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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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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]