we use is the **HF1000** (polyarylethersulfone (PAES)) membrane. It facilitates higher ultrafiltration rates.

The PRISMA FLEX can also use **AN69 dialyzers (M60, M100, M150).** These are created with acrylonitrile and sodium methallyl sulfonate copolymer (AN69) providing diffusion, convection and adsorption. **These can cause an anaphylactic reaction if used with ACE inhibitors.** ACE inhibitors must be stopped with these dialyzers. **WE NO LONGER USE THESE DIALYZERS AT UAB.**

ALL dialyzers must be changed every 72 hours.

PRISMAFLEX STATS

1. Blood Flow Rate: 10-450 ml/min **(We prefer 200 ml/min when not using citrate and 150-180 ml/min when using citrate)**
2. Replacement Fluid Flow Rate: 0- 8000 ml/hr (purple scale)
3. Dialysate Flow rate: 0-8000 ml/hr (green scale)
4. Pre blood pump rate: 0-8000 ml/hr (white scale also known as the citrate line)
5. Patient Fluid Removal Rate: 0 – 2000 ml/hr
6. Total Effluent Rate: 0 – 10,000 ml/hr (yellow scale)

Dialysate Solutions
We use CVVHDF as the primary CRRT modality at UAB. The dialysate is an electrolyte solution used in CVVHDF to provide a diffusion gradient to enhance solute removal. Many dialysate solutions for CRRT are available. The following dialysates are available at UAB:

Components (mEq/L)	**NxStage Standard Bicarbonate**	**NxStage High Bicarbonate with KCL**	**NxStage High Bicarbonate without KCL**
Na	140	140	140
K	**4**	**4**	**0**
Mg	1.5	1.5	1.5
Calcium	0	**3**	**3**
Lactate	0	0	0
Bicarbonate	**25**	**35**	**35**
Dextrose (mg/dl)	100	100	110
Final Volume	5000 ml	5000 ml	5000 ml
FDA Approved	YES	YES	YES

Replacement Fluids

Replacement Fluid (RF) is used to replete the plasma with the volume and electrolytes lost from convection when using high ultrafiltration rates. RF may be given pre-filter or post-filter. Pre-filter RF is preferred since it dilutes the blood before it enters the dialyzer and, thus, decreases clotting. However, giving RF pre-filter also dilutes the solutes in the blood and decreases the urea and creatinine clearance by approximately 15-30%. The following replacement fluids are used at UAB:

Components (mEq/L)	**Trisodium Citrate 0.5%**	**NxStage Standard Bicarbonate**	**NxStage High Bicarbonate**	**NxStage High Bicarbonate without KCL**
Na	140	140	140	140
K	**0**	**4**	**4**	**0**
Mg	0	1.5	1.5	1.5
Calcium	**0**	**0**	**3**	**3**
Sodium Citrate	17 mmol/L	0	0	0
Dextrose (gm/dl)	0	100	100	100
Bicarbonate	**0**	**25**	**35**	**35**
Lactate	0	0	0	0
Final Volume	4000 ml	5000 ml	5000 ml	5000 ml
FDA Approved	No	No	No	No
	Citrate Solution*	**Non-Citrate Solutions**		

All pre-filter replacement fluids on the PRISMAFLEX are delivered through the PBP (Pre-Blood Pump) line and NOT through the purple pre-filter replacement fluid port. The PBP line was made for citrate and delivers the replacement fluid directly to the access site. Even if citrate is not used, all pre-filter replacement fluid is delivered through the PBP.

***Can only be used as pre-filter replacement solution**

When using the standard bicarbonate solution, a calcium drip is required regardless if the patient is on citrate or not since the solution contains no calcium! **You should never use the standard bicarbonate solution without citrate (unless approved by me).**

A calcium drip is not required if using the high bicarbonate solutions with calcium **UNLESS CITRATE IS USED. ANY TIME CITRATE IS USED, A CALCIUM DRIP MUST BE ORDERED REGARDLESS IF THE DIALYSATE HAS CALCIUM OR NOT!!**

DEAERATION CHAMBER: The PRISMA FLEX has a deaeration chamber where clotting can occur. As a result, with the PRISMA FLEX**, a post filter RF at 200 ml/hr is required. We typically use the same solution as the dialysate for the post filter RF (can also use NS but prefer the same solution as dialysate). See last 2 figures below.**

Anticoagulation

1. **Heparin**

   The concentration used in the heparin syringe should be Heparin 20,000 units/20ml. Usually a 2,000 u bolus of heparin is followed by an infusion of 500 u/hr. PTTs are measured from the post-filter port, and the heparin is adjusted to maintain the PTT between 45-60.

   Disadvantages of Heparin

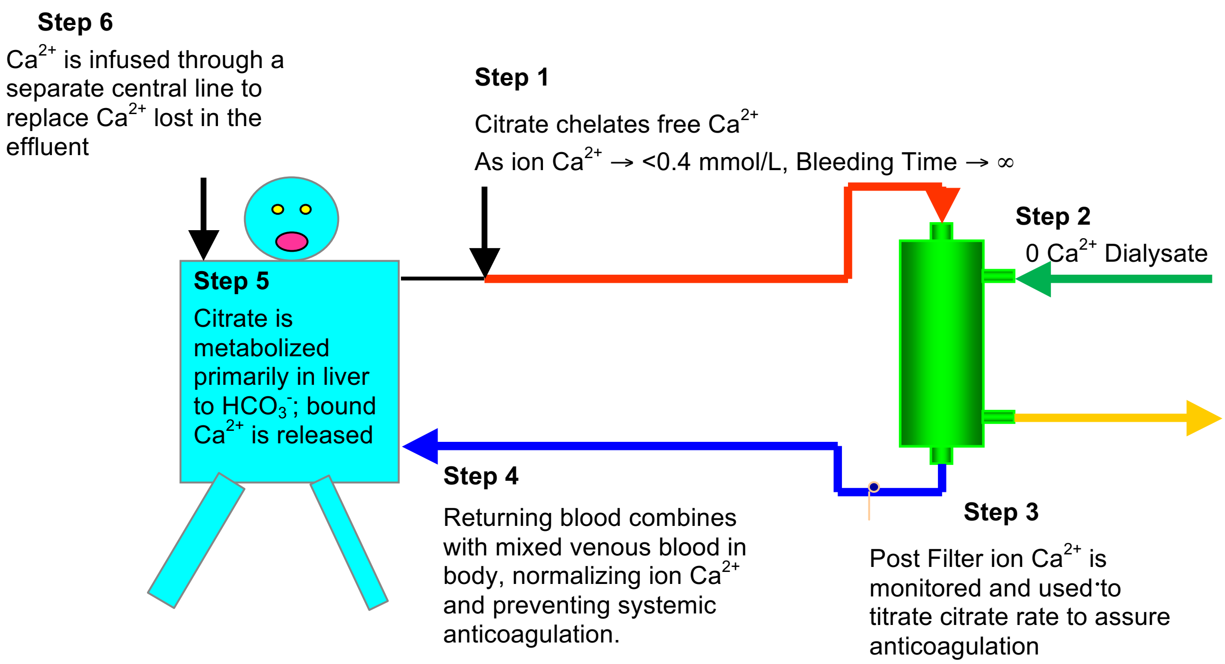
   A. Limits the availability of CRRT since it can't be used in bleeding patients
   B. Associated with a 25-30% risk of life threatening hemorrhage
   C. Associated with thrombocytopenia / HIT

WE DO NOT USE HEPARIN ANTICOAGULATION AT UAB!

2. **Citrate regional anticoagulation**

   Calcium is required for coagulation. Citrate chelates free Ca^{++} in the extracorporeal circuit and prevents activation of Ca^{++}-dependent procoagulants. Citrate is given pre-filter (pre-blood pump) to prevent clotting of the filter. **Instead of 200 ml/min, a blood flow rate between 130 to 180 ml/min is preferred when administrating citrate. An IV calcium infusion is given systemically through a y-connector on the return line of the CRRT circuit**. Ionized calcium (iCa) levels are used to measure the anticoagulant effect of citrate. Post-filter iCa levels are obtained every 6 hours and are used to adjust the citrate infusion to maintain postfilter iCa levels between 0.25 – 0.5 mmol/L. Systemic iCa levels are also obtained every 6 hours and are used to titrate the systemic Ca^{++} drip to maintain systemic iCa levels between 0.9 and 1.3 mmol/L.

   Since 1 mole of trisodium citrate is metabolized to 3 moles of bicarbonate by the liver, patients can develop an alkalosis. The dialysate preferably should not contain Ca^{++} since Ca^{++} will decrease the efficacy of the citrate. Thus, the most common dialysate used with the 0.5% trisodium citrate is Standard Bicarbonate (bicarbonate 25 meq/L, calcium 0).



Precautions with Trisodium Citrate

1. **Patients can develop fatal arrhythmias, hypotension, and tetany from severe hypocalcemia. Systemic iCa levels must be carefully monitored, and the systemic Ca^{++} drip adjusted accordingly. Patients with systemic iCa levels < 0.9 mmol/L should have levels drawn more frequently and the hypocalcemia corrected rapidly.**
2. **Patients can develop alkalosis from high rates of citrate infusion. This can be frequently avoided by discontinuing the acetate from TPN and/or discontinuing IV fluids containing bicarbonate and/or increasing the dialysate rate**
3. **Patients with liver disease and severe lactic acidosis may not be able to metabolize the citrate. This is manifested by systemic hypocalcemia despite high rates of Ca^{++} infusion, increasing anion gap, worsening acidosis, and increased total Ca^{++} to systemic iCa ratio (> than 2.5:1). Do not use citrate with any patient with shock liver (transaminases > 1000) or lactate > 8 mmol/L.**

$$Calcium\ Ratio = \frac{Total\ Ca^{2+}(mg/dL)\cdot 0.25}{Systemic\ ion\ Ca^{2+}(mmol/L)}$$

3. **No anticoagulation**

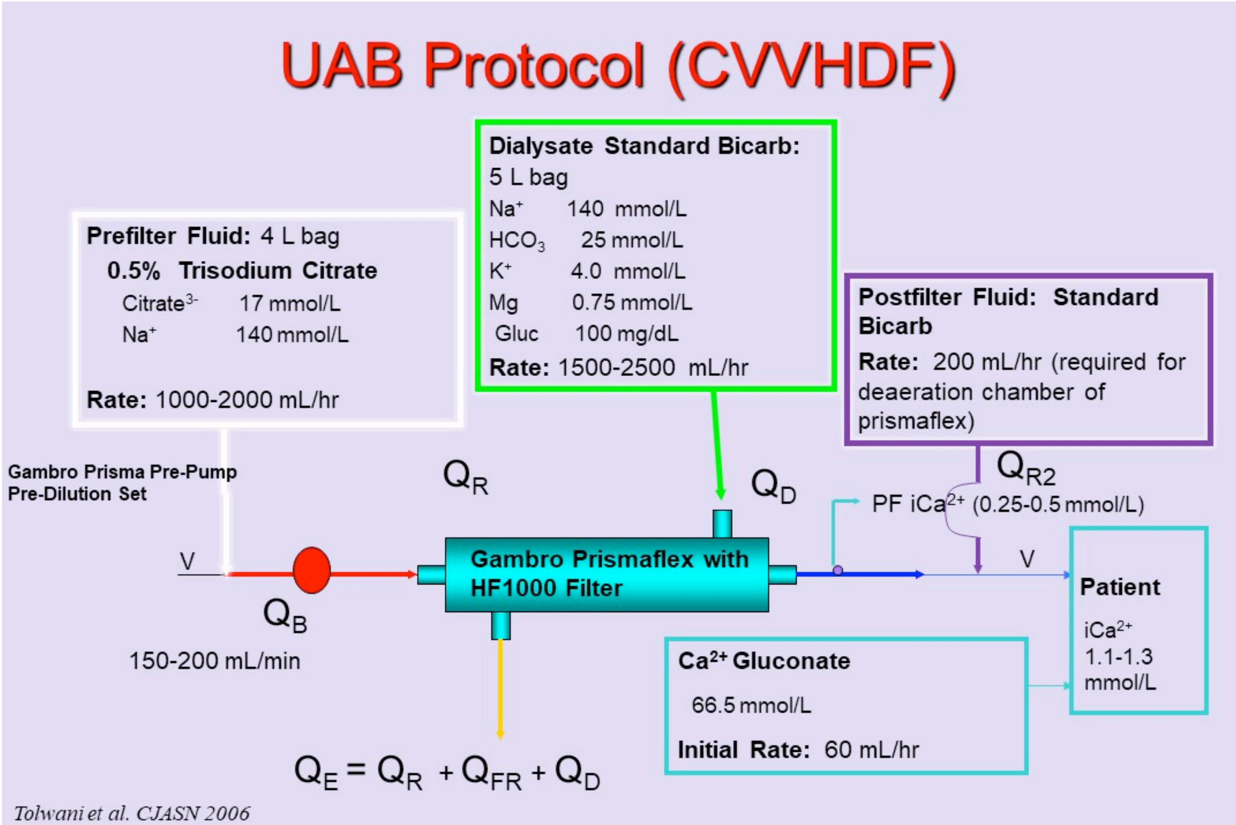
Patients with coagulopathies often can be treated with no anticoagulation without clotting of the hemofilter. By using a pre-filter replacement fluid on the PBP pump to continuously rinse the hemofilter, the incidence of clotting is decreased in these patients.

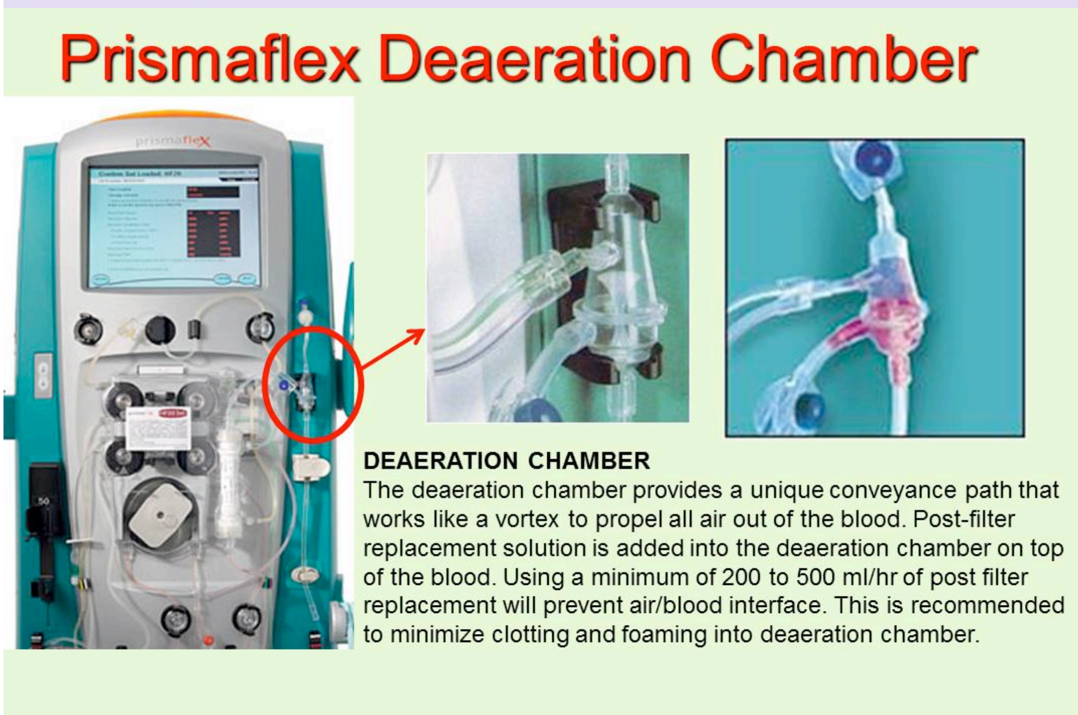
Citrate anticoagulation should not be used with SCUF! We do not do SCUF at UAB and use of SCUF needs to be discussed with me first!!!

Most Commonly Used CRRT Protocols at UAB

CRRT Protocol	**Dialysate**	**Replacement Fluid**	**Calcium Replacement**
#1 (citrate AC)	**Standard Bicarbonate (25)/4.0 KCL at 1.2 L/hr**	**0.5%Trisodium Citrate 1.2L /hr**	**Calcium Gluconate 60 ml/hr**
#2 (No AC)	**High Bicarbonate (35)/ 4.0 KCL/3.0 Ca at 1.2L/hr**	**High Bicarbonate (35)/4.0 KCL/3.0 Ca at 1.2L/hr**	**NO Calcium drip required**
#3 (citrate AC)	High Bicarbonate with 4.0 KCL 1.2 L/hr	0.5% Trisodium Citrate 1.2 L/hr	Calcium Gluconate 60 ml/hr
#4 (No AC; hyperkalemia > 6.5 meq/L)	High Bicarbonate with 0 KCL 1.2 L/hr	High Bicarbonate with 4.0 KCL 1.2 L/hr	No Calcium drip required
#5 (No AC; uncontrolled hyperkalemia > 8 meq/L and actively dying)	High Bicarbonate with 0 KCL 2.5 L/hr	High Bicarbonate with 0 KCL 2.5 L/hr	No Calcium drip required

These are recommended starting rates for the most commonly used solutions and protocols. The choice of dialysate or replacement fluid depends not only on the type of anticoagulation but on the acid-base status of the patient. Acid-base status can also be regulated by increasing or decreasing the rates of the dialysate and/or replacement fluids.





For the citrate protocol, if the post filter ionized calcium levels are > 0.5 mmol/L, increase the citrate replacement fluid by increments of 100 ml/hr and recheck another post filter ionized calcium level in 6 hours per protocol. However, as long as your 0.5% citrate replacement fluid rate is at a minimum of 1000 ml/hr with a blood flow between 130 to 180 ml/min, your post filter ionized calcium levels should be close to therapeutic range. We do not adjust for a lower limit for the ionized calcium level; most of the readings are listed as < 0.25 mmol/L. We do not change the citrate replacement fluid rates for this.

The following labs are obtained at initiation of CRRT:
Check Chem10 q6hrs (this should contain a basic metabolic panel and total calcium, phosphorous, and magnesium)

- Call Fellow if bicarbonate is <15 mmol/L or >35 mmol/L
- Check ionized calcium from the blue port q6hrs
- Call fellow if ionized calcium from the blue port is >0.5 mmol/L
- Check ionized calcium from the patient 1hr after start and then q6hrs
- Notify the fellow if the systemic ionized calcium is <0.9 mmol/L or >1.3mmol/L

Please obtain both patient (systemic) and blue port ionized calciums

After 48 hours, you can stop checking post filter ionized calcium levels. If the patients are stable after 48 hours, all other labs can be changed from q 6 hrs to q 12 hrs.

Titration of the Calcium Gluconate drip:

- Check patient (systemic) ionized calcium q6hrs
- Ionized calcium >1.3 mmol/L then decrease flow by 10ml/hr. Ionized calcium 0.9 to 1.3 mmol/L, no change. Ionized calcium 0.8 to 0.9 mmol/L increase drip by 10ml/hr. Ionized calcium < 0.8 mmol/L increase drip by 20ml/hr and call fellow.

Questions to ask the ICU nurse if you are called for abnormally low ionized calcium results on citrate anticoagulation:

1. Ask nurse from which port ionized calcium results were obtained.
   Post filter ionized calcium results must be from blue port.
   *Systemic ionized calcium results must **not** be drawn from calcium infusion line or pigtail of the dialysis catheter.*

2. Ask nurse to check fluids on machine.
   Citrate should be hung only on the PBP (white scale) of the Prismaflex and never as a dialysate.

3. Ask nurse to check fluid rates on machine.
   0.5% trisodium citrate rate should range between 1000-2000 ml/hr.

4. Ask nurse to check rate and place of infusion of calcium drip.
   *A calcium drip **must** be infused while citrate is used. The calcium drip should be stopped when the Prismaflex machine is disconnected. Typical rates are 60 - 100 ml/hr.*

   The calcium drip should not be infused into the pigtail or central port of the dialysis catheter. *This will cause extensive recirculation of calcium (removal by the CRRT device) and results in higher calcium delivery rates and great variation of calcium delivery every time the CRRT device alarms (causing all the pumps to stop except the blood pump). This results in great variation in the systemic calcium levels and makes them hard to interpret.*

   The calcium drip should be infused back to the patient through a separate IV pump and Y-connector attached to the venous return line of the CRRT circuit. The CRRT dialysis nurses know how to do this. It is important that the venous and arterial ports of the catheter are not switched when this is done (the nurses sometimes do this if the access does not work well).

5. Ask nurse if the patient has received blood products or if the patient's hemodynamics have changed.
   Blood products such as FFP contain citrate and can lower the patient's ionized calcium levels transiently.
   If the patient becomes hypotensive with shock liver, he or she may not be able to metabolize the citrate and may develop signs of citrate toxicity. In that case, a fluid panel profile and systemic total calcium should be checked.

6. If no explanation is found for low ionized calcium levels, have the nurse repeat the levels. If still abnormal, you need to evaluate the patient.

For all the cases above, the underlying cause needs to be treated. Even if the result is a lab error, it is safe to give 1-2 amps of calcium gluconate, increase the calcium infusion rate, and repeat iCa level in one hour. If systemic iCa level remains < 0.9 mmol/L, repeat the above steps until iCa within range and look for citrate toxicity.

ELECTROLYTE DISORDERS

SEVERE ACIDOSIS

For severe acidosis (pH < 7.2, bicarb < 10, or lactic acid > 8), high bicarb solutions should be used for PBP, dialysate and post filter RF. The PBP and dialysate rate should be maximized to 2.5 L/hr.

HYPERKALEMIA

For patients with K 6.5 or lower, CRRT solutions with 4 K should be sufficient. Of note the 0.5% citrate solution has 0 K. Therefore, if used with the standard bicarb solution of 4 K, the effective K becomes 2.0 if the same rates of each solution are used.

For patients on the high bicarbonate solutions with 4 K and persistent hyperkalemia, the dialysate and post filter RF can be changed to high bicarb solution with 0 K. The PBP can remain as high bicarb with 4 K. Thus the effective K is about 2.0 K if using the same rates (PBP 4 K, Dialysate 0 K, post filter RF 0 K).

If patients on the high bicarb solutions with 4 K have persistent mild hyperkalemia (K 5.2-5.5), the post filter RF can be changed to NS while the PBP and dialysate can remain as high bicarb with 4 K.

For patients with severe hyperkalemia (K > 7.5), the high bicarb CRRT solution with 0 K should be used for the PBP, dialysate, and post filter RF. Both the rates of the PBP and dialysate should be maximized to 2.5 L/hr in these patients.

DYSNATREMIAS

Hyponatremia

D5W can be used as post-filter RF to slowly correct patients who have hyponatremia:
D5W rate = [(140 - target Na) / 140] x desired clearance.
For example, using post-dilution CVVHDF in a patient with initial sodium of 120 mEq/L with target sodium concentration of 130 mEq/L at a desired clearance of 3 L/hr using RF/dialysate with 140 mEq/L of sodium, the D5W infusion rate would be [(140 – 130)] / 140] x 3 L = 0.214 L/hr. So the post filter RF would be 210 ml/hr and the dialysate/pre-filter RF should be 2,790 ml/hr (2.79 L/hr + 0.210 L/hr = 3 L/hr)

Hypernatremia

In patients with cerebral edema who need 3% saline to maintain serum Na concentration in range 150 to 155 mEq/L, 3% saline can be delivered as the post-filter RF.
3% infusion rate = [(target Na – 140) / (513 – 140)] x desired clearance.
For example, in a patient with an initial sodium 140 mEq/L with target sodium concentration of 155 mEq/L at a desired clearance of 3 L/hr, the 3% saline infusion rate would be [(155-140)/513-140)] x 3 = 0.120 L/hr or 120 ml/hr. The dialysate/pre-filter RF should be 2880 ml/hr (2.880 L/hr + 0.120 L/hr = 3 L/hr)

MISCELLANEOUS
Patients can become hypothermic on CRRT due to the high fluid rates. As a result, the use of a PRISMAFLEX blood warmer is available.

All patients on CRRT become hypophosphatemic. They should have phos, K, Mag in their TPN or be on non-renal tube feeds (ie No Nepro). Often supplemental phosphate in the form of Phos-NaK needs to be scheduled (1 or 2 pack oral TID). Antibiotics have to be adjusted on CRRT.

SUMMARY OF CRRT EQUATIONS

QB is blood flow rate (ml/min). Remember QB is usually recorded in ml/min (150 to 200). For below equations, multiply QB by 60 to convert to ml/hr.
QR is Replacement fluid flow rate (ml/hr)
QD is Dialysate flow rate (ml/hr)
QFR is fluid removal rate (ml/hr)

CRRT DOSE:
Recommended minimal effluent dose is 20-25 ml/kg/hr (target 25-30 ml/kg/hr to take into account downtime). An acceptable dose has not been established in obese patients. Therefore in patients >100 kg, we use a PBP rate of 1500 ml/hr and Dialysate rate of 1500 ml/hr. We increase dose if we cannot achieve metabolic control.

Dose = Effluent Rate (ml/hr) / Patient Weight (kg)
Effluent Rate for CVVHDF = QR (including Pre-Filter Replacement Fluid Rate, Post-Filter Replacement Fluid Rate, and Pre-Blood Pump Fluid Rate) + QD + QFR

Effluent Rate (ml/hr) definition per CRRT modality:

- CVVH: Total Ultrafiltration (UF) Rate (ml/hr) = Pre-Filter Replacement Fluid Rate (ml/hr) + Post-Filter Replacement Fluid Rate (ml/hr) + Fluid Removal Rate (ml/hr) + Pre-Blood Pump (PBP) Fluid Rate (ml/hr)*
- CVVHD: Dialysate Rate (ml/hr) + Fluid Removal Rate (ml/hr)
- CVVHDF: Total UF Rate (ml/hr) + Dialysate Rate (ml/hr) = Pre-Filter Replacement Fluid Rate (ml/hr) + Post-Filter Replacement Fluid Rate (ml/hr) + Fluid Removal Rate (ml/hr) + Pre-Blood Pump (PBP) Fluid Rate (ml/hr)* + Dialysate Rate (ml/hr)

CRRT DOSE DILUTION FACTOR:
When using Pre-Filter Replacement Fluid and/or Pre-Blood-Pump (PBP) Fluid, the CRRT dose is diluted and therefore decreased. CRRT effluent rate is multiplied by the dilution factor and then divided by patient weight to reflect actual CRRT dose in ml/kg/hr; this takes into account the dilution effect.

Dilution Factor = Plasma Flow Rate (ml/hr) / [Plasma Flow Rate (ml/hr) + Pre-Filter Replacement Fluid Rate (ml/hr) + PBP Fluid Rate (ml/hr)*]

- Plasma Flow Rate (ml/hr) = Blood Flow Rate ml/min (QB) X 60 (min/hr) X (1-HCT)

CRRT FILTRATION FRACTION (FF):

Filter clotting occurs with FF > 20-25%.

Filtration Fraction (FF) = Total Ultrafiltration Rate / (Plasma Flow Rate + Pre-Filter Replacement Fluid Rate + Pre-Blood Pump (PBP) Fluid Rate*)

- Total Ultrafiltration Rate (ml/hr) = Pre-Filter Replacement Fluid Rate (ml/hr) + Post-Filter Replacement Fluid Rate (ml/hr) + Fluid Removal Rate (ml/hr) + Pre-Blood Pump (PBP) Fluid Rate (ml/hr)*
- Plasma Flow Rate (ml/hr) = Blood Flow Rate (QB ml/min) X 60 (min/hr) X (1-HCT)
- **Note: dialysate rate does NOT factor into the FF equation**

** For all formulas above, PBP Rate only applies if utilizing with Prismaflex device*

<u>CITRATE TOXICITY</u>

Detection

- Rising anion gap, worsening metabolic acidosis
- Falling systemic iCa^{2+}
- Escalating Ca^{2+} infusion requirements
- Total Ca^{2+}:Systemic iCa^{2+} Ratio > 2.5:1 (increased Ca^{2+} gap)**

***To convert Total Calcium in mg/dL to mmol/L, multiply Total Calcium by 0.25*