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Major Article

Cleaning the air with ultraviolet germicidal irradiation lessened contact infections in a long-term acute care hospital

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Key Words:
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Background: This study was designed to determine whether removing bacteria from the air with ultraviolet germicidal irradiation (UV-C) at the room level would reduce infection rates.

Methods: We reviewed infection data for 12 months before and after UV-C installation in the special care unit (SCU) of a long-term acute care hospital. All patients admitted to the SCU during the study time frame were included. Microbiologic impactor air sampling was completed in August 2015. Shielded UV-C units were installed in 16 patient rooms, the hallway, and the biohazard room. Air sampling was repeated 81 days later.

Results: After UV-C installation, airborne bacteria (colony forming units [CFU] per cubic meter of air) in patient rooms were reduced an average of 42% (175 vs 102 CFU/m^3). Common health care–associated infections (HAIs) (*Clostridium difficile* [8 cases annually vs 1 case, $P = .01$] and catheter-associated urinary tract infection [20 cases annually vs 9 cases, $P = .012$]) were reduced significantly as were overall infections, in number of cases (average 8.8 per month vs 3.5, $P < .001$), and infection rate (average monthly rate 20.3 vs 8.6, $P = .001$), despite no reported changes to the amount or type of cleaning done, infection control protocols, or reporting procedures. Other infections, traditionally considered contact transmissible (central line–associated bloodstream infection and methicillin-resistant *Staphylococcus aureus*), also declined noticeably.

Conclusions: Continuous shielded UV-C reduced airborne bacteria and may also lower the number of HAIs, including those caused by contact pathogens. Reduced infections result in lessened morbidity and lower costs. Health care facilities might wish to consider continuous shielded UV-C at the room level as a possible addition to their infection prevention and control protocols.

BACKGROUND

Ultraviolet germicidal irradiation (UV-C) in various delivery methods has been clearly demonstrated to reduce bacteria. Seminal work published in 1877 showed that bacteria died when exposed to sunlight.[1] In 1924, Coblentz and Fulton published their work on the germicidal effects of ultraviolet radiation.[2] Sharp, in 1939, demonstrated the ultraviolet dosages needed to kill a variety of bacteria.[3] Through the years, investigations became more specific and the study of delivery methods expanded to include upper-room delivery and the development of a mobile emitter.

Kujundzuc et al used aerosolized active bacterial cells and fungal spores to seed a test room. Results showed UV-C lamps inactivated 75% of fungal spores and 97% of bacterial cells within 60 minutes.[4] In a guinea pig study, Escombe et al showed using upper-room UV-C lights prevented TB infections by 70% over the control group with no UV-C.[5]

However, trials in operational hospital settings that demonstrate the effectiveness of continuous (24/7) UV-C in clearing bacteria from the air have been lacking, as have investigations of whether cleaning the air could help reduce health care–associated infections (HAIs). This study was designed to see whether using continuous shielded UV-C at the room level to lower the bioburden in the air would have a positive effect on the rate and type of

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infections in patients in an intensive care unit of a long-term acute care hospital (LTAC).

HAIs present a problem of sizable proportions. The Centers for Disease Control and Prevention (CDC) reported that in 2011 (the most recent year for available data), 721,800 HAIs were recorded. An estimated 75,000 deaths occurred as a result of an HAI.[6] The CDC has made reduction of HAIs a priority.

To protect their patients, health care facilities are actively seeking ways to reduce pathogens that can result in HAIs. Airborne transmission of disease including influenza and tuberculosis has been well documented.[7-9]

In addition to the prevalence of HAIs, health care facilities must face the problem of antimicrobial resistance. The CDC reports that 1 in 4 catheter- and surgery-related HAIs in LTACs is caused by resistant bacteria identified as an urgent or serious threat. These pathogens include carbapenem-resistant *Enterobacteriaceae*, methicillin-resistant *Staphylococcus aureus* (MRSA), extended-spectrum β-lactamase–producing *Enterobacteriaceae*, vancomycin-resistant enterococci (VRE), multidrug-resistant *Pseudomonas*, and multidrug-resistant *Acinetobacter*.[10]

Beyond the cost in human life and health, HAIs create a huge economic impact. Marchetti and Rossiter, in 2013, estimated the cost of HAIs to U.S. society to be $96-$147 billion annually (in 2007 dollars).[11] Zimlichman et al, in a meta-analysis, reported the average attributable per patient costs of *Clostridium difficile* ranged from $9,118-$13,574 and MRSA costs was an average of $42,300 (in 2012 dollars).[12] Scott reported catheter-associated urinary tract infection (CAUTI) costs ranged from $862-$1,007 per incident. Cumulatively, the annual range for all occurrences of CAUTI was $0.39-$0.45 billion.[13]

HAIs also impact a facility's financial situation in a very direct way. The Deficit Reduction Act of 2005 required the listing of conditions that can cause payments by the Centers for Medicare and Medicaid Services to be reduced. Multiple HAIs are included on the list of conditions for 2017.[14,15] Reducing the number of these infections is a top priority for health care facilities, and this concern helped drive this study.

MATERIALS AND METHODS

The study was conducted in the special care unit (SCU) of a 123-bed LTAC in the east southcentral part of the United States. The analysis included comparing a baseline period during which air samples were obtained with a later period during which continuous UV-C room-level air cleaning occurred.

The SCU is this facility's intensive care unit. All patient rooms are negative pressure with single beds, and were occupied during the pre- and postinstallation time frames. All patients were on ventilators with gloves and gown contact precautions used throughout the study. Similar practices and patient acuity were reported for the preinstallation data review. Throughout the study, no additional cleaning or change in cleaning protocols or heating, ventilation, and air conditioning maintenance was reported in any room. Standard cleaning, maintenance, and infection control procedures were followed. Rooms were cleaned daily. Floors were mopped, trash was emptied, and bathrooms were cleaned. Terminal cleaning after patient discharge included cleaning all surfaces. Vaporized hydrogen peroxide was used, and the room was kept closed until a new patient was admitted.

Baseline sampling occurred August 11-12, 2015, when 130 samples from the SCU were collected onto trypticase soy agar plates (Hardy Diagnostics, Santa Maria, CA) for bacterial counts. Five to 9 samples were taken from each location (16 patient rooms, the hallway, and the biohazard room). The biohazard room is used for soiled linen, patient equipment, sharps containers, food trays, and so on. It is approximately 14 m^2 in size and is under negative pressure. Representative areas sampled included next to the patient bed, near the linen cart, at the nightstand, and near the window.

Samples were collected with SAS 180 samplers (BioScience International, Rockville, MD). All samples were run at 1,000 L (approximately 5.5 minutes), and air was collected onto 90-mm sampling plates. As plates were collected, they were packaged with frozen gel packs and shipped overnight to an independent laboratory (Antimicrobial Test Laboratories, Round Rock, TX; now named Microchem).

The sampler works by pulling 1,000 L of air through a 219-hole perforated cover. The air impacts the agar plates, which are coated with blood or other nutrients. The bacteria that impinges on the plates start to reproduce and form colonies. These colonies are counted (raw colony forming units [CFU]). The CFU counts are adjusted for the probability that >1 viable particle was pulled through a single sampling hole and merged with other particles on the plate to produce a single colony. This adjustment is the correction hole factor, standard in the industry.

After baseline sampling was completed, 24 UV-C units (VidaShield; American Green Technology, South Bend, IN) were installed. Sixteen units were installed in patient rooms (1 unit per room installed in the ceiling over the bed). Seven units were installed in the hallway (every other ceiling light was replaced with a UV-C unit), and 1 was in the biohazard room.

The facility had established housekeeping protocols for occupied patient rooms and also for terminal cleaning at patient discharge, but they had no protocol for cleaning the air. Because there was no program to validate American Society of Heating, Refrigerating and Air-Conditioning Engineers air exchanges and percent air recirculation, all air in the SCU was treated, not just that in patient rooms. Air moves freely among patient areas, doors are opened and closed, and hallways exchange air with other areas, including air from outside the building. UV-C units were installed in the biohazard room to reduce odors in the SCU and lessen the amount of circulating bacteria and fungus in the air.

Each unit contains a fully shielded chamber with a UV-C bulb housed atop a standard 2×4 ceiling light fixture. The shielded ultraviolet lamp produces 15 W of high output UV-C energy at a wavelength of 253.7 nm. Each unit has 4 small fans that pull air through a MERV 6 filter on the way to the irradiation chamber, and then the treated air is pushed back into the room. The intake and exhaust baffles are set at a 30° angle, which moves the air in a pattern that avoids repeatedly recirculating the same air and allows for maximum retention time to treat the air in the chamber. The UV-C units run continuously, 24/7, whether the room downlight is on or off. Once the units were installed, operational rooms were reopened for normal patient use.

On November 15 and 16, 2015, 81 and 82 days after installation of the UV-C units, respectively, air sampling was repeated. The study was originally planned for 6 months, and this was about midway through the study period. The study was later extended for 6 more months to collect additional data. Repeat sampling procedures mirrored those in the baseline sampling period.

Infection records for the SCU during the period of September 2014-August 2015 and September 2015-August 2016 were examined. The following were tracked: resistant organisms, possible ventilator-associated pneumonia, central line–associated bloodstream infection, CAUTI, and *C difficile*. The number of patient days with a central line and with a Foley catheter were also recorded.

Infection surveillance data were gathered according to the CDC's National Healthcare Safety Network surveillance definitions and criteria.[16]

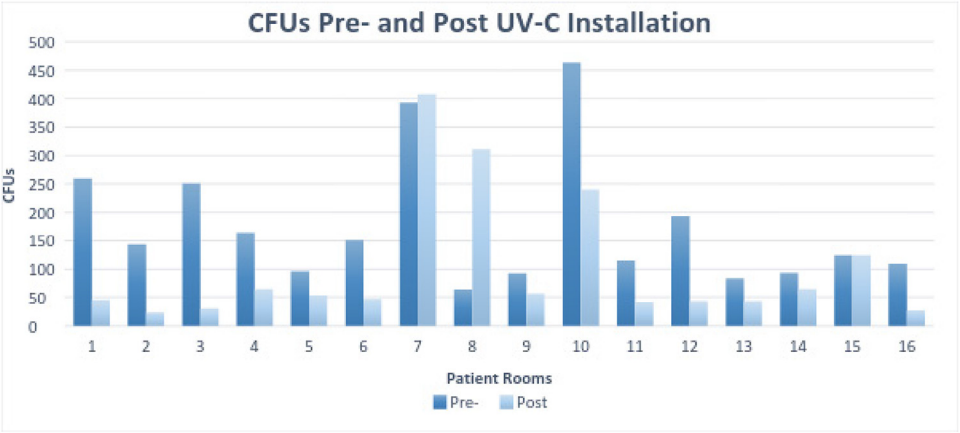

Fig 1. CFUs pre- and postultraviolet germicidal irradiation installation in patient rooms. *CFU*, colony forming units.

Table 1
Air results pre- and postinstallation

Location	Average baseline CFU/m³ corrected	Average postinstallation CFU/m³ corrected	% Corrected change	Difference (%)
Patient rooms	175	102	42 ↓	53
Biohazard room	258	172	33 ↓	40
Hallway	144	77	46 ↓	61

CFU, colony forming units.

RESULTS

XLSTAT software (Addinsoft, New York, NY) was used to compare pre- and postinstallation CFU (corrected) per meter cubed mean values from each area with a 2-tailed independent *t* test. The significance level α was set at 0.05; therefore, any *P* value ≤.05 was statistically significant. The mean CFU meter cubed count from patient rooms revealed an overall significant decrease in bacterial viable air particles by 42% ($P = .035$). Decreases in mean bacterial air particles in the biohazard room (33%) and the hallway (46%) were noted, but these values did not reach the level of statistical significance.

Results for patient rooms are shown in Figure 1.

Table 1 includes the average result for all patient rooms, plus the other areas included in the study.

Infection rates

The infection rate was calculated as number of infections per 1,000 patient days. Table 2 shows the number of infections as well as the infection rate for each month of the study.

DISCUSSION

Health care costs have spiraled upward for decades. HAIs have put patients at risk. We examined whether we could ameliorate both problems by asking whether reducing the pathogens in the air via continuous UV-C at the room level would result in fewer infections in patients.

There has been considerable investigation into the ability of UV-C to disrupt airborne pathogens, but much of that work was conducted in laboratories with seeded environments and selected contaminants, and not in an operational hospital setting. For example, Xu et al reported that ultraviolet germicidal irradiation reduced the room average concentration of culturable airborne bacteria between 46% and 98%, depending on the particular bacterium collected and the ventilation rate of the room.[17] Riley and Permutt conducted a study wherein a model room was aerosolized with *Serratia marcescens* and the effects of UV-C and ceiling fans were investigated. They concluded that moving the air with a large-bladed ceiling fan almost doubled the rate at which organisms were killed.[18] Tseng and Li reported on using UV-C against aerosolized viruses (4 different bacteriophages) in a laboratory test chamber. They concluded that airborne virus could be effectively inactivated with a UV-C dose recommended by the American Conference of Governmental Industrial Hygienists.[19] Miller et al found UV-C to be very effective at inactivating airborne bacteria in a full-scale test room environment.[20]

Anderson reported that in a cluster randomized, crossover trial at 9 U.S. hospitals, adding UV-C to standard cleaning protocols resulted in a significantly lower incidence of multidrug-resistant organisms (33.9 cases per 10,000 exposure days; relative risk, 0.70; 95% confidence interval, 0.50-0.98; $P = .036$).[21] Although this study was done in a live hospital setting, the UV-C delivery method was a mobile UV-C light emitter, which cannot be used in occupied space.

Our study was to explore the efficacy of implementing shielded UV-C at the patient room level where various pathogens are generated or brought into the patient environment by staff and visitors. The results showed a significant reduction in overall airborne bacteria. The success of this intervention is further bolstered by the reduction in overall infection rates for the 12 months of UV-C use versus the preceding 12-month period, without UV-C. Hospital infection control staff report no changes to cleaning protocols during that time. The maintenance staff also did not report any heating, ventilation, and air conditioning system changes during the study period.

We observed that although the infections reduced during our study are not those typically thought of as resulting from airborne transmission, they represent some of the expensive and aggressive HAIs. As Table 3 shows, not all HAI reduction achieved significant *P* value levels, but a clear trend is evident. Although fomites were not the focus of our study, the connections between airborne particles and resuspended particles are cogent to this work.

Roberts et al reported clear evidence of aerial dissemination of *C difficile* spores.[22] Kramer et al reported that most gram-positive bacteria, including MRSA and VRE, can survive on dry surfaces for months. Spores of *C difficile* can survive on surfaces for as long as 5 months.[23]

Table 2
Total infections and infection rate pre- and postinstallation of UV-C units

Pre–UV-C installation			Post–UV-C installation		
Date	No. of infections	Rate	Date	No. of infections	Rate
September 2014	5	11.26	September 2015	5	11.66
October 2014	8	18.78	October 2015	8	21.8
November 2014	10	22.99	November 2015	3	7.35
December 2014	15	41.32	December 2015	2	4.23
January 2015	14	29	January 2016	0	0
February 2015	7	16.39	February 2016	1	2.4
March 2015	10	20.79	March 2016	2	4.8
April 2015	5	11.29	April 2016	6	14.22
May 2015	6	13.48	May 2016	5	12.5
June 2015	9	19.82	June 2016	2	6.06
July 2015	7	16.47	July 2016	6	13.16
August 2015	10	22.57	August 2016	2	6.17
Total	106			42	
Average	8.833333	20.34667		3.5	8.695833

NOTE. The number of INFECTIONS have a *P* value of 0.00 and the infection RATE (per 1000 patient days) is 0.001. Student *t* test, 2-tailed *P* value infection rate .001.
UV-C, ultraviolet germicidal irradiation.

Martinez et al considered the environment as a risk factor for VRE, and concluded that among all other factors associated with VRE transmission, VRE acquisition may depend on room contamination, even subsequent to extensive cleaning.[24]

Hospodsky et al reported that direct human shedding may significantly impact the concentration of indoor air particles, especially in floor dust, which can then become resuspended in the air.[25] Nazaroff's keynote address at the Indoor Air 2014 meeting reviewed many similar studies that concluded fomites are a significant source of bioaerosols.[26]

Shiomori et al demonstrated that MRSA bacteria can recirculate through the air,[27] and that MRSA that has settled from the air onto surfaces can become airborne again when, for example, bedsheets are agitated by patient movement or bed making.[28]

Studies such as these help explain the sharp reduction in infections generally thought to be the result of person-to-person contact. Pathogens can persist for many months on surfaces, and have the potential to become airborne when disturbed. Our study suggests that cleaning the air may have a positive impact on contamination, which in turn can lead to lowered rates of infection.

Once the initial installation of the UV-C units is complete, only annual maintenance is required, which is changing the UV-C bulb and filter. As an engineering control, the cleaning effect of the unit is not dependent on any staff procedure or initiation.

Study limitations include the unpredictable conditions in a live setting. It is possible that staff became extremely vigilant about hand hygiene, for example, or made other behavioral changes to lessen the infection rate; however, none were reported by staff. Also, during September and October 2015, it was discovered that not all UV-C units were on dedicated circuits for the UV-C. In such cases, the UV-C cleaning would stop when the overhead light was switched off. This was corrected in October 2015.

Table 3
Specific organisms and infections pre- and postinstallation

Organism-infection	Preinstallation (cases)	Postinstallation (cases)	Student *t* test, 2-tailed *P* value
Clostridium difficile	8	1	.01
CAUTI	20	9	.012
MRSA	13	6	.107
CLABSI	16	9	.226
VRE	7	6	.764

CAUTI, catheter-associated urinary tract infection; *CLABSI*, central line–associated bloodstream infection; *MRSA*, methicillin-resistant *Staphylococcus aureus*; *VRE*, vancomycin-resistant enterococci.

CONCLUSIONS

Although this study does not claim that the UV-C devices were directly and solely responsible for this dramatic reduction in infections, the decrease in airborne bacteria after installation is significant and a possible connection is postulated. Patient morbidity and financial costs and penalties may be lessened or avoided. More studies are needed to corroborate this finding.

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