Preventing Hospital Acquired Infections From Tap Water: A Review of Issues and Treatment Options

White Paper

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Water distribution systems in healthcare facilities are commonly colonized by bacteria, protozoans, and fungi. Pathogens that do not pose a significant threat to the general population, can cause hospital-acquired infections (HAIs) among patients with compromised immune systems, or other conditions that leave them vulnerable to infection. Incidences of morbidity and mortality from waterborne pathogens in hospitals are widespread. Many such pathogens, particularly those in biofilms, are resistant to treatment with chlorine. Alternative methods of water treatment, such as chlorine dioxide, offer significant advantages. The World Health Organization (WHO) recommends that healthcare facilities develop and implement a water safety plan to minimize risks and costs associated with waterborne pathogens. Treatment of hospital tap water is a critical element that is often overlooked, which has significant influence over incidences of HAIs.

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INTRODUCTION

By the time water reaches a hospital or other healthcare facility, the remaining disinfectant levels (usually chlorine residuals) may be insufficient to eliminate microbes. As a result, the water distribution systems in many healthcare facilities are colonized by a variety of micro-organisms, including bacteria, protozoa, and fungi (Anaissie *et al*. 2002; Exner *et al*. 2005; Williams *et al*. 2013). Pathogens from tap water have even been found to contaminate soaps, cleaning supplies, and antiseptic solutions in healthcare facilities (Williams *et al.* 2013). While many of these organisms fail to pose a significant threat to the general population, patients in healthcare facilities are more susceptible to infections due to open wounds, invasive devices, and/or compromised immune systems. Opportunistic pathogens in water distribution systems are largely unregulated, unmonitored, and aside from *Legionella spp* are not reportable (Williams *et al.* 2013). Therefore, the occurrence and impact of waterborne pathogens are grossly underestimated (Leclerc *et al.* 2002).

Healthcare facilities are well aware of the dangers and costs that nosocomial or hospital acquired infections (HAIs) can pose, and have taken steps to reduce their incidence and severity. Infection control practices for waterborne pathogen-related infections have focused on interrupting contact transmission, for example, through the encouragement of frequent hand washing (Huang et al. 2008) and the enhancement of surface disinfection procedures. However, such programs often fail to recognize the threat posed by pathogens in potable water supplies, hence waterborne infections still occur (Huang et al. 2008). In 2002, a review of past incidents of waterborne nosocomial infections concluded that hospitals caring for patients at high risk for infection do not enforce standards for water quality recommended by U.S. or United Kingdom public health agencies (Anaissie *et al.* 2002). Over a decade later, Williams *et al.* (2013) concluded that this issue had still not been systematically addressed. Due to the potential risks to patients, the World Health Organization (WHO) has recommended that all hospitals develop a water safety plan (WHO 2011).

Developing a water safety plan involves performing a systematic risk assessment that includes identifying relevant pathogens, infection pathways, and health consequences. It is critical to develop a control strategy that focuses on all potential infection pathways (Exner *et al.* 2005; WHO 2011), and to consider water treatment options available for pathogen control.

This paper provides an overview of the impacts of waterborne hospital acquired infections (HAIs), the types of common pathogens found in hospital water, water treatment options, and recommended steps to address this critical issue.

IMPACTS OF HOSPITAL ACQUIRED INFECTIONS

Estimates of the number of HAIs in the U.S. range from 1.7 million to 3.5 million annually, representing 5-10% of all hospitalized patients (Anaissie *et al.* 2002a; Exeter *et al.* 2005). Canadian statistics provide a comparable picture; more than 200,000 patients suffer from HAIs annually, of which over 8,000 are fatal (Public Health Agency of Canada 2015). Data indicate that the occurrence of HAIs has risen dramatically over the past few decades. For example, in 1995, the combined overall rate of HAIs was less than 1 per 1,000 admissions to Canadian hospitals. By 2009, that rate rose to over 6 per 1,000 admissions (Chief Public Health Officer 2013). In addition to the increased incidence of HAIs, the issue of antibiotic resistance is also a concern. Of all HAIs reported in Canada, over 50% are caused by bacteria that are resistant to at least one antibiotic (Chief Public Health Officer 2013).

While it is unclear how many of these cases result from pathogens in hospital water supplies, there are many documented cases of morbidity and mortality from waterborne pathogens (discussed in the section on *Incidence of Pathogens in Hospital Water Supplies* below). A review of waterborne nosocomial infections reported that between 1966 and 2001 there were an estimated 1,400 deaths that resulted from inadequately disinfected water supplies annually in the U.S (Anaissie *et al.* 2002a).

Despite widespread implementation of quality improvement initiatives, the estimated direct medical costs of HAIs ranges from $28 to $45 billion[2] annually in the U.S. (Scott, 2012). Zimlichman *et al.* (2012) found that the average cost of HAI per patient, ranged from $896 (for catheter-associated urinary tract infections) to $45,814 (for central line-associated bloodstream infections).

Programs to reduce HAIs have been widely implemented. Some, such as the one summarized in the Definitive Healthcare database (Definitive Healthcare, 2016), impose financial penalties based on the incidence of hospital acquired conditions (HAC). In this program, 758 U.S. hospitals are set to receive penalties in 2016, totalling an estimated $273 million. These penalties average $360,000 per hospital, but can be as high as $3.3 million.

Clearly there is a critical need to reduce the incidence of HAIs to improve patient outcome and reduce costs imposed on the medical system. Treating hospital water is an often overlooked, but critical element that healthcare facilities must consider to control sources of HAIs.

INCIDENCE OF PATHOGENS IN HOSPITAL WATER SUPPLIES

It is commonly accepted that hospitals and healthcare facilities are colonized by bacteria and other micro-organisms. Hospital water distribution systems, along with equipment or services involving the use of water, have been found to act as reservoirs for waterborne opportunistic pathogens (Anaissie *et al*. 2002a; Exner *et al.* 2005; Williams *et al.* 2013). Although hospitals and healthcare facilities usually receive municipally-treated water, by the time water reaches a hospital, residual disinfectant levels may be insufficient for adequate protection. Furthermore, pathogens that fail to pose a significant threat towards the general population, may however be of concern for patients with compromised immune systems, or other conditions that make them more vulnerable to infection.

The importance of using disinfectants in cleaning solutions was demonstrated in a study that showed how soap and water solutions (without disinfectants) used to clean floors and other surfaces, increased from 10 to 34,000 colony forming units per millilitre (cfu/ml) after cleaning a hospital ward (Rutala *et al.* 2008). However, precautions must also be taken while preparing cleaning solutions, as disinfectants and antiseptics can become contaminated by pathogens, particularly *Pseudomonas spp.* In fact, the most common source of extrinsic contamination of germicides, is from the water used to make working dilutions (Rutala *et al*. 2008).

2 - All currencies in this paper are presented in U.S. Dollars (USD)

The transmission of infections from organisms in tap water may occur through direct contact (e.g. hydrotherapy, bathing), drinking, or inhalation (e.g. when pathogens become airborne after opening a faucet, flushing a toilet, or taking a shower) (Williams *et al.* 2013). The types of pathogens that are most commonly responsible for HAIs include: *Legionella spp*, *Pseudomonas aeruginosa*, other gram-negative bacteria, fungi, and protozoa. A brief review of common pathogens found in hospitals and healthcare facilities, and their impacts is provided below.

Legionella spp

Legionella was the first emerging waterborne pathogen to be discovered that was not primarily transmitted through ingestion or direct contact, but through inhalation (Exner *et al.* 2005). Patients that are particularly at risk for developing pneumonia from this pathogen are those with chronic lung disease, undergoing general anaesthesia, and/or taking corticosteroids. At risk patients are 50% more likely to develop pneumonia when exposed to *Legionella*, and exhibit higher mortality than the general public. In several hospital outbreaks, patients have been infected through exposure to contaminated aerosols generated by cooling towers, showers, faucets, respiratory therapy equipment and room-air humidifiers (Breiman *et al.* 1991; Garbe *et al*. 1985; Hanrahan *et al.* 1987; Jimenez *et al.* 1989, Zuravleff *et al.* 1983). The presence of certain free-living amoebae that support intracellular growth of *Legionella*, enhance its colonization and amplification in water supplies (Fields *et al.* 1989). One study documented that up to 43% of hospitals in Germany were systemically colonized by *Legionella* (Exner *et al.* 1993).

Several studies have discovered a direct correlation between the colonization of *Legionella* and the incidence and mortality rates from Legionnaire's disease (Williams *et al.* 2013). When water supplies are effectively treated for this pathogen, incidences decline to zero. Since continual sources of colonization exist, ongoing control of this bacteria are required (Exner *et al.* 2005). However, it is difficult to control *Legionella*, and chlorine is not a particularly effective treatment (Sidari et al. 2002; Srinivasan et al. 2003; Zhang et al. 2007). There are effective disinfectants available, such as chlorine dioxide and copper silver ionization, which is discussed in the section on *Hospital Water Treatment Options*.

Pseudomonas aeruginosa

Pseudomonas aeruginosa is a common bacteria found in soil, plants, and water; particularly in tap water. It is highly endemic in intensive care units (ICUs), and other hospital locations where patients are treated (Boyle *et al.* 2012; Forroni 1998; Trautman *et al.* 2004). Non-touch faucets have been found to act as a common source of *P. aeruginosa*. This microbe has also been found to contaminate antimicrobial soaps, cleaning supplies and disinfectants (Williams *et al.* 2013). Transmission of *P. aeruginosa* from water systems to patients and *vice versa* has been well documented (Loveday, *et al.* 2014). This bacterium is not detected by routine indicators (e.g. cfu count, *Escherichia coli*, or coliforms) (Exner *et al.* 2005).

P. aeruginosa is known to cause urinary tract infections (UTIs), surgical wound infections, bacteremia, pneumonia, dermatitis, otitis externa, keratitis and other conditions (Exner *et al.* 2005). An estimated 1,400 deaths are caused by infections from waterborne *P. aeruginosa* each year in U.S. hospitals (Anaissie *et al.* 2002). Effective treatment options exist for controlling *P. aeruginosa*, as reviewed in the following section.

Other Gram Negative Bacteria

Several other gram negative bacteria associated with waterborne HAIs have been identified, including *Burkholderia cepacia*, *Stenotrophomonas maltophilia*, *Sphingomonas spp*, *Ralstonia picketti*, *Serratia marcescence*, *Acinetobacter spp*, and *Enterobacter spp* (Williams *et al.* 2013). Many gram negative bacteria have minimal nutritional requirements, which means they can even colonize distilled water (CDC 2003). The use of tap water during patient procedures, specimen collections, and the final stages of instrument reprocessing, have resulted in infections caused by Nontuberculous mycobacteria (NTM) contamination

(Lockwood *et al*. 1989; Sniadack *et al.* 1993).

Conditions caused by exposure to these pathogens range from colonization of the urinary and respiratory tracts, to deeply disseminated infections, leading to pneumonia and blood stream bacteremia (Exner *et al.* 2005). Two genera, *Acinetobacter* and *Enterobacter* are commonly responsible for bloodstream infections, UTIs, and pneumonia.

A dramatic outbreak of bacteremia was caused by *Burkholderia cepacia* found in hospital tap water that was used to dilute alcohol-based skin antiseptics (Nasser *et al.* 2004). Over 410 episodes of bacteremia in 361 patients were documented over a 7-year period. Many other gram negative bacteria colonizing sinks, or biofilms on aerators in sink faucets, have been implicated in infectious hospital outbreaks (Williams *et al.* 2013).

Mortality rates from *Acinetobacter* caused bacteremia, ranges from 17 to 52% in infected hospital patients. Mortality rates of up to 71% from pneumonia caused by *Acinetobacter* or *Pseudomonas spp*. have been documented. It is common for these two genera to also exhibit multi-drug resistance, thus contributing to increased morbidity and mortality rates (Centers for Disease Control and Prevention 2003). Effective treatment options exist for controlling gram negative bacteria, as reviewed in the following section.

Nontuberculous mycobacteria

Nontuberculous mycobacteria (NTM), also known as pathogenic environmental mycobacteria (PEM), have been detected in 80 – 90% of surface water samples, and in concentrations of up to 1,000 cfu/l within treated tap water. Although a 2-log reduction in concentrations is common following water treatment, regrowth may occur in municipal water distribution systems, thus potentially restoring concentrations back to pre-treatment levels (Exner *et al.* 2005). NTM are highly resistant to chlorine residual levels found at the faucet (i.e. 0.05 – 0.2 mg/l), and readily form biofilms (Exner *et al.* 2005).

NTM can cause skin and soft tissue diseases, chronic bronchopulmonary disease, cervical and other lymphadenitis, disseminated infection, and catheter-related infections (Exner *et al.* 1995). These bacteria can colonize patients through consumption of ice and water, inhalation of aerosols, or exposure during showering. In addition to treatment and recovery costs, NTM causes respiratory infections that can lead to adverse drug reactions and disease recurrence (Williams *et al.* 2013). *Mycobacterium xenopii* was shown to cause over 50 cases of bone infections following the contamination of endoscopic surgical material with rinse water in France (Exner *et al*. 2005). Several incidences of infection of inadequately protected central venous catheter (CVC) exit sites during showering have also been documented (Cooksey *et al.* 2008; Kline *et al.* 2004).

NTM exhibits a high resistance to chlorine; these bacteria are 100-330 times more resistant to chlorine than E. coli (Carson et al. 1978; Falkinham 2011; Le Dantec *et al.* 2002; Taylor et al. 2000). This is due in part to the ability of NTM to form biofilms, which are more resistant to treatment (Schulze-Röbbecke and Fisheder 1989). There are however, more effective treatment options to control NTM covered in the following section.

Fungi

Aspergillus spp. and *Penicillium spp.* are the most common fungi found in municipal tap water (Anaissie *et al.* 2002b; Anaissie *et al.* 2003). These filamentous fungi are commonly found in hospital water as well, particularly in association with biofilms (Exner *et al.* 2005; Williams *et al.* 2013). Fungal spores become airborne when taps are opened, and exposure can lead to the development of invasive aspergillosis. Although the incidence of invasive aspergillosis is uncommon, this disease can potentially be life threatening, particularly for immuno-suppressed and neutropenic patients, as well as those taking corticosteroids (Exner *et al.* 2005). The one-year survival rates for patients infected with invasive aspergillosis was 59% for organ transplant recipients, and 25% for stem cell transplant recipients (Kontoyiannis *et al.* 2010; Pappas *et al.* 2010).

Effective treatment methods for controlling fungi in tap are covered in the following section.

Protozoans and Protozoan-Associated Bacteria

Protozoans such as *Cryptosporidium spp.* and *Giardia spp.* can be found in municipal water supplies, and hence hospital tap water, since they are typically resistant to chlorine at concentrations found in potable water (Rutala et al. 2008). *Cryptosporidium* has been documented to cause HAIs (Squier *et al.* 2000). Although within normal hosts, *C. parvum* can cause self-limiting gastroenteritis, it can cause severe life-threating disease in immuno-compromised individuals (CDC 2003).

Several free-living amoeba serve as hosts for aquatic bacteria commonly found in municipal water supplies. In one study, 310 amoeba-associated bacteria belonging to 10 different species were documented in a hospital ICU. The authors of the study concluded that water-related amoeba-associated bacteria were the cause of ventilator-associated pneumonia (VAP) and systemic inflammatory response syndrome (La Scola *et al.* 2003a; 2003b).

Protozoan oocyst are resistant to chlorine treatment (CDC 2003); effective treatment methods are covered in the following section.

Planktonic vs. Biofilm Pathogens

It is estimated that 95% of all microbial cells in drinking water systems exist within biofilms that adhere to pipe surfaces, and that only 5% of microbes are in the water phase (Fleming *et al.* 2013). Biofilms are microbial communities, which are embedded in a matrix of extracellular organic polymers combined with non-organic particles (Exner *et al.* 2005). When formed, biofilms become tightly attached to surfaces and are not easily removed. Biofilms form inside the pipes of water distribution systems, as well as on hospital surfaces (whirlpools, medical devices such as pacemakers, catheters, and endoscopes), haemodialysis systems, sinks, taps, floors, counters, equipment, etc. Once formed, eradicating microbes in biofilms is very difficult.

Microbes in biofilms can produce neutralizing enzymes that inhibit disinfectants. Also, biofilms often exhibit physical gradients (e.g. pH) that make it difficult for disinfectants to penetrate them. For these and other reasons, bacteria within biofilms can be up to 1,000 times more resistant to antimicrobials than the same bacteria in suspension (Vickery *et al.* 2004). The presence of biofilms can have serious implications for immuno-compromised patients, and those with indwelling medical devices (Rutala *et al.* 2008).

Some disinfectants such as chlorine dioxide, are much more effective at eliminating microbial communities within biofilms, in comparison to chlorination. This is reviewed in the section below.

HOSPITAL WATER TREATMENT OPTIONS

Hospitals are faced with two main modes of treatment for controlling pathogens: treatment at the point of entry (POE), or the point of use (POU). POE systems are considered more effective, as they ensure a broader disinfectant effect by treating the entire water supply. POU systems include tap filters and non touch faucets. Table 1 below summarizes the benefits and disadvantages of each treatment option. Further information on treatment options is provided following the Table 1.

Table 1: Summary of Hospital Water Treatment Options.

Treatment Options	Advantages	Disadvantages
Point of Entry Treatments		
Chlorination	• Effective at reducing some bacteria in the water supply; • Chemicals and application process are well known.	• Ineffective at controlling *Legionella;* • Less effective than other treatments at controlling other bacteria, protozoans, and fungi; • Less effective than other treatments at biofilm control; • Reacts with organics to form carcinogenic disinfection by-products (DBPs) – trihalomethane (THM) and haloacetic acid (HAA).
Chlorine Dioxide	• Strong oxidant and persistent disinfectant; • More effective than chlorination and other treatments at controlling bacteria, protozoans, and fungi; • Stable at high temperatures, therefore effective for control of *Legionella;* • More effective than chlorine or other treatments at controlling biofilms; • Does not form carcinogenic DBPs THM and HAA; • Requires no storage of the active disinfectant, because it is generated on-site on-demand from precursor chemicals.	• Chlorate and chlorite formed as DBP.
Ozone	• Strong germicidal properties against bacteria, viruses and protozoans.	• Poor at inactivating biofilms; • No residual is produced, leaving the water supply vulnerable to re-contamination; • Forms a highly carcinogenic DBP – bromate.
UV Radiation	• Strong germicidal properties against bacteria, viruses and protozoans.	• Poor at inactivating biofilms; • No residual is produced, leaving the water supply vulnerable to re-contamination.
Copper-Silver Ionization	• Strong bacteriostatic properties; • Effective for the control of *Legionella.*	• Less effective than other treatments at controlling bacteria; • Poor at inactivating biofilms; • Comparatively high capital, operating and maintenance costs.
Point of Use Treatments		
Tap Filters	• Removes some material from water supply; • Use may be limited to areas requiring higher standard of water disinfection; • Comparatively simple to install.	• Does not disinfect water supply; • Filters must be changed frequently, or they may be come a source of pathogens; • Significant labour and costs are required to change filters regularly.
Non-Touch Faucets	• Comparatively simple to install.	• Do not disinfect water supply; • Vulnerable to contamination.

Point of Entry Water Treatment Options

Treating at the POE includes chemical (*e.g.* chlorination, chlorine dioxide, ozone) and physical (*e.g.* UV) treatment options. The effectiveness and suitability of each are summarized below.

Chlorination

In North America, the majority of municipal water supplies are chlorinated to provide a residual disinfectant in the water distribution system. However, by the time water reaches a hospital from a water treatment plant, disinfectant levels may be insufficient. *Pseudomonas spp.* levels of more than 50,000 cfu/ml have been observed in municipally treated water supplies, with chlorine residuals of 1 ppm (the legal limit in Canada) (Hombach 2006). Some hospitals have chosen to implement additional chlorination systems to enhance disinfectant levels. While there is evidence that this can reduce some pathogens in the water supply, several microorganisms are resistant to chlorine.

Several studies have demonstrated that other disinfection technologies provide superior microbiological control in comparison to traditional chlorination. Gagnon *et al.* (2004) and Chauret *et al.* (2005) demonstrated that chlorine dioxide provides superior inactivation of heterotrophic bacteria than chlorine in bulk water and biofilms. Since chlorine is unstable at higher temperatures, it is not well suited to treating *Legionella spp.* that can colonize hot water tanks (Sidari *et al.* 2002; Zhang *et al.* 2007). Even very high doses of chlorine (50 mg/l) have been shown to be ineffective at controlling *Legionella* in biofilms (Cooper and Hanlon 2010).

There is also evidence that some microbes have developed a resistance to chlorine, particularly gram-positive bacterial strains (Mir *et al.* 1997), and *Legionella pneumophilia* (Cooper and Hanlon 2010). This has important implications for hospitals, health care facilities, and municipal water treatment plants, where chlorination has often been perceived as a cure-all measure (Cooper and Hanlon 2010).

One of the biggest concerns with the use of chlorine is the formation of disinfection by-products (DBP), particularly in water with high organic levels. Trihalomethanes (THM) and haloacetic acids (HAA) form when chlorine residuals react with organic matter in water. A review of DBP reported that all regulated THM and HAA exhibit carcinogenicity in one or more lab species, while several also exhibit genotoxicity. Several regulated THMs have been discovered to be possible or probable carcinogens to humans (Richardson *et al.* 2007). Based on these findings, most jurisdictions enforce regulatory limits on THM and HAA (Richardson *et al.* 2007).

For the reasons mentioned above, the use of additional chlorination to disinfect hospital water supplies is no longer recommended (Health Protection Surveillance Centre 2014). This has led to the development of alternative disinfection strategies (Gagnon *et al.* 2004). The more commonly applied alternative disinfection control methods are summarized below.

Chlorine Dioxide

Chlorine dioxide (ClO_2) is becoming more commonly used as a water treatment disinfectant, including for healthcare facilities. It is a water soluble gas that acts as a strong oxidant and persistent disinfectant (Aieta and Berg 1986; Vogt *et al.* 2010). Chlorine dioxide is used to treat drinking water for over half a billion people worldwide. Since it cannot be transported, it is typically produced on-site using a chlorine dioxide generator.

Chlorine dioxide is a stronger and more persistent disinfectant, which therefore can be added at lower concentrations than chlorine (Aieta and Berg 1986; Gagnon *et al.* 2004; Loret *et al.* 2005; Thomas *et al.* 2004; Vaerewijck *et al.* 2005; Vogt *et al.* 2010). Chlorine dioxide is proven to be more effective at eliminating microorganisms, including bacteria, protozoa, and fungi in comparison to other chemical and physical treatments (Gagnon *et al.* 2004; Huang *et al.* 1997; Ogata and Shibata 2008). In particular, this disinfectant is more stable than chlorine at higher temperatures, and is therefore often used to control *Legionella* in hot water tanks in institutions, including hospitals (Sidari *et al*. 2002; Srinivasan *et al.* 2003; Zhang *et al.* 2007). Chlorine

dioxide has also been proven to be more effective at eliminating biofilms than chlorine, chloramine (Chauret *et al.* 2005; Exner *et al.* 2005; Gagnon *et al.* 2004; Loret *et al.* 2005) or ultraviolet (UV) irradiation (Rand *et al.* 2007; Schwartz *et al.* 2003).

Unlike chlorine, chlorine dioxide does not form appreciable concentrations of DBPs such as THM and HAA (Periera *et al*. 1992; Richardson *et al.* 2007). Chlorite is a common DBP formed with chlorine dioxide, and many jurisdictions regulate its concentrations in potable water. However, chlorite has not been shown to be carcinogenic when tested on animals, and is neither a suspected nor possible human carcinogen (Richardson *et al.* 2007).

Ozone

Ozone is a water soluble gas that has been used at various stages in the water treatment process, because of its strong germicidal properties against bacteria and protozoans. In comparison with other disinfectants in simulated domestic water supply units, Loret *et al.* (2005) found that ozone was more effective than copper silver ions and monochloramines at reducing amoeba cysts. However, ozonation was found to result in the re-emergence of *Legionella* bacteria. Both chlorine dioxide and chlorine are more effective at inactivating biofilms than ozone (Loret *et al.* 2005). Since ozone does not provide a disinfectant residual as chlorine and chlorine dioxide, the use of ozone alone can lead to re-contamination within a water distribution system. Ozone is also considered to be an expensive treatment process (Health Protection Surveillance Centre 2014).

Disinfection by-products created with the use of ozone include bromate, which is the most potent carcinogen of all DBPs regulated by the U.S. EPA (Richardson *et al.* 2007). Bromate levels in ozone treated drinking water in the U.S. have been found to exceed the 10 µg/l regulated level by up to 2.5 times (Richardson *et al.* 2007).

Ultra Violet Irradiation

Ultra violet (UV) irradiation is often used to disinfect drinking water in conjunction with other treatment methods. Although UV disinfection can effectively kill or inactivate microorganisms such as bacteria and fungi, it is not effective at inactivating biofilms (Rand *et al.* 2007; Schwartz *et al.* 2003; Srinivasan *et al.* 2003). Since a line of sight exposure is required to kill or inactivate microorganisms, UV disinfection is most effective when used with high clarity water, where few suspended particles are present to shield microorganisms from light. For this reason, UV irradiation is often used in conjunction with filtration devices to reduce the level of suspended solids.

UV irradiation removes residual disinfectants from water, such as chlorine or chlorine dioxide. Since UV does not provide any residual itself (Health Protection Surveillance Centre 2014), it must be used prior to chlorine or chlorine dioxide treatment to ensure an adequate residual concentration that reduces the potential for re-contamination within a hospital water distribution system.

Copper-Silver Ionization

Copper has long been known to possess biocidal properties. More recently, it has been used in combination with silver ions to treat water for pathogen control, including for *Legionella* (Lin *et al.* 2011; Shih and Lin 2010; Stout and Yu 2003). Copper silver ionization has been shown to be effective in controlling *L. pneumophilia* (Lin *et al.* 2011; Stout and Yu 2003), although there has been evidence of this species develops resistance to copper and silver ions, particularly in hospitals which have used this method for disinfection for several years (Lin *et al.* 2011). Given that both copper and silver are toxic, the USEPA has set maximum levels of 1.3 mg/l for copper and 0.1 mg/l for silver in drinking water (Stout and Yu 2003). These concentrations may be insufficient to control planktonic bacteria, such as *A. baumanii* (Huang *et al.* 2008), and may be insufficient to inactivate bacteria in biofilms. This, coupled with the high comparative capital and maintenance costs (JHH Engineering 2001), make copper-silver ionization a less than ideal method for treating hospital water.

Treatment of Dialysis Water

Special care must be taken while treating water for dialysis patients, as drinking water has long been recognized as unsuitable for this purpose. Dialysis water typically undergoes additional treatment to reduce contaminant levels (Hoenich 2009). Water treatment for this application can involve POE treatment with ozone (Health Protection Surveillance Centre 2014), silver-stabilized hydrogen peroxide (National Patient Safety Agency 2008) or with chlorine dioxide, or carbon filtration followed by reverse osmosis (RO). However, these treatment options can present problems. When hospitals use supplemental POE disinfectants, there is some concern over the inability of carbon filtration and RO to reduce disinfectant concentrations to safe levels. If ozone is used to treat water, it must be removed by UV irradiation prior to use (de Carvalho 2007; Tarrass *et al.* 2010). The use of silver-stabilized hydrogen peroxide to disinfect a hospital water supply in the U.K. led to one death, and several injuries to dialysis patients (National Patient Safety Agency 2008). No adverse reactions in dialysis patients have been documented for hospitals that use chlorine dioxide to disinfect water supplies (Hoenich 2009). However, additional research is required to confirm these findings with respect to haematological parameters.

Point of Use Water Treatment Options

Some hospitals have implemented water treatment infrastructure at the point of use (POU). Such options include tap filters and non-touch faucets.

Tap Filters

Although filters placed on taps act as a barrier, they do not disinfect the water supplies, and hence do not eradicate waterborne organisms (Srinivasan et al. 2003; Zhang et al. 2007; Trautmann et al. 2008; Williams et al. 2011). Disposable filters are quick and easy to install and exchange, however they must be changed frequently to ensure that they do not become a source of pathogens (Warris *et al.* 2010; Williams *et al.* 2011). Once the filtration capacity of a filter has been exceeded, these units may become breeding grounds for pathogens, resulting in water that is more risky than prior to their installation (Department of Health 2006). The requirement to replace filters frequently can lead to significant labour and costs. A 2004 study found that the cost of outfitting and maintaining 55 points of water supply in a European hospital was significant: $103,000 for single use filters, and $109,000 for reusable filters per year (Magdelaine *et al.* 2005). For these reasons, disposable tap filters should only be used as a temporary solution when there is no effective alternative (Department of Health 2006).

Non-touch Faucets

Non-touch or electronic taps have been installed into many hospitals in an attempt to minimize contamination. However, Sydnor *et al.* (2012) found that electronic faucets became more contaminated with bacteria than older manual faucets in the same facility. This occurs because non-touch taps are easily contaminated by pathogens such as *Pseudomonas aeruginosa*, where low water pressure and higher water temperatures create ideal conditions for bacterial growth (Exner et al. 2005). A study conducted on a newly constructed hospital, revealed that *P. aeruginosa* was able to persist in non-touch taps despite chlorination, and it is very difficult to decontaminate such taps with biocides and disinfectants (Van der Mee-Marquet *et al.* 2005).

DEVELOPING A HOSPITAL WATER SAFETY PLAN

As per WHO guidelines, every healthcare facility should develop and implement a water safety plan (WHO, 2011). This plan should include the following:

1) ***Regular testing of your facility's water sources for pathogens*** at various points in the distribution system. Include testing for common pathogens, (*Legionella spp*, *Pseudomonas spp.*, *E. coli*) as well as

other types of pathogens that are responsible for HAIs. Test at various points throughout the water distribution system – at the point of entry, in hot water tanks, and taps throughout the facility. Include testing of soaps, detergents and antiseptic solutions, as well as ice machines and whirlpools.

2) ***Tracking incidences, outcomes and costs associated with HAIs***, including those that are potentially related to contact with potable water sources.

3) If pathogen incidence and/or HAIs warrant, ***selecting and implementing the best option for water treatment***. A POE treatment technology with maximum control of pathogens offers the best option for ensuring the safety of the hospital water supply and minimizing waterborne-associated HAIs.

4) ***Consider modifying your water distribution system*** to reduce or eliminate stagnant sections of pipe, which can act as breeding grounds for micro-organisms.

5) ***Include information on waterborne pathogens in your education*** of medical staff, facility managers, hospital administrators, and cleaning staff, to promote best practices.

If your hospital has been recently constructed, or has undergone renovations, it is particularly important to disinfect its water supply prior to admitting patients.

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ABOUT OSORNO

As an innovative bio-environmental company, Osorno offers a variety of solutions for water and wastewater treatment for small communities and healthcare facilities. Through our internal design processes and partnerships with engineers, contractors, and distribution partners, we provide technologies, products, and components for water disinfection systems to ensure optimal performance. Osorno also offers water assessment services.

In 2003, Osorno pioneered the use of chlorine dioxide disinfection technology in Canada. We install and maintain these systems to treat drinking water for several communities, as well as for water distribution systems in hospitals. Despite free chlorine concentrations of 1 mg/l in the water supplied by the City of Calgary and a working UV disinfection system, high levels of bacteria were found at several faucets in a newly constructed hospital in Alberta. Osorno flushed the complete water distribution system by adding 1 mg/l chlorine dioxide, which caused bacteria levels to drop to zero.

Osorno services its clients through:

- Water chemistry expertise;
- Development of innovative technologies;
- Process control and automation services;
- Remote monitoring and operation of water and wastewater treatment plants;
- Superior levels of cybersecurity;
- Flexibility and customization options, and
- Exceptional maintenance and operational support.

Concerned about pathogens in your hospital water supply?

Contact Osorno today for a no-cost assessment of potential problems and treatment solutions in your water distribution system.

Interested in verifying the water quality in your hospital?

Contact our experts to discuss your concerns and request a brief water quality review at no cost.

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