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Original Article

Assessment of the effectiveness of ultraviolet-C disinfection on transmission of hospital-acquired pathogens from prior room occupants

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Abstract

Objective: To evaluate the effectiveness of ultraviolet-C (UV-C) disinfection as an adjunct to standard chlorine-based disinfectant terminal room cleaning in reducing transmission of hospital-acquired multidrug-resistant organisms (MDROs) from a prior room occupant.

Design: A retrospective cohort study was conducted to compare rates of MDRO transmission by UV-C status from January 1, 2016, through December 31, 2018.

Setting: Acute-care, single-patient hospital rooms at 6 hospitals within an academic healthcare system in Pennsylvania.

Methods: Transmission of hospital-acquired MDRO infection was assessed in patients subsequently assigned to a single-patient room of a source occupant with carriage of 1 or more MDROs on or during admission. Acquisition of 5 pathogens was compared between exposed patients in rooms with standard-of-care chlorine-based disinfectant terminal cleaning with or without adjunct UV-C disinfection. Logistic regression analysis was used to estimate the adjusted risk of pathogen transfer with adjunctive use of UV-C disinfection.

Results: In total, 33,771 exposed patient admissions were evaluated; the source occupants carried 46,688 unique pathogens. Prior to the 33,771 patient admissions, 5,802 rooms (17.2%) were treated with adjunct UV-C disinfection. After adjustment for covariates, exposed patients in rooms treated with adjunct UV-C were at comparable risk of transfer of any pathogen (odds ratio, 1.06; 95% CI, 0.84–1.32; $P = .64$).

Conclusion: Our analysis does not support the use of UV-C in addition to post-discharge cleaning with chlorine-based disinfectant to lower the risk of prior room occupant pathogen transfer.

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More than 2.8 million antibiotic-resistant infections occur in United States hospitals each year that result in >35,000 patient deaths.[1] The estimated annual national cost to treat hospital-acquired infections (HAI) that are multidrug-resistant organisms (MDROs) is >\$4.6 billion.[2] Previous research has suggested that a prior room (source) occupant who is an MDRO carrier increases the risk to the subsequent room (exposed) occupant of infection with that MDRO.[3–7] These findings suggest that inadequate terminal (ie, postdischarge) room cleaning may be an environmental source of pathogen transmission.

No-touch automated ultraviolet-C (UV-C) disinfection technology has been shown to reduce pathogen burden on environmental surfaces and is theorized to reduce pathogen transmission from environmental source.[8] These devices are most commonly used to reduce transmission of MDROs including methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE), *Clostridioides difficile*, and drug-resistant gram-negative bacilli. The underlying mechanism of UV-C disinfection is electromagnetic radiation that is germicidal at wavelengths of 100–280 nm, which destroys the DNA of bacteria, viruses, and other microorganisms, preventing them from multiplying and causing infections and disease.[9]

Despite a plausible theoretical basis, studies on the use of UV-C disinfection to reduce the incidence of HAI have been conflicting, inconclusive, or have had methodological shortcomings.[10] A recent multicenter, cluster-randomized trial provided a nuanced view of

the effectiveness of UV-C technology, with a demonstrated reduction in microbial contamination;[11] however, a potential additional benefit of UV-C disinfection was not observed for facilities using chlorine-based cleaning products.[12] A second, smaller, cluster-randomized trial of UV disinfection in 5 inpatient units with immunocompromised patients did not find a reduction in acquisition of VRE or *C. difficile* when used daily and after patient discharge.[13]

Therefore, we evaluated more definitively the extent to which discretionary (ie, nonrandomized) use of adjunct UV-C disinfection across a large hospital system might reduce the incidence of source occupancy transmission of hospital-acquired pathogens with varying exposure time. We approached this analysis in a 2-sided manner given the possibility that implementation of adjunct UV-C disinfection could potentially influence hospital staff adherence to standard chlorine-based disinfectant terminal room cleaning procedures. Thus, we evaluated the effectiveness of UV-C disinfection as an adjunct to chlorine-based disinfectant terminal room cleaning to potentially reduce the likelihood of source occupant MDRO transmission to subsequent exposed occupants.

Methods

Setting

The University of Pittsburgh Medical Center (UPMC) is a 40-hospital integrated academic healthcare system providing care principally within central and western Pennsylvania. Acute-care, single-patient rooms at 6 different hospitals were included in this retrospective cohort study to assess MDRO transmission from January 1, 2016, through December 31, 2018. Individual hospitals incorporated UV-C disinfection at different times during the study period. To explore possible temporal changes, the outcome was evaluated for each hospital during the 12 months preceding implementation of UV-C disinfection (Supplementary Fig. S1).

This project underwent formal ethical review and was granted approval as a quality improvement study by the UPMC Quality Improvement Review Committee (project no. 1899). Methods and results are reported in accordance with Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement[14] and Standards for Quality Improvement Reporting Excellence (SQUIRE) guidelines (Supplementary Checklist).[15]

Data collection

Data on patient-to-patient transfers of MDRO pathogens were collected during the study period from 6 UPMC hospitals. All potential source patients had documented carriage during that admission of 1 or more of the MDRO pathogens of interest. Subsequent exposed patients were considered at risk of acquisition of an MDRO (putatively from the room environment). Exposed occupants were excluded if they had a history or admission diagnosis of the specific MDRO.

The analysis data set was restricted to patient rooms with at least 1 each of a source-exposed patient pair with and without adjunct UV-C disinfection after source-patient discharge. The data set was also restricted to periods at each facility when the UV-C devices were in use as an adjunct to postdischarge cleaning. Data on patient admissions and MDRO status (including acquisition) were collected from existing repositories by the data analyst team. UV-C disinfection data (ie, date, time, room, treatment parameters and device ID) were uploaded directly from the devices to an existing web-based portal maintained by the device manufacturer (Tru-D, Memphis, TN). These data were directly downloaded by infection prevention and control staff and linked to patient occupancy data using date, time, and room information. Room data were periodically validated by infection prevention and control or environmental services staff, and any records for which a room could not be clearly identified were excluded.

Treatment condition and covariates

The primary treatment condition variable of interest was discretionary use versus nonuse of adjunct UV-C across the aforementioned acute-care facilities within UPMC. Though the deployment strategies differed, all or nearly all facilities used the devices for postdischarge cleaning on a discretionary basis as a part or the entirety of the deployment plan. The use of UV-C disinfection was not randomly assigned and was analyzed observationally. All hospitals routinely used chlorine-based environmental disinfection during the study period, and the postdischarge cleaning protocols did not change with UV-C disinfection use.

Covariates of interest that were captured included the amount of time that source patients and exposed patients spent in their rooms, the time interval between source patient discharge and admission of subsequent exposed patients to the previously infected room, and the pathogen(s) these exposed patients had acquired during their hospital stay.

Study outcomes

The primary study outcome was the acquisition by the exposed occupant of an MDRO that was colonizing or infecting the source occupant. The outcome was measured for the acquisition of 1 or more MDRO and for the individual MDRO of interest: MRSA, VRE, carbapenem-resistant Enterobacterales (CRE), extended-spectrum β-lactamase–producing organisms (ESBLs), and *C. difficile*. MDRO susceptibility was defined using Clinical and Laboratory Standards Institute (CLSI) guidelines.[16] MRSA was defined as *Staphylococcus aureus* that was nonsusceptible to oxacillin and methicillin, VRE were defined as enterococci that were nonsusceptible to vancomycin, CRE were defined as carbapenem nonsusceptibility for a gram-negative Enterobacterales, ESBL were defined as gram-negative bacilli phenotypically resistant to ceftazidime or cefotaxime. If exposed occupants had a positive culture on the date after they were admitted to the room up to 1 day after their discharge date, it was considered a pathogen patient-to-patient transfer (incident case). If the culture date occurred ≥2 days after the exposed occupant was discharged, it was not considered a transfer (incident case). In an exploratory analysis, we evaluated the effect estimate by hospital, by MDRO, and for individual hospital–MDRO pairs.

Statistical methods

The incidences of patient-to-patient transfer of MDRO are presented as counts and percentages. Patient room characteristics by treatment cleaning regimen (no UV-C versus UV-C use after source patient discharge) were presented as means, standard deviation, and percentiles, and were compared using the Wilcoxon rank-sum test. Unadjusted rates of MDRO transfers were compared by room treatment cleaning regimen by likelihood ratio χ^2 tests. This procedure was followed by logistic regression analysis to estimate the independent effect of adjunct use of UV-C on subsequent acquisition of an MDRO. Irrespective of room-treatment cleaning regimen, unadjusted rates of pathogen

Table 1. Summary of Analysis Data Set

Pathogen	No. of Source Patients	Subsequent Exposed Patients	
		No UV-C Disinfection No. (%)	UV-C Disinfection No. (%)
Clostridioides difficile	2,554	1,033 (40.4)	1,521 (59.6)
MRSA	16,138	14,282 (88.5)	1,856 (11.5)
VRE	21,367	17,323 (81.1)	4,044 (18.9)
CRE	1,311	1,012 (77.2)	299 (22.8)
ESBL	5,318	4,432 (83.3)	886 (16.7)
Any Pathogen	33,771	27,969 (82.8)	5,802 (17.2)

Note. UV-C, ultraviolet-C disinfection; MRSA, methicillin-resistant _Staphylococcus aureus_; VRE, vancomycin-resistant enterococci; CRE, carbapenem-resistant Enterobacteriaceae; ESBL, extended-spectrum β-lactamase–producing organisms.

Table 2. Characteristics of Source and Exposed Patients

Characteristic	UV-C	Median	IQR	P Value[a]
Time source patient in room, d	No	3.9	(2.2–7.1)	<.001
	Yes	4.9	(2.9–9.9)	
Time exposed patient in room, d	No	2.8	(1.3–5.1)	<.001
	Yes	3.1	(1.6–6.0)	
Time between patients, min	No	5	(3–20)	<.001
	Yes	10	(4–29)	
Length of UV-C disinfection, min	No	...		N/A
	Yes	17	(12–22)	

Note. UV-C, ultraviolet-C disinfection; IQR, inter-quartile range.
[a]P values are from a Wilcoxon rank-sum test.

transfer were compared for the period before versus after the UV-C regimen was initiated by use of likelihood ratio χ^2. Analyses were performed using Stata version 16.0 software (StataCorp, College Station, TX).

Results

Patient population and covariates

In total, 33,771 single-room admissions were evaluated. Among them, the source occupants had 46,688 unique pathogens, for a mean of 1.4 per source occupant (Table 1). Of the 33,771 room admissions, 5,802 patients (17.2%) subsequently occupied a room that was treated with adjunct UV-C disinfection. Among the battery of pathogens evaluated, MRSA and VRE were most prevalent among the source patients. The covariates are described in Table 2. Rooms that underwent UV-C disinfection between source and exposed patients had a significantly longer source-patient admission, time between admissions, and exposed-patient admission than rooms that did not undergo UV-C disinfection.

Incidence of pathogen transfer

The unadjusted overall pathogen transfer rate was 1.6% for exposed patients in standard chlorine-based disinfectant rooms versus 2.4% for exposed patients in rooms treated with adjunct

Table 3. Unadjusted Pathogen Transfer Rate by Cleaning Room Condition

Possible Pathogen Transfer	No.	Standard Cleaning No. Transfers/ Total (%)	Standard Cleaning +UV-C No. Transfers/ Total (%)	P Value
Clostridioides difficile	2,513	8/1,018 (0.8)	10/1,495 (0.7)	.73
MRSA	13,922	75/12,323 (0.6)	9/1,599 (0.6)	.82
VRE	16,330	286/13,455 (2.1)	96/2,875 (3.3)	< .001
CRE	1,283	1/992 (0.1)	1/291 (0.3)	.40
ESBL	4,869	14/4,055 (0.3)	4/814 (0.5)	.55
Any Pathogen	29,259	382/24,277 (1.6)	118/4,982 (2.4)	< .001

Note. UV-C, ultraviolet-C disinfection; MRSA, methicillin-resistant _Staphylococcus aureus_; VRE, vancomycin-resistant enterococci; CRE, carbapenem-resistant Enterobacterales; ESBL, extended-spectrum β-lactamase–producing organisms.

Table 4. Logistic Regression Model of Factors Associated with Pathogen Transfer

Factor	Odds Ratio	95% CI	P Value
Minutes source patient in room[a]	1.13	(1.01, 1.26)	.03
Minutes exposed patient in room[a]	3.98	(3.54, 4.48)	<.001
Minutes between patients[a]	0.99	(0.93, 1.05)	.71
UV-C used between patients	1.06	(0.84, 1.32)	.64

Note. UV-C, ultraviolet-C disinfection; CI, confidence interval.
[a]Natural log transformation used in model.

UV-C ($P < .001$) (Table 3). The apparent higher rate of transfer among patients in rooms treated with adjunct UV-C occurred at a single hospital (facility C, 0.9% with no UV-C vs 3.8% with UV-C; $P < .001$) and was driven overall by a higher transfer rate of VRE (2.1% vs 3.3%; $P < .001$) (Supplementary Table S1). After adjustment for facility, source patient time spent in room, time between admissions, and exposed patient time spent in room, the exposed patients in rooms treated with adjunct UV-C were at comparable risk of transfer of any pathogen (odds ratio, 1.06; 95% CI, 0.84–1.32; $P = .64$) (Table 4). A longer time spent in the room among exposed occupants was strongly associated with risk of acquisition of an MDRO ($P < .001$).

Among all patients (irrespective of disinfectant regimen), the crude overall pathogen transfer rate was 1.7% both before and during the period when discretionary adjunct UV-C implementation was initiated (Supplementary Table S2), with comparable rates by individual pathogen.

Discussion

We conducted a retrospective observational study to compare the likelihood of the exposed occupant acquiring the same species of MDRO as a source occupant. Among the 5,802 rooms across 6 hospitals treated with UV-C disinfection, we deetected no significant difference in the rate of 1 or more MDROs or any single studied MDRO compared to the 27,969 rooms for which UV-C disinfection was not used. Results of our analysis indicate that adjunct UV-C disinfection does not provide incremental value in reducing transfer of MDRO above and beyond standard of care.

Although our findings are in accord with some other studies indicating no association (ie, protective effect),[13] they are in contrast to other studies that suggest a protective effect of adjunct UV-C disinfection that is coupled with plausible biological rationale.[11] This study differs from prior observational studies by not using a before-and-after design[10] but using concurrent enrollment with methodology established by other "prior occupant" studies that have inferred transmission via the environment.[17,18] The BETR trial demonstrated the potential benefit of UV disinfection, though when comparing use of bleach-based disinfectant with or without UV disinfection, no significant difference was observed.[12] In a secondary analysis, the potential impact was most significantly seen for pathogens more likely to be transmitted via the environment (*C. difficile* and VRE), although not as strongly demonstrated for multidrug-resistant *Acinetobacter* spp and MRSA.[12] In this study, rates of transmission were different for each pathogen (Table 3) and were consistent with the BETR findings highest for VRE followed by *C. difficile*.

In this study, the overall rate of pathogen transfer was 1.6% among rooms receiving only chlorine-based disinfection compared with 2.4% among those with UV-C disinfection as an adjunct to chlorine-based disinfection, and the overall rates of transmission before and after the study period showed no significant change (1.7%). The risk of transmission putatively from a prior room source occupant is slightly lower than recently published studies and is typically 3% or greater.[4–7] This difference may be due to a strict definition of putative transmission used in this study, and our measure may be an underestimate of transmission by including all units (rather than intensive care only).

An important consideration not measured in our study was whether use of UV-C disinfection regimen was entirely adjunctive to use of the standard chlorine-based disinfectant protocol. We did not observe differences in the effectiveness of UV-C disinfection by pathogen except for VRE with paradoxically showed a higher rate of transmission. Although we do not have evidence, it is possible that in some instances of UV-C disinfection was used partially in lieu of the standard cleaning protocol. Thus, we do not know the extent to which the standard chlorine-based disinfectant protocol versus adjunct UV-C disinfection regimen plus standard protocol were fully implemented (ie, according to protocol) across patient rooms. Thus, we were unable to perform a precise comparison of each regimen. However, this raises the potential concern that the use of UV-C disinfection may result in less optimal room cleaning.

This study had several limitations. We used a case-finding method. Although we used a similar methodology as prior studies using genus, species, and resistance profiles of the pathogens within a specified time interval to identify transmission from prior room occupants, we did not perform active surveillance of either source patients or exposed patients. For isolates that were identified, we did not perform a method of genetic typing to confirm relatedness. Additionally, active surveillance for MRSA and VRE may have varied among study facilities, and in 2018, some study facilities discontinued the routine use of contact precautions for MRSA, VRE, and select non-CRE gram-negative pathogens.[19] Differences in application or adherence of active surveillance and contact precautions may affect case ascertainment and change the likelihood of transmission in the room environment. However, these are facility-level approaches, and adjusting for facility in our analysis may account for these differences. We omitted UV-C disinfection events for which a room was not recorded; these were infrequent and, based on our facilities' usual practice, were most likely attributable to UV-C use in a nonpatient room. The quality

of room cleaning was not available for each potential transmission event. In the study facilities, a fluorescent-marker method is used to evaluate the quality of postdischarge cleaning.[18] During the period July 2016 through December 2018, the median thoroughness of disinfection score at the study facilities ranged from 87% to 97%, suggesting a consistent observation of high-quality cleaning (data not shown).

Strengths of this analysis include a large sample size, assessment of multiple pathogens, and use of "source occupant" analysis to directly assess patient-to-patient transfer of MRDOs. In addition, despite the observational design of the study, we were able to statistically control for several important covariates, such as the time between cleaning of the source patient (infected) room and subsequent exposed patient admission. Although this was not a randomized controlled trial (a significant limitation), our research helped to draw reliable inferences on the effect of adjunct use of UV-C disinfectant on risk of pathogen acquisition.

Our analysis does not provide support for the hypothesis that use of adjunct UV-C lowers the risk of patient-to-patient pathogen transfer above and beyond the use of standard chlorine-based disinfectant.

Conflicts of interest. All authors report no conflicts of interest relevant to this article.

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