Water quality in haemodialysis: clinical considerations

Dr Shyam Dheda
Princess Alexandra hospital
Breakdown

- Set the scene – where it all fits in
- Focus on HHD
- Clinical implications
- Water purification systems in HHD
  - Water sources
  - Describe parts of the circuit, each component
  - Water disposal
  - Disinfection and maintenance
  - Additional equipment
- Discuss water monitoring & testing
  - Water reports
  - Microbiological testing
- What the frack!
Why bother with HHD?

• Cost - cheaper
• Independence
• QOL
  – Work
  – Transport
  – Flexibility
  – Accessibility
• Clearances, fluid balance, LV mass

• In-Center hemodialysis six times per week versus three times per week, New Engl J Med 363;24
So what's the difference with HHD?

1. more frequent and longer sessions
2. longer period of non use
3. various water supply qualities
4. various installation environments
5. smaller carbon filters
6. patient responsibility
7. smaller and simpler
Water source
A typical water treatment process includes several steps to remove unwanted substances from water.

1. **First Filtration**
   Water is filtered through screens that remove fish, leaves, and trash.

2. **Coagulation**
   Alum is added to form sticky flocs. Mud, bacteria, and other particles stick to the flocs. The water then passes into settling basins, where the flocs sink.

3. **Second Filtration**
   The water trickles down through sand or gravel, which filters out algae, bacteria, and some chemicals.

4. **Chlorination**
   Chlorine is added to kill remaining organisms.

5. **Aeration**
   Forcing air through the water releases gases, reducing unpleasant odors and taste.

6. **Additional Treatment**
   Sodium or lime may be used to soften hard water. Some communities add fluoride, which helps prevent tooth decay.
Fig. 9 – Average total aluminum (panel A), arsenic (panel B), copper (panel C), iron (panel D), lead (panel E), and zinc (panel F) concentrations for the pilot-scale events: (■) Quality of the first-flush, (□) Quality after the first-flush (average of tank 1 and tank 2), ••• USEPA primary or secondary drinking water standards or action levels: aluminum (200 µg/L), arsenic (10 µg/L), copper (1300 µg/L), iron (300 µg/L), lead (15 µg/L), and zinc (5000 µg/L). - - - Ambient sampler. One standard deviation is shown.
Know where your water comes from, importance of knowing the source.

LIVER FAILURE AND DEATH AFTER EXPOSURE TO MICROCYSTINS AT A HEMODIALYSIS CENTER IN BRAZIL

Elise M. Jochimsen, M.D., Wayne W. Carmichael, Ph.D., JiSi An, M.Sc., Denise M. Cardo, M.D., Ph.D., Susan T. Cookson, M.D., Christianne E.M. Holmes, M.D., M. Bernadete de C. Antunes, M.D., Djalma A. de Melo Filho, M.D., Tereza M. Lyra, M.D., Victorino Spinelli T. Barreto, M.D., Sandra M.F.O. Azevedo, Ph.D., and William R. Jarvis, M.D.

Visual disturbance
Nausea and vomiting
Headache
Muscle weakness
Epigastric pain
Confusion
Bleeding*
Fever
Seizure

* Bleeding from the nose, gums, and anal tract was reported.

Figure 2. System of Water Treatment and Distribution in Caruaru, Brazil.
Contaminants – what are we trying to remove?

• Particulate matter
• Inorganic
  – metals, Al, Fl
• Chemical
  – toxins, pesticides, organic
• Microbiological
  – Endotoxin
  – G + cell walls
  – fragments
The water filtration system

THOU SHALT PURIFY THE WATER THAT THOU DRINKEST
Prosecution after an outbreak of subacute aluminum intoxication in a hemodialysis center

Kenrick Berend, Geert-Jan A. Knoops, Frederik A. de Wolff

Abstract

Criminal prosecution of physicians for the death of patients has been extraordinarily rare, but there seems to be a rising trend.
A dialysis water circuit
Home dialysis circuit

Figure 2: Standard home installation – external plumbing:
The filters: 1u particle filters

- particulate matter = sand, clay, silt, colloidal matter
- prevent fouling of the RO membrane
- traps any carbon flecks
- typically use a 10-inch filter
- standard scheduled changes
The filters: activated carbon

- remove chlorine and related compounds – THM
- not removed by RO
- worker & polisher (bugs)
- requires backwash/each Rx
- ISO – 10 min EBCT, $I_{no} > 900$
- carbon change
Morbidity

Illness in Hemodialysis Patients After Exposure to Chloramine Contaminated Dialysate

MARGARET A. TIPPLE,* NEIL SHUSTERTMAN,† LEE A. BLAND,* MARY ANN MCCARTHY,‡ MARTIN S. FAVERO,* MATTHEW J. ARDUINO,* MARIE H. REID,§ AND WILLIAM R. JARVIS*

BRIEF REPORT

CASE REPORTS

Hemodialysis-Associated Methemoglobinemia in Acute Renal Failure

Juan Pablo DeTorres, MD, James A. Strom, MD, Bertrand L. Jaber, MD, and Katherine P. Hendra, MD, FCCP

Patients on maintenance hemodialysis are vulnerable to chloramine toxicity if chloramines are inadequately removed. We report two critically ill patients with acute renal failure who developed methemoglobinemia during hemodialysis in the intensive care unit. During the same period, methemoglobin levels measured from 30 patients in the outpatient dialysis facility were undetectable. Methemoglobin levels normalized when the carbon filtration system of the portable dialysis machine was replaced with a larger unit to remove chloramines more effectively. Causes, treatment, and prevention of chloramine toxicity in patients receiving dialysis in the intensive care unit are discussed.

© 2002 by the National Kidney Foundation, Inc.
The filters: RO unit

• Cross flow technology
The filters: RO unit

- Reject water
  - water saving RO
  - water recycling
  - reject water storage

- Measurements of RO conductivity efficiency is only a guide
The filters: RO unit

- Monitor conductivity
  - Seasonal change
  - >10% fluctuation
- Lifespan (membrane failure vs schedule)
- Fouling and scaling
- Disinfection (chemical vs heat)
- Calibration and leaks
When good RO’s go bad!

Fluoride Contamination of Hemodialysis Water Supply

This is an archived document and is no longer current information.

August 19, 1993

FDA Report

To: Hemoedialysis Personnel and Water or Dialysate Service Contractors

This is to alert you to a recent incident in which three hemodialysis patients died and several others were hospitalized after exposure to high levels of fluoride in their dialysate, and to urge that you take certain precautions to prevent other incidents of this kind. Please share this Safety Alert with those within your organization who are responsible for water treatment, dialysate delivery systems (including water treatment systems), and patient care.

In this incident, which was investigated by the Food and Drug Administration (FDA) and the Centers for Disease Control and Prevention (CDC), the fluoride concentration in the dialysate was reported to be 15-25 ppm; the ANSI/AAMI standard identifies 0.2 ppm as the acceptable level of fluoride in dialysate.

The high concentrations occurred because the deionizer used to remove fluoride and other contaminants had become exhausted. Part of the problem may have been the warning lights on the deionizer tanks which are used to alert personnel that the deionizer is exhausted. The previous model at the facility used a single light to indicate that the system was functioning properly; when the light went out, the system was nearing exhaustion and needed replacement or regenerating.

The updated model has since been installed at the facility and different levels are now indicated with...
Piping

- backflow devices
- non corrodirble, smooth, heat resistant
- adhesives, bonding agents
- brass
The filters: Endotoxin filters

• create ultra-pure water
• standard practice
• dead end versus cross flow
• regular flush
• pressure tested – check integrity
• created substitution fluid
• changed every 12 weeks
The filters: additional equipment

• Merlin
  – borehole
  – Pre-filtration

• Softener
  – InCntr not home – why?
  – decrease water hardness

• Multimedia

• Water temperature regulator

• Booster pumps
Testing the water!
Water quality testing

• needs to meet minimum criteria for chemical and microbiological characteristics
• ISO (EBPG, AAMI)
<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Drinking water standards: mg/l</th>
<th>Standard dialysis water mg/l</th>
<th>Ultrapure dialysis fluid</th>
<th>Symptoms and disease associations:</th>
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</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>0.1</td>
<td>0.01</td>
<td></td>
<td>Anaemia, neuropathy, bone disease</td>
</tr>
<tr>
<td>Total chlorine</td>
<td>5</td>
<td>0.1</td>
<td></td>
<td>Haemolysis</td>
</tr>
<tr>
<td>Chloramine</td>
<td>3</td>
<td>0.1</td>
<td></td>
<td>Haemolysis</td>
</tr>
<tr>
<td>Copper</td>
<td>2</td>
<td>0.1</td>
<td></td>
<td>Haemolysis</td>
</tr>
<tr>
<td>Fluoride</td>
<td>1.5</td>
<td>0.2</td>
<td></td>
<td>Bone disease</td>
</tr>
<tr>
<td>Lead</td>
<td>0.01</td>
<td>0.005</td>
<td></td>
<td>Haemolysis, neuropathy, gout</td>
</tr>
<tr>
<td>Nitrate</td>
<td>50 - 100</td>
<td>2</td>
<td></td>
<td>Hypotension, Haemolysis</td>
</tr>
<tr>
<td>Sulphate</td>
<td>250</td>
<td>100</td>
<td></td>
<td>Acidosis</td>
</tr>
<tr>
<td>Zinc</td>
<td>3</td>
<td>0.1</td>
<td></td>
<td>Anaemia</td>
</tr>
<tr>
<td>Antimony</td>
<td>0.003</td>
<td>0.006</td>
<td></td>
<td>Encephalopathy, cancer</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0.01</td>
<td>0.005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barium</td>
<td>2</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beryllium</td>
<td>0.06</td>
<td>0.0004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.002</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chromium</td>
<td>0.05</td>
<td>0.014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>0.001</td>
<td>0.0002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selenium</td>
<td>0.01</td>
<td>0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silver</td>
<td>0.1</td>
<td>0.005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thallium</td>
<td>NS</td>
<td>0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>2</td>
<td></td>
<td></td>
<td>Anaemia</td>
</tr>
<tr>
<td>Calcium</td>
<td>200</td>
<td>2 (0.05)</td>
<td></td>
<td>Muscle weakness</td>
</tr>
<tr>
<td>Magnesium</td>
<td>TDS (600)</td>
<td>4 (0.15)</td>
<td></td>
<td>Muscle weakness</td>
</tr>
<tr>
<td>Sodium</td>
<td>180</td>
<td>70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td>TDS</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Microbiological criteria:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microbial count (CFU/ml)</td>
<td>Individual bacterial levels, Ecoli</td>
<td>&lt; 100 CFU/ml</td>
<td>&lt;0.1 CFU/ml (1)</td>
<td>Hypotension, inflammation</td>
</tr>
<tr>
<td>Endotoxin Concentration EU/ml</td>
<td>NS</td>
<td>&lt; 0.25 EU/ml</td>
<td>&lt;0.03 EU/ml</td>
<td>Hypotension, inflammation</td>
</tr>
</tbody>
</table>
- Daily chlorine testing
- ISO – annual testing
- Cost of testing vs outcome
- Localising where the problem is?
Water testing – THM’s

- Reaction of chlorine with organic matter associated with liver damage, carcinogenicity and birth defects
- EPA derivation (80 → 8ppb)
- **Precursor** to Cl breakthrough

<table>
<thead>
<tr>
<th>Time Collected</th>
<th>Date Collected</th>
<th>Time Registered</th>
<th>Date Registered</th>
<th>Year</th>
<th>Consultant</th>
<th>Lab No</th>
<th>Ref. Number</th>
<th>Specimen Type</th>
<th>Units</th>
<th>Limit of Reporting</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00</td>
<td>02 Oct</td>
<td>08:30</td>
<td>08 Apr</td>
<td>2013</td>
<td>VANC~PAH</td>
<td>637831073</td>
<td>PAH8800/269908</td>
<td>Water Feed(Retic)</td>
<td>µg/L</td>
<td>1</td>
</tr>
<tr>
<td>11:52</td>
<td>12 Feb</td>
<td>11:33</td>
<td>11 Apr</td>
<td>2014</td>
<td>VANC~PAH</td>
<td>628507155</td>
<td>PAH8522</td>
<td>Water Feed(Retic)</td>
<td>µg/L</td>
<td>1</td>
</tr>
</tbody>
</table>

| Chloroform     | 45             | 58              | < 1             | µg/L | 1         |
| Bromodichloromethane | 19         | 22              | < 1             | µg/L | 1         |
| Dibromochloromethane     | 6            | 7               | < 1             | µg/L | 1         |
| Bromoform       | < 1           | < 1             | < 1             | µg/L | 1         |
| Total Trihalomethanes | 70        | 87              | < 4             | µg/L | 4         |
### Standard Water Analysis

**Lab No: 55519-6136**  
**Specimen:** Water Feed (Retic)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Ref. Range</th>
<th>Cations</th>
<th>Units</th>
<th>Ref. Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>665 uS/cm</td>
<td></td>
<td>Sodium Na⁺ (6.50 - 8.50)</td>
<td>55 mg/L</td>
<td>(&lt; 180)</td>
</tr>
<tr>
<td>pH</td>
<td>7.80</td>
<td></td>
<td>Potassium K⁺ (2.8)</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Total Hardness</td>
<td>124 mg/L</td>
<td>(&lt; 200)</td>
<td>Calcium Ca⁺⁺ (38.5)</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Alkalinity</td>
<td>124 mg/L</td>
<td></td>
<td>Magnesium Mg⁺⁺ (22.2)</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Silica</td>
<td>16.5 mg/L</td>
<td>(&lt; 500)</td>
<td>Hydrogen H⁺ (0.0)</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Total Diss Solids</td>
<td>414 mg/L</td>
<td>(&lt; 500)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>True Colour</td>
<td>4 Hazen</td>
<td>(&lt; 15)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td>&lt;1 NTU</td>
<td>(&lt; 5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other Dissolved Elements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron Fe</td>
<td>&lt;0.010 mg/L</td>
<td>(&lt; 0.30)</td>
<td>Bicarbonate HCO₃⁻ (150)</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Manganese Mn</td>
<td>&lt;0.01 mg/L</td>
<td>(&lt; 0.10)</td>
<td>Carbonate CO₃²⁻ (0.5)</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Zinc Zn</td>
<td>0.04 mg/L</td>
<td>(&lt; 3)</td>
<td>Hydroxide OH⁻ (0.0)</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Aluminium Al</td>
<td>0.01 mg/L</td>
<td>(&lt; 0.20)</td>
<td>Chloride Cl⁻ (100)</td>
<td>mg/L</td>
<td>(&lt; 250)</td>
</tr>
<tr>
<td>Boron B</td>
<td>0.1 mg/L</td>
<td>(&lt; 4.0)</td>
<td>Fluoride F⁻ (0.8)</td>
<td>mg/L</td>
<td>(&lt; 1.5)</td>
</tr>
<tr>
<td>Copper Cu</td>
<td>&lt; 0.03 mg/L</td>
<td>(&lt; 2.00)</td>
<td>Nitrate NO₃⁻ (3.8)</td>
<td>mg/L</td>
<td>(&lt; 50.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sulphate SO₄²⁻ (40)</td>
<td>mg/L</td>
<td>(&lt; 250)</td>
</tr>
</tbody>
</table>
Importance of water testing? What we can’t avoid!

Hospital technician 'wanted to kill as many patients as possible by pouring bleach into kidney dialysis machine tanks because he was being fired'  
- Donald Foster III suspended from job as equipment technician in July for allegedly asking dialysis patients for their prescription pain killers  
- Police allege that Foster returned to medical centre week later and filled dialysis tanks with bleach  
- Accused of wanting to kill dialysis patients in order to bankrupt the company  
- Held on $525,000 bond and charged with attempted murder and burglary

By Daily Mail Reporter  
Published: 22:42 GMT, 2 August 2012 | Updated: 20:20 GMT, 8 September 2012
Microbiological testing

• bacterial culture and endotoxin testing do not detect gram positive cell wall proteins i.e. peptidoglycan, bacterial fragments, unculturable organisms or dead bacteria

• nutrient poor environment – R2A

• intervention/action levels are set as per ISO at 50% of the maximum allowable level

• biofilm
Limulus (horseshoe crab)

This picture is important because:

1. Seafood contains higher concentrations of Cu, Al and Pb that can accumulate in HD pts?

3. Contaminants in seafood are more dangerous in patients without RRF?
A unique home HD setup

A) Borehole
   - Depth 60m
   - Distance 2km

B) Intermediate pumping station
   - Distance 1km

C) 1st (40kL) storage tank
   2nd (10kL) storage tank

D) 1st filtration system
   - Merlin RO
   - 2 x 1μ filters

E) 2nd pump

F) 2nd filtration system
Surat Coal seam basin
Pollution – how?

Fig. 4. Schematic representation of infrastructures and potential impacts. Source: UNEP/GRID-Geneva, 2012.
# Chemicals used in frac-ing

<table>
<thead>
<tr>
<th>Additive type</th>
<th>Description/purpose</th>
<th>Examples of chemicals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proppant</td>
<td>‘Props’ open fractures to allow gas to flow freely</td>
<td>Silica sand, zirconium oxide, ceramic beads</td>
</tr>
<tr>
<td>Acid</td>
<td>To dissolve clay to allow the gas to flow</td>
<td>Hydrochloric acid (3 - 28%)</td>
</tr>
<tr>
<td>Breaker</td>
<td>Reduces the viscosity of the fluid to release the proppant into the fractures</td>
<td>Peroxydisulphates</td>
</tr>
<tr>
<td>Bactericide/biocide</td>
<td>Inhibits growth of organisms that could contaminate methane</td>
<td>Glutaraldehyde: 2-bromo-2-nitro-1,2-propanediol</td>
</tr>
<tr>
<td>Buffer</td>
<td>Adjusts and controls the pH</td>
<td>Sodium or potassium carbonate</td>
</tr>
<tr>
<td>Clay stabiliser</td>
<td>Prevents swelling of clay which might block pores</td>
<td>Tetramethyl ammonium chloride</td>
</tr>
<tr>
<td>Corrosion inhibitor</td>
<td>Reduces rust formation on well casings</td>
<td>Methanol, ammonium bisulphate</td>
</tr>
<tr>
<td>Crosslinker</td>
<td>Increases the viscosity of the fluid so that it can carry more proppants</td>
<td>Potassium hydroxide, borate salts</td>
</tr>
<tr>
<td>Friction reducer</td>
<td>Allows fluids to be injected at optimum rates</td>
<td>Sodium acrylate-acrylamide copolymer, polyacrylamide</td>
</tr>
<tr>
<td>Gelling agent</td>
<td>Increases viscosity of fluid</td>
<td>Guar gum, petroleum distillate</td>
</tr>
<tr>
<td>Iron control</td>
<td>Prevents precipitation of carbonates, which could plug off the formation</td>
<td>Ammonium chloride, ethylene glycol, polyacrylate</td>
</tr>
<tr>
<td>Solvent</td>
<td>Used to control the wettability of contact surfaces</td>
<td>Aromatic hydrocarbons</td>
</tr>
<tr>
<td>Surfactant</td>
<td>Reduces fluid surface tension thereby aiding fluid recovery</td>
<td>Methanol, isopropanol, ethoxylated alcohol</td>
</tr>
</tbody>
</table>
• In FEBRUARY 2013, Queensland Premier Campbell Newman announced a Crime and Misconduct Commission (CMC) inquiry into the approval of two of the State’s biggest coal seam gas (CSG) projects.

• To date, no official examination of the alleged breaches of health and environmental protection laws has been conducted into the approval process of the Santos and QGC coal seam gas projects in Queensland.

• '… do not fall within the CMC’s jurisdiction.'

QUEENSLAND

FRACKED
Conclusion

- HHD mirrored on an in centre system
- HHD - Higher water exposure, smaller systems, varied feed water, longer disuse
- good working relationship with the local council
- patient fatigue
- comprehensive water analysis is the only quantitative measure
- redundancy