The Science of Secondary Disinfection: Protecting Your Hospital’s Water Supply

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Learning Objectives

- Discuss the epidemiological evidence showing that water is a source of HAIs
- Enable you to be a stronger partner with Risk Management and Engineering in the development of water safety management plans
- Become a key opinion leader within your facility on the selection of the appropriate secondary disinfectant
Why This and Why Now?

△ Increased recognition of water as a source of HAIs
Key Takeaways

- Water can be a source and vector of infection

- Strong body of evidence in scientific literature showing infection risk, illness and death from contaminated water

- *Pseudomonas*, NTMs, *Legionella*, *Acinetobacter*, *Stenotrophomonas* and filamentous fungi can colonize water systems and subsequently cause infection

- These organisms have been linked to HAIs (WHAI)s

- Risk reducing strategies include risk assessment, microbial testing, secondary disinfection and POU filters
Water can cause infection and illness if hospital water systems are not properly engineered and managed.

POTABLE WATER
HYDROTHERAPY POOLS
DECORATIVE WATER FEATURES
COOLING TOWERS

SHOW ME THE EVIDENCE
A Growing Concern:
The Connection of Healthcare Associated Infections to Water

Anaissie et al, 2002
Arch Intern Med vol 162

Kanamori et al, 2016
Water entering a hospital is not sterile

Design and use creates biofilms

Pathogens may be present in biofilms

Water can be a source and vector of infection

Infection risk can be reduced
Drinking Water Supply Chain

- Fresh water is not sterile water and often contains bacteria generally referred to as its heterotrophic plate count (HPC)

- Bacteria are entering your premises every day and establishing themselves in your premise plumbing system

- A 200 bed hospital could easily be pulling 100,000 + gallons of fresh water each day from its municipality
Microbiological Burden
What Level of Microbial Load are we Talking About?

Let’s assume that each ml of water contains 10 HPC per mL

- 3,785 mL in one gallon

- 10 X 3,785 = 37,850 HPC per gallon

- Hospital uses 100,000 gallons

- 37,850 X 100,000 = ~ 3.8X10^9 HPC

Could nearly 4 billion bacteria be entering your hospital’s water system daily?

- Any bad actors within the 4 billion?
- What happens next?
Ecology of Waterborne Pathogens
A Biologist’s Viewpoint

Bacteria and fungi are really no different from us?

To survive and thrive, they need to find food, water, shelter and a place to raise their families.
Water entering a hospital is not sterile.

Design and use creates biofilms.

Pathogens may be present in biofilms.

Water can be a source and vector of infection.

Infection risk can be reduced.

Design and use creates biofilms.

Pathogens may be present in biofilms.
Cycle of Biofilm Production
Biofilm of *Pseudomonas aeruginosa*
Water can be a source and vector of infection.

Water entering a hospital is not sterile.

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Pathogens may be present in biofilms.

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Infection risk can be reduced.
Water as a Source and Vector of Infection

- Multiple reports of infections linked to water
  - *Legionella pneumophila*
  - *Pseudomonas aeruginosa*
  - *Stenotrophomonas maltophilia*
  - *Acinetobacter baumannii*
  - *Mycobacterium chelonae*
  - *Aspergillus* and *Fusarium* spp.

- Literature citations of WHAIs
  - Bone marrow transplant units
  - Oncology wards
  - Surgical ICUs
  - Subacute care units
  - Neonatal units

References:
- Anaissie *et al.*, 2002
- Anaissie *et al.*, 2003
- Cervia *et al.*, 2010
- Exner *et al.*, 2005
- Holmes *et al.*, 2009
- Walker *et al.*, 2013
- Kanamori *et al.*, 2016
Legionnaires’ disease

Perhaps the most granular example of how a hospital’s water system can be the source and vector of infection

Source CDC; Margaret Williams, Claressa Lucas, Tatiana Travis
Public Health Insights

About 5,000 people are diagnosed with Legionnaires’ disease annually in the U.S.
- Average hospital stay is 10.2 days at an average cost of $30,000
- The number of people diagnosed with Legionnaires’ disease grew by nearly four-fold between 2000 and 2014
- Under-recognized, under-diagnosed and under-reported

Average fatality rate is about 10%

People who are most susceptible to infection are
- Over the age of 50
- Those with risk factors related to smoking, chronic lung disease or a weakened immune system

There are approximately 20 outbreaks of Legionnaires’ disease annually in the U.S.

http://www.cdc.gov/mmwr/volumes/65/wr/mm6522e1.htm?s_cid=mm6522e1_w
Reported Cases of LD in the U.S.

Possible Reasons for Rise

- Urine antigen test availability
- Increased surveillance
- Increased awareness and testing
- Increase in susceptible population
- More *Legionella* in the environment
- Warmer temperatures
- Aging infrastructure
- Water-saving building modifications

Source: U.S. CDC (with thanks)
## Legionellosis Risk By Age Group

<table>
<thead>
<tr>
<th>Age group (years)</th>
<th>Number of cases</th>
<th>% of cases</th>
<th>Incidence rate per 100,000 population</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;9</td>
<td>79</td>
<td>0</td>
<td>0.02</td>
</tr>
<tr>
<td>10-19</td>
<td>125</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>20-29</td>
<td>516</td>
<td>2</td>
<td>0.13</td>
</tr>
<tr>
<td>30-39</td>
<td>1473</td>
<td>7</td>
<td>0.36</td>
</tr>
<tr>
<td>40-49</td>
<td>3622</td>
<td>16</td>
<td>0.81 (6-fold) 17-fold</td>
</tr>
<tr>
<td>50-59</td>
<td>5401</td>
<td>24</td>
<td>1.44</td>
</tr>
<tr>
<td>60-69</td>
<td>4658</td>
<td>21</td>
<td>1.94</td>
</tr>
<tr>
<td>70-79</td>
<td>3672</td>
<td>16</td>
<td>2.29</td>
</tr>
<tr>
<td>&gt;80</td>
<td>2864</td>
<td>13</td>
<td>2.66</td>
</tr>
</tbody>
</table>

[http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6032a3.htm](http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6032a3.htm)
CDC investigated 27 outbreaks of Legionnaires’ disease

Leading sources (in order of prevalence)
- Water from showers and faucets
- Cooling towers
- Hot tubs
- Industrial equipment
- Decorative fountains and water features

90% of the LD outbreaks could have been prevented through improved water safety management plans
- Process failures such as not having a water safety management plan
- Human error, such as a hot tub filter not being cleaned or replaced
- Inadequate levels of disinfectant

http://www.cdc.gov/mmwr/volumes/65/wr/mm6522e1.htm?s_cid=mm6522e1_w
CDC Insights: Observed Deficiencies

- Inadequate **disinfection** in potable water”
- Inadequate **disinfection** in cooling tower”
- Inadequate **disinfection** in hot tub”
- **Disinfectant** not routinely added to decorative fountain”
- “Stagnation...closed wing with unused potable water system”
- “Use of tap water in personal respiratory device”
- “Insufficient clinical testing for **Legionella** among patients with healthcare-acquired pneumonia”
CDC Legionnaires’ Disease Investigations

27 outbreaks investigated over a 15 year period

- Hotels and resorts accounted for 44% of outbreaks and 6% of deaths
- Healthcare facilities accounted for 34% of outbreaks, 57% of illnesses and 85% of deaths

Source: CDC MMWR June 7, 2016
## Hospital and LTC-Associated Outbreaks of LD

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Source</th>
<th>Year</th>
<th>Illnesses and Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Term Care Center</td>
<td>Potable water</td>
<td>2002</td>
<td>31 illnesses, 2 deaths</td>
</tr>
<tr>
<td>Long Term Care Center</td>
<td>Cooling towers</td>
<td>2005</td>
<td>82 illnesses, 23 deaths</td>
</tr>
<tr>
<td>Hospital</td>
<td>Potable water</td>
<td>2006</td>
<td>10 illnesses, 3 deaths</td>
</tr>
<tr>
<td>Senior Living Facility</td>
<td>Potable water</td>
<td>2006</td>
<td>6 illnesses, 0 deaths</td>
</tr>
<tr>
<td>Senior Living Facility</td>
<td>Potable water</td>
<td>2009</td>
<td>10 illnesses, 1 death</td>
</tr>
<tr>
<td>Hospital</td>
<td>Decorative Fountain</td>
<td>2010</td>
<td>8 illnesses, 0 deaths</td>
</tr>
<tr>
<td>Hospital</td>
<td>Potable water</td>
<td>2011</td>
<td>13 illnesses, 1 death</td>
</tr>
<tr>
<td>Long Term Care Center</td>
<td>Potable water</td>
<td>2011</td>
<td>10 illnesses, 8 deaths</td>
</tr>
<tr>
<td>Hospital</td>
<td>Potable water</td>
<td>2012</td>
<td>21 illnesses, 5 deaths</td>
</tr>
<tr>
<td>Long Term Care Center</td>
<td>Unknown</td>
<td>2013</td>
<td>19 illnesses, 5 deaths</td>
</tr>
<tr>
<td>Long Term Care Center</td>
<td>Cooling tower</td>
<td>2013</td>
<td>41 cases, 6 deaths</td>
</tr>
<tr>
<td>Veterans’ Home</td>
<td>Unknown</td>
<td>2015</td>
<td>56 cases, 11 deaths</td>
</tr>
</tbody>
</table>

Sources: U.S. CDC and Haupt et al, 2012

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Water as a Source and Vector of Infection (1)

- Multiple reports of infections linked to water
  - *Legionella pneumophila*
  - *Pseudomonas aeruginosa*
  - *Stenotrophomonas maltophilia*
  - *Acinetobacter baumannii*
  - *Mycobacterium chelonae*
  - *Aspergillus* and *Fusarium* spp.

- Literature citations of WHAIs
  - Bone marrow transplant units
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Anaissie *et al*, 2002
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Cervia *et al*, 2010
Exner *et al*, 2005
Holmes *et al*, 2009
Walker *et al*, 2013
Kanamori *et al*, 2016
74% of taps without temperature selection were contaminated with *P. aeruginosa* (2001)

In 15 of 45 patients, the genotypes of *P. aeruginosa* infections matched isolates from faucets in patient rooms

132 patient cases of *P. aeruginosa* were investigated
- In 42% of these cases, the DNA fingerprint of *P. aeruginosa* infections from patients was identical to the DNA fingerprint of *P. aeruginosa* found in the inner part of faucets in an ICU

38 patient cases of *P. aeruginosa* were investigated
- 39% of water samples from electronic faucets in areas including hematology units and ICUs yielded *P. aeruginosa*.
Water as a Source and Vector of Infection (3)

- A 2009 study showed that NTMs are enriched > 100-fold above background water samples in showerhead biofilms.

- In 2010, a hospital-acquired outbreak of LD sickened 8 people. The source was identified as a decorative fountain in the hospital public area.

- A 2014 study showed that NTM was found in 106/183 (58%) of endpoint water samples over a three year surveillance period.

- A 2015 study showed the source of a postoperative breast infection by *Mycobacterium fortuitum* to be the hospital water supply.

- A pseudo-outbreak of *Elizabethkingia meningoseptica* infection in 30 patients over a 22 month period was epidemiologically linked to the hospital water system.

- A pseudo-outbreak of *Penicillium* spp traced to contaminated water faucets in an outpatient obstetrics and gynecology clinic.

Crago et al, 2014
Feazel et al, 2009
Haupt et al, 2102
Jaubert et al, 2015
Moore et al, 2016
Sood et al, 2017
## Opportunistic Premise Plumbing Pathogens

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>faucets</td>
</tr>
<tr>
<td><em>Stenotrophomas maltophilia</em></td>
<td>faucets</td>
</tr>
<tr>
<td><em>Legionella pneumophila</em></td>
<td>Showers, faucets, sinks</td>
</tr>
<tr>
<td><em>Mycobacterium avium</em></td>
<td>Faucets</td>
</tr>
<tr>
<td><em>Mycobacterium gordonae</em></td>
<td>Faucets</td>
</tr>
<tr>
<td><em>Mycobacterium mucogenicum</em></td>
<td>Showers, faucets, cisterns</td>
</tr>
<tr>
<td><em>Mycobacterium fortuitum</em></td>
<td>Faucets</td>
</tr>
<tr>
<td><em>Elizabethkingia meningoseptica</em></td>
<td>Faucets</td>
</tr>
<tr>
<td><em>Aspergillus</em> spp.</td>
<td>Sinks and water tanks</td>
</tr>
<tr>
<td><em>Penicillium chrysogenum</em></td>
<td>Showers and faucets</td>
</tr>
</tbody>
</table>
Source of Exposure

- Showers
- Faucets
- Rinsing
- Bathing
- Drinking
- Ice chips
- Instrument decontamination
Device Decontamination Paths

Cleaning

Sterile Water Rinse (eye)

Packaged

Steam Sterilization

Low Temp Gas Sterilization

Not Packaged

Liquid Chemical sterilization

High Level Disinfection

Pasteurization

Final Rinse w/ Critical Water
Necessary to remove chemical residues

Must maintain sterility or HLD

Utility Water? <100 cfu/ml

Critical Water? <10 cfu/ml

Sterile Water?

Considerations: Endoscopes
• Biofilm
• Air/Alcohol Flush
• Sterile Water
Questions for Consideration

- What water are you using for your final rinse?
- Utility water or critical water or sterile water?
- Does your facility have an ongoing sampling/test plan for water quality and is microbiological testing included?
- Is the recommended frequency for filter changes followed by your facility or by your contract service provider?
- Are you relying on your critical water supply to be sterile?
Infection risk can be reduced

Water entering a hospital is not sterile
Design and use creates biofilms
Pathogens may be present in biofilms
Water can be a source and vector of infection

Infection risk can be reduced
Strategies to Reduce Infection Risk

- Consideration of water as a source in outbreak investigation

- Use a systematic approach by developing a water safety management plan
  - Temperature control
  - Microbiological monitoring
  - Secondary disinfection
  - Point-of-use filters
  - Use sterile water if devices are rinsed and for eye wash stations
  - Cleaning and disinfection
    - Decorative fountains and water features (or remove completely)
    - Ice machines
    - Sinks
    - Faucet aerators (or remove completely)
    - Tubs and hydrotherapy pools
    - Cooling towers
Let’s look at secondary disinfection

“Our water is chlorinated by our municipality, so why do I need secondary disinfection?”
How Residual is Impacted

1 ppm  0.4 ppm

1 ppm  0.06 ppm
Municipalities protect their water distribution system with an approved disinfectant per the SDWA.

At the building level we need to ensure that protection is maintained if lost through building operation, complexity, water retention, pre-treatment, conditioning or heating.
You Have Several Options

- Chlorine
- Chloramine
- Chlorine Dioxide
- Copper Silver Ions
- Ozone
- UV light
Chlorine ($\text{Cl}_2$)

**Technology**

- Greater than 100 years of use, most commonly used disinfectant
- Relatively inexpensive
- Powerful oxidant, inactivates broad spectrum of pathogens
- Needs concentration and time
- Provides residual chlorine needed for continuous protection
- “Free chlorine” = $\text{HOCl}$ and $\text{OCl}^-$
Chlorine (Cl$_2$)

Limitations

- Efficacy depends on system pH
  - pH 6 – 7; HOCl predominates
  - pH >8.5; OCl$^-$ predominates

- Possible corrosion issues at high levels due to its chemistry

- Potential for carcinogenic byproducts (THM and HAA)

- Liquid, concentrated chlorine solutions are unstable, subject to degradation
Monochloramine (NH$_2$Cl)

Technology

- Nearly 100 years of use
- Commonly used by public water systems
- Chloramine is formed by mixing (NH$_4$)$_2$SO$_4$ + NaClO
- Persistent and stable
  - Low reactant disinfectant
- Lower disinfection by-products
Monochloramine (NH₂Cl)

Limitations

- Requires precise mixing ratios of chlorine and ammonia
  - Monochloramine is preferred but improper mixing may lead to di/tri-chloramine
- Weak oxidant and is less effective than chlorine and chlorine dioxide as a disinfectant
- Can cause corrosion in pipes
- Can lead to formation of nitrosamines
- Some bacteria can degrade MCL by oxidizing ammonia
- May lead to higher levels of biofilm and NTMs
Chlorine Dioxide (ClO$_2$)

**Technology**

- Nearly 100 years of use

- Stable over wider pH range than chlorine
  - Less corrosive than chlorine

- More powerful disinfectant than chlorine
  - Inactivates broad spectrum of pathogens
  - Effective at 0.2 to 0.6 mg/L

- Does not form THM or HAA

- Water soluble gas – easy to measure

- Generate onsite
Chlorine Dioxide (ClO₂)

Limitations

- ClO₂ cannot be compressed, thus cannot be shipped
- MCL is 0.8 ppm
  - Chlorite and chlorate can form
  - ClO₂ levels must be monitored and controlled
- Location, location, location
Copper-Silver (Cu-Ag) Technology

More than 40 years of use

First commercial use as a chlorine replacement

Copper and silver ions are generated when an electric current is passed between the electrodes in water flow

- Cu/Ag ion ratio of 10:1 is important and regulatory limits are established
  - < 1.3 mg/L Cu
  - <0.1 mg/L Ag

Applicable for hot water loops
Copper-Silver (Cu-Ag)

Limitations

△ Accurate control is vital because of the important ratio of 10:1

△ Copper and silver electrodes need to be maintained
  ▪ Electrodes need to be replaced periodically

△ Corrosion issues and copper deposition reported

△ Several studies have suggested that bacteria may develop resistance to Cu-Ag
Ozone ($O_3$)

Technology

- Generated on-site as a gas from either air or liquid oxygen
- Used in drinking water treatment for disinfection and oxidation
- As a primary disinfectant, it is very effective against *Cryptosporidium* and *Giardia*
- Does not form THM or HAA
Ozone (O₃)

Limitations

- Ozone decomposes quickly and a residual cannot be maintained.
- Highly corrosive to steel, concrete and rubber gaskets.
- On-site generation of ozone requires containment or a separate structure, thus not practical.
- High operational and maintenance demands.
- Ozonation of water containing Br can produce bromate (MCL 10 ug/L).
Ultra Violet Light

Technology

- UV light inactivates a broad spectrum of pathogens
- Established technology for environmental decontamination
- Deployed in US public water systems primarily to control *Cryptosporidium*
- Inactivates bacteria in water that flows through the UV reactor
Ultra Violet Light

Limitations

- Antimicrobial activity of UV only occurs in line of sight
  - Point disinfection - UV is only effective in the water that flows through UV reactor
  - No residual disinfection downstream where biofilms may already exist

- Lamp and sleeve fouling impairs UV output and effectiveness

- Lamp breakage plan required

- Bacteria including *Legionella* can repair UV damaged DNA in the presence of light
Many things should be considered to safely, reliably and effectively select the right technology and supplier.

- Do we have a secondary disinfection system?
- Is engineering engaged?
- What chemistry is right for my facility?
- If not why not?
- What factors do we need to consider?
- How will engineering monitor and control it?
Water can be a source and vector of infection

Strong body of evidence in scientific literature showing infection risk, illness and death from contaminated water

Pseudomonas, NTMs, Legionella, Acinetobacter, Stenotrophomonas and filamentous fungi can colonize water systems and subsequently cause infection

These organisms have been linked to HAIs (WHAIIs)

Risk reducing strategies include risk assessment, microbial testing, secondary disinfection and POU filters
Learning Objectives

- Discuss the epidemiological evidence showing that water is a source of HAIs
- Enable you to be a stronger partner with Risk Management and Engineering in the development of water safety management plans
- Become a key opinion leader within your facility on the selection of the appropriate secondary disinfectant
Spreading knowledge.
Preventing infection.