Mini-lecture

Essentials of HD Machine

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Dialysate Circuit Outline

The main components of the dialysate circuit include:

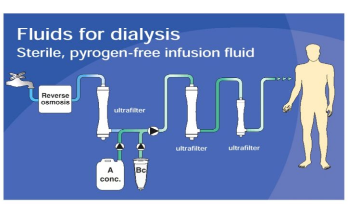
- Deaeration
- Dialysate proportioning and conductivity
- Dialysate formulation
- Monitors, alarms, and conductivity
- Ultrafiltration: Volumetric and flow-sensor control
- Dialysate disinfection and rinsing
- Emergencies

Introduction

- **The process of hemodialysis pumps the patients' blood against dialysate that may be generated by the dialysis machine or at a central location**
- **Dialysis machines are essentially composed of pumps, monitors, and alarms that allow safe proportioning of dialysate**
- **Knowledge of the components of a dialysate circuit are important for patient safety and care**
- **It is important for each nephrologist to become familiar with his/her dialysis machine for patient safety**
- **The blood circuit will not be reviewed here**

Purifying water for hemodialysis

a. water softener
b. carbon adsorption
c. reverse osmosis
d. deionization



DEFINITIONS OF WATER QUALITY FOR HEMODIALYSIS

	Bacteria(cfu/ml)	Endotoxin(EU/ml)
AAMI	200	2
European Pharmacopeia	100	0.25
Ultrapure	0.1	<0.03
Sterile	10^{-6}	<0.03

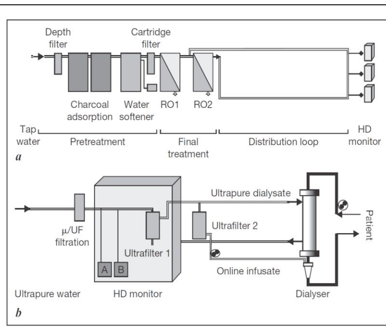


Fig. 1. Water treatment system and dialysis apparatus to obtain fluids for online treatments. ***a*** Water plant with pretreatment and final treatment based on a double RO in series. ***b*** Water from distribution loop enters the dialysis monitor and, after a first ultrafiltration to obtain ultrapure dialysate, is passed through a second ultrafilter to obtain substitution fluid. HD = Haemodialysis; μ/UF filtration = micro- or ultrafiltration.

Cappelli G, et al. Contrib Nephrol 2007; 158

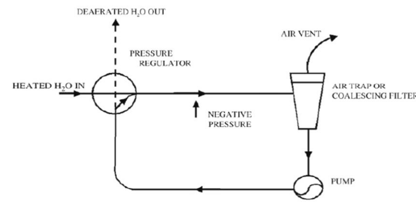
Dialysis Machine Dialysate Circuitry

- **Once pure product water has been generated, bicarbonate and acid solutions are mixed with water to form dialysate solution**
- **Mixing or proportioning may be done by the individual machine or centrally in a dialysis unit**
- **Several components of proportioning ensure safe dialysate that is monitored by a series of alarms, pumps, and monitors**
- **Fluid ultrafiltration occurs by volumetric or flow sensor controllers**
- **Disinfection prevents bacterial overgrowth**

Dialysate Circuit Key Components

- **The key components of the dialysate circuit include:**
  - Heating
  - Deaeration
  - Proportioning
  - Monitoring
  - Ultrafiltration
  - Disinfection

Deaeration



Dialysate Proportioning

- **Proportioning assures proper mixing of heated and treated water to produce the appropriate dialysate solution**
- **Proportioning pumps mix premade fresh dialysate acid (A) and bicarbonate (B) solution**
- **Acid solutions contain acid/chloride salts including sodium, potassium, calcium, magnesium, and acetate**
- **Bicarbonate solutions are made fresh, since pre-prepared bicarbonate can release CO_2 and encourage bacterial growth**

Dialysate Proportioning

- **Dialysate solutions are passed through a small filter prior to and after formation**
- **Potential problems include:**
  - Incorrect bicarbonate or acid concentrate
  - Inadequate dialysate mixing
  - Clogged filters
  - Device alarms disarmed by the operator
  - Precipitation of calcium or bicarbonate salts

Dialysate Formulation

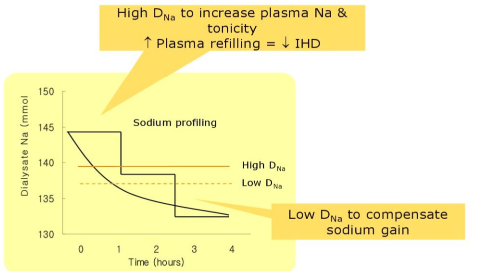
Electrolyte	Concentration
Sodium	134–145meq/L
Potassium	0–4meq/L
Calcium	0.0–3.5meq/L (2.25standard)
Magnesium	0.5–1.0meq/L
Chloride	100–124meq/L
Bicarbonate	32–40meq/L
Glucose	0–250mg/dL

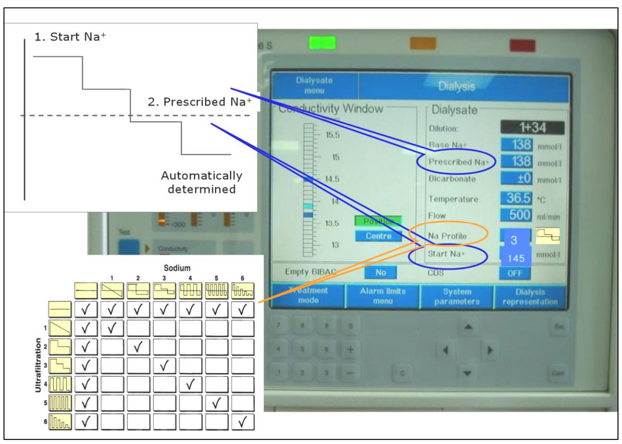
Dialysate Modeling

- **Sodium**
  - Sodium modeling can be used to maintain hemodynamic stability during ultrafiltration. However, some controversy exists regarding its use due to the increased incidence of patient thirst, which may lead to more intradialytic weight gain and fluid retention
  - Sodium modeling programs are available on dialysis machines and allow alteration of sodium concentration over time

Sodium Profiling Hemodialysis

- Time-dependent profile of high ~ low D_{Na}
  : period to maintain plasma tonicity ~ to compensate Na load



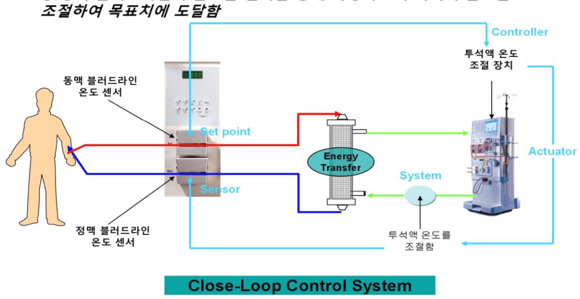


Dialysate Monitoring

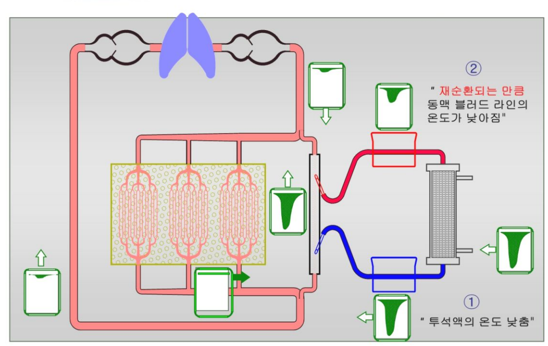
- **pH**
  - The recommended pH range is 6.8–7.6. Not all machines have a monitor, but dialysate pH should be monitored each session
- **Temperature**
  - A heat sensor monitors dialysate temperature near the dialyzer and provides a short feedback loop for changes. Temperature should be between 35° – 42° C
    - Low temperatures can cause shivering
    - High temperatures can cause protein denaturing or hemolysis

Blood Temperature Monitor

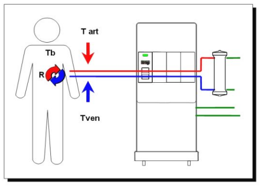
- ***동,정맥 블러드라인의 온도를 센서를 통해 측정하고 투석액의 온도를 조절하여 목표치에 도달함***



재순환의 측정



체온 조절의 원리



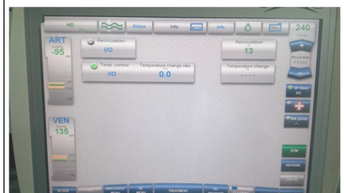
Body Temperature:

$T_{art} = T_{ven} \cdot R + T_{body} \cdot (1 - R)$

T_{art}: arterial blood temperature
T_{ven}: venous blood temperature
R: recirculation (CPR + ACR)
T_{body}: central body temperature
here:
average vena cava temperature
after correction for CPR and
evantually ACR

Control Principle:

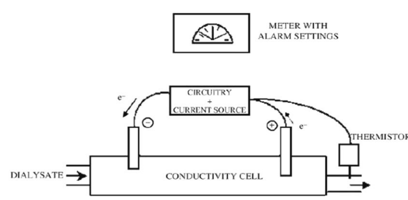
기계에서 artery 온도와 venous온도를
측정하고 recirculation을 측정하여 이를 근거로
환자의 core temperature를 알게 된다.
투석액의 온도를 조절하여 원하는 venous,
artery 온도를 낮추어 심부체온이 상승되지
않도록 한다.



Dialysate Monitoring

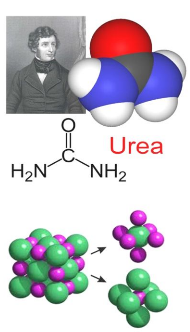
- **Conductivity**
  - Conductivity is the amount of electrical current conducted through a dialysate and reflects electrolyte concentration
  - A constant voltage is applied across two electrodes 1 cm apart in the dialysate flow. If the concentration of electrolytes changes, the voltage will change
  - Conductivity should be between 12–16mS/cm (millisiemens per centimeter). The greater the number of ions, the greater the conductivity of the dialysate
  - Conductivity can be affected by temperature, or concentration of acid to base
  - Alarms will stop dialysate flow if conductivity is out of limits

Conductivity

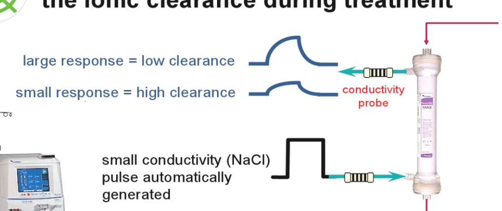


Urea - NaCl

- The Urea molecule (M_W 60) is approximately the same size as the sodium chloride (M_W 58,5)
- Urea and sodium chloride are closely related in clearance characteristics
- Urea transfer can be derived from the measurement of sodium chloride transfer
- Sodium chloride is available in the dialysis fluid
- The sodium ion concentration is easily measured with a conductivity cell



Diascan automatically measures the ionic clearance during treatment



Available in every treatment at no extra cost
- Quality control of delivered dose
- Assessment of plasma conductivity
- Surveillance of vascular access patency

Alarms—Conductivity

- **Conductivity alarms can occur in the following:**
  - An empty concentrate jug
  - Change in electrolyte concentration of dialysate
  - Abnormal water inlet pressure
  - Water leaks or puddles beneath the mixing chamber
  - Concentration line connector unplugged
- **The conductivity settings should never be adjusted while the patient is on the dialysis machine**

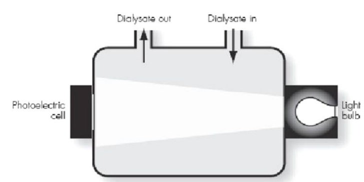
Alarms—Temperature and Pressure Monitors

- **Temperature Monitor**
  - A malfunctioning heating element can cause abnormal dialysate temperatures
    - Cool temperatures (<35° C) will result in shivering
    - Warm temperature (>42° C) can cause protein denaturing or hemolysis (>45° C)
- **Pressure Monitor**
  - The pressure range is –400 to +350 mmHg with an accuracy of ± 10%
    - Alarm limits are set at ± 10% of the pressure setting
    - Pressure in the dialysate compartment should not exceed that in the blood compartment or there is an increased risk of blood contamination by unsterile dialysate secondary to dialyzer membrane rupture and back filtration
    - Ultrafiltration (UF) is controlled by transmembrane pressure (TMP)
    - TMP = PBO – PDO

Blood Leak Monitor

- **Blood should not cross the blood/dialysate membrane**
- **Leakage of blood into the dialysate circuit is detected by the blood leak monitor, which is usually located downstream from dialyzer**
- **Infrared or photoelectric cells detect decreases in light from source**
- **Red blood cells scatter light and trigger alarm, which deactivates the blood pump**

Blood Leak Monitor



If the light beam is interrupted by blood, an alarm will sound, and the blood pump will stop.

Volumetric-based Ultrafiltration

- **Ultrafiltration is the process of removing fluid from the patient in a controlled fashion, during which volume is accurately measured**
- **Most dialysis machines use volumetric-based control, which uses a balancing chamber(s) composed of 2 compartments separated by a flexible membrane**
- **One side of the membrane allows fresh dialysate in, while the other allows spent or used dialysate out**

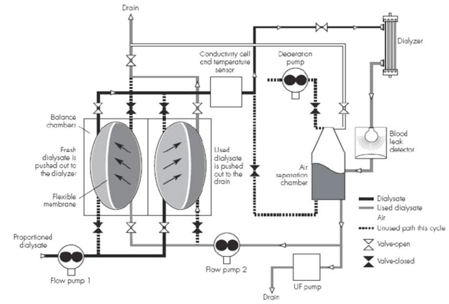
Volumetric-based Ultrafiltration

- **Valves are connected on the inlet and outlet and allows fluid to enter one side of the chamber, which pushes an equal amount of fluid out of the other side of the chamber**
- **One chamber fills with used dialysate and pushes fresh dialysate to the dialyzer, while the other chamber is filling with fresh dialysate and pushes used dialysate to the drain**
  - One pump moves proportioned dialysis to the balance chambers; a second pump pulls dialysate from the dialyzer and pushes it to the balance chambers

Ultrafiltration Pump

- **The UF pump or the fluid removal pump removes fluid from the closed loop, which results in fluid removal from the dialyzer membrane**
- **Most UF pumps are piston type and placed in the used dialysate flow path by negative pressure**
- **When the UF pump is off, there is no pressure gradient between the blood and dialysate and no fluid is removed from the patient**

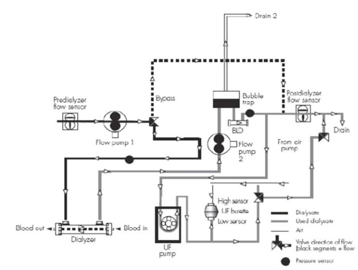
Volumetric UF Control



Ultrafiltration: Flow Control

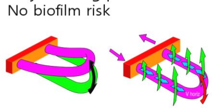
- **Flow-control UF has flow sensors on the inlet and outlet side of the dialyzer that allow control of dialysate flow**
- **A post-dialyzer UF pump removes fluid at an UF rate calculated by the dialysis machine**

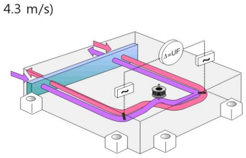
Ultrafiltration: Flow Control



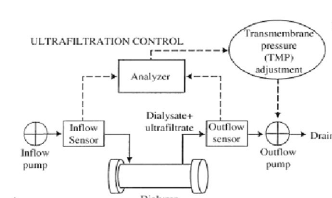
Ultrafiltration: Flow Control

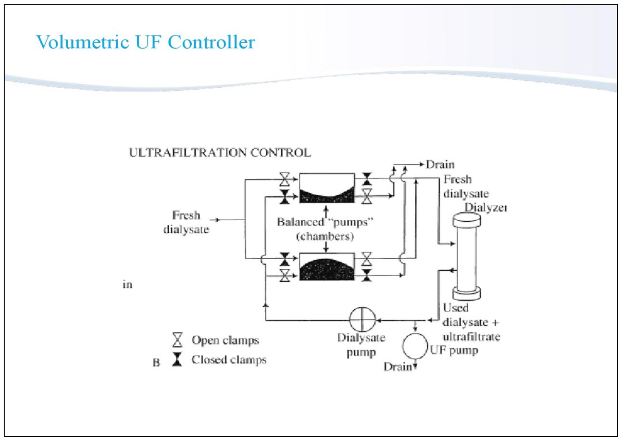
- **Differential system**
  - it measures directly the net *uf*
  - Accuracy not affected by the total dialysate/infusion volume managed
- **High flow velocity inside** (up to 4.3 m/s)
  - easy cleaning procedure
  - No biofilm risk

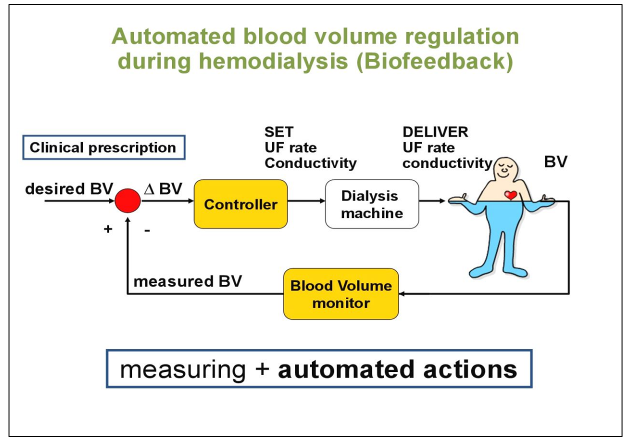


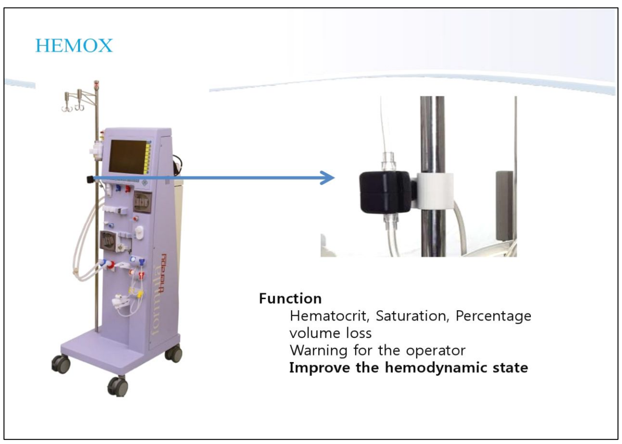


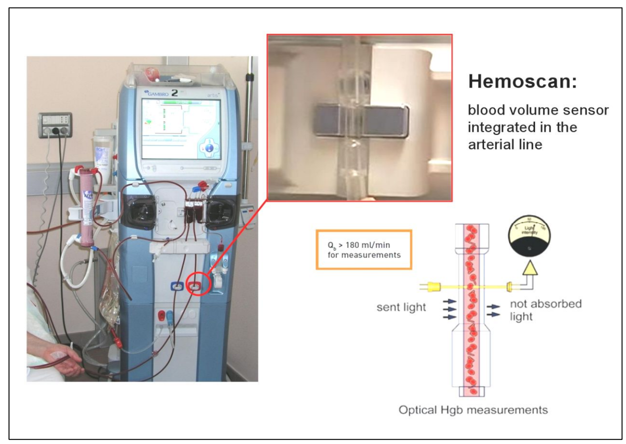
Flow Sensor UF Controller

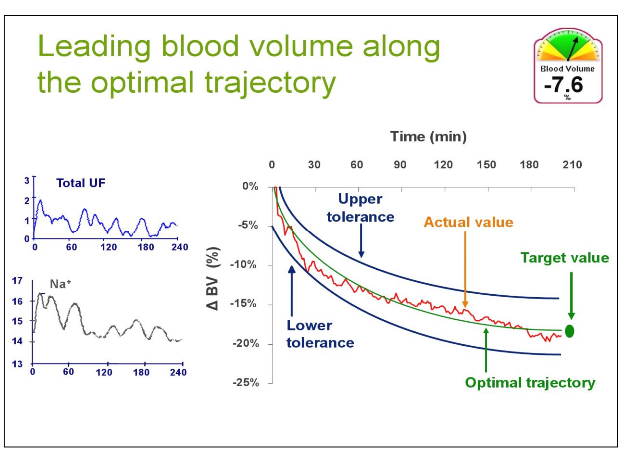


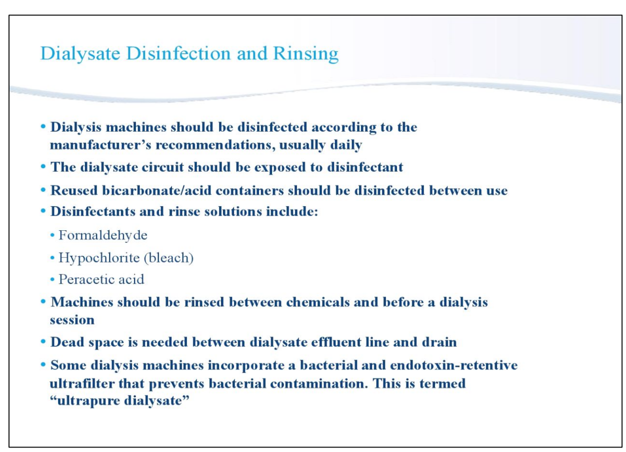

Volumetric UF Controller
ULTRAFILTRATION CONTROL
Drain
Fresh dialysate
Dialyzer
Fresh dialysate
Balanced "pumps" (chambers)
in
Used dialysate + ultrafiltrate
Dialysate pump
UF pump
Drain
Open clamps
B
Closed clamps


Automated blood volume regulation during hemodialysis (Biofeedback)
Clinical prescription
SET
UF rate
Conductivity
DELIVER
UF rate
conductivity
BV
desired BV
Δ BV
Controller
Dialysis machine
+
-
measured BV
Blood Volume monitor
measuring + automated actions

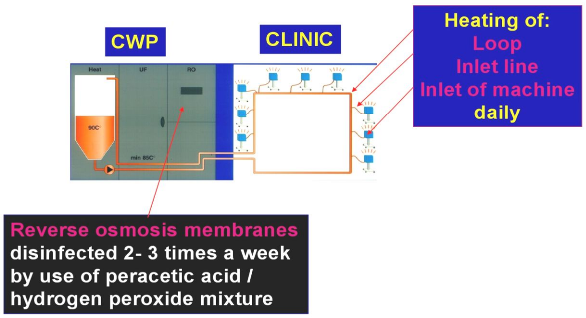

HEMOX
Function
Hematocrit, Saturation, Percentage volume loss
Warning for the operator
Improve the hemodynamic state


Hemoscan:
blood volume sensor integrated in the arterial line
sent light
not absorbed light
Optical Hgb measurements


Leading blood volume along the optimal trajectory
Blood Volume
-7.6
Time (min)
0
30
60
90
120
150
180
210
Total UF
Na+
0%
-5%
-10%
-15%
-20%
-25%
Δ BV (%)
Upper tolerance
Actual value
Target value
Lower tolerance
Optimal trajectory


Dialysate Disinfection and Rinsing
• Dialysis machines should be disinfected according to the manufacturer's recommendations, usually daily
• The dialysate circuit should be exposed to disinfectant
• Reused bicarbonate/acid containers should be disinfected between use
• Disinfectants and rinse solutions include:
• Formaldehyde
• Hypochlorite (bleach)
• Peracetic acid
• Machines should be rinsed between chemicals and before a dialysis session
• Dead space is needed between dialysate effluent line and drain
• Some dialysis machines incorporate a bacterial and endotoxin-retentive ultrafilter that prevents bacterial contamination. This is termed "ultrapure dialysate"

CENTRAL WATER PLANT(CWP) DISINFECTION



Emergencies—Clinical

- **Dialysis machine proportioning problems can result in severe serum electrolyte abnormalities. Some of these emergencies include:**
  - High or low serum sodium, potassium, calcium or magnesium
  - High or low plasma osmolarity due to hyper- or hypo-osmolar dialysate
- **Clinical emergencies can occur if significant levels of contaminants are in the dialysate**
  - Copper or cupraphane may be released from heating element or dialyzer and can cause severe hemolysis
  - Chloramines and nitrates can cause severe hemolysis
  - Fluoride can cause severe pruritis, nausea, and ventricular tachycardia or fatal ventricular fibrillation
  - Aluminum can cause bone disease, anemia, and fatal progressive neurologic deterioration commonly known as dialysis encephalopathy syndrome
  - Lead, copper, zinc, and aluminum can leach from metal pipes and cause anemia

Conclusions

- **Dialysis circuitry requires monitoring to assure patient safety**
- **Water safety and knowledge of dialysate circuitry is the purview of all nephrologists caring for dialysis patients**
- **Every nephrologist should “know their machine” in order to safely troubleshoot problems**