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Major Article

Clinical, operational, and financial impact of an ultraviolet-C terminal disinfection intervention at a community hospital

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Cost analysis
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UV-C disinfection
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Background: Hospital-acquired infections (HAIs) are a significant contributor to adverse patient outcomes and excess cost of inpatient care. Adjunct ultraviolet-C (UV-C) disinfection may be a viable strategy for reducing HAIs. This study aimed to measure the clinical, operational, and financial impact of a UV-C terminal disinfection intervention in a community hospital setting.

Methods: Using a pre-post study design, we compared the HAI rates of 5 multidrug-resistant bacteria (*Acinetobacter baumannii*, *Klebsiella pneumoniae*, methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant *Enterococcus*, and *Pseudomonas aeruginosa*) from 6 culture sites before and after a 12-month facility-wide UV-C intervention. To measure impact of UV-C disinfection on hospital operations, mean inpatient emergency room wait time was calculated. Finally, we conducted a cost saving analysis to evaluate the financial benefits of the intervention.

Results: Overall, 245 HAIs among 13,177 inpatients were observed during a 12-month intervention period, with an incidence rate of 3.94 per 1,000 patient days. This observed HAIs incidence was 19.2% lower than the preintervention period (4.87 vs 3.94 per 1,000 patient days; $P = .006$). The intervention did not adversely impact emergency department admissions (297.9 vs 296.2 minutes; $P = .18$) and generated a direct cost savings of $1,219,878 over a 12-month period.

Conclusions: The UV-C disinfection intervention was associated with a statistically significant facility-wide reduction of multidrug-resistant HAIs and generated substantial direct cost savings without adversely impacting hospital operations.

Hospital-acquired infections (HAIs) are highly associated with increased mortality, morbidity, length of inpatient stay, and associated cost.[1-3] HAIs may be caught during routine inpatient acute care, and many are preventable. An estimated 722,000 infections are caught by hospital inpatients each year in the United States, of which approximately 75,000 die during hospitalization.[4] In addition, hospitals' inpatient cost of care attributable to HAIs is often not reimbursed, which significantly increases the financial burden to hospitals.[4,5] New methods to reduce HAIs are needed.[6]

A previous study estimated that approximately 20%-40% of HAIs come from exogenous sources (eg, patient environment, hands of health care workers),[7] and subsequent research shows the hospital environment plays a role in the intrahospital transmission of numerous HAI-causing multidrug-resistant organisms (MDROs).[8] MDROs can survive on inanimate surfaces for days to months, are incompletely removed during terminal disinfection, and contaminate mobile clinical equipment and the hands of health care providers.[8-10] Direct evidence of horizontal MDRO transmission is summarized in a meta-analysis wherein 6 multidrug-resistant bacterial species, including *Acinetobacter baumannii*, *Klebsiella pneumoniae*, methicillin-resistant *Staphylococcus aureus* (MRSA),

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Pseudomonas aeruginosa, vancomycin-resistant *Enterococcus* (VRE), and *Clostridium difficile*, are associated with increased risk of patient acquisition from a prior room occupant.[11] Other studies also indicated that improvements of environmental hygiene are associated with decreased risk of pathogen acquisition.[12,13]

With the advance of no-touch disinfection technology, mobile ultraviolet-C (UV-C) (UV-C light at 254 nm) disinfection devices and other automated technologies are increasingly common as adjunct environmental disinfectant methods.[14,15] Previous studies have proven UV-C devices are germicidal against numerous MDROs and can reduce bioburden when used as an adjunct to standard terminal cleaning protocols.[14,16-18] To date, 6 studies have demonstrated endemic HAI reductions associated with UV-C disinfection interventions, including 1 multifacility randomized controlled trial.[13,18-22] HAI reductions have been reported for MRSA, VRE, *A baumannii*, *K pneumoniae*, and *C difficile*. However, to our knowledge, no study has examined the site of infection or assessed the financial benefits of UV-C interventions, and this information is very important for policy makers.[23]

The purpose of this study is to conduct a comprehensive assessment of a UV-C disinfection intervention at a community hospital, using a pre-post study design.

METHODS

Settings

Following previous studies, we used the following criteria to define HAIs: (1) cultures collected after 48 hours of admission, (2) diagnosis at admission different from HAI diagnosis, and (3) colonization or infection contributing to increased length of hospital stay.[13,18] Patients who met all of these criteria were treated as HAI cases in this study.

The pre-post designed study was completed at Providence Holy Cross Medical Center in Mission Hills, California, a 377-bed community hospital. The preintervention data were collected between April 2015 and March 2016, whereas the intervention was implemented during April 2016 and March 2017. The preintervention and intervention data were extracted from hospital medical records. We compared the HAI rate of 5 key MDROs before and after a facility-wide UV-C disinfection intervention implemented by specialized operators.

Intervention

UV-C disinfections were completed as an adjunct step after standard terminal disinfection protocols in all acute care inpatient units, excluding maternity and nursery units, from April 2016-March 2017. All inpatient transfers from intensive care units (ICUs) had the highest priority for UV-C disinfection. Inpatient rooms from non-ICU units, including telemetry, medical-surgical, and oncology, with nonstandard transmission precautions had second priority. Non-ICU inpatients rooms with standard precautions had last priority. Operating and emergency rooms were treated on a weekly schedule that varied throughout the intervention.

All UV-C disinfections were performed by specialized operators contracted from Clean Sweep Group, Inc using Skytron IPT UV-C devices (Skytron, Grand Rapids, MI). UV-C operators used the Clean Sweep Group, Inc (Los Angeles, CA) Automated Management Platform to electronically determine room disinfection priority as previously listed and follow a universal operational protocol.

During the study period, there were no changes to environmental services standard terminal disinfection protocols. Additionally, there were no changes in the transmission precautions or disease surveillance protocols. Also, no new handwashing plan for the health care providers was initiated during the intervention period.

MEASURES

Intervention measures

Routine operation data for the UV-C intervention were recorded, including disinfection duration and frequency per location. Impact on facility operations was measured by comparing inpatient emergency room wait time and duration from decision-to-admit to emergency room departure during the preintervention and intervention periods.

Clinical measures

The HAI incidence rate of 5 MDROs was calculated facility-wide in aggregate, per species, and per culture site. *C difficile* was excluded from the analysis because of variation in the microbiologic testing during the pre- and postintervention period.

HAIs were determined from index clinical cultures per species and culture site taken 3 calendar days or later after hospital admission. Nonindex clinical cultures for each patient were excluded, including samples 6 months prior to the preintervention for readmitted study patients or those present while the study began. The same HAI surveillance criteria were used for the pre- and postintervention periods.

Excluding the maternity and nursery units, all inpatients were included in the study. Patient days and inpatient stays were determined from the hospital's inpatient census records.

The aggregate, per study organism, and per culture site HAI incidence per 1,000 patient days before and after the UV-C disinfection intervention were calculated separately, by dividing the total number of HAIs by the number of total patient days and multiplying by 1,000.

Data analysis

All data analysis was done with SAS version 9.3 (SAS Institute, Cary, NC). To calculate the HAI 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 is equal to the incidence rate at preintervention multiplied by the total person-time observed at the 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. The χ^2 test was used to test the difference between these 2 proportions.

Cost savings analysis

The framework for measuring cost savings of the UV-C intervention was adopted from Spencer et al, wherein the estimated hospital cost savings (cost avoidance) is determined by the difference in expected versus observed HAI patient stays.[15]

The method to calculate excess cost per MDRO HAI patient stay was adapted from the O'Brien et al formula for secondary case (HAI) *C difficile* infections: excess inpatient length of stay multiplied by the mean cost of inpatient stay per day.[24] Excess length of stay was determined by comparing the MDRO HAI patients' All Patients Refined Diagnosis Related Groups expected length of stay versus the observed length of stay, and a hospital-specific estimate of mean cost per day was used in the calculation. Patients with hospital-acquired *C difficile*, or other hospital-acquired organisms, were not included in the cost analysis unless they met the surveillance criteria of the 5 MDROs previously described, in which case the hospital-acquired organism is an unmeasured comorbidity as explained in the discussion section. The intervention cost was not subtracted from the reported cost savings.

Ethical statement

This study was funded and approved by Providence Holy Cross Medical Center. Inpatients were not directly involved in this study; therefore, no inform consent was obtained from the study population.

RESULTS

Intervention measures

Overall, 8,449 room disinfections were completed during the intervention period, with a mean of 23.15 room disinfections per day. The mean room disinfection duration for the measured organisms was 10.1 ± 4.3 minutes. In addition, 84.6% (n = 7,150) of disinfections were in inpatient rooms, 3.2% (n = 269) were scheduled disinfections in the operating room, 11.1% (n = 936) were completed in the emergency room, and the remainder were completed in auxiliary spaces (1.1%, n = 94). In addition, we found that sex and race were slightly different between the patients in the preintervention period and the intervention period (Table 1).

Mean inpatient emergency room stay time was similar between the preintervention period (297.9 ± 101.4 minutes) and the intervention period (296.2 ± 101.4 minutes) ($P = .18$). However, mean duration from inpatient decision-to-admit to emergency room departure slightly increased from 115.9 ± 60.6 minutes to 119.2 ± 68.4 minutes ($P < .001$).

Clinical measures

Overall, a total of 313 HAI cases were identified during the preintervention period, with a total number of patient days of 64,262 and an HAI incidence of 4.87 per 1,000 patient days. During the intervention period, a total of 245 HAI cases were identified, with a total number of patient days of 62,242 and an HAI incidence of 3.94 per 1,000 patient days. The facility-wide HAI incidence rates of all

Table 1
Preintervention and intervention period study population characteristics

Characteristics		Preintervention (n = 12,747)	Intervention (n = 13,177)	*P* value
Mean age ± SD*		62.9 ± 19.9	62.5 ± 19.8	.10
Female sex†		6,479 (50.8)	6,486 (49.8)	.025
Race	White	6,303 (49.4)	6,117 (46.4)	<.001
	Black	615 (4.8)	572 (4.3)	
	Asian	535 (4.1)	603 (4.5)	
	Pacific Islander	103 (0.8)	109 (0.8)	
	Native American	12 (0.09)	11 (0.08)	
	Other	4,996 (39.1)	5,512 (41.8)	
	Unknown, patient refused, or missing	183 (1.4)	253 (1.9)	

NOTE. Values are n (%) or as otherwise indicated.
*Age not available for 259 inpatients (preintervention: n = 96; intervention: n = 163).
†Sex not available for 248 inpatients (preintervention: n = 93; intervention: n = 155).

Table 2
Facility-wide aggregate hospital-acquired infection rate per 1,000 patient days from target multidrug resistant organisms

Period	Inpatient stays	MDRO-HAIs	Patient days	MDRO-HAI rate
Preintervention	12,747	313	64,262	4.87
Intervention	13,177	245	62,242	3.94
Rate difference (*P* value)	N/A	N/A	N/A	0.93 (.007)

MDRO-HAI, multidrug-resistant organism hospital-acquired infection; *N/A*, not applicable.

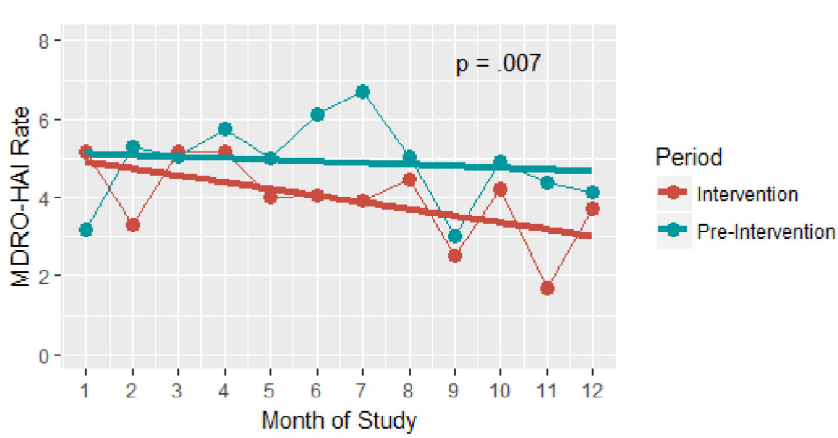

Fig 1. Monthly facility-wide hospital-acquired infection rate per 1,000 patient days per target multidrug-resistant organism per study period. *MDRO-HAI*, multidrug-resistant organism hospital-acquired infection.

target organisms were 19.2% lower in the intervention period than the preintervention period (4.87 vs 3.94 per 1,000 patient days, respectively), with a rate difference of 0.93 (95% confidence interval, 0.20-1.67, $P = .007$) per 1,000 patient days (Table 2, Fig 1).

Table 3
Facility-wide hospital-acquired infection rate per 1,000 patient days per target multidrug-resistant organism

MDRO	Preintervention rate (HAIs)	Intervention rate (HAIs)	*P* value	% change
AB	0.34 (22)	0.16 (10)	.03	–53.07
KP	1.16 (73)	1.22 (76)	.36	7.49
MRSA	1.42 (91)	0.98 (61)	.02	–30.79
PA	1.29 (83)	1.16 (70)	.22	–12.93
VRE	0.68 (44)	0.45 (28)	.05	–34.30

AB, *Acinetobacter baumannii*; *KP*, *Klebsiella pneumoniae*; *MRSA*, methicillin-resistant *Staphylococcus aureus*; *PA*, *Pseudomonas aeruginosa*; *VRE*, vancomycin-resistant *Enterococcus*.

Table 4
Facility-wide hospital-acquired infection rate per 1,000 patient days per culture site

Culture site	Preintervention rate (HAIs)	Intervention rate (HAIs)	*P* value	% change
Blood	0.14 (9)	0.24 (15)	.14	72.1
Body fluid	0.31 (20)	0.27 (17)	.41	–12.2
Nares	0.47 (30)	0.18 (11)	.003	–62.1
Sputum	1.70 (109)	1.12 (70)	.004	–33.7
Urine	1.45 (93)	1.22 (76)	.15	–15.6
Wound	0.81 (52)	0.90 (56)	.32	11.2

We also calculated the incidence of HAIs per organism, and we found that the HAI incidence rates of 3 organisms were significantly reduced by comparing the intervention period: 53.1% reduction for *A baumannii* ($P = .03$), 30.8% reduction for MRSA ($P = .02$), and 34.3% for VRE ($P = .05$) (Table 3).

HAI rates from 2 of 6 culture sites were significantly reduced during the intervention, including nares (62.1%; $P = .003$) and sputum-respiratory (33.7%; $P = .004$) samples (Table 4, Fig 2).

Colonization pressure for the target organisms during the intervention was 13.0% (1,713/13,177 admissions), which is slightly lower than the preintervention period (14.3%; 1,829/12,747 admissions; $P = .002$). All inpatient device utilization ratios were marginally lower during the intervention period.

Cost savings

There were 56 fewer MDRO HAI patient stays in the intervention period than the preintervention period (preintervention: n = 241; intervention: n = 185). Cumulative excess length of stay was reduced by 739.3 patient days during the intervention period with an estimated cost savings of $1,219,878 (Table 5).

DISCUSSION

The prevention of HAIs is a clinical and financial priority for U.S. hospitals. We evaluated the effect of UV-C disinfection in a community hospital through a pre-post intervention design. This study

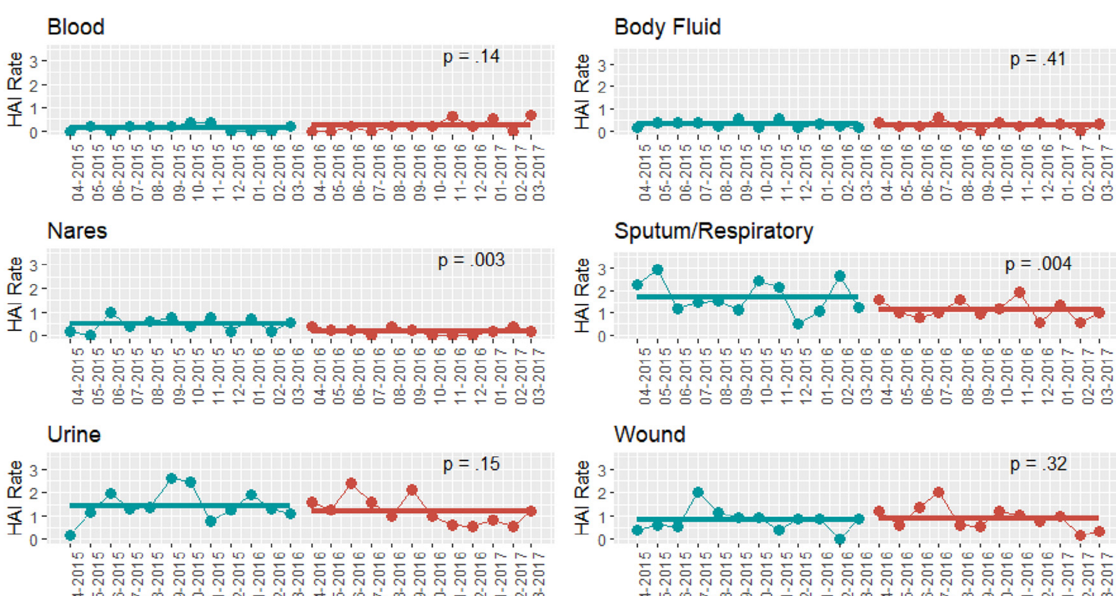

Fig 2. Monthly facility-wide hospital-acquired infection rate per 1,000 patient days per culture site. *HAI*, hospital-acquired infection.

Table 5
Cost savings estimate

	Preintervention period	Intervention period	Δ
MDRO-HAI inpatient stays (HAIs)	241 (313)	185 (245)	–56
Mean APR-DRG expected LOS, d	14.3	14.5	0.2
Mean observed LOS, d	20.7	19.0	–1.7
Mean excess LOS, d	6.5	4.4	–2.1
Total excess LOS, d	1562.5	823.2	–739.3
Mean cost per patient	$10,697.61	$7,341.88	–$3,355.74
Estimated cost savings	$2,578,125.00	$1,358,247.00	–$1,219,878.00

APR-DRG, All Patients Refined Diagnosis Related Groups; *HAI*, hospital-acquired infection; *LOS*, length of hospital stay; *MDRO-HAI*, multidrug-resistant organism hospital-acquired infection.

extends existing literature by evaluating the effect of UV-C disinfection on 5 multidrug-resistant HAIs and culture site, assessing impact on hospital operations, and estimating saved cost in a community-hospital setting. The 12-month UV-C intervention was associated with a significant cumulative reduction of HAIs from 5 environmentally transmissible MDROs, a significant reduction of HAIs in the nares and sputum, and generated substantial hospital cost avoidance without adversely impacting hospital operations.

Overall, our intervention successfully reduced about one-fifth of the MDRO HAIs, and significant reductions for 3 out of 5 MDROs were observed (marginal significance for VRE). This finding is consistent with previous UV-C studies, including a 34% reduction of HAIs and a relatively high reduction of *A baumannii* infections observed by Napolitano et al.[18] However, different from Napolitano et al,[18] a marginal significant reduction was observed for VRE. Rates per culture site indicate the UV-C intervention most impacted acquisitions and infections of the mucous membranes, specifically in the respiratory tract, including nares and sputum. Our study provides further evidence that robust UV-C disinfection interventions can reduce multidrug-resistant HAIs when used as an adjunct to standard terminal disinfection protocols.

Our results indicate that the UV-C disinfection strategy increased the mean duration from inpatient decision-to-admit to emergency room departure. This result is consistent with a previous study, which also mentioned that the adding of a UV-C step increased the inpatient decision-to-admit to emergency room departure.[13] The increase was modest (4 minutes) and occurred approximately 3.5% of the original time. However, the added terminal disinfection time for the UV-C intervention did not adversely impact emergency room inpatient wait times. These findings demonstrate the UV-C intervention did not create operational barriers in a community-hospital setting.

Our study also evaluated the potential financial benefit of the UV-C disinfection. Although unidentified comorbidities or other hospital-acquired conditions may have contributed to excess length of stay among some MDRO HAI patients, our calculated range of 4.4-6.5 days is conservative compared with previous reports ranging from 10.7-19.2 excess inpatient days.[5,25] The mean attributable cost per MDRO HAI patient stay was $7,341.88-$10,697.61 among our study patients, which is modest compared with previous studies ($18,641.60-$22,491.40, adjusted to December 2016 US dollars).[25-27] The mean expected All Patients Refined Diagnosis Related Groups was similar in the preintervention and intervention periods; however, the excess length of stay was reduced by >2 days in the intervention. The reduction in mean excess length of stay during the intervention period suggests UV-C disproportionately impacted HAIs associated with longer excess length of stay. A cost saving of $1,219,878 was observed in our study, which significantly reduced the HAI-related financial burden of the hospital.

Our study has several limitations. First, considering UV-C is a horizontal intervention, we cannot attribute all of or any specific reduction of HAIs per organism or culture site to the UV-C intervention using a pre-post study design. Second, potential confounders such as unmeasured inpatient- and hospital-level risk factors may have impacted our clinical results, including but not limited to, antibiotic exposure, patient acuity, improvement to manual disinfection, or hand hygiene compliance. For example, sex and race are slightly different between the preintervention and intervention periods, which may bias the results of this study. Third, HAI surveillance based on clinical cultures is prone to various collection biases, for example culturing practices of doctors may have differed throughout the study period or positive clinical cultures may have reflected pathogen colonization rather than active infection. Fourth, inpatients were not screened for all HAIs on admission; therefore, community-acquired infections may have been misclassified as hospital-acquired. Fifth, our study did not include an environmental microbiologic analysis nor did it seek to identify pathogen transmission mechanisms that may have led to a reduction of HAIs; however, our analysis per culture site (Tables 3 and 4, Fig 2) may shed light on the portal of entry from environmentally transmitted organisms. Sixth, our study did not include hospital-acquired *C difficile* infections because of changes in the microbiology test during the study period. Finally, unidentified comorbidities or hospital-acquired conditions, for example *C difficile* HAIs, may have contributed to excess length of stay in the cost analysis.

In conclusion, the UV-C intervention significantly reduced HAIs in a community hospital setting and substantially reduced the hospital's financial burden of HAIs without adversely impacting the hospital admissions process. A robust adjunct UV-C disinfection intervention may be a viable strategy to reduce endemic HAIs and associated costs.

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