A Primer on Continuous Renal Replacement Therapies

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About this Primer

You know how you try to learn something very complex from a textbook and you don't "get it", but then a seasoned colleague tells you the same thing in simple, understandable words and then adds some humor to the whole serious subject and suddenly a light goes on and you say "Oh, so THAT'S what it means!!" Well, this entire primer is like that.

This primer presumes that the reader, a dialysis nurse or patient care technician, knows the basics of intermittent Hemodialysis.

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1 Kidney Basics

1.1 How do the Kidneys work?

The kidneys are two bean-shaped organs located toward the back of the body on either side of the spine near the waistline. They are about the size of a fist and are protected by other organs and two of the lower ribs. Although the kidneys weighs only about 0.5% body weight, they receive about 25% of the body's total blood supply per minute. Industrious organs, these kidneys. You are in trouble if you pi** them off.

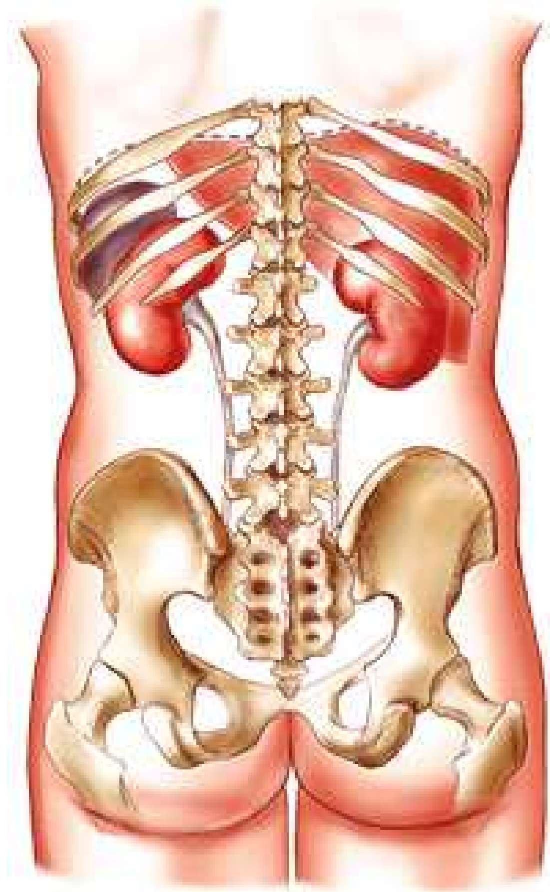

Figure 1: The Normal Kidneys

Your kidneys receive the blood from the renal artery, process it, return the processed blood to the body through the renal vein and remove the wastes and other unwanted substances in the urine. Urine flows from the kidneys through the ureters to the bladder. In the bladder, the urine is stored until it is excreted from the body through the urethra.

Normal functioning kidneys serve the body in several very important ways. They:

- Clean your blood and remove waste products
- Balance water and salt to control fluid in the body
- Control blood pressure
- Help make red blood cells and strong bones
- Control the amount of potassium, calcium, magnesium and phosphorus in the blood

1.2 What are the types of Kidney disease?

Acute Kidney Injury

Some kidney problems happen quickly, such as when an accident injures the kidneys. Losing a lot of blood can cause sudden kidney failure. Some drugs or poisons can make the kidneys stop working. These sudden drops in kidney function are called acute kidney injury (AKI). Earlier, people used to refer to this condition as acute renal failure (ARF).

AKI may lead to permanent loss of kidney function. But if the kidneys are not seriously damaged, acute kidney disease may be reversed.

Chronic Kidney Disease

Other kidney problems, however, happen slowly. A person may have "silent" kidney disease for years. Gradual loss of kidney function is called chronic kidney disease (CKD) or chronic renal insufficiency. People with CKD may go on to develop permanent kidney failure. They also have a high risk of death from a stroke or heart attack.

End-stage Renal Disease

Total or nearly total and permanent kidney failure is called end-stage renal disease (ESRD). People with ESRD must undergo dialysis or transplantation to stay alive.

1.3 What are the symptoms of Kidney Disease?

Failing Kidneys can cause a variety of disturbances in the body. Some of the common symptoms of kidney failure are:

- Decreased urine output
- Shortness of breath
- Swelling of legs and face
- Decreased appetite
- Nausea & Vomiting
- Headache
- Easy fatiguability
- High blood pressure
- Change in mental status
- Abnormal blood and urine tests

2 Molecular transport mechanisms

2.1 What are molecular transport mechanisms?

Remember all that stuff diffusion, convection, ultrafiltration and adsorption that they taught in grade school? They describe the molecular transport mechanisms.

Once again, (and as always, "with a lot of lies thrown in"), this stuff isn't that hard. While we are at it, we'll learn about hemofiltration and ultrafiltration as well. But before that, let us meet a very important character in this whole mix, the semi-permeable membrane.

2.2 What is a Semi-Permeable Membrane?

It is a is a membrane that will allow certain molecules or ions to pass through it. It has these holes in it, see? (Fig. 2)It won't allow other molecules. Remember those bouncers at night clubs? The "bouncer" (semipermeable membrane) permits only the "beautiful people" (certain ions), the "regulars" (water, oxygen, glucose) and the "hard-bodied bar chicks"(certain molecules) to pass through freely.

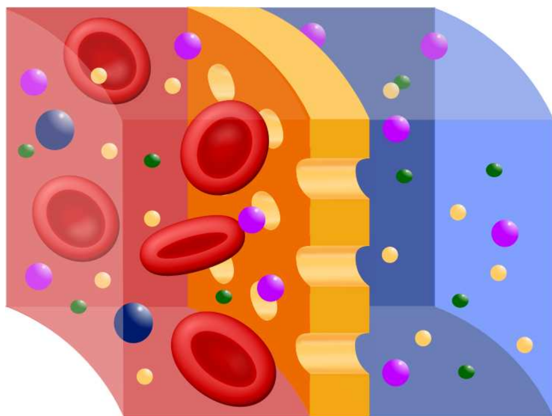

Figure 2: Semi-Permeable membrane

2.3 What is Diffusion?

It's an interesting thing about molecules – they're adventurous. They want to go places. But – and they're very serious about this - it's really important for them to spread themselves around evenly; they want to travel with their friends, or not at all. If they see a place where they're under-represented, over across yonder semi-permeable membrane for example, (Montana, maybe), well, off they're gonna go, until there's just as many over there across the border in Montana as there are over here in Idaho. Wyoming maybe. Nice, compulsive little ICU-personality molecules-so cute!

That's the basic idea behind "diffusion across a concentration gradient". Why can't these people just speak English? If there's too much molecules over here on this side, and not hardly none of 'em over on that side, why then, they're just gonna get up and go over across there – it's what they do, as the Great Physicist decreed, way back there in the Bang.

Of course the membrane has to have holes in it to let 'em through, right? Just the right size holes too, 'cause ya don't wanna be losing your albumins and all, or your red cells, know what I'm sayin', yo? We just discussed this, remember? If you don't, head over to section 2.2

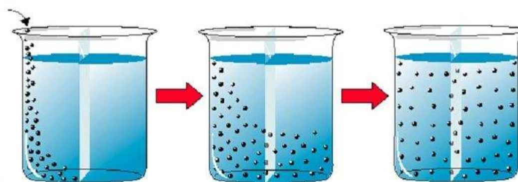

Figure 3: Molecular diffusion

2.4 What is Convection?

For our purposes, let's keep it simple: convection refers to the movement of molecules within fluids.

Did you ever hike up a mountain in summer only to be disappointed when you saw a trickle of water

in place of a waterfall? If you went back after the rains, you would see a great torrent of water dragging leaves, pieces of wood and small pebbles. Well, that is convection - water movement dragging along other molecules.

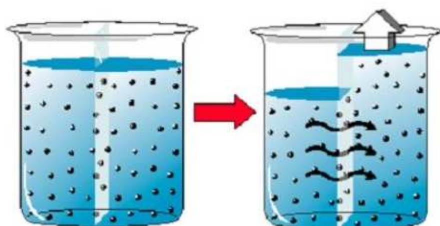

Figure 4: Convection

2.5 What is Ultrafiltration?

Hemofiltration and ultrafiltration appear to be the same thing: fluid (in the form of water molecules) can pass through the semipermeable filter membrane, and by applying a suction pump on the far side of the membrane, you can suck water out of the patient, through the filter, at apparently whatever rate you'd like. This is called "creating a transmembrane pressure gradient", for those of you who like the big words. A pressure gradient can be created by applying positive pressure on the same side, negative pressure on the opposite side, or by creating an increased concentration of certain ions on the opposite side.

It turns out that when you do this, small solute molecules get dragged out through the membrane pores along with the water – this is what they mean by "convective transport", or "solvent drag". Solvent drag turns out to have nothing whatever to do with concentration gradients – the molecules just get swept along out through the filter pores. In the process, a lot of fluid gets removed from the patient (as "ultrafiltrate") – and so we have to give some back. The movement of solutes through the membrane ("convective flux") is calculatable using all sorts of horrid renal mathematics, but happily we can leave that to the engineers; we just run the machine, which is tricky enough.

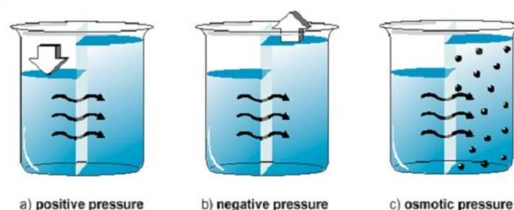

Figure 5: Ultrafiltration

2.6 What is Adsorption?

A**d**sorption, the binding of molecules or particles to a surface, must be distinguished from a**b**sorption, the filling of pores in a solid. The binding to the surface is usually weak and reversible. Just about anything including the fluid that dissolves or suspends the material of interest is bound. This is bad news for us, guys. This process reduces the efficiency of the filter.

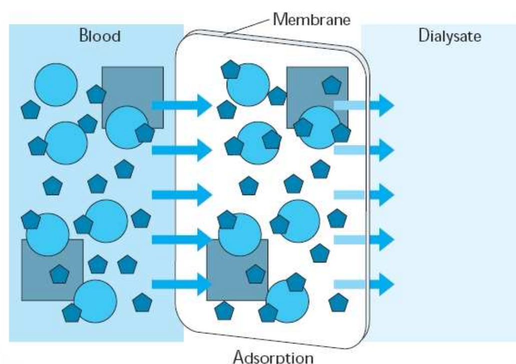

Figure 6: Adsorption

2.7 What is Dialysate?

So - when you dialyze someone, you put their blood (hypertonic – very full of stuff that needs removing. Picturize sea water) on one side of a membrane – and put some hypotonic solution on the other side

(that's the dialysate. Picturize drinking water), and off the little critters go a-running over the membrane border there, from where they get washed away and sent back into the Great Pond, or wherever. And the number of BUN and creatinine molecules in the blood decreases, along with a bunch of even smaller ones like the electrolytes, which is why we spend so much time worrying about giving them back.

So, dialysate is a physiologic sterile solution that is infused countercurrent to the blood flow and is made up of electrolytes, glucose, buffers and other solutes. The direction of flow is opposite that of blood because this allows a greater diffusion gradient, increasing effectiveness of solute removal. Typical flow rates are 200 to 1800 ml/hour, depending on the type of therapy that is prescribed.

Options:

- Commercially prepared pre-mixed dialysate.
- Commercially prepared peritoneal dialysate. They contain high concentration of glucose. When using this type of dialysate, close monitoring of the patient's blood glucose is required. A high glucose load is not desirable in sick patients who are prescribed CRRT.
- Custom dialysate compounded by the pharmacy.

2.8 What is Replacement Solution?

It is a solution that is infused directly into the blood at points along the blood pathway. As can be seen in the figure, it drives convective transport. Despite the name, **it does not replace anything**.

- Facilitates the removal of small, middle and large solutes
- Physician prescribed. Usually normal saline with additives.
- Components are adjusted to meet patient needs.

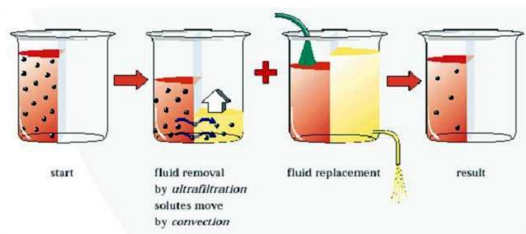

Figure 7: Replacement solution

Options:

Replacement solution can be given pre-filter or post-filter. Most people prefer to give it pre-filter because it prolongs filter life.

2.9 What is Creatinine Clearance?

Simple enough – how well are the kidneys getting rid of the creatinine in the blood? The level in the blood is compared to the level in the urine. There are all sorts of calculations and formulas to help predict what the clearance rate ought to be – all I want to know at the bedside is: are the BUN and creatinine going down? Just call me stupid...

2.10 What is Filtration Spectrum?

This has to do with the size of the molecules that can pass through the pores of the filter in the circuit. The spectrum is size: molecules up to "this" big and no bigger will pass through the pores.

Things that will pass through:

- Little ions like sodium, potassium – no sweat.
- A little bigger: ammonia, glucose, bicarb.
- A little bigger even: some meds: heparin, some antibiotics.

Things that will not pass through:

- Too big: protein, and therefore anything that binds to it: dilantin, etc.

3 CRRT Basics

3.1 What is CRRT?

"Any extracorporeal blood purification therapy intended to substitute for impaired renal function over an extended period of time and applied for or aimed at being applied for 24 hours/day"

-Bellomo R, Ronco C, Mehta R. Nomenclature for Continuous Renal Replacement Therapies. AJKD. Vol. 28, No. 5, Suppl 3, Nov. 1996

This group of words describes a group of therapies:

- SCUF - **S**low **C**ontinuous **U**ltra **F**iltration
- CVVH - **C**ontinuous **V**eno **V**enous **H**emofiltration
- CVVHD - **C**ontinuous **V**eno **V**enous **H**emo**D**ialysis
- CVVHDF - **C**ontinuous **V**eno **V**enous **H**emo**D**ia**F**iltration

3.2 Why CRRT instead of Hemodialysis?

The basic idea is that hemodialysis treatments produce really enormous changes in the patient's body over a pretty short time: they can pull off volume very quickly, change electrolyte and BUN/Creatinine concentrations quickly – that kind of thing, and patients with hemodynamic problems just don't like that very much. I mean, if your patient's kidneys have "taken a hit" because of a hypotensive episode, does it make sense to do it again, hauling off large volumes with a hemodialysis treatment while they're on pressors?

CRRT is apparently much more gentle. The whole circuit holds only about 127cc, compared to a lot more for an HD circuit, and even though the device processes blood rapidly, (200cc/minute is fast – what is that?: 12,000cc = 12 liters an hour! Hoo-wah!), fluid is replaced by the machine as fast as it is being pulled off, plus or minus some every hour, depending on what you want to do. It can also run 24/7 – it's a pretty stable form of treatment. HD doesn't routinely replace anything, although you can give volume back while it's run.

CRRT also apparently is effective in removing septic materials: cytokines and endotoxins, and there may be a more routine role for it coming in the management of septic patients.

One last point is that CRRT avoids "disequilibrium syndrome" (I have that one all the time. In fact, my teacher once said that I was fit to be a cadaveric organ donor because I was brain dead. But that's another story...), which involves the patient developing acute cerebral edema after rapid HD. Making the blood suddenly hypotonic encourages water to soak into the hypertonic brain cells.

Variable	CRRT	IHD
Continuous renal replacement	+	-
Hemodynamic stability	+	-
Fluid balance achievement	+	-
Unlimited nutrition	+	-
Superior metabolic control	+	-
Continuous removal of toxins	+	-
Easy to perform	-	+
Stable intracranial pressure	+	-
Rapid removal of poisons	-	+
Limited anticoagulation	-	+
Patient mobility	-	+

Table 1: Comparison of CRRT and HD

3.3 What is SCUF?

Surgeons Can't Understand Fluids ! No, seriously - the patient's blood passes through a filter, and pressure is applied which is enough to push water molecules across the membrane in large amounts. Treatment characteristics:

Blood flow rate (Qb): 50-200 ml/min
Filtrate rate (Qf): 5-8 ml/min
Transmembrane pressure (TMP): 30 mm Hg
Membrane: High-flux
Reinfusion: No
Diffusion: No
Convection: Yes

3.4 What is CVVH?

The patient's blood is passed through a filter and replacement solution helps in convective clearance. See Fig 7 on page 5. A schematic of CVVH is shown in the following figure.

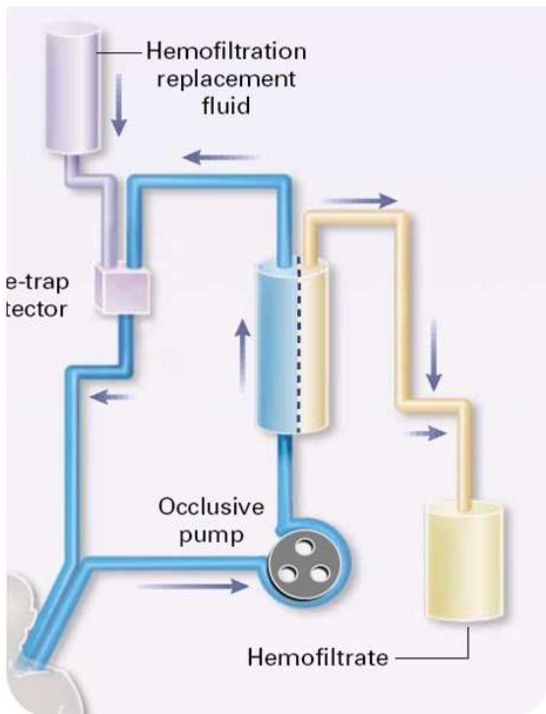

Figure 8: CVVH

Treatment characteristics:

Blood flow rate (Qb): 50-200 ml/min
Filtrate rate (Qf): 15-20 ml/min
Transmembrane pressure (TMP): 50 mm Hg
Membrane: High-flux
Reinfusion: Yes
Diffusion: Low
Convection: High

3.5 What is CVVHD?

In this circuit, there is no replacement fluid. Instead, sterile dialysate flows in the direction opposite blood flow. This therapy depends on diffusive clearance. See Fig. 3 on page 3. A schematic of CVVHD is shown in the following figure:

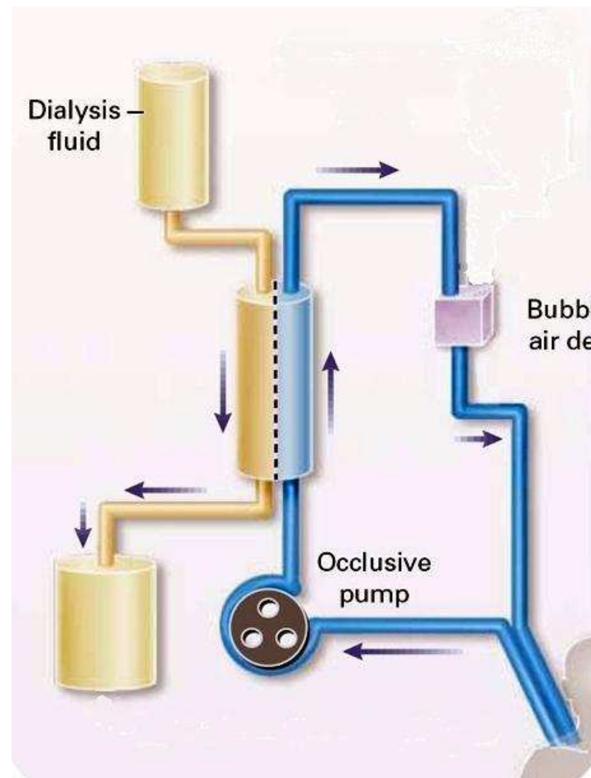

Figure 9: CVVHD

Treatment characteristics:

Blood flow rate (Qb): 50-100 ml/min
Filtrate rate (Qf): 1-5 ml/min
Dialysate flow rate (Qd): 10-30 ml/min
Transmembrane pressure (TMP): 50 mm Hg
Membrane: Low-flux
Reinfusion: No
Diffusion: High
Convection: Low

3.6 What is CVVHDF?

It is the combination of both hemofiltration and hemodialysis applied to a CRRT circuit. This therapy depends on convective as well as diffusive clearance. A schematic of the circuit is shown in the following figure:

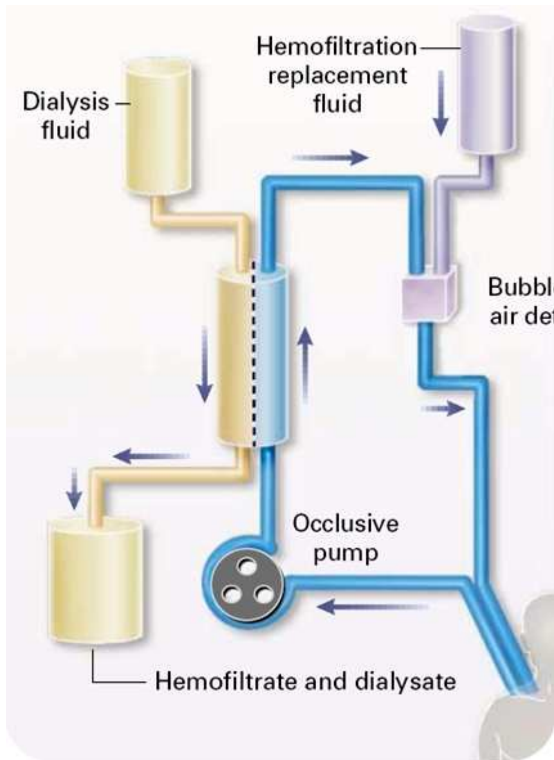

Figure 10: CVVHDF

Treatment characteristics:

Blood flow rate (Qb): 100-200 ml/min
Filtrate rate (Qf): 10-20 ml/min
Dialysate flow rate (Qd): 20-40 ml/min
Transmembrane pressure (TMP): 50 mm Hg
Membrane: High-flux
Reinfusion: Yes
Diffusion: High
Convection: High

3.7 Can you summarize various CRRT techniques?

Sure. Just take a look at the table below:

	SCUF	CVVH	CVVHD	CVVHDF
Filtrate (ml/hr)	100	1000	300	800
Filtrate (L/day)	2.4	24	7.2	19.2
Dialysate flow (L/hr)	0	0	1	1
Replacement fluid (L/day)	0	21.6	4.8	16.8
Urea clearance (ml/min)	1.7	16.7	21.7	30
Convection	+	++++	+	++
Diffusion	0	0	++++	++++
Simplicity	++++	++	++	+
Cost	+	+++	+++	++++

Table 2: Summary of CRRT techniques

4 Hardware

4.1 What is the basic hardware setup?

Take a look at the figure below.

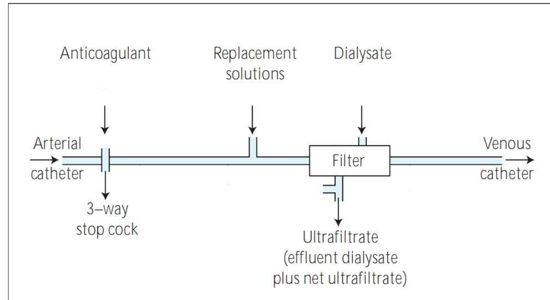

Figure 11: Basic CRRT Setup

At first look, it appears godawful, doesn't it? However, if you look closely, there are only four components:

1. Blood path
2. Replacement fluid path
3. Dialysate path
4. Effluent path

4.2 What is the Blood path?

The blood path is simple: from the patient ("arterial" catheter port), pulled out by the blood pump, to the filter, back out of the filter, to the air/clot/debris trap/detector, then back into the patient. The arterial line is colored red and the venous line is blue.

4.3 What is the Replacement fluid path?

This is what you're giving the patient back. Fluid is drawn from replacement fluid bags by a pump, warmed up, and simply pumped along back into the circuit ahead of the filter. Why ahead? Well, we discussed that, remember? Please refer to section 2.8 on page 5. Replacement lines are violet in color.

4.4 What is the Dialysate path?

Simple. It is the dialysate fluid that is pumped in the filter in a direction opposite to blood flow. Helps in diffusive clearance. These lines are green in color.

4.5 What is the Effluent path?

The effluent (also called ultrafiltrate) is the stuff you're removing from the patient's blood: water, solutes, BUN, creatinine, all that stuff. Technically known as "pee". Ultrafiltrate gets pulled off from the outer space of the filter by a pump, applying a negative pressure – aka "suction". It passes through a blood-leak detector, which tells you if blood has gotten out of the filter tubules into the ultrafiltrate – bad, because it means your filter has ruptured. Bummer. Take the system down. After that it goes to a collection bag. Should be nice and yellow. So cool.

4.6 What is a Hemofilter?

This is where the action happens. Take a look at the filter: see that big white clump of bitsy tubes going along it, inside, lengthwise? They are like straws, only much smaller and the blood flows through those. Dialysate flows in the opposite direction outside the straws. You'll notice that there's some space around the clump of tubes between them and the clear plastic wall of the filter itself.

Figure 12: Hemofilter cut section

4.7 What are the two spaces in the filter?

The first space is where the blood is: inside the bundle of little white tubes. The second space is the one outside the bundle of tubules. Imagine cutting off one of the ends of the filter, crossways. Now pick up the part that's left, and look down into it, as if you were looking down a cardboard tube. See the thick outer plastic wall of the filter? Now see the bundle of little tubes, cut off? And see how there's a space around the bundle, between the wall and the bunch of tubes? That's the second space – the space on the outside of the membrane. Make sense?

4.8 What is the membrane?

Another way: all of those little tubes have walls, right? Take another look at Figure 12 . Those walls are full of carefully engineered little tiny holes that let molecules pass through, but only up to a certain size. Semi-permeable. My son's head is semipermeable: anything to do with cars goes right in, but chemistry – bounces right off. Maybe I need to change his filter.

Added up together, all those walls form a large area for water and solutes to pass out of the blood, and that whole area is the "filtration membrane"

4.9 What is Transmembrane Pressure?

How hard is it for the water and the solutes to get across that membrane? Too hard? The little holes in the tiny tubes may be getting clotted up. Too low – you sure you're hooked up to the patient? Your goal is to keep the TMP $<$ 20 mm Hg. The filter is happy and you, in turn are happy.

4.10 What is a Dialysis Catheter?

Dialysis catheters are made up of specially designed polymers. They are used to draw and return blood to the patient. Most catheters have two lumens. Some can have even three. If you look at Figure 13, you will see a red and a blue adapter at the end of the catheter. The red or "arterial" end is used to draw blood from the patient. Blood is returned through the blue or the "venous" end. Do you see the small holes near the tip of the catheter? The arterial end uses those to "suck" blood into the machine. The venous end "pushes" blood back in through a hole right at the tip. This way, you minimize re-circulation between the "clean" and "unclean" blood.

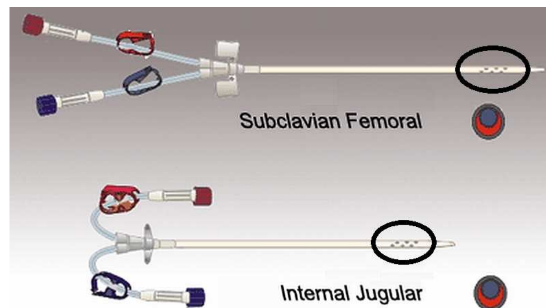

Figure 13: Dialysis Catheter

Sometimes, the side holes may find themselves up against the vessel wall. If you hook up the "pull" line from the machine to that port, will it be able to suck out 200cc/min of blood from the patient? No way, man – it'll just suck up tight against that vessel wall,

and you'll get bupkes. The "arterial" transducer will yell at you: "I'm pulling too hard!" - (the suction will reach the set limit of negative pressure), and the machine will shut down.This is why they teach us to "swap the ports": hooking up the return line to that port will probably be just fine – blood will go back into the patient through that port with no problem. Make sense?

Or you could rotate the catheter – it's the holder that's stitched in place, and the tube itself will turn – turn it over, and now the port that was against the wall should be facing into the bloodstream. Make sure, however, that the Renal attending or Fellow knows about this.

4.11 Does it matter where the catheter is placed?

Does it ever! We see catheters placed in the fems, subclavians, the IJ's – a bigger vessel is usually better, but problems can always pop up, especially in heavier patients – a catheter may bend where it goes into the skin, even though it followed Harry Seldinger's nice wire right in there, and you may have all sorts of trouble positioning the patient so that the machine will be able to pull and push blood in and out of her. Him. Them.

4.12 What is the catheter flushed with?

Actually the catheter is flushed with saline, but we instill heparin or Acid Citrate Dextrose solution after wards to keep it from clotting off. Make sure that your coagulopathic patient doesn't get orders for heparin catheter flush, and make sure that you don't prime his system with heparinized saline unless specifically ordered (and even then you should probably argue about it).

Also make sure that you **aspirate the catheter ports before using them**! The heparin solution we use is pretty concentrated – 1000 to 5000 units per cc. You want to give all of that to your patient at once? I didn't think so.

4.13 What is the blood flow rate?

This is the speed at which blood is pulled through the main blood path: it's measured as the number of cc's passing through the blood path each minute. It depends on factors like the patient's BP, the type of replacement fluid used, etc. Look at your physician's order set.

4.14 What is the air-detector for?

This is part of the main blood path. The air detector is the last part of the machine that monitors the main blood path, looking through the blood going by before it goes back into the patient. It's just below the big venous trap that collects debris, clots, and (hopefully) any air in the tubing. Would you like to have your machine keep on nicely pumping along if no blood was in the tubing? Sort of a bad idea. If the detector sees air – the machine stops.

The thing is, this whole machine setup really sort of is the octopus from hell, the "thing with a thousand arms". If something is clamped wrong, then one of the 138 and a half screw connectors may start to suck air into the system, and that air will make its way along through the system towards the patient – the air detector sees it and stops the machine. It does take time, but eventually you can get comfortable with the setup. I always run along the three tubing paths before I start the thing up, making sure that things are tight, and that clamps are open and closed as they ought to be.

It is possible to save an air-contaminated system sometimes, depending on how much got in there – but this is a hands-on maneuver that you have to learn with a preceptor. The other problem is that air in the filter will tend to clot it up. Everybody got that?

4.15 What is the blood-leak detector?

This is part of the ultrafiltrate path. Remember that the ultrafiltrate is pulled out of the little tubules –

if they break, then red cells start showing up in the ultrafiltrate path. Not good – this translates as "filter rupture" – time for a new circuit.

Some people will just change out the filter, which I think is a terrible idea. For one thing, the circuit is at least moderately pressurized, right? You want Hep B pressurized blood spraying around in you local area? Not to mention sterility issues. Just change the whole damn thing.

4.16 What are all the transducers for?

The transducers are telling you what the pressures are in the system. As with transducers everywhere, the trick is to try to remember what they're "looking at". An arterial-line transducer for example is looking at the pressure in the radial artery, through the stiff tubing that connects the transducer to whatever vessel you're trying to measure the pressure of. These machine transducers are doing the same kind of thing: they're watching something, and the trick is to try to visualize what it is.

4.17 What does the arterial transducer tell me?

There are five transducers built into our system, and the first two are easy – they're looking at the blood flows in and out of the patient: one is looking at the flow coming out (the "arterial" side), and the other looks at the flow going back in ("venous").

Interpreting the arterial transducer number is a little trickier than usual, because it's measuring a negative pressure. You need to remember that transducers measure pressures that rise and fall. Positive and negative. In this case, the pump is pulling blood out of the patient through the "arterial" port of the catheter – and pulling is measured as a negative number. Like a "NIF" – the negative inspiratory force that you measure when you're trying to see if your patient is ready to extubate, which is also measured as a negative number. Wall suction is measured negatively. My brain is often measured negatively – actually my son's brain... but I promised I wouldn't yell any more.

Anyhow. Suppose your arterial catheter pressure is a nice "low" number – meaning only about, say, negative 20mm Hg - everything is good, and your patient decides to sit up, or curl up, flip over, or leap out of the bed and do a pirate dance – if the catheter kinks, the machine will continue pulling, harder and harder, but only up to a limit. The number indicators on our machine help you here, because as the negative pressure gets "higher and higher" – meaning "greater and greater", except it's negative, right? – then the numbers will change and tell you what's happening. And when it reaches it's limit, the machine will stop and alarm, to the effect of "Uh, excuse me, you want to come over here? I think I'm kinked!" This can also happen if the arterial port is up against the vessel wall, something you'll usually discover when you aspirate the ports manually at start up – try switching.

4.18 The venous transducer?

This one's a little easier – the venous side is going back into the patient, and it has to be pushed back in, so the venous side transducer is looking at a positive pressure. Higher numbers mean that the machine is having to work harder to push – if the catheter isn't kinked, this usually means that clot debris is building up in the venous trap, plugging up the works. If the pressure gets too high, the system may have to be changed – again some people try changing out only part of the circuit, and that is possible with the Omni DL, but I wouldn't recommend it.

4.19 What about the other transducers?

Instead of looking at the catheter flows, two of these are looking at the pressures on one side or the other of the filtration membrane. One is looking at the pressure of the blood as it's going into the filter. Remember, the blood on the inside of the little filter tubules is on the inside of the membrane, and the

ultrafiltrate is on the outside. Another transducer is looking at the pressure coming from the blood leak detector, which is full of ultrafiltrate ("pee") – which is on the other side of the membrane.

If the pressure across the membrane – the "trans-membrane" pressure – rises, it means what?: that the fluid is having a harder time getting across, probably because some of the openings in the tubules are getting plugged up with clot. If the pressures get really high – time to change to blood path and filter. Or preferably, the whole system.

A last transducer looks at the pressures involved in the replacement fluid circuit. If something is clamped, this will honk at you.

I'd like to point out that even though the transducers can be temporarily clamped, it's really unsafe to leave them that way, since pressures can go off the scale on one end or the other, and you really do need to know if the machine is becoming unhappy, and why.

5 Lock & Load

5.1 How do I prime the machine?

At this point we do machine prime: meaning, we set up all three tubing sets on the machine, and let the pumps prime it up with whatever solution is ordered; either NS or NS with a bit of heparin per liter, which helps keep the filter from clotting.

There are all sorts of steps in the priming dance that you have to learn – really, after the first hundred times, it's lots easier.

5.2 Should I prime with Heparin or without?

Lots of our patients are anticoagulated for one reason or another – sometimes they're doing it all by themselves as a result of being "hepatorenal". These people really don't need any help from extra heparin, and they often do a good job of keeping their machine circuits free of clots. Pretty nice of them. Not to mention the problems of HIT...In short, look at the physician's order set. If you are in doubt, call them and ask.

5.3 How do I make sure the circuit is ready to run?

Once you've gotten the whole entire enormous thing set up, the machine primes itself. I takes about 5 minutes, and may need some tweaking as you go. Once it's done, you're all set – you can let the system just sit now, and it will be ready to go when you need it.

5.4 How do I prep the catheter?

Our policy is to soak the catheter ends between two 4x4's saturated with alcohol for several minutes. We use sterile gloves and an OR mask when we work with the catheter connections.

Don't forget to aspirate 10cc from each of the catheter lumens! Sometimes – not always - these lines are inserted and flushed with concentrated heparin, which your liver-failure patient does NOT need to have injected! You also want to aspirate any little clots in the ports.

See if both sides of the line draw rapidly – whichever one draws the easiest is going to be the "arterial" side, regardless of whether it's blue or red. Be very aware of what you're doing with the line clamps as you do the hookup.

5.5 What can I infuse through the system and what I can't?

We use three sites on the circuit to infuse: we put a stopcock manifold at the end of the return line, and that's where we usually infuse the replacement calcium, although there's no reason that you can't give it through another central port or peripheral line. Other things that are compatible can run there as well.

However – bear in mind that these infusions are bypassing the final air filter detector, right? This is a big deal, because the flow rate of the blood through the CRRT circuit is really fast. Actually, it's always true that air can get sucked into your patient through a loose connector. So there's always a risk, especially at central venous sites, right? So imagine what could happen at an infusion site when the system flow is 200cc per minute, instead of, say 50cc an hour! Without an air detector, a really impressive air embolus could occur. Be very aware of your connections.

The other infusion sites are on the venous return line: one above the air trap, and one further back. The CRRT goddess points out that while giving red cells through the trap is usually fine, it's probably not a good idea to run FFP there, since the clotting factors may go to work within the filter in the trap.

5.6 What labs do I need to look at before starting?

You really want to have a good look at the basic everything: for example, is the hematocrit okay? The system holds 127 cc of blood, which isn't a stupendous amount, but if the patient's crit is 19, you might want to transfuse. What if the system goes down, and you can't give that blood volume back?

Coags okay? – high? Low? Potassium low? (Probably not, right?) Baseline BUN/creatinine, and what are they now? Calcium for sure, both serum and ionized. Magnesium, and phosphorus, definitely. And oh yeah, is the patient acidotic, and why?

6 Up and Running

6.1 How do I get things started up?

Machine's all set, right? Out of priming mode, final check, turnover and pump rates all correct, all that good stuff? At this point set the business ends of the tubing down near the catheter tips, usually on a chux, still connected to the priming bags.

- Keep things clean.

- Mask, gloves.

Give a moment's thought: do you want to give the patient the volume in the circuit? Yes? Hook up both lines and go. No? Hook up the arterial side, turn on the machine, and let the patient's blood displace the priming fluid up into the priming bag on the venous end. Then hook up the venous connector and go. In practice, we usually give them the volume in the circuit – supposedly no more than a hundred cc's.

6.2 How do I calculate the first hour's removal?

You should get plenty of practice in figuring this out when you get precepted on the machine, but it's the same as any other "run": add up all the "ins" for the hour, and adjust the machine to run even, positive, or negative.

6.3 How do I figure out the calcium drip rate?

This is usually the renal fellow's call. They pretty much use a standard scale, and leave orders for an ionized calcium check before things get going – we're supposed to replace calcium with "x", for a result of "whatever", and repeat if necessary, then start up the drip. This means that if you can reliably assume that you're going to put your system up in an hour or so, you can go ahead and use that order. Just make sure the team knows that you're doing it.

6.4 How long can a system stay up?

There's definitely a voodoo aspect to this. I've seen systems stay up for 3-4 days at a time, which is when IV tubings and things get changed anyway. Other times the systems will crash after an hour or two, usually because the catheter isn't in a good place, or because the system managed to suck in some air during priming. Air in your system equals clotting, by definition, so this kind of priming problem almost guarantees difficulties with the system when it goes up. Citrate systems will often go quite a while, but the bicarb systems can be a real bear to keep going – they clot, crash, and get into trouble more frequently.

6.5 How should I take care of the catheter?

Carefully. They're pretty flexible, so patients can roll around with them in, but the blood won't flow through them rapidly if they kink – always a problem in one way or another. Make sure the connections stay sterile, the site dressing is clean/dry/intact and all that good stuff.

6.6 What about labs when the system is up & running?

Calcium again, obviously – is it obvious by now that the system pulls off tons of small electrolytes? Potassium tends to drop quickly as well – we usually have a PRN order to replace it (no faster than 20meq/hour) to keep the level around 4.0. Some patients need it infusing almost constantly.

Which way is the hematocrit going? PTT? CRRT does something to platelets – sequesters them in the filter, maybe?

7 Problems

7.1 Why would the machine "go down"?

Usually there is a kink somewhere, probably the catheter, or a clot, probably in the venous trap. You want to keep an eye on the trap – give the machine a 200cc NS flush to get a look if you can't see clearly. (And remember that that bolus does go into the patient.) A growing clot may suddenly just drop to the bottom of the trap and occlude the line. If you're lucky, it won't be completely blocked, and you'll be able to give the patient her blood back from the system – if not, she may need a packed red cell transfusion.

7.2 Are there ways that can be prevented?

Keeping the system nicely anticoagulated is the whole key, along with keeping the catheter flows nice and smooth. Kinky catheter flows are apparently hemolytic, and the debris forms clots in the system, not to mention destroying lots of your patient's red cells.

7.3 What if I can't figure out what's wrong?

Other CRRT systems in general are fussy, unpredictable beasts. Not the Omni-DL, though. Did the patient cough, briefly drive up the arterial pressure and get the arterial transducer wet? Did just enough air get into the system somewhere to set off the air detector, even though you might not be able to see it in the line? Arrggh! This is one of those situations where two heads are definitely better than one (or half of one in my case) – you'll see the senior nurses rending their garments and calling each other for help sometimes.

7.4 Where are the clots likely to form in the circuit?

The arterial and venous traps are the most visible places, but actually the filter is the place where I understand most of the clotting problems go on – all those little tubes, y'know. Sometimes you can look at the ends of the filter and see some clots forming there – gives you a clue as to what's going on in the filter as a whole. What will the transmembrane pressure be doing?

7.5 What does it mean if the arterial pressure starts getting low?

"Low"? You mean: "more lower than before", which is to say, "a greater negative pressure"? Or "not quite as low as it was before", meaning "higher towards zero", and therefore "less"? Ack!

If the arterial pressure zips downwards towards -100, the machine is pulling too hard; it's having to work too hard to pull blood out of the patient, and it'll stop and alarm. The catheter may be kinked – did you turn the patient over in bed? Did he flex his leg? Or maybe you need to switch ports. If a clot is growing in the trap filter – you may need to plan for a tubing change.

Let's summarize a "low arterial pressure" alarm:

1. Blockage of arterial blood flow from the vascular access
2. Compression or kinking of the arterial bloodline
3. Wrong position/Poorly working vascular catheter
4. Blood pump set at a rate higher than the vascular access can supply
5. Hypotension
6. Vasoconstriction - tightening of the patient's blood vessels

7.6 What if the arterial pressure gets high?

You have the following possibilities:

1. A bloodline separation
2. A leak between the patient and the monitoring site
3. A decrease in blood pump speed
4. Infusion of saline or medications

7.7 What if the venous pressure starts getting high?

This means the machine is pushing too hard – remember? But the transducer isn't looking directly at the catheter lumen that goes back into the patient – it's actually looking at the pressure in the venous trap. If the flow through the trap and it's filter is smooth and quick, then the pressure will be in a nice range. If the catheter kinks anywhere along the venous line, the machine will have to push harder to get the blood to move – the pressure will rise.

To summarize, the following conditions can cause a high venous pressure alarm:

1. A blockage in the blood tubing between the monitoring site and the venous port of the catheter
2. Poor position of the catheter
3. Clotting access

7.8 What causes a low venous pressure alarm?

1. Separation of blood tubing from the venous port of the catheter
2. Drop in blood flow rate
3. Blockage in the blood tubing before the monitoring site
4. A severely clotted dialyzer

7.9 What if the blood backs into one of the transducers?

If a patient coughs, bears down, Valsalvas, or other wise briefly hypertenses, the pressure going into the arterial side of the system will rise as the patient's does, and it may back up into the arterial transducer. The machine will stop, but it's an easy fix: take a 10cc syringe (use a new one every time), take off the wet transducer, push the blood column back down, screw on a new transducer, plug it back in, and off you go. The trick is learning to see it happen.

The venous transducer can do the same thing, but it usually means that things may be clotting up in the venous trap. Be careful pushing the blood back down in the transducer tubing – you may dislodge a big clot and get into serious problems – although if this is happening with any frequency, it's sort of your clue that a crash may be coming.

7.10 Could something be wrong with the catheter?

Besides being kinked? The ports might need switching. Sometimes the site is just no good – if a patient is heavy the catheter may stay bent, and you may just have to struggle along until the docs are convinced that they have to try another site. Sometimes several sites.

7.11 What if the TMP is getting high?

The filter is probably getting clotted up. This means that you may not be able to get good amounts of ultrafiltrate out of it – time to change the setup.

7.12 What is the air detector stops the machine?

Air get into the line somewhere? The detector is pretty sensitive, so that even if there's only "micro" air in the line it will shut down the pump. There's

a procedure for pulling back on a syringe attached to the venous trap, while running the pump at slow speed, but you need to get someone to do this with you about 300 times before you're comfortable with it. The first 290 are the hardest...

7.13 What is the blood leak detector goes off?

This one looks at the ultrafiltrate – blood here means that some of the little tubules in the filter have ruptured. Not good – time to change the blood path and filter. How high was the TMP, anyway?

7.14 When should I take the system down?

If you see big clots forming in the traps or on the ends of the filter, that would be a clue. A really high and rising TMP would be another one.

7.15 What should I do if the system is about to crash?

Besides praying to God, you mean. Get your catheter flushes ready: two 10cc syringes of NS, and two of whatever catheter flush your patient needs: either heparin or ACD solution. If it looks like an imminent crash, slow the pump rate down, give the patient her blood back, and go ahead and take it down.

7.16 Could something on the machine pop and spray?

I don't think this has happened lately – I haven't heard of it, although if the TMP pressures were high enough I guess it could. Unpleasant idea – who thinks up these questions, anyhow?

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