Technician Study Review
Part one

Jim Curtis, CHT

Scientific Principles Related to Dialysis

SOLUTION

- A solution is a combination of a solvent and a solute.
- The solute is any substance that can be dissolved into the fluid solvent.
- An example of this would be salt water, where water is the solvent, and salt is the solute.

BLOOD

- Blood is simply a solution, with water as the solvent, and many, many solutes including electrolytes and glucose.
- Blood also has many suspended particles such as red and white blood cells.
- In order to apply these scientific principles to treat our patients we must expose their blood solution to the dialysate solution by putting a semi-permeable membrane between them

DIALYSATE

- A solution that uses water as the solvent, and the solutes are electrolytes and glucose. The electrolytes (potassium, calcium, sodium, magnesium, chloride) are in concentrations similar to that found in a patient’s blood.
- We can manipulate a patient's electrolyte level by what we put into the dialysate.

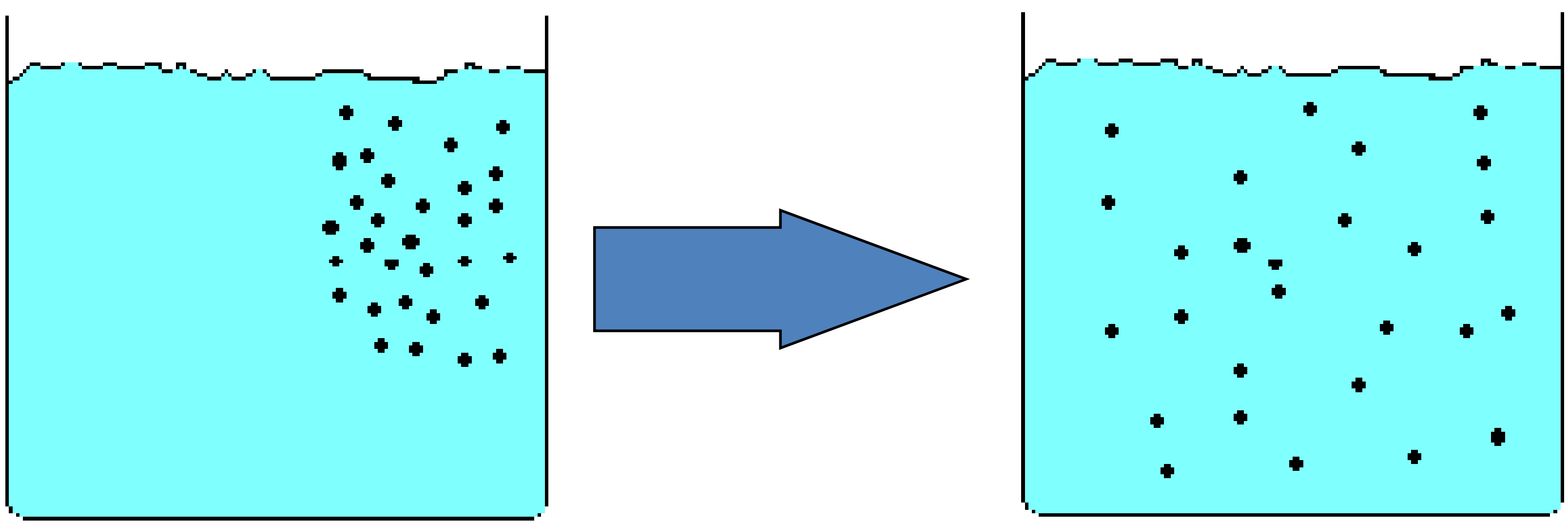
SEMIPERMEABLE MEMBRANE

- A semipermeable membrane is a barrier that will allow certain size particles to pass through it, but not larger ones.
- One common example of this would be a household colander.
- Dialyzer membranes have smaller poor sizes, less than 100 Angstrom units

DIFFUSION

- Diffusion is the process by which molecules or similar particles move spontaneously from a region where they are present at a relatively high concentration into regions of lower concentration.
- The process does not depend on stirring or other mechanical stress

Diffusion



Factors Affecting Diffusion

- Solution Characteristics
  - Concentration Gradient
  - Molecular weight
  - Temperature
- Membrane Characteristics
  - Membrane Permeability
  - Surface Area
  - Flow Geometry

Concentration Gradient

- The more different the concentrations are on two sides of a membrane, the more solute movement there will be. (Fick's Law)
- Solutes move from an area of greater concentration to an area of lower concentration.
- Diffusion stops when the concentrations in a given area are equal.

Molecular Weight (size) of the Solutes

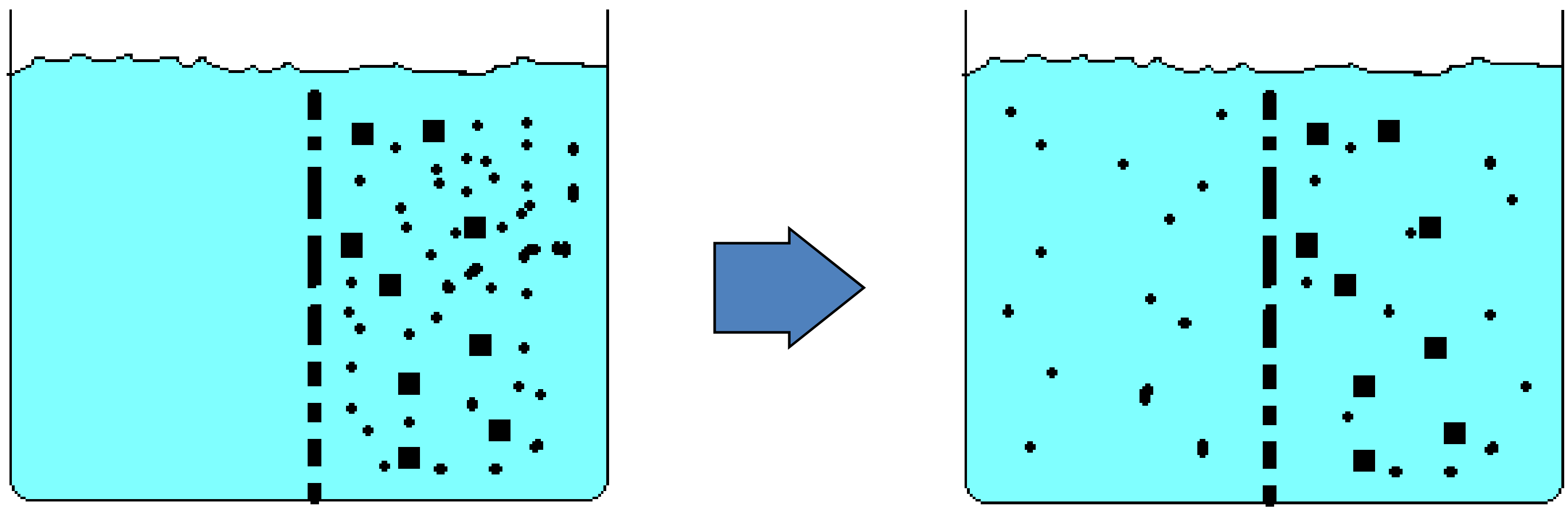
- Solutes with smaller molecular weights diffuse more easily and quickly than larger ones. (Graham's Law)

Temperature

- Warmer temperatures promote faster diffusion.
  - Hot Tea
- Colder temperatures decrease rate of diffusion.
  - Ice

Diffusion across a Semipermeable Membrane

- Only molecules smaller than the pores will pass through



Membrane Permeability

- A membrane with more pores allows faster diffusion
- Larger pores allow larger molecules to pass through the membrane.
- Thickness and design of a membrane also play a role in the rate of diffusion

Surface Area

- Surface area is the amount of membrane in direct contact with blood and dialysate.
- Larger surface areas allow more diffusion.
- Smaller surface area allows less diffusion

Flow Geometry

- In Dialysis, a countercurrent flow of blood to dialysate (blood flows one way while dialysate flows the opposite way) allows the fastest diffusion, because fresh dialysate is always in contact with blood.

Diffusion in Dialysis

- The hollow fiber in the dialyzer is a semi-permeable membrane.
- Blood passes through the inside, and the fiber is surrounded by the dialysate solution.
- Molecules will pass back and forth between the blood and dialysate.
- They will always move from an area of higher concentration to an area of lower concentration.

Diffusion in the Dialyzer

- Waste products in the patient's blood stream will diffuse across the membrane into the dialysate.
- The dialysate will then be sent to the drain, and fresh dialysate will flow into the dialyzer to maintain a high concentration gradient so that we can remove as much waste products as possible.

Diffusion in The Dialyzer 2

- Electrolyte balance is also maintained by diffusion.
- To control their concentrations, we add electrolytes to the dialysate solution.
- These molecules will equilibrate at a level half way between the concentrations in the blood and the dialysate.

Diffusion in the Dialyzer 3

- The concentration gradient between the blood and dialysate is kept as high as possible by having the blood and dialysate flow in opposite directions (counter-current flow). If the fluids moved in the same direction (con-current flow), the solutes equilibrate quickly, and then just flow through the rest of the dialyzer together.

Diffusion in the Patient

- We change the chemical concentrations of the blood in the dialyzer.
- That blood then returns to the patient's body, where it slowly begins to dilute the rest of the blood.
- The concentration of solutes drops in the patient’s vascular system, Creating a concentration gradient between the blood in the veins and the blood within cells.

Diffusion in the Patient 2

- These cells have their own membranes
- Solutes will pass through them into the vascular system
- Where they will eventually end up in blood that passes through the dialyzer.
- This process continues through the length of the dialysis treatment

FILTRATION AND ULTRAFILTRATION

- Filtration is the removal of particles in a solution by mechanical means. It is generally accomplished by forcing the solution through a filter, and any matter that is too large to pass through is trapped or rejected by the filter.
- Ultrafiltration refers to filtration of very small particles, even as small as large molecules

Ultrafiltration in Dialysis

- Water is taken out of the patients blood by ultrafiltration.
- The removal of water is also assisted by the addition of glucose to the dialysate.

Ultrafiltration in Dialysis 2

- The Dialysis machine creates a hydraulic pressure difference between the solutions in the blood compartment and the dialysate compartment
- The pressure is higher in the blood compartment.
- This pressure is a mechanical force that pushes fluid through the membrane.

Convection

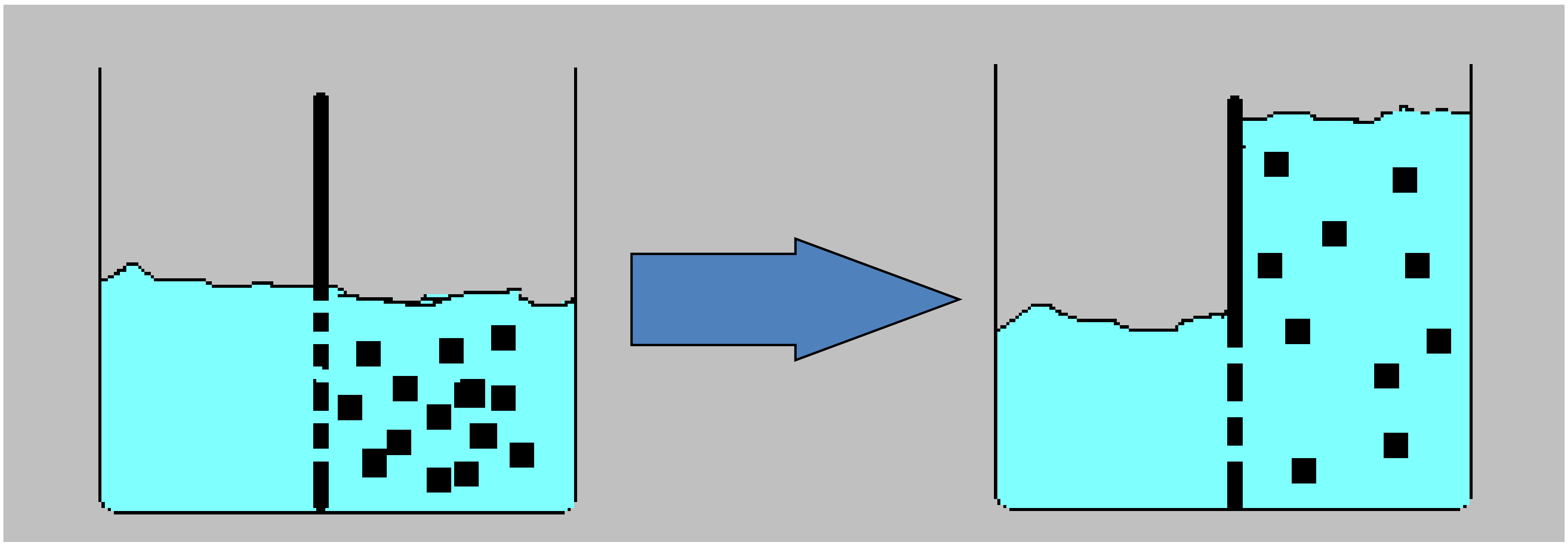
- Anything dissolved in the solution that is smaller than the membrane pores passes through with the water.
- This movement is called “solute drag”.
- Larger solutes and particles will not pass through.

OSMOSIS

- Osmosis is the process by which a liquid passes through a semipermeable membrane from an area of low solute concentration to a higher concentration.
- It is similar to diffusion, except the molecules are too large to pass through the semi-permeable membrane, so fluid is drawn across the membrane, diluting the solution, and achieving equilibrium.

OSMOSIS

The effect of Osmotic Pressure (osmolality)

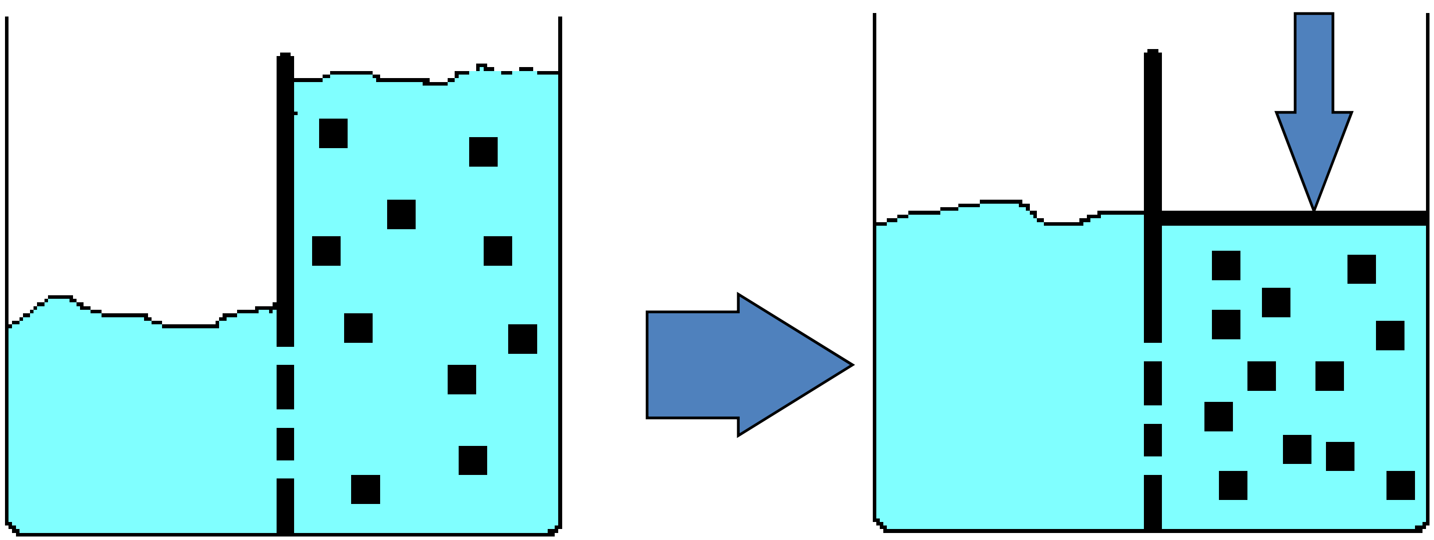


Osmosis

- Hydraulic pressure can overcome osmotic pressure
- If you increased the hydraulic pressure on the solution side of the container, you could overcome the osmotic pressure, and cause the water to move from the concentrated solution back into the pure water side. (Reverse Osmosis)

Reverse Osmosis

Hydraulic Pressure overcoming the effect of Osmotic Pressure



Important terms relating to osmosis

- Hypertonic
  - a more concentrated solution with a relatively higher osmolality
- Hypotonic
  - a less concentrated solution with a relatively lower osmolality
- Isotonic
  - a solution with an equal osmolality.
- In Dialysis these terms are used when comparing a solution relative to blood

Osmosis in Dialysis

- Osmosis plays another important role in fluid removal. Consider what happens within the body when a patient is being dialyzed. Due to diffusion, the chemical concentration in the blood can be lower than the concentration in the cells. Due to ultrafiltration, fluid is being removed from the vascular system.

Osmosis in Dialysis

- The higher osmolality of the blood in the cells will tend to pull fluid out of the vascular system at the same time that the dialyzer is pulling it off.
- Since only a small percentage of the body’s fluid is in the vascular system, it becomes depleted and the patient's blood pressure drops

Osmosis in Dialysis

- To help with fluid removal we increase the osmolality of the dialysate by adding more sodium.
- This sodium diffuses into the blood, and causes a higher osmolality.
- This maintains the volume in the vascular space, and the patient's blood pressure is kept stable.

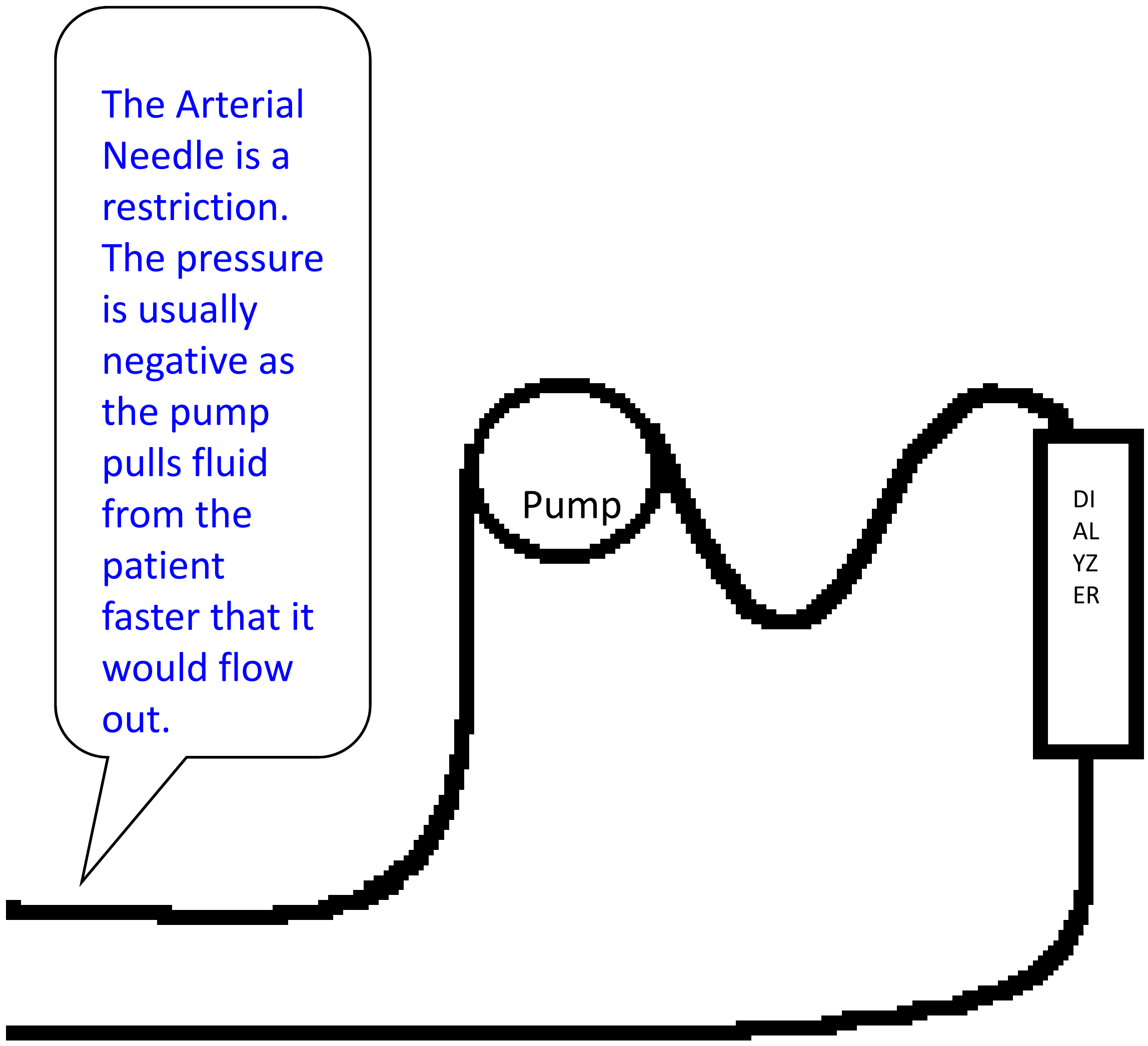
FLUID DYNAMICS

- Fluid is a substance (liquid or gas) which changes shape at a steady rate when acted upon by a force.
- Dynamics deals with the motion and equilibrium of systems.
- The movement of fluid through tubing (flow) is subjected to physical forces.
- The flow rate of a fluid is the amount of fluid that flows through the tubing over a specified period of time.
- The flow velocity is the speed the fluid moves through a specified length of tubing.

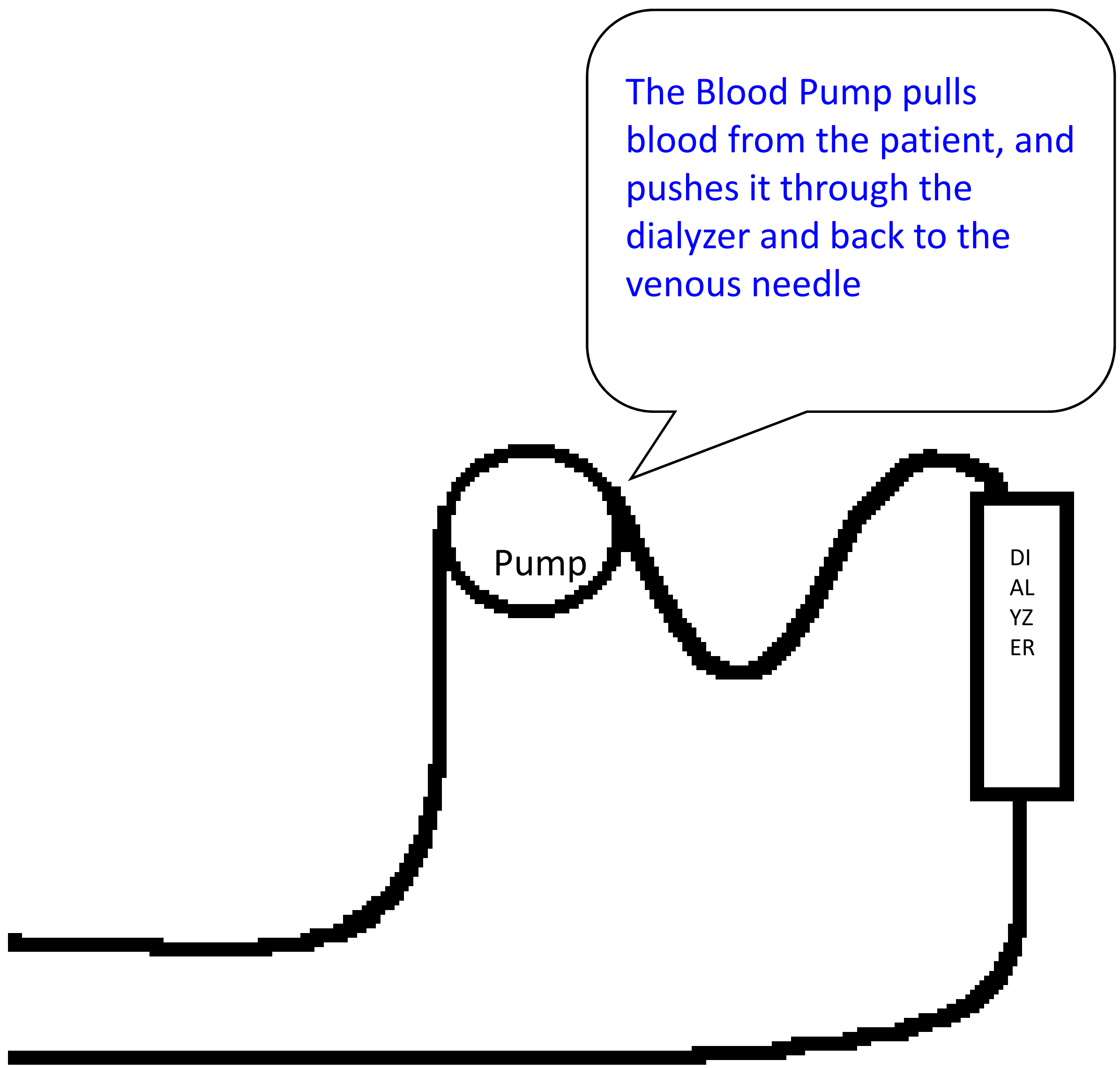
Resistance and Pressure

- There is always some resistance to the flow of fluid through a tubing due to simple friction, but the resistance will greatly increase when you cause a restriction.
- The pressure in any fluid system will always be a function of flow and resistance. The greater the flow and the greater the resistance, the greater the pressure

Fluid Dynamics in the Blood Circuit



Fluid Dynamics in the Blood Circuit



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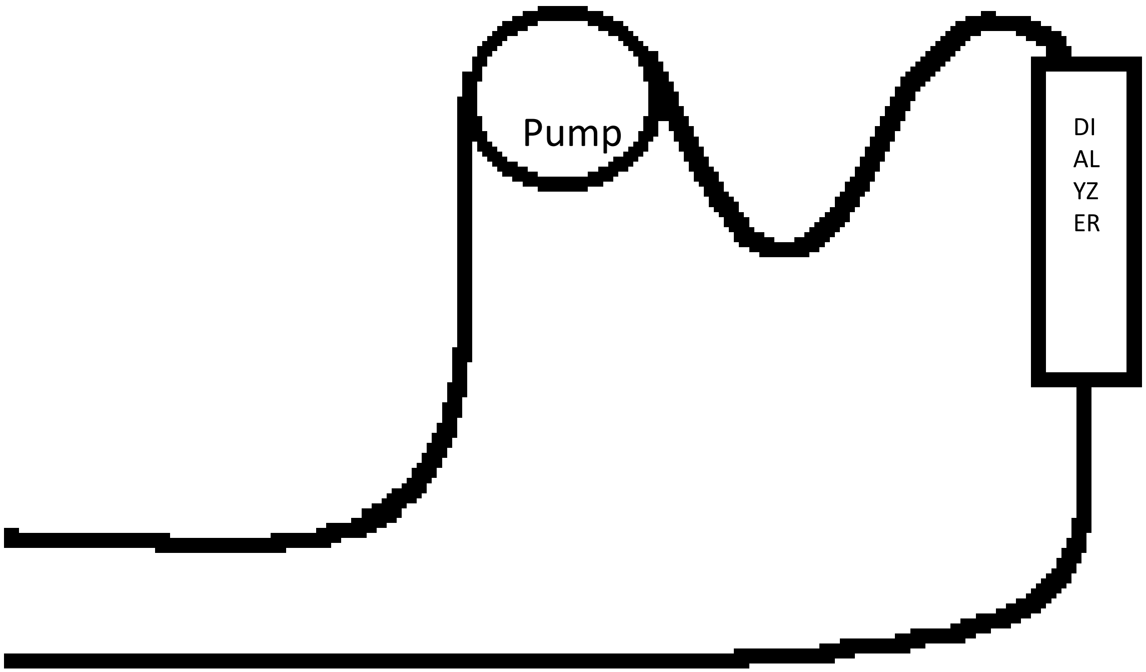
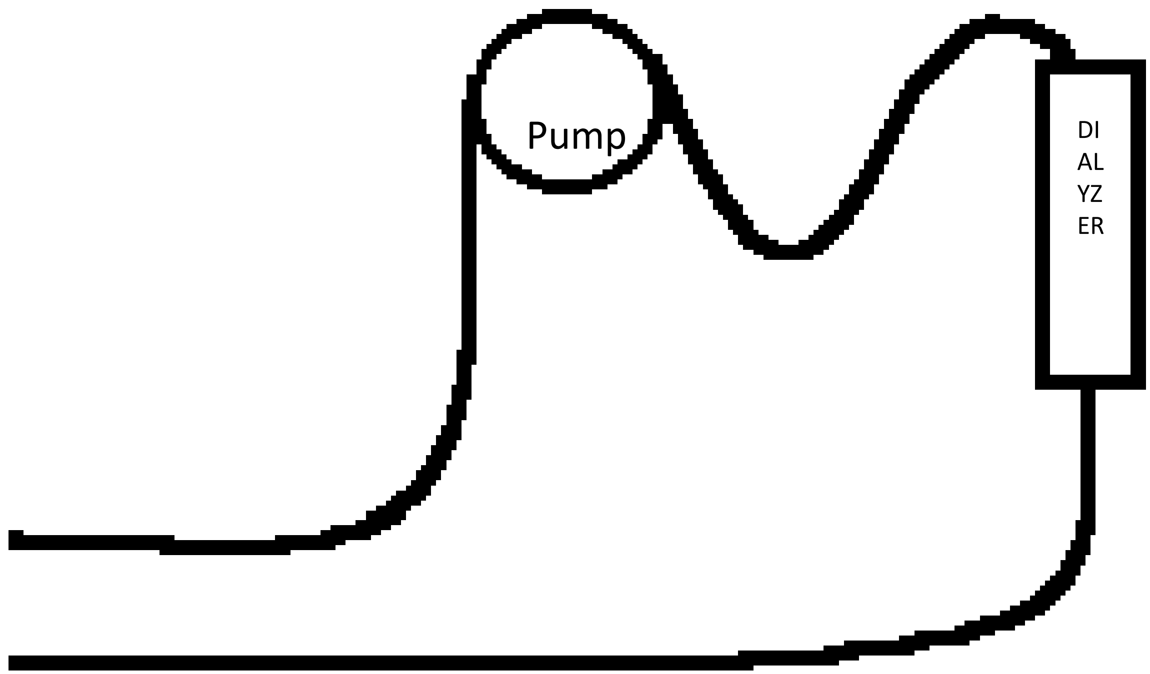


The Dialyzer also acts as a restriction on the Blood. The fluid looses pressure due to friction as it passes through the thousands of tiny hollow fibers

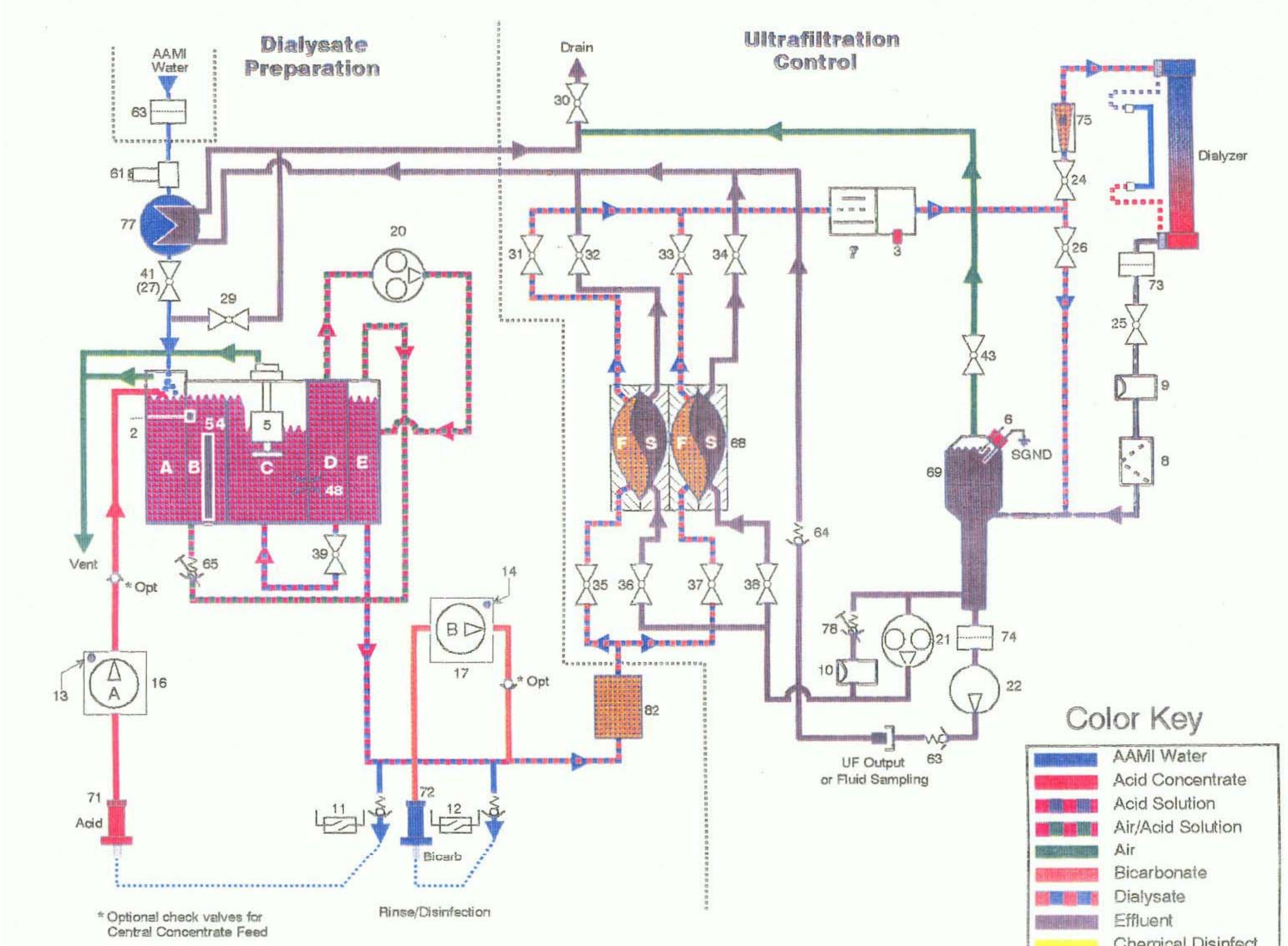
Fluid Dynamics in the Blood Circuit



The venous needle is the final restriction in the system, and determines what the minimum pressure in the dialyzer will be

Dialysis Devices

Jim Curtis, CHT



Fresenius 2008H Hydraulic Flow Diagram

Concentrate proportioning

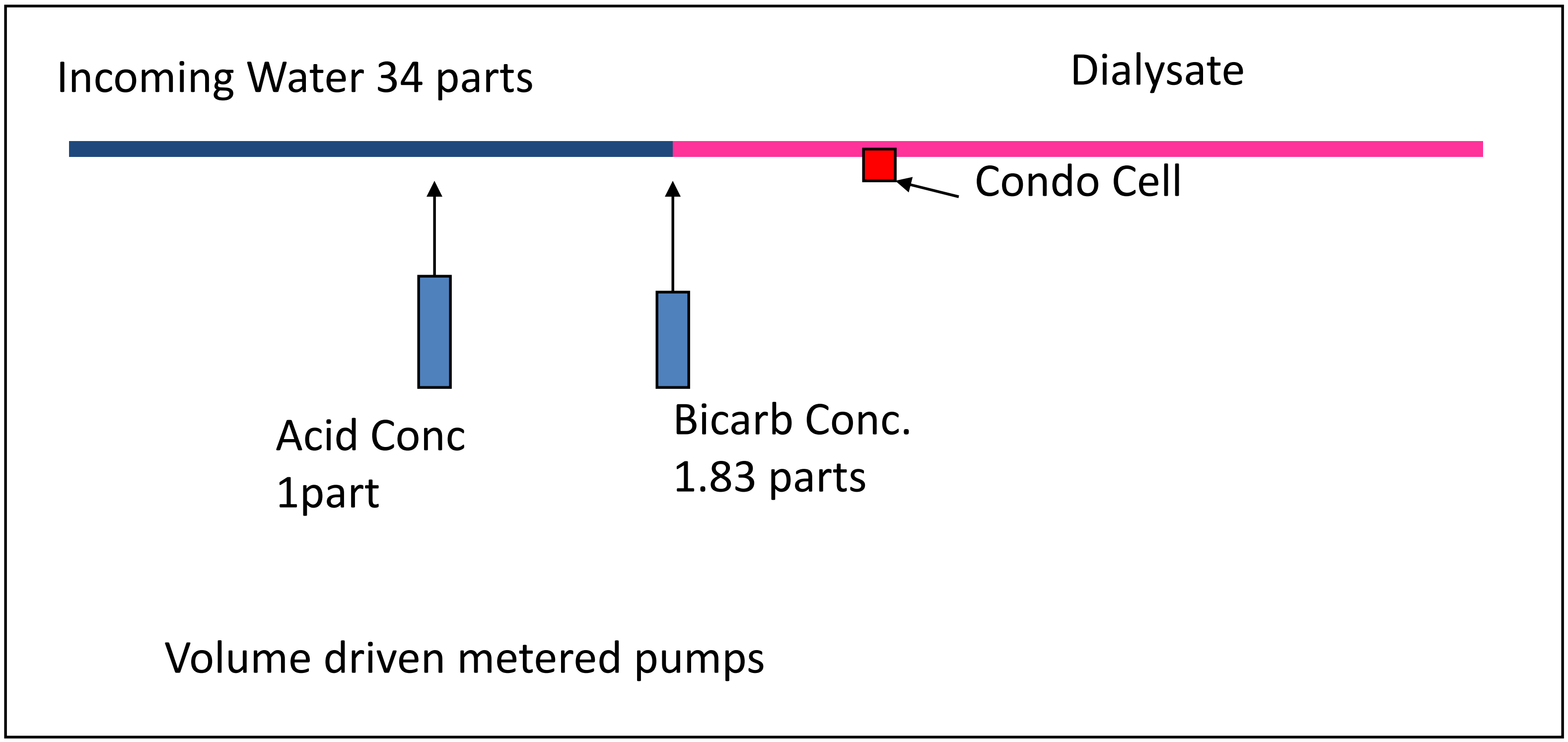
- Volumetric proportion
  - in volumetric proportioning, all three streams are calibrated to deliver a fixed volume

Concentrate proportioning

- Servo controlled proportioning.
  - a servo feedback control system compares the conductivity measured by the acid/acetate or bicarbonate control conductivity cell with the value selected by the operator

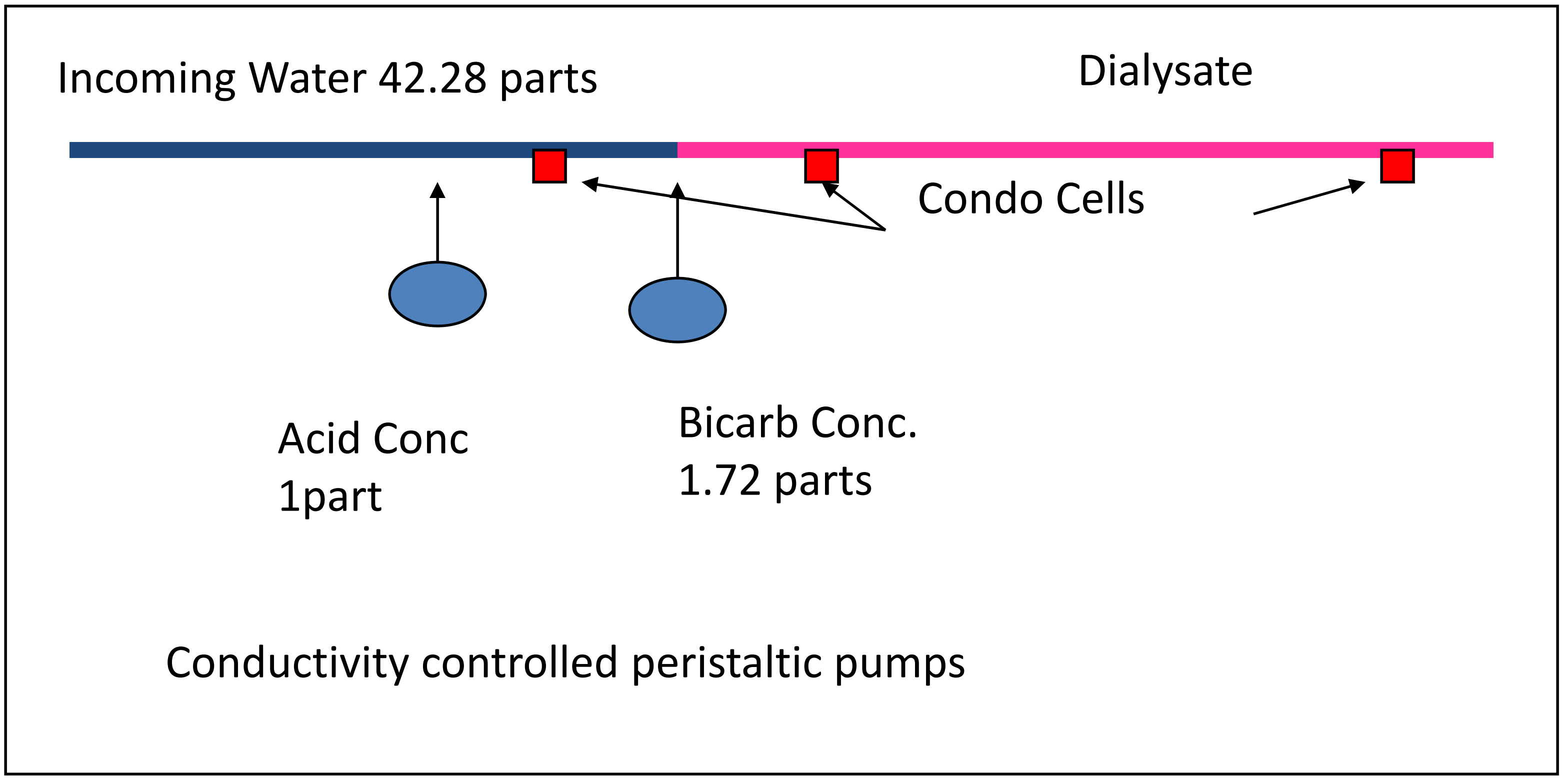
Volumetric Proportioning

- Drake Style Concentrate



Servo Proportioning

- Cobe Style Concentrate



Proportioning Ratios

- 35X (Fresenius Style)
  - 1:1.225:32.775
- 36.83X (Drake Style)
  - 1:1.83:34
- 45X (Cobe Style)
  - 1:1.72:42.28

Bicarbonate Dialysis

- requires two concentrates since concentrated calcium and bicarbonate will produce a precipitate.
  - some systems use dry bicarbonate alone (Cobe and Fresenius Style),
  - other systems use concentrates that are bicarbonate mixed with sodium chloride (Drake Style).

Bicarbonate Dialysis 2

- mismatch of the different types of concentrates available can yield a expected conductivity.
- reliance solely on the conductivity to ensure safety is cautioned, all relevant factors should be considered (including pH).

AAMI standard A3.1.1

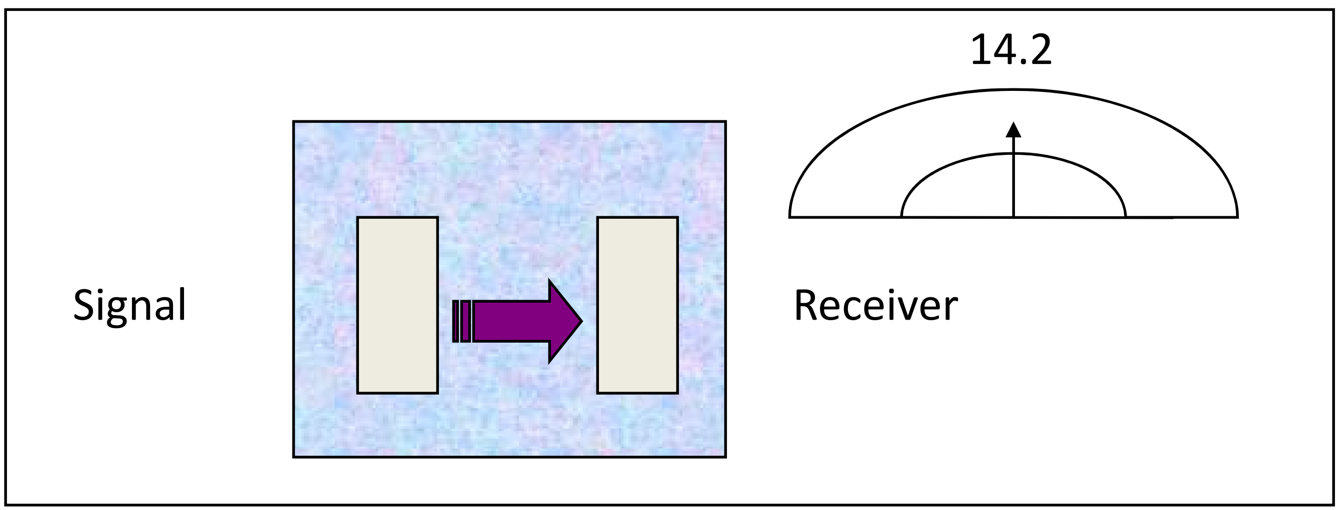
- “Recognition and application of appropriate concentrates to produce the desired dialysate is the responsibility of the operator.”
  - alarm set points shall be set at $\pm$ 5 percent from the nominal value of the particular dialysate in use and shall activate a visual and an audible alarm.

AAMI standard A3.1.1 (2)

– a volumetric proportioning system must have an on-line conductivity monitor downstream of the mixing point.
– systems for dual proportioning to produce bicarbonate dialysate using conductivity servo control shall have separate on-line conductivity cells to control and monitor each proportioning system.

Conductivity Measurement

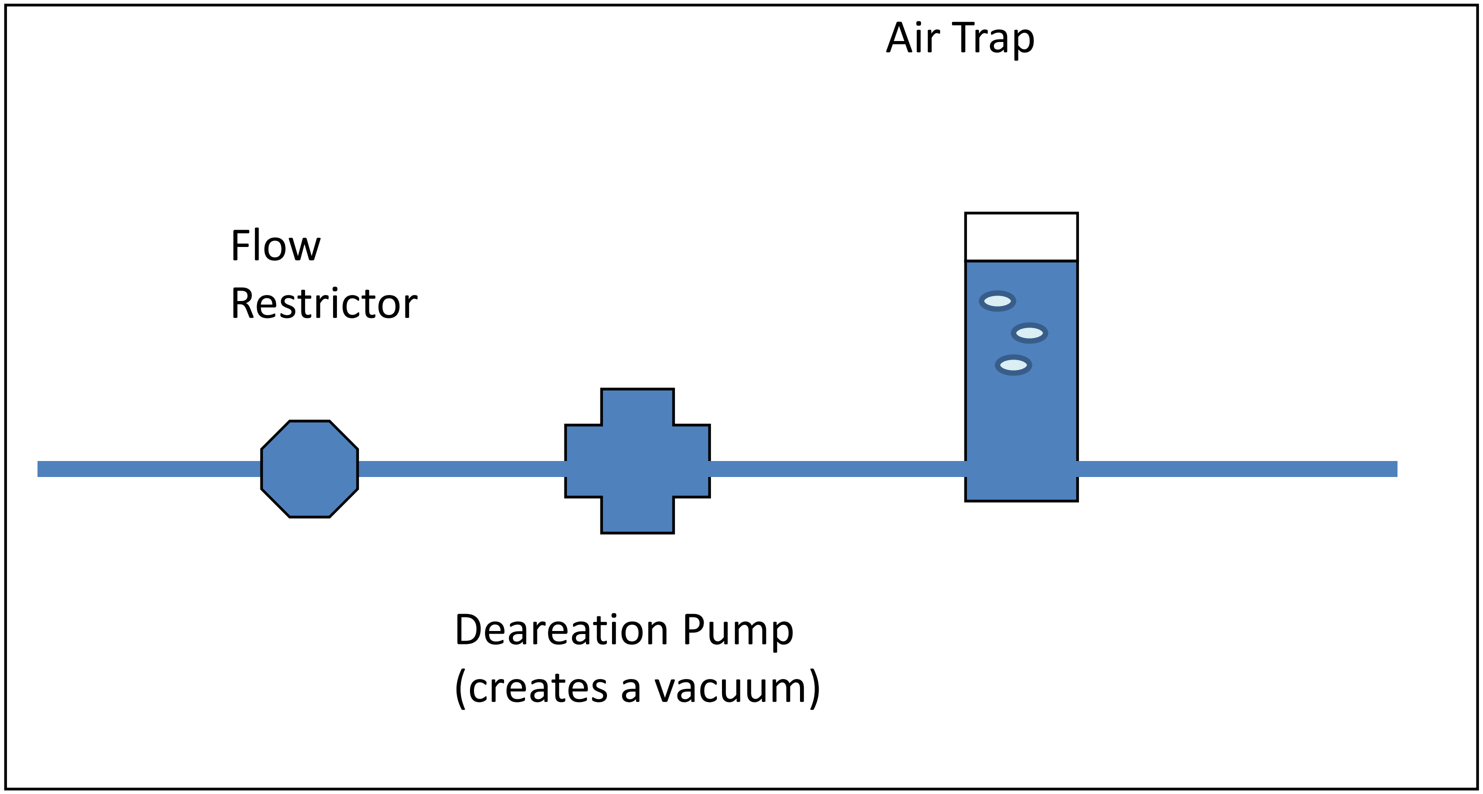
- An electrical current is sent from one probe to another. The more dissolved electrolytes, the more electricity will pass (the higher the conductivity)



Deareation Device

- Should remove all entrained air
- Dissolved air in the dialysate circuit may adversely affect the dialysis system monitors, hemodialyzer efficiency, ultrafiltration control, and patient safety.
- Air may cross the membrane and create foam in the blood compartment.

Deaeration Device



Temperature control

- Maintains the dialysate within the physiological range.
- a temperature greater than 42 degrees Centigrade denatures protein and results in hemolysis
- a temperature less than 35 degrees Centigrade may produce chilling and hypothermia

Temperature control

- A visual and an audible response is required for a temperature alarm.
- Dialysate flow will be diverted from the dialyzer during a temperature alarm.

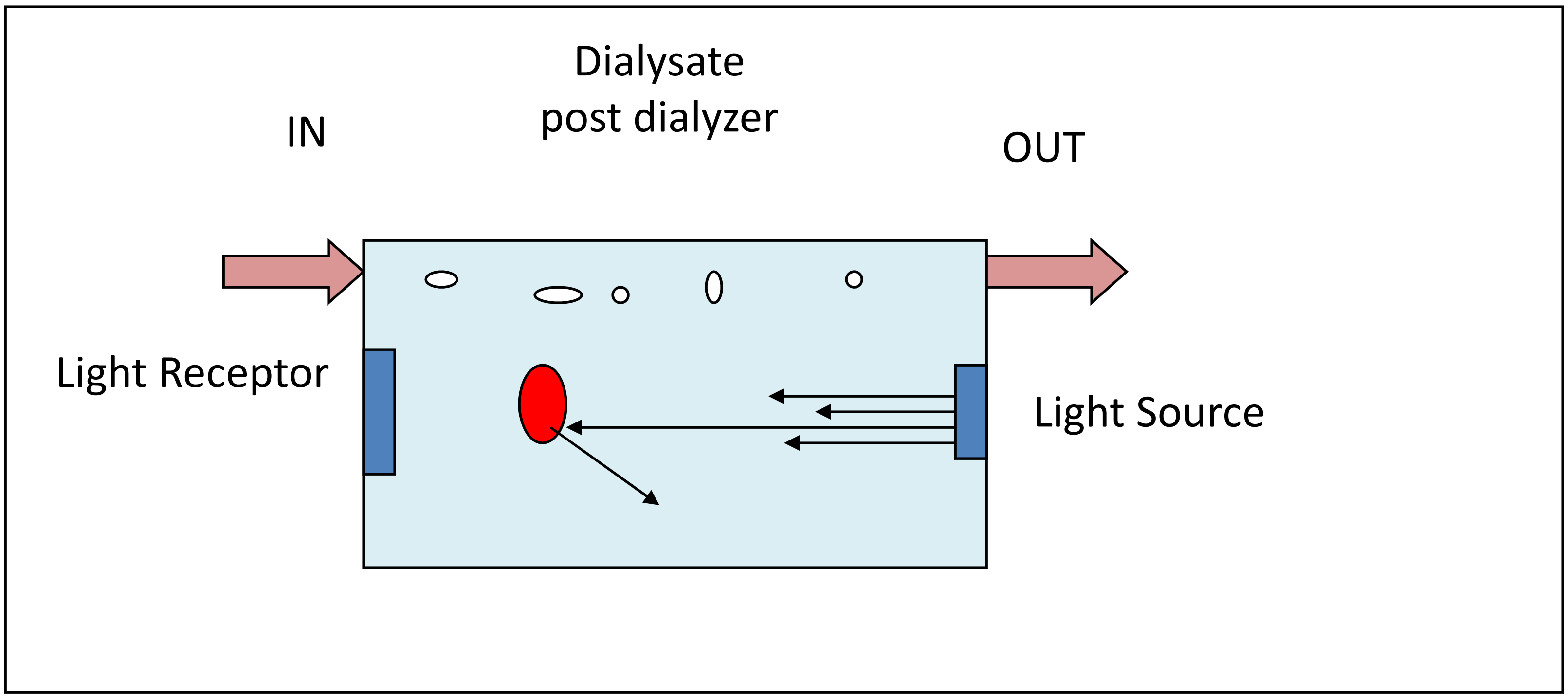
Blood Leak Detector

- designed to monitor the occurrence of a rupture in the membrane of a dialyzer
- detects changes in optical density in dialysate downstream of the dialyzer.
- emits an infrared light beam across an optical path through the dialysate onto a receiver opposite the light source.

Blood Leak Detector

- Blood entering the optical path would decrease the intensity of the light and signal a change in density of the dialysate.
- The change in density activates the alarm sequence.
  - The sensitivity of the blood leak alarm system is 0.35 ml/L

Blood Leak Detector



Blood Leak Detector

- The blood pump should stop automatically for a blood leak alarm.
- Blood-side pressure should never be less than dialysate-side pressure.
- Ultrafiltration should be minimized automatically or manually to decrease the loss of blood.

Bypass Valve

- Interrupts the flow of dialysate to the dialyzer during an improper dialysate condition.
- Dialysate flow will be automatically diverted from the dialyzer to the drain during a dialysate alarm condition.

Bypass Valve

- An audible and visual alarm response will be evident during a bypass condition.

Bypass function

- Dialysate temperature above 42 degrees Centigrade will cause hemolysis.
- Temperature limits are usually set at 35 degrees Centigrade for the low limit and 39 degrees Centigrade for the high limit.

Bypass function

- A dialysate conductivity varying more than $\pm$ 5 percent from the nominal value of the concentration in use shall cause a dialysate alarm.

Ultrafiltration Control

- Fluid removal is dependent upon the transmembrane pressures created by the differential between the blood-side and dialysate-side pressures.
  - TPM UF Control (Cannot use hi flux or hi efficiency dialyzers)
  - Volumetric UF Control
  - Flow-metric UF Control

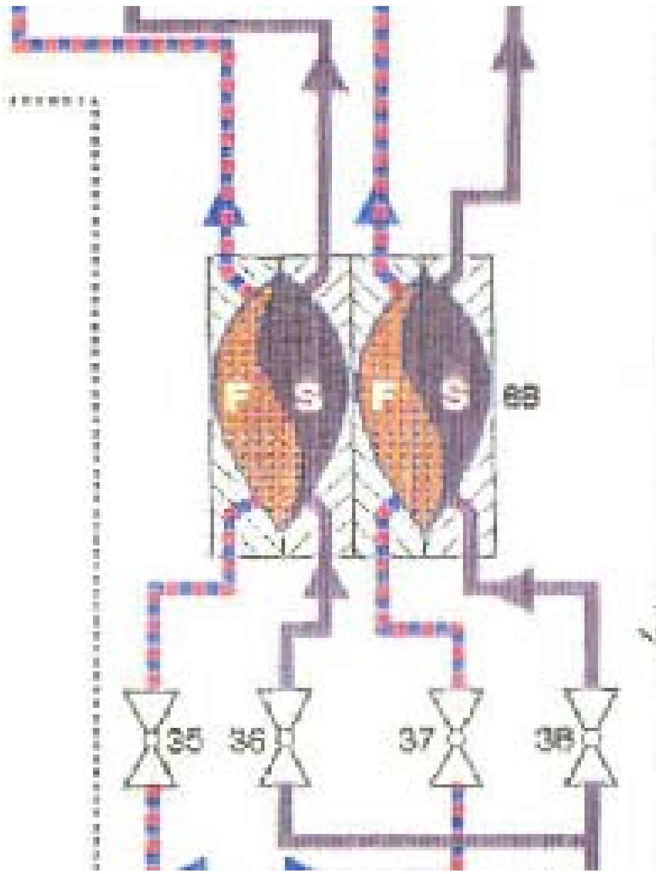
TMP Ultrafiltration Control

- The blood side pressure is dependent on the blood pump rate, the gauge of the fistula needle in use and the adequacy of the access flow.
- The dialysate-side pressure is regulated by an adjustable restrictive valve located upstream of the dialyzer.

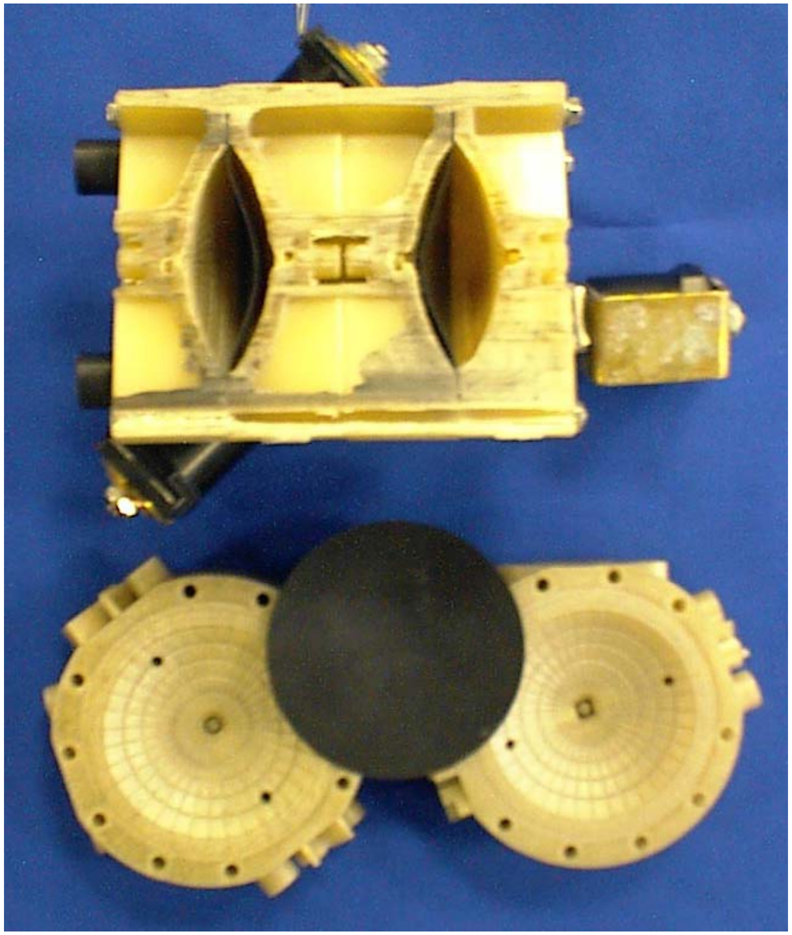
Volumetric UF controlled

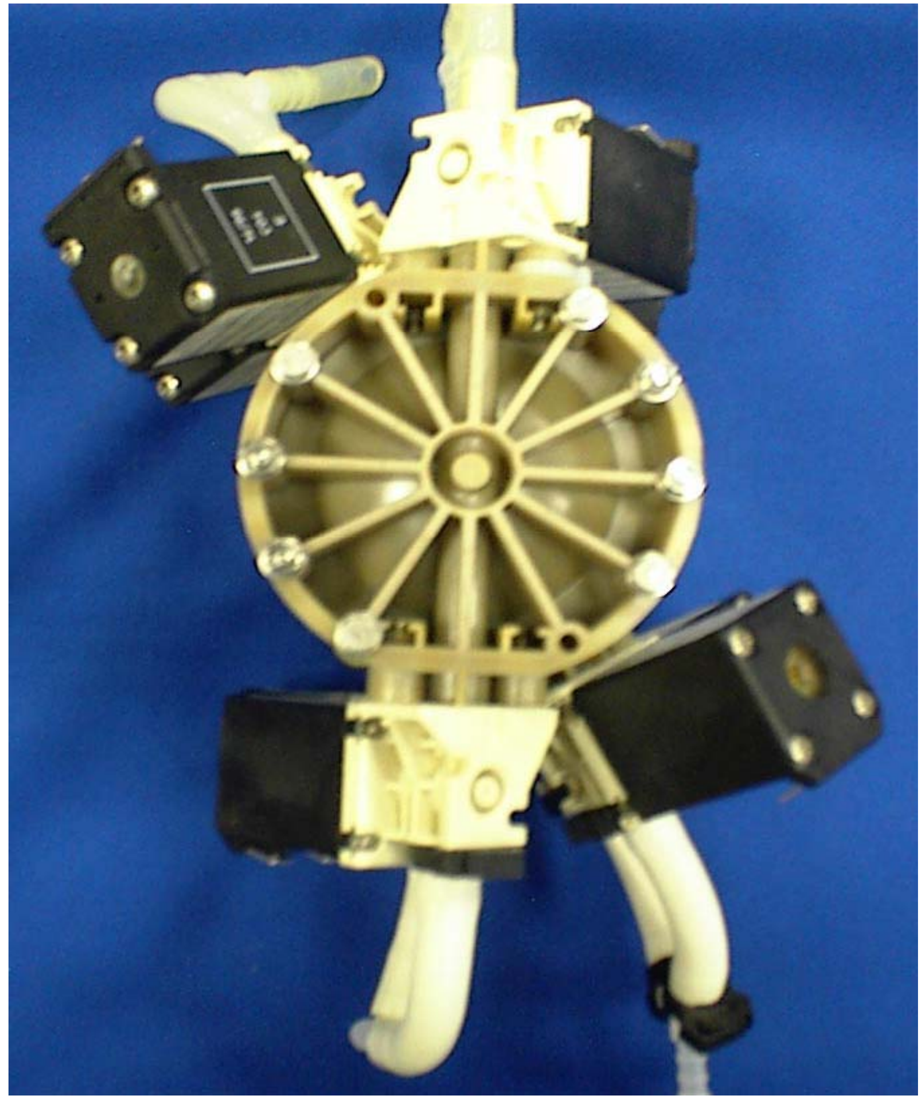
- Machine utilizes a balancing chamber system. The balance chamber assures that equal amounts of fluid enter and exit the dialyzer.
- The chamber is divided into two equal chambers, with each chamber divided by an elastic membrane.

Balancing Chamber



Balancing Chamber

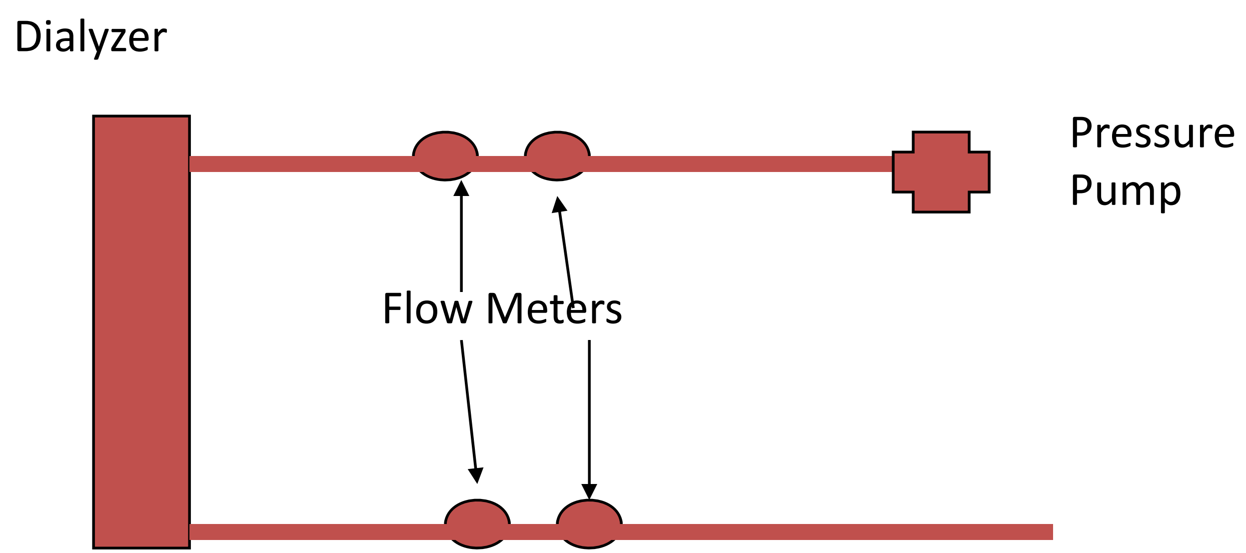




Flow-metric control ultrafiltration

- Uses flow measuring devices that are in line before and after the dialyzer.
- The ultrafiltration is measures by the difference between the flow rate into the dialyzer and the flow rate out of the dialyzer.
- A microprocessor adjusts the TMP to achieve the desired ultrafiltration rate.

Flow-metric UF Controller



•Extracorporeal Circuit

- Blood Pump
  - Peristaltic pump controls blood flow rate
- Pressure Alarms
  - Arterial and Venous
  - Monitors pressure and alarms when parameters violated
  - Stops blood pump

•Extracorporeal Circuit 2

- Air in blood detector
  - Ultrasonic devices senses air in blood
  - Stops blood pump, clamp line clamp
- Venous Line Clamp
  - Mechanically stops flow of blood through tubing

Gadgets and Gizmos

- Profiling--ultrafiltration
- Profiling--sodium
- Profiling--bicarbonate
- Clearance testing during the run (conductive)

Gadgets and Gizmos 2

- Recirculation measurement
  - saline, temperature, ultrasound, hematocrit
- Blood temperature monitoring
- Push button sodium bolus delivery
- Blood / Saline Sensor
- Ultra-filters

Gadgets and Gizmos 3

- Blood volume monitoring
- Automatic Disinfection and Rinse
- Automated blood pressure monitoring
- Patient specific prescription cartridge

Dialyzers and Dialysis Adequacy

"The dialyzer is where the tire meets the road"... Peter Lepanto

DIALYZER CHARACTERISTICS

- Membrane Material
  - Biocompatibility
- Solute Removal - Clearance
  - Diffusion
  - Convection
  - Adsorption

Dialyzer Membranes

Cellulose

- Cuprophan
- Cupromonium Rayon
- Hemophan
- Cellulose Acetate
- Cellulose Triacetate

Synthetic

- PAN
- AN 69
- PMMA
- Polysulphone
- Polyflux
- Purema

BIOCOMPATIBILITY

- The choice of membrane material affects how the blood will react when in contact with the membrane

- Reactions to Bioincompatability
- Indicators of Bioincompatability

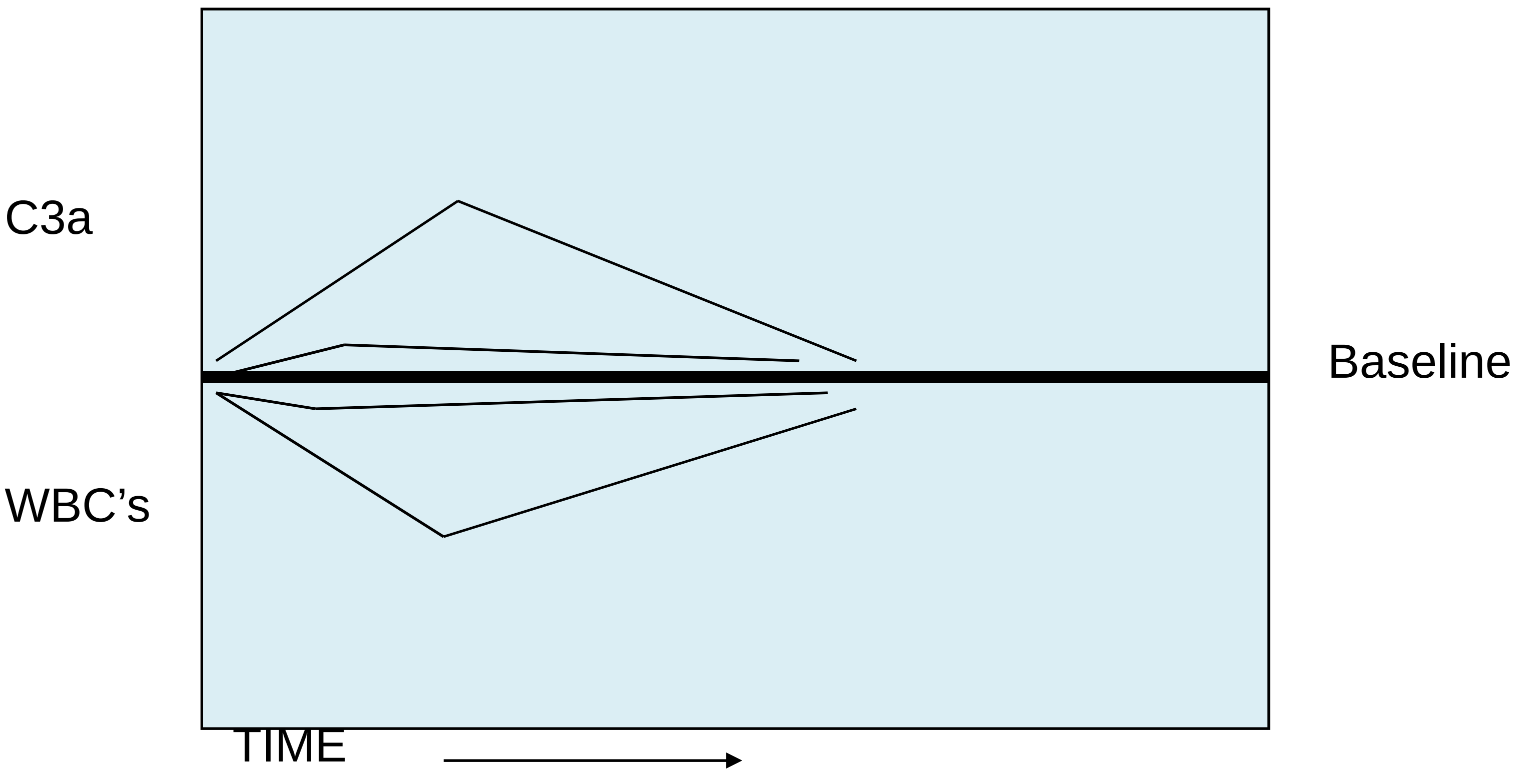
Reactions to Bioincompatability

- Mild / unnoticed
- DAA
- Severe - anaphylactic shock

INDICATORS OF BIOINCOMPATABILITY

- Compliment activation
  - increase in circulating C3a level
  - Decrease in white blood cells
- Hyper coagulation

COMPLIMENT ACTIVATION



SOLUTE REMOVAL

- Diffusion
- Convection
- Adsorption

Dialyzer Clearance

- Clearance (K) specifications for dialyzers indicate the amount of a specific Solute will be “cleared” from the patients blood in a given amount of time
- For example, if the specs say a dialyzer has a clearance of 350 ml/min at a Qb of 400 ml/min, it means that in one minute 350 ml’s of blood will be cleared of urea, and the remaining 50 ml/min will have the same amount of urea that it started with

Solute Removal: Diffusion

- In diffusion, molecules move from an area of high concentration to an area of low concentration. The higher the concentration gradient, the more rapid the diffusion

- Diffusive clearances are dependant upon:
  - blood flow rates
  - dialysate flow rates
  - membrane surface area

Solute Removal: Convection

- Also known as "Solute Drag", molecules move with the fluid as it crosses the membrane.

- Convective clearances are dependant upon:
  - molecular weight cutoff
  - Dialyzer KUF
  - ultrafiltration rate

Solute Removal: Adsorption

- Many molecules, such a proteins, adhere to the wall of the dialyzer membrane. While these substances are removed from the blood, they do not enter the dialysate.

- Removal of solutes by Adsorption is dependant upon:
  - surface area
  - membrane material
  - how much material the membrane has already adsorbed

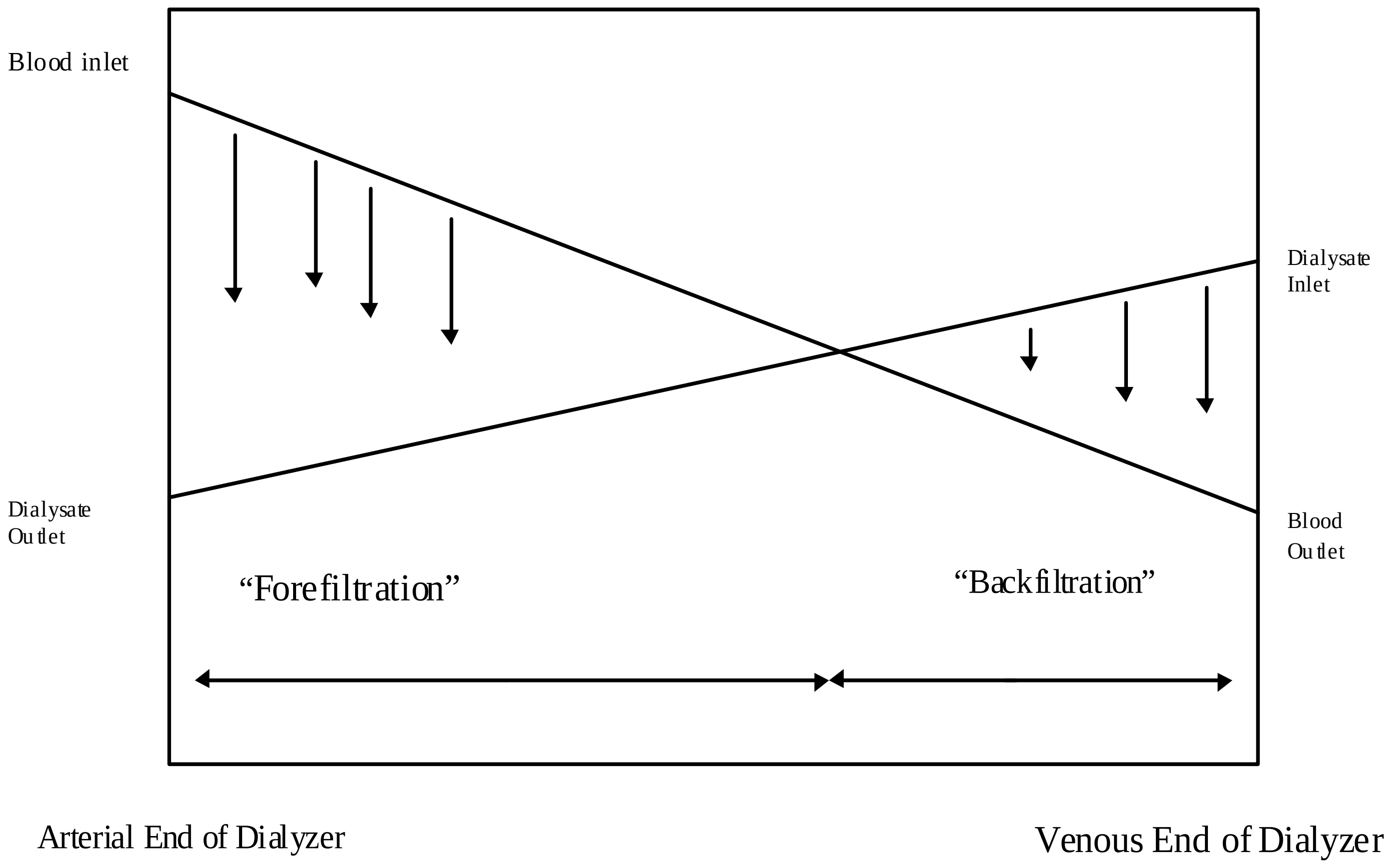
BACK FILTRATION

- Backfiltration is the movement of fluid from the dialysate compartment into the blood compartment of the dialyzer.
- Endotoxin transfer
  - This concern is more theoretical than real
- Convective clearances

Backfiltration: Convective Clearances

- Backfiltration is exactly the mechanism in which dialyzers are able to remove large molecular weight substances during a dialysis treatment. The flow of fluid into the blood compartment on the venous end causes the flow of fluid, and solutes, out on the arterial end. Backfiltration makes convection happen.

Backfiltration



Getting Enough Treatment

How We Measure the Dose of Dialysis

Urea Reduction Rate (URR)

Urea Kinetic Modeling (Kt/V)

Urea Reduction Rate

URR is simply measuring the level of BUN in a patients blood at the beginning of dialysis, and at the end of the treatment, and calculating how much the BUN level was reduced

Factors affecting URR

Dialyzer Clearance

- Dialyzer characteristics
- Blood flow rates

Time on Dialysis

URR Example

Pre Dialysis BUN is 100

Post Dialysis BUN is 35

The Formula is 100*(1-(Post/Pre))

100*(1-(35/100))

=100*(1-(.35))

=100*.65 = 65% URR

What YOU can do to improve your patients URR

- Turn up blood pump speed quickly at the beginning of the treatment
- Give adequate heparin, and report on excessive clotting in the dialyzer
- Be careful when drawing BUN samples

Urea Kinetic Modeling

Urea Kinetic Modeling is a means of measuring the dose of dialysis by multiplying the dialyzer clearance (K) by the time on dialysis (t), and dividing this product by the patients volume (V)

Factors affecting Kt/V

Dialyzer Clearance (K), in ml/min

- Dialyzer characteristics
- Blood flow rates

Time on Dialysis (t), in minutes

The patient's volume (V), in cc's

Kt/V Example #1

Dialyzer provides a clearance of 350 ml/min

Patient runs 3 1/2 hours (210 minutes)

Patients volume is 58 liters (58,000 cc's)

Kt/V = 350*210 / 58,000 = 1.27

Kt/V Example #2

Desired Kt/V is 1.2

Dialyzer clearance is 350 ml/min Patient's volume is 55 liters

What is the required time?

Kt/V = 1.2 = 350*X / 55,000

66,000 = 350*X

189 = X   You need to run 3 hours, 9 minutes