Water for Hemodialysis
SYSTEM CONSIDERATIONS
What is our Primary Goal?
To Provide Safe, Adequate Treatments To Our Patients
SO HOW DO WE PROTECT OUR PATIENTS?

- **Education**
- **Proper water system design**
  - Correct type and size of components
  - Chemical compatibility of all materials used in the water treatment system.
- **Proper Monitoring**
- **Compliance to Current Water Treatment Standards**
Why Do I Need to Be Trained On Water Treatment?
Patient Care Staff are Responsible For Understanding the Clinical Ramifications of Water Treatment

Everyone Must Be Able to Identify Problems with the Water Treatment System Which May Result in a Potential Threat to the Patient’s Health and Safety
HOW CAN I ENSURE MY WATER SYSTEM IS WORKING SAFELY?

- Understand what is in water and how it affects the patient.
- Be knowledgeable about your water treatment system.
- Be alert for problems.
- Monitor your water treatment system correctly and often.
WHY IS WATER AND WATER TREATMENT SO IMPORTANT?

- Water is considered as part of the prescription to the patient.
- Water makes up 90% of the solution used for dialysis (dialysate).
- What happens in the water treatment area can directly affect the patient and has the potential to harm many patients simultaneously.
- Only a semi-permeable membrane separates the patient’s blood and dialysate.
  - Even tiny amounts of chemicals and contaminants in the water can be dangerous to the patient.
EXPOSURE TO WATER

Average person:
15 Liters / week
Drinking, Recreation
Normal excretion:
gastro-intestinal

Dialysis
Patient:
400 Liters / week
a lifetime in 3 years
No excretion
Artificial Kidney
process - diffusion
thin membrane
side effects
Even small amounts of contaminants are dangerous to patient
SOURCES OF WATER

Inorganics

Pesticides, Herbicides

Bacteria, Endotoxins

& Algae

Ground water

Surface water

Salts & Minerals

Bacteria, Endotoxins
& Algae
TYPES OF WATER

♦ Surface Water
  - Contains varying degrees of silt, mud, dirt, debris, chemicals, metals, toxins
  - Generally contains more organic material than ground water: bacteria, algae, microbials

♦ Ground Water
  - Generally contains more inorganic material; minerals, salts, etc.
  - Some bacteria, algae, organics
Organics are carbon based; Inorganics are not
- Organics: Pesticides, Herbicides (and chloramine)
- Inorganics: Salts, Minerals, Chemicals

Contaminant levels determined by...
- Location, season, local industry, contact time
  - Well water - higher salt, calcium; microscopic plants
  - Reservoirs - higher bacteria, viruses; lower salts
- Municipality adding chemicals for public safety
  - Alum - flocculant; Fluoride - teeth; Chlorine - bacteria
<table>
<thead>
<tr>
<th>POSSIBLE CONTAMINANTS IN WATER</th>
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</thead>
<tbody>
<tr>
<td><strong>Sediment and Particles:</strong></td>
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<tr>
<td><strong>Salts and Other Chemicals:</strong></td>
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<tr>
<td><strong>Metals and Heavy metals:</strong></td>
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<tr>
<td><strong>Trace Metals:</strong></td>
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</tbody>
</table>
## PATIENT CONDITIONS:
**GENERAL SIGNS, SYMPTOMS, AND CAUSES**

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Possible Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anemia</td>
<td>Aluminum, Copper, Chloramine, Zinc</td>
</tr>
<tr>
<td>Bone Disease</td>
<td>Aluminum, Fluoride</td>
</tr>
<tr>
<td>Hemolysis</td>
<td>Chloramine, Nitrates, Copper</td>
</tr>
<tr>
<td>Hypertension</td>
<td>Calcium, Sodium</td>
</tr>
<tr>
<td>Hypotension</td>
<td>Bacteria, Endotoxin, Nitrates</td>
</tr>
<tr>
<td>Metabolic acidosis</td>
<td>Low pH, Sulfates</td>
</tr>
<tr>
<td>Muscle weakness</td>
<td>Calcium, Magnesium</td>
</tr>
<tr>
<td>Nausea/Vomiting</td>
<td>Bacteria, Calcium, Copper, Endotoxin, Low pH, Magnesium, Nitrates, Sulfates, Zinc</td>
</tr>
<tr>
<td>Neurological Deterioration</td>
<td>Aluminum</td>
</tr>
<tr>
<td>Trace Metal</td>
<td>Acute Effects</td>
</tr>
<tr>
<td>-------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Vomiting, diarrhea, burning abdominal pain, dehydration, throat constriction, pulmonary edema, liver failure</td>
</tr>
<tr>
<td>Barium</td>
<td>Vomiting, diarrhea, abdominal pain, tremors, convulsions, hypertension, cardiac arrest</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Vomiting, diarrhea, abdominal cramps, dry throat, cough, dyspnea, headache, shock, coma, renal failure</td>
</tr>
<tr>
<td>Chromium</td>
<td>Skin diseases</td>
</tr>
<tr>
<td>Lead</td>
<td>Personality changes, metallic taste, anorexia, abdominal pain, vomiting, constipation, neurological problems</td>
</tr>
<tr>
<td>Mercury</td>
<td>Acute: Vomiting and diarrhea, salivating, abdominal pain, burning mouth pain, uremia</td>
</tr>
<tr>
<td>Selenium</td>
<td>Loss of hair and nails</td>
</tr>
<tr>
<td>Silver (N)</td>
<td>Vomiting, diarrhea, shock, vertigo, convulsions</td>
</tr>
</tbody>
</table>
SYSTEM DESIGN

- The source water is analyzed to determine the highest possible levels of contaminants. Factors considered may include:
  - Source of Water
  - Bacterial load
  - Temperature fluctuations
  - In-organic contaminant level testing
  - Available water pressure
  - Silt content
  - pH

- Only after the water analysis is complete and all factors are considered, is the necessary equipment selected.
PRETREATMENT PROCESS

Patient Protection
- Chlorine & chloramine removal

Component Protection
- Chlorine removal
- Hardness removal
- Particle removal

Optimum operating pressure & temperature
PRETREATMENT COMPONENTS

- Blending/Tempering Valve
- Booster Pump
- Particle Filters
- Softener
- Carbon Filters
- On-Line Monitors & Sample Taps
PRETREATMENT DIAGRAM
BLENDING VALVE

H
C
BLENDING VALVE
BLENDING VALVE

- Optimal & stable water temperature
  - Stable RO water production
  - Optimal carbon filter operation
- Flow range requirements
  - Dialysis operations
  - Backwash & regeneration cycles
- Monitored with in-line thermometer
BLENDING VALVE DIAGRAM
PRETREATMENT DIAGRAM
BOOSTER PUMP

H → BLENDING VALVE → BOOSTER PUMP
C →
BOOSTER PUMP

- Raises inlet water to preset pressure
  - Stable RO operation
  - Adequate backwash & regeneration cycles
  - Eliminate wide pressure fluctuations

- Monitoring
  - In-line pressure gauges
BOOSTER PUMP
MULTI MEDIA DEPTH FILTER

- Particle removal to 10 microns
- Backwashable
- Large capacity
- Monitoring
  - In-line pressure gauges
  - Timer setting
MULTIMEDIA DEPTH FILTER DIAGRAM
MULTI MEDIA DEPTH FILTER
PRETREATMENT DIAGRAM

SOFTENER

BLENDING VALVE → BOOSTER PUMP → DEPTH FILTER → SOFTENER

Arrows indicate the flow direction:

H → BLENDING VALVE
C → BOOSTER PUMP

DaVita
WATER SOFTENER

🌟 Ion exchange process
- Removes calcium & magnesium "hardness" ions
- Adds "soft" sodium ions

🌟 Monitoring
- Hardness test kits/strips
- Timer setting
- Brine tank salt level
WATER SOFTENER
INSTALATION REQUIREMENTS

✦ Capacity ≥ 1 day’s operation
✦ Regenerable Softeners
  • Include RO “lockout”
  • Regenerate with pellet salt
WATER SOFTENER - PRINCIPLE OF ION EXCHANGE

Resin Bead

1

2

3

Resin Bead

Ca
Mg
Ca
Na

Ca
Mg
Ca
Na

Ca
Mg
Ca
Na

DaVita®
PERMANENT SOFTENER DIAGRAM

- Control Valve
- Inlet
- Outlet
- Upper Distributor
- Freeboard
- Drain
- Riser Tube
- Brine Tank
- Resin Bed
- Underbed Media
- Lower Distributor
EXCHANGE SOFTENER DIAGRAM

Inlet

Couplings

Outlet

Upper Distributor

Riser Tube

Resin Bed

Lower Distributor
PRETREATMENT DIAGRAM
CARBON FILTERS

H
BLENDING VALVE

C
BOOSTER PUMP

DEPTH FILTER

SOFTENER
CARBON FILTERS
CARBON FILTERS

吸附过程
- 氯胺分解及吸附（患者保护）
- 自由氯吸附（ reverse osmosis 保护）

监控
- 测试套件/条带
- 时钟设定
- 串联压力表
CARBON ADSORPTION

ACTIVATED CARBON GRANULE

ADSORPTION

FREE CHLORINE

CHLORAMINE

ORGANICS
CARBON FILTERS

INSTALLATION REQUIREMENTS

- Series-connected pairs
- Sample taps after primary & secondary filters
- RO “lockout” on backwashable filters
- Include accidental bypass protection
CARBON FILTERS

SIZING REQUIREMENTS

• Empty Bed Contact Time (EBCT)
  - $EBCT, \text{min} = \frac{(GAC \text{ Volume, ft}^3 \times 7.48)}{\text{Flow, gpm}}$

• EBCT calculated for all beds combined

• Minimum EBCT $\geq 10$ minutes
**CARBON FILTERS MEDIA SELECTION**

- Granular activated carbon (GAC)
- Iodine number ≥ 900
- Mesh size 12 x 40 or smaller
- Coal-based carbon should be acid-washed
PAIRED BACKWASHABLE CARBON FILTERS
EXCHANGE CARBON FILTER ROTATION

- GAC #1: Remove
- GAC #2: Primary
- NEW GAC: Secondary
CARBON FILTERS
SERIES CONFIGURATION
CARBON FILTERS
SERIES-PARALLEL CONFIGURATION
PRETREATMENT DIAGRAM
CARTRIDGE FILTER

H
BLENDING VALVE → BOOSTER PUMP → DEPTH FILTER → SOFTENER → CARBON FILTERS → CARTRIDGE FILTER

C
CARTRIDGE FILTER

- Particle removal to 5 microns or smaller
- Pre-RO installation
- Opaque cartridge housings mandatory
- Remove particles of 5 microns or smaller
- Monitoring
  - In-line pressure gauges
CARTRIDGE FILTER
TYPICAL PRETREATMENT SYSTEM DIAGRAM
WATER TREATMENT STAGES

Pretreatment

Purification & Distribution
PURIFICATION PROCESS

- Remove inorganic & organic substances
  - Inorganics (chemicals)
  - Bacteria
  - Bacterial endotoxin
- Monitoring
  - In-line monitors & gauges
  - Lab testing for chemicals, bacteria & endotoxin
PURIFICATION COMPONENTS

- Reverse Osmosis (RO)
- Deionization (DI) + Ultrafiltration (UF)
REVERSE OSMOSIS

- Pump & membrane system *reverses* osmotic flow to produce purified water
- Removes chemicals, bacteria & endotoxin
- Monitoring
  - In-line conductivity monitors
  - In-line flow & pressure gauges
  - Lab testing for chemicals, bacteria & endotoxin
TYPICAL RO MACHINE DIAGRAM
RO SYSTEM
CONVENTIONAL RO
RO SYSTEM
CWP
PERCENT REJECTION

% Rejection = \left( \frac{\text{Feed TDS} - \text{Product TDS}}{\text{Feed TDS}} \right) \times 100

\text{Example:}
\begin{align*}
\text{Feed TDS} &= 400 \\
\text{Product TDS} &= 10
\end{align*}

400 - 10 = 390
390 \div 400 = 0.975
0.975 \times 100 = 97.5\%

Water quality entering the RO

Water quality exiting the RO

Converts answer into a percentage
DEIONIZATION

- Ion exchange process removes both cations & anions
- **DANGEROUS** when exhausted
- Often increase bacterial & endotoxin levels

**Monitoring**
- Mandatory in-line resistivity monitor w/alarms
- Lab testing for chemicals
DANGEROUS
DEIONIZER EXHAUSTION

Sodium Chloride

Cation Resin

Anion Resin

Hydrofluoric Acid
“MIXED-BED” DI & MONITORING SYSTEM

Bed contains mixture of anion & cation resins

Temperature-compensated resistivity monitor with audible & visual alarms at 1 megohm-cm

Remote monitor with audible & visual alarms

Inlet
Couplings
Upper Distributor
Resin Bed
Riser Tube
Lower Distributor
Outlet
Divert Valve
TYPICAL WORKER-POLISHER MIXED-BED DI INSTALLATION
DEIONIZATION (DI) SYSTEM
ULTRAFILTRATION

- Filtration process removes bacteria & endotoxin
- Required downstream of DI
- Required downstream of Ultraviolet Irradiators (UV)

Monitoring

- In-line pressure gauges
- Lab testing for bacteria & endotoxin
HOLLOW FIBER
ULTRAFILTER DIAGRAM
Water Storage tanks are typically used in systems which consume large amounts of water for procedures such as reuse.

Water Storage tanks are not used in all water treatment systems.

Water Storage tank systems have the following characteristics:

• Conical bottom, sealed storage tank
• Recirculation pump to circulate the water through the distribution loop
• Level and alarm switches to control the RO Unit and the recirculation pump
• Bacteria filter on the tank overflow
WATER STORAGE TANK AND RECIRCULATION PUMP
ULTRAVIOLET (UV) LIGHT

- UV lights are used to kill bacteria
- UV light is produced by a mercury vapor lamp which emits light through a quartz sleeve into the water passing through the light. Bacteria exposed to the light will be killed.
- Since UV lights kill bacteria, they can produce endotoxins and must be followed by either RO or endotoxin filters.
- UV lights are incorporated into the water treatment system as specified by the manufacturer and are not required on all water treatment systems.
UV light kills most remaining bacteria

Dead bacteria produce endotoxins

If a UV light is present - must be followed by an endotoxin filter

Water does not contact the light itself

UV light shines through a quartz tube

ULTRAVIOLET (UV) LIGHT

Water
ULTRAVIOLET (UV) LIGHT AND RADIANCE MONITOR

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OTHER SYSTEM COMPONENTS

All components on the RO product side of the water treatment system must be composed of inert materials. This means that they will not leach any unwanted materials into the water used for dialysis.

Inert materials used in dialysis systems include:

• PVC (polyvinylchioride)
• Stainless Steel
• Glass
OTHER SYSTEM COMPONENTS

There are several other system components which are important to the safe and effective operation of your water treatment system. These include, but are not limited to:

• Distribution loop
• Flow Meters
• Pressure Regulators
• Pressure Gauges
• Sample Ports
• Venturi assemblies
OTHER SYSTEM COMPONENTS
Questions