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Major article

The effectiveness of UV-C radiation for facility-wide environmental disinfection to reduce health care–acquired infections

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Background: Health care–acquired infections (HAIs) constitute an increasing threat for patients worldwide. Potential contributors of HAIs include environmental surfaces in health care settings, where ultraviolet-C radiation (UV-C) is commonly used for disinfection. This UV-C intervention-based pilot study was conducted in a hospital setting to identify any change in the incidence of HAIs before and after UV-C intervention, and to determine the effectiveness of UV-C in reducing pathogens.

Methods: In a hospital in Culver City, CA, during 2012-2013, bactericidal doses of UV-C radiation (254 nm) were delivered through a UV-C–based mobile environmental decontamination unit. The UV-C dosing technology and expertise of the specifically trained personnel were provided together as a dedicated service model by a contracted company. The incidence of HAIs before and after the intervention period were determined and compared.

Results: The dedicated service model dramatically reduced HAIs (incidence difference, 1.3/1000 patient-days, a 34.2% reduction). Reductions in the total number and incidence proportions (28.8%) of HAIs were observed after increasing and maintaining the coverage of UV-C treatments.

Conclusion: The dedicated service model was found to be effective in decreasing the incidence of HAIs, which could reduce disease morbidity and mortality in hospitalized patients. This model provides a continuously monitored and frequently UV-C–treated patient environment. This approach to UV-C disinfection was associated with a decreased incidence of HAIs.

Infections acquired by a patient from the health care environment and distinctly different from those with which the patient presented are defined as health care–acquired infections (HAIs).[1] HAIs constitute an increasing threat to hospitalized patients globally.[2] Worldwide, these infections claim the lives of tens of thousands of people each year owing to their complex pathogenesis and usual resistance to common treatments.[3] HAIs have been found to double the mortality and morbidity risks of any admitted patient, and to result in an approximately 90,000 deaths annually in the United States.[4] In addition, these infections result in additional costs to health care institutions and their patients.[5]

Based on a previous study, environmental surfaces in hospitals seem to be among the potential contributors for the transmission of pathogens to hospitalized patients, by providing a reservoir for contamination.[6] Direct contacts with contaminated surfaces and health care workers are the proposed modes of such transmission.[6] Currently, traditional environmental cleaning along with development of awareness and education regarding hygiene and sanitation, including proper handwashing, are considered the primary prevention methods for the reduction of HAI risk. Unfortunately, however, the effectiveness of these strategies often varies.[7,8] Thus, the development of an effective disinfection method for health care facilities is critical to ensure efficient reduction of HAI risk for patients.

To address this need, numerous studies have demonstrated the effectiveness of ultraviolet-C radiation (UV-C) in eradicating a

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Conflict of interest: N.A.N. reports that at the time of this writing, he is an employee of Hollywood Community Hospital at Brotman Medical Center (HCH/BMC). N.A.N. is not a shareholder, officer, or employee of Clean Sweep Group Inc. W.T. reports that he received funding from Clean Sweep Group Inc. W.T.'s sole responsibility is statistical analysis of epidemiology data from the HCH/BMC pilot study. He is not a shareholder, officer, or full-time employee of Clean Sweep Group Inc or HCH/BMC. The funding body played no role in study design, data collection (data were based on computer records), data analysis and interpretation, writing of the report, or the decision to submit the manuscript for publication. T.M. reports no conflicts of interest.

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variety of bacterial species.[9,10] On exposure to UV-C, the DNA and RNA of the microorganisms are "deactivated" by the absorption of photons.[11,12] In the present study, we used a mobile environmental decontamination unit that delivers lethal doses of 254-nm UV-C radiation to eliminate harmful pathogens. The objective of the study was to evaluate the effectiveness of implementing hospital-wide UV-C treatment for environmental disinfection in reducing the incidence of HAIs.

METHODS

This pilot study was conducted over a 6-month period, from October 2012 to March 2013, at Hollywood Community Hospital/Brotman Medical Center Campus (HCH/BMC) in Culver City, CA. HCH/BMC is a licensed health care facility that provides acute and subacute care to Culver City, West Los Angeles, and the surrounding communities. HCH/BMC is licensed for 420 beds, has a daily census of 180-200 patients, and admits approximately 9000 patients per year. All acute care units, including 239 beds and 125 patient rooms, were included in the present study.

This pilot program developed and implemented a dedicated service model. This model was defined by 3 components: (1) use of a web-based data and job monitoring tool, SteriTrak, which allowed for UV-C treatment scheduling, data review, reporting, and device utilization analysis; (2) UV-C dosing technology delivered by the UV-C–based mobile environmental decontamination unit (IRiS 3200m; Infection Prevention Technologies, Auburn Hills, MI), in conjunction with a Nautiz X5 hand-held controller (Handheld Group, Lidköping, Sweden) and door motion modules; and (3) dedicated UV-C device technicians, nonenvironmental services staff contracted through Clean Sweep Group, Inc (CSGI) and trained specifically to manage and operate the UV-C device.

The IRiS 3200m is a wheeled mobile device that uses 16 vertically mounted 200 W amalgam lamps to deliver a measured dose of 254-nm UV-C electromagnetic energy. The unit did not require repositioning within the treatment space. The duration of treatment depended on room volume, reflectivity of surfaces, and measurement of UV-C.

The technicians were protected from UV-C exposure through the safeguards engineered into the IRiS 3200m, which includes motion-sensing technology used in both the 3200m and the door motion sensors, which automatically extinguishes all UV-C–emitting lamps when motion is detected. The CSGI technicians and the HCH/BMC epidemiologist were responsible for monitoring HAIs and for scheduling, implementing, and tracking environmental disinfection.

In this study, bacterial identification and sensitivity to antibiotic testing were done for common health care–acquired pathogens. All of the data analyzed in this study were collected from in-patient medical records. The study involved no patient care or treatments.

Phase 1: Efficacy trial

This phase occurred in the months leading up to the pilot study to assess the microbial reservoir after terminal cleaning of the environment by the environmental services (EVS) staff, and to test the efficacy of the IRiS 3200m in delivering lethal doses of UV-C electromagnetic energy. A sequential series of 54 environmental cultures were swabbed in empty inpatient isolation rooms. An adenosine triphosphate (ATP) hygiene monitoring tool (System-SURE Plus; Hygiena, Camarillo, CA) was used to identify contaminated surfaces; the swab locations for samples B and C were fixed to match that for sample A. The swabbing technique consisted of using sterile Amies gel transport medium swabs to culture a 2 × 2 inch square area in a cross-serpentine pattern on 9 adjacent "high-touch" sites (eg, bed rails, door knobs, call buttons, vital sign monitors, bedside tables) immediately after discharge (sample A) in a total of 6 rooms. Successive sets of cultures were swabbed after normal environmental cleaning (sample B) and then once again the room had been treated with UV-C (sample C). The decontamination interventions before collection of samples B and C were administered in accordance with recommended standard procedures.

Table 1
Number of samples obtained during the phase 1 efficacy trial

Patient room	Surface 1*	Surface 2*	Surface 3*	Total swabs
A	Bed rail	Bed table	Bathroom floor	9
B	Room door handle	Hamper lid	Toilet handle	9
C	Room door handle	Bed rail	Bathroom door handle	9
D	Bathroom door handle	Bed rail	Bed table	9
E	Call button	Bathroom faucet handle	Bed table	9
F†	Keyboard	Bedside phone	Counter	9
Total				54

*Three swabs per surface: before EVS, after EVS, and after UV-C.
†Nursing station.

Because this study did not attempt to compare the environmental contamination of surfaces between the patient rooms and used ATP measurement to determine remaining levels of ATP after different types of room disinfection, samples were collected from different surfaces within the same room to capture a variety of high-touch surfaces. As a result, the surfaces sampled varied among the rooms.

Samples A consisted of cultures taken after the discharge of the patient in isolation and before EVS terminal cleaning to assess baseline microbial contamination. Samples B comprised cultures taken adjacent to matched A and C samples, after EVS terminal cleaning and before UV-C disinfection. Samples C comprised samples taken adjacent to matched A and B samples, after UV-C disinfection.

The microbiology laboratory at HCH/BMC processed the environmental cultures obtained during the efficacy trial. The rooms, locations, and quantities of swabs used for the efficacy trial are listed in Table 1.

Phase 2: Pilot study

Location for disinfection

The pilot study included multiple areas, including cardiac and surgical intensive care, cardiac/telemetry, medical/surgical, and acute rehabilitation units, and concentrated on every ICU room with a discharge, regardless of the patient's isolation status, and every non-ICU room from which a patient on isolation precautions had been discharged.

Method of disinfection

The IRiS 3200m with SteriTrak was used for disinfection in this pilot study. To test the correlation between the coverage of UV-C treatment and HAI reduction, facility-wide patient rooms were identified at the beginning of the study and defined based on the type of unit in which the room was located, and whether the inpatients in these units were screened for infection-causing pathogens and could be isolated and tracked for the duration of the study. Here we defined the coverage of treatment as the proportion of the treated rooms out of the total rooms that were eligible for treatment (coverage = number of treated room/total rooms eligible for treatment × 100%). All facility-wide acute and critical care units (ICU, telemetry, step-down, medical-surgical, and rehabilitation)

Table 2
Percentage of hospital rooms included in the effectiveness analysis in 1 hospital

Month	Percent (n/N)
October 2012	68 (85/125)
November 2012	92 (115/125)
December 2012	100 (125/125)
January 2013	100 (125/125)
February 2013	100 (125/125)
March 2013	100 (125/125)

were included; and nonacute or non-inpatient units (psychiatric, emergency, and operating rooms) were excluded. Patient rooms that were identified for inclusion in this study were treated with UV-C once the previous patients had been discharged, and the rooms were terminally cleaned by EVS.

A total of 125 rooms were included in the facility-wide study for which the HAI incidence data were used to determine the effectiveness of the intervention. However, owing to workload issues, we could not cover all rooms at the beginning, and we finally covered all of them at the third month of the intervention (Table 2). To make the control period and intervention period comparable, the rooms that were not covered in the first 2 months of the intervention period also were not included in the control period.

Standard process for disinfection of hospital rooms

During the study, when a patient was discharged, after the terminal cleaning (bioload removal) of the room and before admission of the next patient, the UV-C intervention was performed using the IRiS 3200m unit. The disinfection process involved 4 steps:

1. Room staging. In this step, furniture and clinical equipment were staged within the space to receive maximum UV-C exposure.
2. Safety protocol initiation. The space was then cleared of all people, and a door motion sensor was placed on each entrance. This eliminated the risk of UV-C exposure to staff, because activation of a door monitor would automatically shut down the UV-C unit.
3. Device implementation. CSGI technicians positioned the IRiS 3200m within the space to maximize the disinfection efficacy.
4. Device activation. CSGI technicians activated the IRiS 3200m remotely from outside the room. The machine then initiated the programmed cycle. Once the cycle was completed, the machine shut off automatically, and the room was deemed disinfected and ready for the next admission. The IRiS 3200m uses 2 treatment settings, one for vegetative organisms (vegetative treatment) and the other for spore-forming organisms (spore treatment). The treatment setting was determined by the type of isolation sign posted on the door, specifying whether the identified pathogen was vegetative or spore-forming. The mean vegetative and spore-forming treatment times for the patient care area square footage within the facility were 8 minutes and 18 minutes per patient room, respectively.

Definitions of HAIs, incidence proportion, and incidence rate

The following inclusion criteria were used by HCH/BMC to identify HAIs at baseline and intervention stages: (1) cultures collected after 48 hours of admission; (2) diagnosis at admission different from the HAI diagnosis; and (3) colonization or infection contributing to increased length of hospital stay. Patients who met all of these criteria were treated as incident cases in this study. The incidence proportion was defined as the number of HAI cases divided by the total number of hospitalized patients. The incidence rate was defined as the number of HAI cases (or incidence cases) divided by the total patient-days for the hospitalized patients.

Table 3
Incidence rate of HAI at baseline and follow-up for patients at 1 hospital

Time	Number of HAIs	Patient-days	Incidence rate (per 1000 patient-days)
Baseline (10/2011- 2/2012)	66	17,933	3.7
Study period			
October 2012	13	3010	4.7
November 2012	7	2748	2.6
December 2012	4	2947	1.4
January 2013	6	3335	1.8
February 2013	7	3268	2.2
March 2013	7	2876	2.4
Overall	44	18,184	2.4

Data analysis

All data analysis was done with SAS version 9.3 (SAS Institute, Cary, NC). Poisson regression was used to analyze the relationship between the coverage of the UV-C treatment and the incidence of HAIs, with HAI incidence during the study period serving as the dependent variable and treatment coverage as the independent variable. The 2-sample t test was applied to test the statistical significance of the disease reduction. To estimate the overall reduction in HAI rate, we treated the proportion of HAIs in the control period as 100%, and by comparing the actual number of observed HAIs during the intervention period with that in the control period, we got the proportion of HAIs for the intervention period. We then used the 2-sample t test to test the difference between these 2 proportions.

To calculate the incidence rate reduction, we first determined the expected number of cases without intervention for the intervention period using the following formula: number of expected cases for the intervention period without intervention = incidence rate at baseline $\times$ total person-time observed at intervention period. We considered the proportion of expected cases for the intervention period without intervention to be 100%, and by comparing the actual number of HAIs during the intervention period with the expected number of cases for the intervention period without intervention, we determined the actual disease proportion. We then used a 2-sample t test to test the difference between these 2 proportions. We used a similar method for incidence proportion-based detection of disease reduction.

RESULTS

A total of 54 environmental samples were included in this efficacy trial (Table 1). Among these, A samples yielded growth on 55.6% of samples (10/18 positive for growth), B samples yielded growth on 50% of samples (9/18 positive for growth), and C samples yielded growth on 11.1% (2/18 positive for growth). There was no statistical difference in the number of positive cultures before and after EVS terminal cleaning ($P = 1.0$, t test). Significantly fewer positive environmental cultures were collected after the UV-C intervention compared with after EVS terminal cleaning ($P = .03$).

The intervention period spanned October 1, 2012, to March 31, 2013. During this period, 44 HAIs were detected in 3011 patients throughout the facility, and a total of 18,184 patient-days were accumulated, with an incidence proportion of 1.5% and an incidence rate of 2.4/1000 patient-days (Table 3). Eighty-five patient rooms out of a total of 125 patient rooms (68.0%) were disinfected in October, 115 patient rooms (92.0%) were disinfected

Table 4
Case reduction for each specific pathogenic organism based on incidence proportion

Study organism	Baseline infection count	Intervention infection count	Baseline incidence rate	Intervention incidence rate	Incidence rate change, %	*P**
A baumannii	7	2	0.39	0.11	−71.80	.005
C difficile	22	12	1.23	0.66	−46.20	<.001
K pneumoniae	8	0	0.44	0	−100.00	<.001
MRSA	7	7	0.39	0.38	−1.20	1
VRE	18	16	1	0.88	−12.30	.14

*Two-sample *t* test.

in November, and all 125 patient rooms (100%) were routinely disinfected from December 2012 through March 31, 2013.

The results demonstrate that the number of HAIs decreased significantly with the increased coverage of UV-C treatments (P <.001, Poisson regression analysis).

HAI reduction

Overall case reduction

To determine overall HAI reduction, we used the pre-intervention number of HAIs as the expected baseline of HAIs for the intervention period. Under this assumption, compared with baseline, the UV-C treatments resulted in a 33.3% reduction in the number of HAI cases (P <.001). This reduction was determined by comparing the baseline number of 66 HAIs with the 44 HAIs detected during the intervention period [100% - {(44/66) × 100%}].

HAI incidence proportion reduction

At baseline, 66 HAIs were detected among the 3215 patients facility-wide, for an HAI incidence proportion of 2.0%. Using the incidence proportion of HAIs at baseline, we expected to identify 66 HAIs during the intervention period [(66/3215) × 3011]. The incidence proportion during the intervention period was 1.5% (44 HAIs out of 3011 patients). Compared with baseline, the intervention resulted in a statistically significant HAI reduction of 28.8%.

HAI incidence rate reduction

During the intervention period, 44 HAIs were identified in a total of 18,184 patient-days, for an overall incidence rate of 2.4 per 1000 patient-days. Using the HAI incidence rate at baseline, we expected to identify 66 HAIs during the intervention period [(66/17,933) × 18,184]. Compared with the baseline period, the reduction in incidence rate was 34.2% (3.7 per 1000 patient-days during the baseline period; Table 3), which was statistically significant (P <.001).

HAI reduction for specific organisms

Table 4 presents case reduction data for each specific pathogenic organism based on the incidence proportion calculated in this study. We found significant reductions in HAIs associated with 3 of the 5 identified organisms, including a 71.4% decrease for *Acinetobacter baumannii*, a 42.7% decrease for *Clostridium difficile*, and a 100.0% decrease for *Klebsiella pneumoniae*. We found no statistically significant reductions in HAIs caused by methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococcus* (VRE).

DISCUSSION

Overall, the dedicated service model intervention at HCH/BMC was potentially correlated with a statistically significant reduction in the overall number of HAIs caused by *A baumannii*, *C difficile*, and *K pneumonia*. Previous studies have indicated that malignant diseases, immune deficiencies, diabetes, and various necessary procedures in hospitalized patients may increase the risk for HAIs.[13-15] HAIs can increase disease morbidity and mortality in these patients, which could lead to poor disease recovery and also extend the total number of days needed to provide care for these patients. All of these factors might have significantly increased the average length of stay, morbidity, and mortality of patients. Through the implementation of dedicated service model, a reduction in incidence proportion and rate of HAIs was observed.

In this study, statistically significant reductions in HAIs associated with 3 of 5 organisms were identified. Moreover, reductions in MRSA and VRE cases were identified as well, although these reductions were not statistically significant. To further reduce HAIs, more studies, including studies specifically targeting MRSA and VRE, are needed.

This study was based on data generated under the normal working conditions, processes and HAI definitions of the hospital. Furthermore, we used the hospital's archival HAI data between October 2011 and March 2012 to establish the baseline parameters. By doing so, we were able to compare year-to-year data that accounted for seasonal variance.

The dedicated service model used for this study removed the common practice of adding UV-C management on to the already heavy workload of the EVS staff. This model allowed for increased UV-C device utilization and the efficient application of facility-wide treatments.

As an observational study, this pilot study had several limitations. First of these was the lack of inpatient screening, because we were not able to identify patients who might have been admitted with colonization or infection. Instead, we used surveillance definitions and criteria set by the Centers for Disease Control and Prevention's National Healthcare Safety Network, in which an infection is considered an HAI if the date of occurrence of the site-specific infection criterion was on or after the third calendar day of admission to an inpatient location, with the day of admission as calendar day 1. A second limitation was that the potential confounders could have existed for infection control and prevention through both clinical practice and EVS, owing to the variability in hospital staff members' individual practices and behaviors.

CONCLUSION

In summary, the dedicated service model piloted at HCH/BMC was potentially associated with a significant decrease in HAIs associated with 3 of the 5 organisms identified. Our data also showed a decrease in the HAI incidence proportion and incidence rate at HCH/BMC. Potential cofounders might have existed owing to our inability to control them while conducting the study in a functioning hospital, as well as owing to the variation in behaviors among staff members. The efficacy of UV-C radiation technology as a disinfection tool is widely accepted; however, future research focused on implementing UV-C technology in health care settings needs to determine its accurate preventive capacity and long-term benefits.

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