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Ultraviolet Germicidal Irradiation (UVGI) in Hospital HVAC Decreases Ventilator Associated Pneumonia

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ABSTRACT

Hospital Acquired Infections (HAIs) constitute a major health threat impacting millions of people globally, and increase patient morbidity and mortality with an economic impact of up to $45 billion in the US alone. Gram negative bacteria are of particular concern, are responsible for more than 30% of all HAIs and are becoming increasingly multi-drug resistant. These universal health concerns surrounding HAIs have driven organizations such as ASHRAE to investigate reservoirs of pathogenic microorganisms and the role of the HVAC in the amplification and transmission of HAIs. (*ASHRAE HVAC Design Manual for Hospitals and Clinics).*

The objective of this study was to evaluate the role of HVAC systems serving hospital critical patient care areas, as potential environmental reservoirs for opportunistic Gram negative bacteria attributed to Hospital Acquired Infections. This prospective interventional pre and post multi-center trial was conducted in six tertiary care hospitals. A total of thirteen HVAC systems were sampled for microbial loads. The hospitals were located in New York (1), Michigan (1), Pennsylvania (2) and Washington, DC (2). was An aim was to determine if the installation of Ultraviolet Germicidal Irradiation (UVGI) systems in the HVAC equipment would reduce HVAC and patient care environment microbial loads and lead to reduced incidence of Ventilator Associated Pneumonia (VAP) in critically ill patients. All thirteen HVAC systems demonstrated the presence of gram negative bacteria with 65 of 65 cultures testing positive prior to UVGI intervention. Pseudomonas species was isolated in 50.1% and Acinetobacter species in18.5% of samples cultured. The 65 samples that were cultured 90 days post UVGI intervention demonstrated a 5 log reduction in colony forming units (CFU). Additional studies by the New York hospital demonstrated a reduced incidence of VAP in a high risk cohort. The Incidence of VAP fell from 74% (n=31) to 39% (n=18) and the number of episodes per patient decreased (control: 1.2 pre UVGI intervention to 0.4 post UVGI intervention). (Ryan et al)

INTRODUCTION

Hospital acquired infections (HAIs) constitute a major health threat affecting millions of people globally and are the direct cause of morbidity and mortality in large numbers of patients. According to U.S. Public Health

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and CDC publications, these infections increase the Length of Stay (LOS), culminating in the U.S. with 1.7 million infections and 99,000 deaths each year as well as estimated direct medical costs of up to $45 billion. Additionally, the World Health Organization has cited a resulting emergence of antibiotic-resistant microorganisms.

Statistics from the U.S. National Healthcare Safety Network demonstrate that Gram negative bacteria account for the most frequent hospital acquired infections, including 71% of urinary tract infections, 65% of pneumonia episodes, 34% of surgical site infections, and 24% of bloodstream infections. Infections caused by Gram negative bacteria are an even higher percentage of nosocomial infections in Europe. An international study published in JAMA 2009, cites a rising trend of infections caused by Gram negative pathogens. The JAMA study demonstrated Gram negative bacteria present in 62% of microbial isolates, with *Pseudomonas aeruginosa* as the most prevalent. *Pseudomonas aeruginosa* is the leading cause of hospital acquired pneumonia (nosocomial pneumonia) and Ventilator Associated Pneumonia (VAP). Multiple studies (Koenig, SM, Truwit, JD, 2006*)* have demonstrated increased duration of hospital stay, morbidity and mortality rates of up to 62% and the highest mortality in patients associated with Gram negative *Pseudomonas aeruginosa* or *Acinetobacter species* infection.

MATERIALS AND METHODS

Study Settings and Design

This study design was a prospective interventional pre and post multi-center trial performed at six tertiary care hospitals in New York (1), Michigan (1), Pennsylvania (2) and Washington, DC (2). The intent of this research was to determine if the HVAC systems, serving hospital critical patient care areas, were potential environmental reservoirs for pathogenic Gram negative bacteria. A total of thirteen HVAC systems and the patient care areas from the six hospitals were cultured for the presence of bacteria. Additionally, it was intended to determine if the installation of UVGI systems in the HVAC equipment would reduce the HVAC and patient care environment microbial loads.

Sample points cultured included the HVAC system's cooling coils, condensate drain pans, air supply and return diffusers within patient care areas. Baseline cultures were taken just prior to intervention of the UVGI and ninety days post UVGI installation. During the period of intervention the UVGI ran 24 hours a day. The New York hospital conducted additional analysis to determine if the UVGI intervention would reduce the incidence of Ventilator Associated Pneumonia (VAP) in a level three plus Neonatal Intensive Care Unit (NICU). NICU Physicians and Infectious Disease personnel studied the impact of UVGI on the rates of VAP in a patient subpopulation consisting of patients less than 30 weeks gestational age and on ventilator support 14 days or longer. (Ryan et al, 2011)

HVAC and Environmental Sampling

HVAC and patient care environment samples were collected using methods standardized for inanimate surface (AIHA: AIHA Field Guide. 1996) and were analyzed by an independent laboratory (Pure Earth Environmental Laboratory, Inc, Pennsauken, NJ). Each sample collected was one square inch (2.54 x 2.54 cm) from the air effluent side of condensate cooling coils and drain pans of the HVAC systems. Additional samples were collected from the air supply and air return diffusers of patient care environment surfaces. Surface wipe

samples were obtained using a BBL culturette (Becton Dickinson, Franklin Lakes, NJ) with a sterile rayon-tipped swab that was moistened with a modified Stuart's transport medium before sampling one square inch of surface area. The completed swab specimen was placed back into its original container, sealed, placed immediately into a clean cooler, and shipped via next day air to the laboratory for identification and quantification of fungi and bacteria to the species level. Upon arrival at the laboratory, each surface wipe was immersed in a sterile test tube containing 10 ml /0.338 oz of sterile distilled water. The test tube sample was kept at room temperature for 10 minutes and then placed in a rotary shaker (3.81 throw, 220 rpm) for one minute. The resulting suspension or dilution was then inoculated (0.1 ml/.0038 oz aliquots) on a 2% malt extract agar (MEA for fungal growth) and a trypticase soy agar (TSA for bacteria growth). The results provided estimates of the total number of viable propagules per ml of suspension. The samples were immediately incubated at 34.5°C/94.1°F to 35.5°C/95.9°F.

UVGI System Design

The UVGI systems selected for this study consisted of multiple horizontal rows of UVGI lamps located 12 to 18 inches (304.8 to 457.2 mm) from the air effluent side of the condensate cooling coils and spaced 18 to 24 inches (457.2 to 609.6mm) apart as shown in **Figure 1 and Figure 2**. The spacing of rows and distance from coils was dependent upon

the size and configuration of each HVAC cooling coil. The UVGI devices selected were configured with high output medium pressure UVGI lamps (Steril-Aire, Inc. of Burbank, CA). It was understood the selected high output devices would lose up to 40% of output after 9,000 hours of operation. UVGI intensities were calculated to deliver an adequate UVGI dose to prevent the establishment and growth of a biofilm on HVAC coils and drain pans for a period of one year. The reproductive characteristics of microorganisms are well understood; bacteria will double every twenty to thirty minutes and fungi will reproduce every three to four hours. Accordingly, it was determined to identify a specific bacterium and fungus for purposes of UVGI system design standardization. *Pseudomonas aeruginosa* and *Aspregillus niger* were the microorganisms selected for this purpose. *Pseudomonas aeruginosa* is an opportunistic gram negative bacterium most attributed to VAP in critically ill patients (Vincent JL, et al 2009). *Aspergillus niger* is a spore forming fungus requiring the highest dosage of UVGI energy for inactivation and is problematic to immunocompromised patients.

Figure 1. UVGI System Design

Each UVGI array was designed to deliver an initial minimum intensity of not less than 1235 $\mu W/cm^2$ and 741 $\mu W/cm^2$ after 9,000 hours of continuous operation at any point across the irradiated surfaces of the coil. (Note: cm^2 = 0.155 $inch^2$) These intensities allowed for a minimum coil surface inactivation efficiency of 99.9% on *Pseudomonas aeruginosa* in fewer than thirty seconds and 99.9% on *Aspergillus niger* in fewer than ten minutes for the entire 9,000 hours of operation. To achieve a 99.9% inactivation rate on *Pseudomonas aeruginosa* and *Aspergillus*

niger requires UVGI dose of 16,486 μW -seconds/cm² and 406,339 μW -seconds/cm² respectively (Kowalski WJ, Bahnfleth WP, 2000). These published data would indicate that an initial 99.9% coil surface inactivation rate, of *Pseudomonas aeruginosa*, would be achieved in less than 14 seconds of exposure time (16,486 μW-seconds/cm² ÷ 1235 μW/cm² = 13.3 seconds) and less than 23 seconds (16,486 μW-seconds/cm² ÷ 741 μW/cm² =22.3 seconds) after 9,000 hours of continuous operation. Similarly an initial 99.9% inactivation *Aspergillus niger* could be achieved in less than 6 minutes (406,339 μW-seconds/cm² ÷ 1235 μW/cm² = 329 seconds or 5.5 minutes) and less than 10 minutes (406,339 μW-seconds/cm² ÷ 741 μW/cm² = 548 seconds or 9.1 minutes) after 9,000 hours of continuous operation. These inactivation rates eliminated the existing biofilm and prohibited its' re-growth within the HVAC system. This in turn improves HVAC hygiene and eliminates the HVAC as a viable reservoir for Gram negative bacteria and other opportunistic microorganisms.

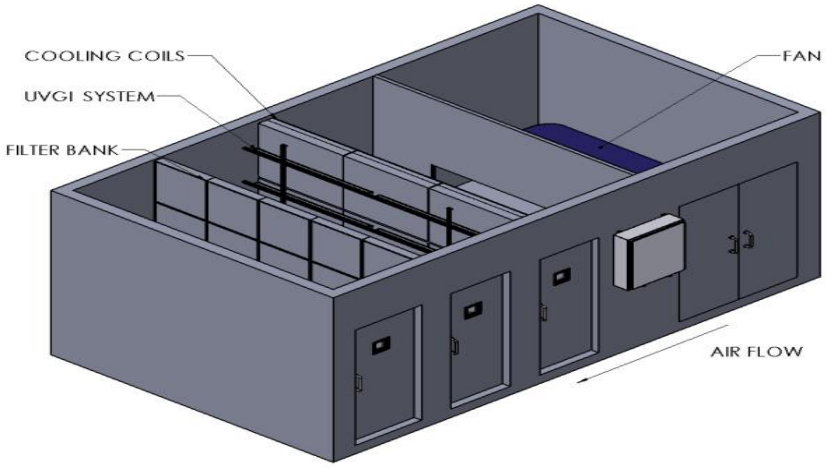

Figure 2. Typical UVGI System Location

RESULTS

Microbial samples were collected from 13 HVAC systems and room air diffusers from 6 tertiary care hospitals. The HVAC microbial samples were collected from the air effluent side of the condensate cooling coils and drain pans. The air diffuser microbial samples were collected from the patient care units being supplied air from the sampled HVAC systems. Baseline, Pre UVGI intervention, samples collected from the 13 HVAC systems was 3 three to 7 days prior to UVGI installation. Post UVGI intervention samples were collected ninety days post UVGI installation. The UVGI systems ran continuously for the entire duration of the 90 day post UVGI intervention period.

The data collected demonstrated the presence of Gram negative and positive bacteria on 65 of the 65 samples cultured from HVAC coils and drain pans **as shown in Table 1**.

Table 1. Top 9 Bacteria Percentiles Isolated From Study HVAC System Cooling Coils and Drain Pans

Bacteria - 65 Samples Collected from 13 HVAC Systems	Gram Negative	Gram Positive	# of Samples Testing Positive	% of Samples Testing Positive
Pseudomonas sp.	x		33	50.1
Bacillus sp.		x	12	18.5

Acinetobacter sp.	x		11	16.9
Staphylococcus sp.		x	4	6.1
Corynebacterium		x	4	6.1
Enterobacter sp.	x		4	6.1
Klebsiella sp.	x		2	3.1
Serratia	x		2	3.1
Stenotrophomonas sp.	x		2	3.1

Air supply and return diffusers demonstrated the presence of Gram negative and positive bacteria in 13 of the 13 samples collected **as shown in Table 2**. Six of the top nine bacteria isolated from the HVAC systems and patient care unit air diffusers were classified as Gram negative and three as Gram positive **as shown in Table 1** and **Table 2**. The number one bacterium isolated from the HVAC systems and patient unit air diffusers was *Pseudomonas* **as shown in Table 1 and Table 2**.

Table 2. Top 9 Bacteria Percentiles Isolated From Study HVAC System Patient Care Air Diffusers

Bacteria - 13 Samples from 13 Air Return & Supply Diffusers	Gram Negative	Gram Positive	# of Samples Testing Positive	% of Samples Testing Positive
Pseudomonas sp.	x		4	30.8
Acinetobacter sp.	x		3	23.1
Bacillus sp.		x	3	23.1
Staphylococcus sp.		x	2	15.4
Corynebacterium		x	2	15.4
Enterobacter sp.	x		2	15.4
Klebsiella sp.	x		2	15.4
Serratia	x		2	15.4
Stenotrophomonas sp.	x		1	7.7

Baseline concentrations of bacteria for HVAC systems and air diffusers were impressive. The mean HVAC bacteria concentration was reported at >1,700,000 Colony Forming Units (CFU)/cm² of coil and drain pan surface area; the air diffusers demonstrated bacteria concentration >1,000,000 CFU/cm² **as shown in Table 3**. The post UVGI intervention demonstrated a 5-log reduction (10^{-5}) of bacteria in the HVAC systems and on surfaces of the patient care unit air diffusers **as shown in Table 3**.

Table 3. Pre and Post UVGI Installation Bacteria Reported HVAC and Air Diffusers

Sample Locations	Pre UVGI Installation Bacteria CFU/cm² Mean (SD)	90 Day Post UVGI Installation Bacteria CFU/ cm² Mean (SD)
HVAC cooling coils, condensate drain pans & final filters	1,736,396 (1,348,668)	33.3 (115.5)
Patient care area supply and return diffusers	1,092,779 (1,313,629)	28.5 (40.3)

This table reports the mean (standard deviations) of the concentration of bacteria isolated from the HVAC systems and patient care area air diffusers pre and post UVGI installation. Note: 1 cm^2 = 0.155 $inch^2$

The NY Hospital's Neonatal Intensive Care Unit (NICU) reported a greater than 50% reduction in VAP in a high risk patient population from pre UVGI to post UVGI installation (Ryan RA, et al 2011). Ryan reported a pre UVGI intervention incidence of VAP in the high risk patient population of approximately 74%. It was also reported that VAP was 88% polymicrobial with pathogen species similar to those isolated in the HVAC, on NICU surfaces and patient tracheal aspirates. Ryan reported the number of post UVGI intervention VAP episodes in the high risk sub set of patients was decreased to 55% after the first 6 months and to 44% after 18 months **as shown in Table 4**. Throughout the duration of the study average ventilator days, gestational age of patients, clinical practices, infection control protocols and housekeeping practices were unchanged **as shown in Table 4**.

Table 4. Demographic Profile of NICU and High-risk Cohort and VAP Results (Ryan RM, et al)

	Pre UVGI		Post UVGI	
All NICU patients	**1/01-6/01**	**1/02-6/02**	**7/02-12/02**	**1/03-6/03**
Admissions, *n*	310	345	368	316
Average daily census, *n*	42.4	46.4	46.6	39
% Inborn	66	59	69	60
% patient tracheal MLI ≤ 1	14	30	39	44
No. of babies admitted <30 weeks	54	57	73	51
No. of babies <30 weeks & ventilated for ≥ 14 days (% of all babies <30 weeks) High-risk cohort (mean(s.d.))[a]	31 (57)	25 (44)	24 (33)	18 (35)[b]
Gestational age, weeks	26.4 (1.9)	25.7 (1.5)	26.2 (1.6)	26.0 (1.6)
Birth weight, (g)	901 (173)	816 (140)	853 (105)	845 (188)
Total parental nutrition/central-line days	37 (12)	41 (9)	45 (13)	51 (17)
Length of stay, days	98 (57)	92 (26)	89 (24)	105 (40)
Ventilator days	50 (33)	44 (23)	44 (27)	48 (28)
No. of VAP episodes per high-risk patient	1.2	0.7	0.8	0.4[a]
% with at least one VAP	74	56	54	39
No. of VAP episodes per high-risk patients with any VAP	1.7	1.3	1.5	1.1[b]
No. of antibiotics per high-risk patient	2.6 (2.7)	1.7 (1.7)	1.9 (2.4)	1.0 (1.5)[b]
Antibiotic days	20.9 (24.2)	17.3 (20.8)	18.8 (25.3)	9.5 (14.7)

Abbreviations: UVGI, ultraviolet germicidal irradiation: MLI, microbial load index: NICU, neonatal intensive care unit: s.d., standard deviation: VAP, ventilator associated pneumonia: g, grams. [a] *n = 2,0,3 and 1 in each time period met exclusions criteria (congenital heart disease, complex congenital anomalies, other NICU stays, ventilator days >200 or died or were transferred while on ventilator support):* [b] *$p<0.01$ compared with pre UVGI.*

DISCUSSION

Airborne transmission is a known route of infection for airborne diseases such aspergillosis, Legionnaire's, tuberculosis, smallpox, influenza, varicella and measles (Beggs, CB 2003). Multiple studies have also implicated airborne transmission of bacteria (Jones AM et al 2003; Kumari DN et al. 1998), fungi (Prazmo Z et al 2003; Morey 1988) and viruses (Sawyer LA et al 1988; Tellier R 2006). The HVAC system has been documented to be a viable reservoir and amplifier of pathogenic bacteria and fungi and these pathogens can be transmitted by the way of the HVAC system. HVAC environmental contamination has also been recognized by The Environmental Protection

Agency (EPA) and the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). Studies performed by Hugenholtz and Fuerst demonstrate that even HVAC systems that appeared clean, contained surface bio-loads from 10^5 to 10^7 CFU/$cm^{2.}$ and condensate cooling water from 10^5 to 10^6 CFU/ml.

UVGI has been proven for its microbiological lethality and is recognized as an intervention that reduces dissemination of airborne infections (Riley RL, Nardell EA, 1989). This study focused on the use of UVGI applied to the air effluent side of the HVAC cooling coils in six tertiary care Hospitals. We sought to evaluate how UVGI systems, when applied to the HVAC system coil components, would decrease pathogens in the HVAC. Additionally we hypothesized that pathogens in the air and surface of critical care settings would be decreased with an ultimate reduction in nosocomial pneumonia in tertiary care settings.

This study demonstrates hospital HVAC systems become significant reservoirs for Gram negative bacteria and other opportunistic microorganisms known to be associated with serious Hospital Acquired Infections (HAIs). The study further demonstrates hospital HVAC systems play a role in disseminating these microorganisms to critical patient care areas **as shown in Table 1 and Table 2**. The Centers for Disease Control and Prevention (CDC) recommends High Efficiency Particle Air (HEPA) filters be applied downstream in hospital HVAC systems as a means to prevent the spread of airborne microorganisms. (Sehulster LM et al. 2004) However, all filter types eventually become contaminated and are prone to leakage, releasing significant quantities of pathogens into the indoor environment.(Brickner PW et al. 2003, Woods GL et al. 1988)

Improved HVAC hygiene with UVGI systems designed with a predetermined level of UVGI intensities within the energy field can prevent the HVAC from becoming a reservoir for opportunistic microorganisms. This study further demonstrates that improved HVAC hygiene will lead to improved environmental hygiene **as shown in Table 3**.

Research conducted by Ryan, et al demonstrated improved HVAC and environmental hygiene, with the application of UVGI in the HVAC, led to a lower incidence of HAI's and decreased patient morbidity and mortality. (Ryan RM et al. 2011)

CONCLUSION

This study demonstrated the UVGI systems with a designed predetermined UVGI dose efficiency led to improved HVAC and patient environment hygiene. The improved environment hygiene, in turn, led to improved clinical outcomes with reduced patient morbidity and mortality. Understanding that the HVAC is a significant reservoir and disseminator of Gram negative bacteria and other opportunistic microorganisms is critical for Healthcare Facility Professionals. Awareness of this common HVAC issue will help hospitals plan for, and improve the accreditation process with The Joint Commission. UVGI systems installed within HVAC systems serving critical patient care units plays a role in Healthcare facility Plans for Improvement (POC). This will further improve the quality of healthcare by creating a safer hospital environment for patients, staff and visitors. (HVAC Design Manual for Hospitals and Clinics, ASHRAE 2013).

Additional evaluation and studies are needed by organizations such as ASHRAE to establish the required intensities for UVGI energy fields, within the UVGI system, to properly maintain HVAC and patient care environment hygiene. This will allow Design Engineer Professionals to correctly apply UVGI in Healthcare applications and transform the HVAC system into an infection prevention tool. Finally, large multi-center

randomized trials are needed to further characterize the effects of UVGI on the full spectrum of adult, pediatric and neonatal hospital populations.

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