ORIGINAL ARTICLE

Decontamination of Targeted Pathogens from Patient Rooms Using an Automated Ultraviolet-C-Emitting Device

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OBJECTIVE. To determine the effectiveness of an automated ultraviolet-C (UV-C) emitter against vancomycin-resistant enterococci (VRE), *Clostridium difficile*, and *Acinetobacter* spp. in patient rooms.

DESIGN. Prospective cohort study.

SETTING. Two tertiary care hospitals.

PARTICIPANTS. Convenience sample of 39 patient rooms from which a patient infected or colonized with 1 of the 3 targeted pathogens had been discharged.

INTERVENTION. Environmental sites were cultured before and after use of an automated UV-C-emitting device in targeted rooms but before standard terminal room disinfection by environmental services.

RESULTS. In total, 142 samples were obtained from 27 rooms of patients who were colonized or infected with VRE, 77 samples were obtained from 10 rooms of patients with *C. difficile* infection, and 10 samples were obtained from 2 rooms of patients with infections due to *Acinetobacter*. Use of an automated UV-C-emitting device led to a significant decrease in the total number of colony-forming units (CFUs) of any type of organism (1.07 $\log_{10}$ reduction; $P < .0001$), CFUs of target pathogens (1.35 $\log_{10}$ reduction; $P < .0001$), VRE CFUs (1.68 $\log_{10}$ reduction; $P < .0001$), and *C. difficile* CFUs (1.16 $\log_{10}$ reduction; $P < .0001$). CFUs of *Acinetobacter* also decreased (1.71 $\log_{10}$ reduction), but the trend was not statistically significant ($P = .25$). CFUs were reduced at all 9 of the environmental sites tested. Reductions similarly occurred in direct and indirect line of sight.

CONCLUSIONS. Our data confirm that automated UV-C-emitting devices can decrease the bioburden of important pathogens in real-world settings such as hospital rooms.

Infect Control Hosp Epidemiol 2013;34(5):466-471

The hospital environment is receiving increasing attention as a source for acquisition and spread of pathogens among hospitalized patients. In particular, 4 key organisms appear to survive in the environment long enough to place patients at risk. Vegetative bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA),[1,2] vancomycin-resistant enterococci (VRE),[3] and *Acinetobacter* spp.[4-6] may persist on environmental surfaces for days or weeks. *Clostridium difficile* spores can persist on environmental surfaces for up to 5 months.[7] In fact, acquisition of these organisms from the environment has previously been demonstrated, particularly when a patient is admitted to a room from which a patient colonized or infected with these important pathogens was just discharged.[8-11]

Standard approaches to environmental cleaning are inadequate.[12-14] As a result, new, automated technologies are being investigated to determine how best to enhance terminal room disinfection of the hospital environment. One such technology is ultraviolet (UV) radiation. UV-C light near a wavelength of 254 nm induces the formation of pyrimidine dimers from thymine and cytosine.[15] These dimers in turn cause breaks in microbial DNA that make genetic replication impossible, thus destroying the organisms or rendering them unable to grow or reproduce.[16]

The evidence that automated UV-C emitters can enhance disinfection of the hospital environment is growing. To date, authors of previously published studies have demonstrated that UV-C can effectively eradicate MRSA, VRE, *Acinetobacter*, and *C. difficile* under experimental conditions.[15-20] To our knowledge, however, only 2 studies have evaluated the effectiveness of automated UV-C emitters in real hospital envi-

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Received October 1, 2012; accepted November 21, 2012; electronically published April 9, 2013.

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https://doi.org/10.1086/670215 Published online by Cambridge University Press

ronments.[19,21] These studies confirmed that the automated UV-C emitter reduced the bioburden of MRSA, VRE, and *C. difficile* in clinical settings.[19,21]

The objective of this study was to add to this growing literature by (1) determining the effectiveness of an automated UV-C emitter against VRE and *C. difficile* in a multicenter clinical environment and (2) evaluating the effectiveness of this automated UV-C emitter against *Acinetobacter* spp. in real-world clinical settings.

METHODS

This study was performed at 2 tertiary acute care hospitals, Duke University Medical Center (753 beds) and the University of North Carolina Health Care (804 beds), from July 2011 through September 2012. The study protocol was reviewed by institutional review board committees at both institutions and determined to be exempt.

We performed an interventional study on a convenience sample of hospital rooms. Three pathogenic organisms were targeted: VRE, *C. difficile*, and *Acinetobacter* spp. Hospital rooms were identified using microbiological and infection control databases to search for patients placed on contact precautions as a result of colonization or infection with a target organism.

After a targeted room was identified, environmental cultures were obtained after patient discharge but before standard terminal room disinfection by environmental services personnel. A minimum of 5 environmental sites were cultured in triplicate from each room, using Rodac plates. The 5 environmental sites targeted for culture included the bedside rail, bedside table, chair arm, overbed table, and sink counter. When one of these surfaces was not available, supply carts were cultured. The toilet, shower floor, and floor adjacent to the toilet were also cultured in targeted rooms from which a patient with *C. difficile* infection was just discharged. Each environmental culture site was assessed and recorded as in either direct or indirect line of sight of the automated UV-C-light-emitting device. The automated UV-C-emitting device was then used in the room. Environmental cultures were repeated in triplicate from the same environmental sites, following application of UV-C light. Following these cultures, environmental services performed a standard terminal room disinfection per standard hospital protocol, and the room was made available for the next patient.

Automated UV-C-Emitting Device

Each institution had access to 1 automated UV-C-emitting device (Tru-D SmartUVC; Lumalier). The automated UV-C device emits light at a wavelength of 254 nm and measures the reflected dose of light, using 8 sensors mounted on the device. Each device was programmed to deliver a reflected dose of 12,000 μWs/cm^2 for vegetative bacteria (VRE or *Acinetobacter*) or 22,000 μWs/cm^2 for spores (*C. difficile*). The device was operated by trained study personnel. The device was rolled into the targeted room and placed approximately in the center of the room. Care was taken to ensure that drawers and cabinets were opened before using the machine. In particular, the UV-C device was placed in a location to ensure that light was emitted into the room's bathroom whenever possible. The time required for the device to deliver the above minimum reflected doses was measured.

Microbiological Methods

Dey/Engley (D/E) Neutralizing Agar or *Clostridium difficile* Selective Agar was used in the Rodac plates. All plates were incubated at 37°C for 48 hours; all *C. difficile* plates were incubated anaerobically. For patient rooms targeted for vegetative bacteria, 2 quantitative microbiologic outcomes were determined: the total number of colony-forming units (CFUs) of any organism present on each plate and the total number of CFUs of the targeted pathogen present on each plate. For *C. difficile*, only the total number of CFUs of the targeted pathogen present on each plate was determined. In either scenario, the number of targeted pathogens was quantified by first identifying morphologies suggestive of the target organisms. These colonies were then subcultured and identified using standard microbiological methods.

Statistical Methods

Standard descriptive statistics were used, including medians and interquartile ranges (IQRs) for non-normally distributed continuous variables. The Wilcoxon signed rank sums test was used to determine differences between the number of CFUs before and after use of the UV-C device. For these analyses, quantitative results from triplicate cultures were aggregated so that the comparison unit for statistical comparison was the number of CFUs per environmental site, not per plate. The McNemar test was used to determine differences between the proportions of positive plates before and after use of the UV-C device.

RESULTS

We sampled 229 environmental surfaces from the rooms of 39 patients during the 15-month study period. In total, 142 samples were obtained from 27 rooms of patients who were colonized or infected with VRE, 77 samples were obtained from 10 rooms of patients with *C. difficile* infection, and 10 samples were obtained from 2 rooms of patients with infections due to *Acinetobacter*. The median time for the UV-C vegetative cycle to be completed was 25 minutes (IQR, 20–35); the median time for the UV-C spore cycle to be completed was 45 minutes (IQR, 42–61).

The total number of CFUs of any type of pathogen detected on culture plates from all sampled environmental sites decreased from 28,642 to 2,444 following use of the UV-C device (1.07 $\log_{10}$ reduction; Table 1). The median number of CFUs per sample decreased from 110 (IQR, 49–251) to 4 (IQR, 1–11) following use of the UV-C device ($P < .0001$). Similarly, the total number of CFUs of target organisms from all cultured environmental sites decreased from 1,488 to 66 follow-

https://doi.org/10.1086/670215 Published online by Cambridge University Press

https://doi.org/10.1086/670215 Published online by Cambridge University Press

TABLE 1. Efficacy of Ultraviolet-C (UV-C) Decontamination in 39 Patient Rooms That Had Been Occupied by Patients under Contact Precautions for 3 Target Organisms (Vancomycin-Resistant Enterococci [VRE], $n = 27$; *Clostridium difficile* [CD], $n = 10$; *Acinetobacter* spp. [AB], $n = 2$): Reduction in Colony-Forming Units (CFUs) and Comparison of Decontamination in Direct versus Indirect Line of Sight

	Overall (direct and indirect combined)				Direct				Indirect				
	No. of samples[a]	CFUs before UV-C (log_{10})	CFUs after UV-C (log_{10})	Decontamination, log_{10} red	No. of samples	CFUs before UV-C (log_{10})	CFUs after UV-C (log_{10})	Decontamination, log_{10} red	No. of samples	CFUs before UV-C (log_{10})	CFUs after UV-C (log_{10})	Decontamination, log_{10} red	P[b]
Total CFUs	152	28,642 (4.46)	2,444 (3.39)	1.07	143	26,656 (4.43)	2,276 (3.36)	1.07	9	1,986 (3.30)	168 (2.23)	1.07	.24
All target organisms	229	1,488 (3.17)	66 (1.82)	1.35	194	782 (2.89)	19 (1.28)	1.61	35	706 (2.85)	47 (1.67)	1.18	.11
VRE	142	712 (2.85)	15 (1.18)	1.68	135	712 (2.85)	15 (1.18)	1.68	8	0	0	...	.15
CDI	77	724 (2.86)	50 (1.70)	1.16	51	19 (1.28)	3 (0.48)	0.80	26	705 (2.85)	47 (1.67)	1.18	.51
AB	10	52 (1.71)	1 (0)	1.71	9	51 (1.71)	1 (0)	1.71	1	1	0	...	.41

NOTE. CDI, *Clostridium difficile* infection.

[a] Samples are aggregated so that triplicate cultures are counted as 1 sample.

[b] P value determined by Wilcoxon signed rank sums test comparing CFUs/sample in direct versus indirect line of sight.

ing use of the UV-C device (1.35 $\log_{10}$ reduction; $P < .0001$). A greater than 1 $\log_{10}$ overall reduction was achieved for all 3 target organisms following use of the UV-C device. VRE CFUs decreased from 712 to 15 following use of the UV-C device (1.68 $\log_{10}$ reduction; $P < .0001$), *C. difficile* CFUs decreased from 724 to 51 (1.16 $\log_{10}$ reduction; $P < .0001$), and *Acinetobacter* decreased from 52 to 1 (1.71 $\log_{10}$ reduction; $P = .25$; Table 1).

A greater than 1 $\log_{10}$ reduction was observed in cultures obtained from sites in both direct and indirect line of site for total CFUs of any organism, total CFUs of the 3 targeted organisms, VRE CFUs, and *Acinetobacter* CFUs (Table 1). A 0.80 $\log_{10}$ reduction was observed for *C. difficile* in direct line of sight, but a 1.18 $\log_{10}$ reduction was observed in indirect line of sight. No statistically significant differences were observed in the reductions that occurred in direct versus indirect line of sight disinfection for any of these categories.

The total number of CFUs was reduced following use of UV-C light at each of the 9 environmental locations tested for total CFUs of any organism and each of the 3 targeted organism (Table 2); the greatest reduction was observed on the overbed table (98%), while the lowest reduction was observed on the bathroom floor adjacent to the toilet (74%). VRE was identified on 49 (11%) of 428 plates before use of the UV-C device and only 6 (1%) of 428 plates afterward ($P < .0001$; Figure 1). The proportion of *C. difficile*–positive plates similarly decreased from 10% to 5% ($P = .03$). While the proportion of *Acinetobacter*-positive plates decreased from 13% to 3%, this trend was not statistically significant ($P = .38$).

DISCUSSION

Numerous studies have demonstrated that current strategies for terminal room disinfection are inadequate. In fact, 50% or more hospital surfaces may go untouched and uncleaned following terminal room disinfection.[12] UV-C light is a novel method to enhance terminal disinfection of hospital rooms. Our multicenter, prospective study confirms that automated UV-C emitters substantially decrease the bioburden of important pathogens, such as VRE and *C. difficile*, from patient rooms in real-world settings. In addition, our data suggest that an automated UV-C emitter can help reduce the bioburden of *Acinetobacter* spp. It was likely that the reduction in the bioburden of *Acinetobacter* spp. was not statistically significant because of the low frequency of *Acinetobacter* infection in our study hospitals.

Authors of several studies have investigated the efficacy of automated UV-C emitters against important pathogens in nonclinical, experimental conditions.[15-17] For example, Boyce et al[18] used a quantitative disk carrier method to evaluate the efficacy of UV-C light emitters in reducing the burden of *C. difficile* spores in patient rooms. Disks inoculated with 10^5 to 10^6 nontoxigenic *C. difficile* spores were placed in specific locations in 25 patient rooms and then exposed to light from an automated UV-C-emitting device. *C. difficile* spores were reduced between 1.4 and 2.9 $\log_{10}$.[18]

To our knowledge, however, only 2 previously published studies have evaluated the effectiveness of automated UV-C emitters in clinical conditions following patient discharge. Rutala et al[19] cultured 10 targeted environmental surfaces in 8 rooms of patients previously placed in contact precautions because of colonization or infection with MRSA. An automated UV-C-emitting device was used before cleaning. UV-C irradiation led to decreases in total CFUs per culture plate, in the number of samples positive of MRSA, and in MRSA counts per plate.[19] Nerandzic et al[21] performed a similar experiment in 66 rooms of patients previously placed in contact precautions for MRSA or *C. difficile*. The proportion of sites

TABLE 2. Overall and Organism-Specific Reductions in Colony-Forming Units (CFUs) on 9 Specific Hospital Room Surfaces Following Ultraviolet-C (UV-C) Decontamination in 39 Patient Rooms That Had Been Occupied by Patients under Contact Precautions for Vancomycin-Resistant Enterococci (VRE; $n = 27$), *Clostridium difficile* (CD; $n = 10$), and *Acinetobacter* spp. (AB; $n = 2$)

		Total CFUs of any organism		VRE-positive plates ($N = 428$)		CD-positive plates ($N = 225$)		AB-positive plates ($N = 30$)	
Site	No. of samples	Before UV-C median (IQR)	After UV-C median (IQR)	Before UV-C	After UV-C	Before UV-C	After UV-C	Before UV-C	After UV-C
Bedside rail	37	147 (54–352)	4 (1–21)	10/74	0/75	1/30	2/30	1/6	0/6
Bedside table	39	122 (60–183)	5 (1–9)	7/81	2/81	3/30	1/30	2/6	1/6
Chair arm	40	208 (73–495)	7 (2–23)	10/81	2/81	0/33	1/33	1/6	0/6
Overbed table	40	103.5 (40–176)	2 (1–5)	9/84	1/84	0/30	0/30	0/6	0/6
Sink counter	32	77 (33–129)	5 (2–21)	7/59	0/60	2/30	0/30	0/6	0/6
Supply cart	6	88 (42–316)	8 (1–34)	4/21	1/21	...	...	...	...
Toilet	15	48 (13–66)	3 (1–8)	0/15	0/15	6/30	3/30	...	...
Shower floor[a]		...	...	...	...	0/15	0/15	...	...
Bathroom floor adjacent to toilet	14	100 (83–289)	26 (0.5–160)	2/12	0/12	10/30	4/30	...	...

NOTE. CDI, *Clostridium difficile* infection; IQR, interquartile range.

[a] Only tested in CDI rooms, so no total CFUs were calculated.

https://doi.org/10.1086/670215 Published online by Cambridge University Press

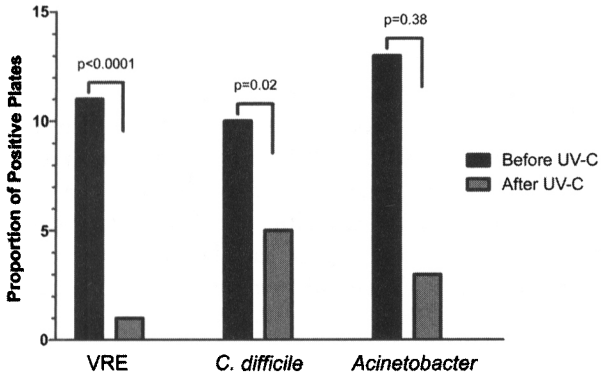


FIGURE 1. Change in proportion of positive plates for target organisms before and after use of an automated ultraviolet-C emitter.

positive for MRSA or *C. difficile* significantly decreased following UV-C irradiation. While the proportion of surfaces positive for VRE decreased from 2.7% to 0.4%, this trend was not statistically significant ($P = .07$).[21]

Our multicenter study utilized similar methods and confirmed that application of measured doses of UV-C light produced greater than 1 $\log_{10}$ reductions in the bioburden of *C. difficile* spores. These reductions also were observed from environmental sites in both direct and indirect line of sight locations relative to the portable UV-C-light-emitting device. Unlike the study by Nerandzic et al,[21] we also targeted and sampled patient rooms from which a patient on contact precautions for VRE had been discharged. In this setting, UV-C light led to a 1.68 $\log_{10}$ reduction in colony counts of VRE at sampled environmental sites.

We are not aware of prior studies that have evaluated the efficacy of automated UV-C emitters in reducing the environmental bioburden of *Acinetobacter* in clinical settings such as patient rooms. In our study, UV-C light led to a 1.71 $\log_{10}$ reduction in the environmental bioburden of *Acinetobacter*. Similarly, the proportion of sampled locations positive for *Acinetobacter* decreased from 13% to 1%. Unfortunately, we were able to enroll only 2 rooms for *Acinetobacter* that met enrollment criteria during our study. Thus, our analysis was statistically underpowered.

Our results and the results cited above demonstrate that UV-C is less effective at killing bacteria in clinical settings compared with experimental, nonclinical conditions. For example, the application of UV-C light via automated devices has been shown to decrease the bioburden of MRSA, VRE, *C. difficile*, and *Acinetobacter* by 3–4 $\log_{10}$ in experimental conditions (eg, inoculated formica sheets or discs).[19] In contrast, the use of an automated UV-C light emitter produced a 1.07 $\log_{10}$ reduction in total CFUs and a 1.35 $\log_{10}$ reduction in targeted pathogens in our study. Because cultures were obtained before and after application of UV-C light in rooms that had not undergone standard cleaning and disinfection, it is possible that the efficacy of UV-C was adversely affected by the presence of dirt and debris on surfaces and equipment. For example, the authors of a recent study of the efficacy of hand-held UV-C devices reported that these devices were ineffective for the disinfection of 72% of the 68 computer keyboards located in hospital wards if mechanical cleaning was not performed before attempted disinfection with UV-C light.[22] In another study, UV-C was effective in disinfecting ultrasound probes only if it was applied after surfaces were disinfected with mechanical friction and a chemical disinfectant.[23] Nerandzic et al[21] previously investigated the effectiveness of an automated UV-C emitter following cleaning by environmental staff. No samples from 26 rooms were contaminated with MRSA following both terminal room disinfection and use of the automated UV-C emitter.[21] These studies and our results suggest that UV-C disinfection may be more effective when used after traditional cleaning protocols. Thus, cleaning must remain an important part of terminal room disinfection, but in its absence or on locations missed by cleaning staff, more than 90% of pathogenic bacteria will still be killed when an automated UV-C device is used.

Our study has limitations. First, we utilized a convenience sample of patient rooms from 2 acute care tertiary care hospitals. Thus, our data may not be generalizable to other settings. Second, the minority of our samples identified pathogens of interest. While this may have limited some of our statistical power, our findings are actually consistent with other published studies. That is, in general, approximately 10%–20% of surfaces are typically contaminated with pathogenic bacteria.[19,21] Third, we were able to study only 2 rooms of patients infected with *Acinetobacter* spp., thus limiting the statistical power of our results. Finally, our study did not provide any patient-specific information, thereby limiting our ability to make conclusions about the impact of this technology for specific patient groups (eg, immunocompromised patients).

The use of UV-C radiation in medical settings is expanding to novel settings and through novel methods. For example, UV-C has recently been used to decontaminate specific rooms in long-term care facilities[24] and has been trialed with hand-held devices.[22,25] Our data support and expand on previously published studies to confirm that automated UV-C-emitting devices can decrease the bioburden of important pathogens in hospital rooms. Whether this method actually leads to improved patient safety, decreased acquisition of pathogenic bacteria, and decreased rates of health care–associated infections remains to be seen.

ACKNOWLEDGMENTS

We would like to thank Lumalier for donating 2 Tru-D devices for use during this study. Lumalier did not provide funding for the study and did not contribute to the study design or writing of the manuscript.

Financial support. The study was funded by the Centers for Disease Control and Prevention (CDC) Prevention Epicenters Program (U54CK000164). Colleagues from the CDC assisted in the review of study design but not did

https://doi.org/10.1086/670215 Published online by Cambridge University Press

participate in manuscript preparation, submission, or review. D.J.A. reports that he has received additional grant support from the National Institutes of Health/National Institute of Allergy and Infectious Diseases (K23AI095357), the Robert Wood Johnson Foundation, and Merck.

Potential conflicts of interest. All authors report no conflicts of interest relevant to this article. All authors submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and the conflicts that the editors consider relevant to this article are disclosed here.

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