

ORIGINAL ARTICLE

Room Decontamination with UV Radiation

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OBJECTIVE. To determine the effectiveness of a UV-C-emitting device to eliminate clinically important nosocomial pathogens in a contaminated hospital room.

METHODS. This study was carried out in a standard but empty hospital room (phase 1) and in a room previously occupied by a patient with methicillin-resistant *Staphylococcus aureus* (MRSA) or vancomycin-resistant *Enterococcus* (VRE) infection (phase 2) in an acute care tertiary hospital in North Carolina from January 21 through September 21, 2009. During phase 1, 8 × 8 cm Formica sheets contaminated with approximately 10⁴–10⁵ organisms of MRSA, VRE, multidrug-resistant (MDR) *Acinetobacter baumannii*, or *Clostridium difficile* spores were placed in a hospital room, both in direct line of sight of the UV-C device and behind objects. After timed exposure, the presence of the microbes was assessed. During phase 2, specific sites in rooms that had housed patients with MRSA or VRE infection were sampled before and after UV-C irradiation. After timed exposure, the presence of MRSA and VRE and total colony counts were assessed.

RESULTS. In our test room, the effectiveness of UV-C radiation in reducing the counts of vegetative bacteria on surfaces was more than 99.9% within 15 minutes, and the reduction in *C. difficile* spores was 99.8% within 50 minutes. In rooms occupied by patients with MRSA, UV-C irradiation of approximately 15 minutes duration resulted in a decrease in total CFUs per plate (mean, 384 CFUs vs 19 CFUs; $P < .001$), in the number of samples positive for MRSA (81 [20.3%] of 400 plates vs 2 [0.5%] of 400 plates; $P < .001$), and in MRSA counts per MRSA-positive plate (mean, 37 CFUs vs 2 CFUs; $P < .001$).

CONCLUSIONS. This UV-C device was effective in eliminating vegetative bacteria on contaminated surfaces both in the line of sight and behind objects within approximately 15 minutes and in eliminating *C. difficile* spores within 50 minutes.

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Surface disinfection of noncritical surfaces and equipment is normally performed by manually applying a liquid disinfectant to the surface with a cloth, wipe, or mop. Recent studies have identified substantial opportunities in hospitals to improve the cleaning of frequently touched objects in the patient's immediate environment.¹⁻³ For example, of 20,646 standardized environmental surfaces (14 types of objects), only 9,910 (48%) were cleaned at terminal room cleaning.³ Epidemiologic studies have shown that patients hospitalized in rooms previously occupied by individuals infected or colonized with methicillin-resistant *Staphylococcus aureus* (MRSA),⁴ vancomycin-resistant *Enterococcus* (VRE),⁵ or *Clostridium difficile*⁶ are at significant risk of acquiring these organisms from contaminated environmental surfaces. These data have inspired the development of room decontamination devices that avoid the problems associated with manual disinfection.⁷

Devices using UV-C light (wavelength, 254 nm) have also been proposed for room decontamination. One UV-C device uses an array of UV sensors, which determines and targets shadowed areas to deliver a measured dose of UV energy that destroys microorganisms. This unit is fully automated and ac-

tivated by a hand-held remote control, and the room ventilation does not need to be modified. It measures UV light reflected from the walls, ceiling, floors, or items in the room and calculates the time required to deliver the programmed lethal dose for pathogens.⁸ After decontamination, it powers down and an audible alarm notifies the operator. The purpose of this article is to summarize our evaluation of the ability of this device to decontaminate rooms that were experimentally or naturally contaminated with epidemiologically important pathogens, such as MRSA, VRE, a multidrug-resistant (MDR) strain of *Acinetobacter baumannii*, and *C. difficile* spores.

METHODS

The study was performed at University of North Carolina Health Care, an acute care tertiary hospital in Chapel Hill, North Carolina, during the period January 21 through September 21, 2009.

Phase 1: Clinical Translational Research Center

A single UV-C device was investigated (Tru-D; Lumalier Corporation). This device delivers a reflected dose of 36,000 μ Ws/

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cm² (ie, when Tru-D powers down, the sensor facing the least reflected area of the room has received a reflective dose of 36,000 $\mu\text{Ws}/\text{cm}^2$) for *C. difficile* spores and 12,000 $\mu\text{Ws}/\text{cm}^2$ for vegetative bacteria. Phase 1 testing was performed in a patient room (10.9 m² main room with 1.2 m² bathroom) in the Clinical Translational Research Center. This testing was performed using Formica sheets (approximately 8 × 8 cm) on which a template of a Rodac plate had been drawn. The vegetative bacteria were grown on sheep's blood agar and serial dilutions made with trypticase soy broth (Remel). The *C. difficile* spore preparation was stored in Dulbecco's modified Eagle's medium (HyClone), and serial dilutions were made with trypticase soy broth. An inoculum of approximately 10⁴–10⁵ organisms per Rodac template (10 μL of a 10⁶–10⁷ cell inoculum of the test organism) of the 4 test organisms was spread separately on the Formica sheet by use of a sterile glass hockey loop. The 4 test organisms were *C. difficile* spores (BI strain), a clinical isolate of MRSA (USA300 strain), a VRE strain (ATCC strain 51299), and a clinical isolate of MDR *A. baumannii* (Table 1). After the templates were inoculated, they were left to dry a minimum of 10 minutes at room temperature. Die-off experiments revealed that the VRE, MRSA, and *A. baumannii* had no significant die-off within a 6-hour sampling period (less than 0.27 log₁₀ reduction). The Formica sheets were then placed in 10 locations at least 15 cm from the wall throughout the patient room (ie, far side of the bedside table, facing the wall; side of the chair, facing the wall; top of the overbed table; outside of the bathroom door; top of the toilet seat; back of the head of the bed, facing the wall; floor [right side of bed]; foot of the bed, facing the door; side of the sink, facing the bedside table; and back of the computer, facing the wall). After the Formica pieces were placed on the indicated item or attached to the item with tape, the room was vacated and the UV-C device was remotely activated for the test organism being evaluated (for approximately 15 minutes for vegetative bacteria or for approximately 50 minutes for spores). After decontamination, Rodac plates (Becton Dickinson) containing DE Neutralizing Agar (Becton Dickinson) were used to culture each Formica template. These plates were then incubated

as appropriate for the test organism (aerobically at 37°C for 48 hours for bacteria and anaerobically [Anaeropack; Mitsubishi Gas Chemical] at 37°C for 48 hours for *C. difficile*). After incubation, the numbers of colony-forming units (CFUs) of the test organisms on each plate were quantified. The *C. difficile* culture was treated with heat at 56°C for 10 minutes, and the presence and resistance of *C. difficile* spores (and not vegetative bacteria) were verified by exposing the stock preparation to dilute hydrochloric acid as specified in the AOAC International sporicidal activity test.⁹ The suspension was then stained to confirm the presence of spores (more than 90% spores).

Phase 2: Rooms of Patients under Contact Precautions

Phase 2 involved the culturing of samples from 10 targeted sites (5 replicates per site) in the rooms of patients who had been placed under contact precautions to prevent transmission of MRSA or VRE (Table 2). The patient rooms evaluated had a mean area of 18.2 m² (including bathroom if present), and the mean UV exposure time per room was approximately 17 minutes. The 10 sites evaluated are shown in Table 2 with 5 replicates at each site. The first set of samples were collected (using Rodac plates with DE Neutralizing Agar) after patient discharge, and the second set of samples were collected after UV-C treatment of the room and before environmental services staff conducted standard room decontamination. If a site listed in Table 2 was unavailable, another site was cultured, resulting in samples from 16 different sites being cultured. All plates were incubated at 37°C for 48 hours. After 48 hours, all plates were read quantitatively to determine the total number of CFUs per site. In addition, each plate was evaluated specifically for the organism of interest (eg, MRSA or VRE), and that organism was quantitated.

The Student *t* test (2-tailed) was used to test the hypothesis that there was a significant difference in the presence of bacteria on surfaces treated with UV radiation compared with untreated surfaces (Table 2) or a difference between the effect of direct UV-C and indirect UV-C (Table 1). Surfaces were evaluated on whether the UV-C radiation received was direct

TABLE 1. UV-C Decontamination of Formica Surfaces in Patient Rooms Experimentally Contaminated with Methicillin-Resistant *Staphylococcus aureus* (MRSA), Vancomycin-Resistant *Enterococcus* (VRE), Multidrug-Resistant (MDR) *Acinetobacter baumannii*, and *Clostridium difficile* Spores

Organism	Inoculum	UV-C line of sight						<i>P</i>
		Total		Direct		Indirect		
		No. of samples	Decontamination, log ₁₀ reduction, mean (95% CI)	No. of samples	Decontamination, log ₁₀ reduction, mean (95% CI)	No. of samples	Decontamination, log ₁₀ reduction, mean (95% CI)	
MRSA	4.88 log ₁₀	50	3.94 (2.54–5.34)	10	4.31 (3.13–5.50)	40	3.85 (2.44–5.25)	.06
VRE	4.40 log ₁₀	47	3.46 (2.16–4.81)	15	3.90 (2.99–4.81)	32	3.25 (1.97–4.62)	.003
MDR <i>A. baumannii</i>	4.64 log ₁₀	47	3.88 (2.59–5.16)	10	4.21 (3.27–5.15)	37	3.79 (2.47–5.10)	.07
<i>C. difficile</i> spores	4.12 log ₁₀	45	2.79 (1.20–4.37)	10	4.04 (3.71–4.37)	35	2.43 (1.46–3.40)	<.001

NOTE. Patient rooms had a mean area of 12.1 m² including bathroom. CI, confidence interval.

TABLE 2. UV-C Decontamination of Surfaces in 8 Patient Rooms That Had Been Occupied by Patients under Contact Precautions for Methicillin-Resistant *Staphylococcus aureus* (MRSA)

Site	Total CFUs per site, mean		MRSA-positive plates/total plates	
	Before UV-C	After UV-C	Before UV-C	After UV-C
Sink ($n = 8$)	134	11	7/40	0/40
Toilet seat ($n = 6$)	559	9	1/30	0/30
Tray table ($n = 8$)	171	4	1/40	0/40
Bedside rail ($n = 7$)	497	16	7/35	0/35
Chair arm ($n = 12$)	276	11	12/60	0/60
Bathroom floor, in front of toilet ($n = 6$)	940	53	16/30	1/30
Floor near bed ($n = 8$)	967	76	23/40	1/40
Monitor ($n = 4$)	24	2	0/20	0/20
Medical cart ($n = 7$)	351	9	5/35	0/35
Laundry bin top ($n = 5$)	442	8	1/25	0/25
Sink counter ($n = 1$)	12	1	0/5	0/5
Chair seat ($n = 1$)	95	2	1/5	0/5
Blood pressure machine ($n = 1$)	111	8	1/5	0/5
Bedside dresser ($n = 4$)	176	5	1/20	0/20
Floor at foot of bed ($n = 1$)	668	14	4/5	0/5
Floor at sink ($n = 1$)	729	82	1/5	0/5
Total	384	19	81/400	2/400

NOTE. The average MRSA count per MRSA-positive plate was 37 CFUs before UV-C disinfection and 2 CFUs after disinfection. Each sample site was evaluated with use of 5 Rodac plates, so, for example, the $n = 8$ sample before UV-C disinfection at the sink site represents 40 plates (8 rooms \times 5 samples at the sink in each room); the CFU count of 134 is the mean of the the count of the 5 plates in the 8 rooms at the sink site (1,070 total CFUs/8 sink sites = 134, which is the average of 5 replicates at the 8 sites). The area of a Rodac plate is approximately 26 cm². CFU, colony-forming unit.

or indirect by placing a laser pointer at the location of the UV-C device, following the path of the laser, and determining whether the laser point was visible on the site.

RESULTS

In our test room, the effectiveness of UV-C radiation in reducing the counts of vegetative bacteria on surfaces was more than 99.9% in approximately 15 minutes, and the reduction in *C. difficile* spores was 99.8% within 50 minutes. The total CFU log₁₀ reduction, as well as the log₁₀ reduction after direct and indirect exposures, is shown in Table 1. UV-C radiation was more effective when there was a direct line of sight to the contaminant (MRSA, $P = .06$; VRE, $P = .003$; *A. baumannii*, $P = .07$; *C. difficile*, $P < .001$), but meaningful reduction (mean reduction, 3.3–3.9 log₁₀) did occur when the contaminant was not directly exposed to the UV-C (eg, on the back of the computer or the back of the head of the bed). The UV-C dose delivered, as measured by a portable radiometer placed in the patient room on the bed, was 472 mJ/cm² for MRSA, 661 mJ/cm² for VRE, 627 mJ/cm² for *A. baumannii*, and 2,123 mJ/cm² for *C. difficile* spores.

After treatment, there was a significant reduction in total CFUs per plate (mean, 384 CFUs vs 19 CFUs; $P < .001$), in

the number of samples that tested positive for MRSA (81 [20.3%] of 400 plates vs 2 [0.5%] of 400 plates; $P < .001$), and in the MRSA counts per MRSA-positive plate (mean, 37 CFUs vs 2 CFUs; $P < .001$) (Table 2). The same relationship was revealed for VRE-contaminated patient rooms (data not shown).

DISCUSSION

UV irradiation has been used for the control of pathogenic microorganisms in a variety of applications, such as control of legionellosis, as well as disinfection of air, surfaces, and instruments.^{10–12} At certain wavelengths, UV light will break the molecular bonds in DNA, thereby destroying the organism. UV-C has a characteristic wavelength of 200–270 nm, which lies in the germicidally active portion of the electromagnetic spectrum of 200–320 nm. The efficacy of UV irradiation is a function of many different location and operational factors, such as intensity, exposure time, lamp placement, and air movement patterns.^{10–12} These studies showed that this technology is an acceptable and environmentally friendly method to disinfect surfaces in healthcare facilities.

The system that we evaluated is unique in that it uses measured UV-C intensities reflected from the walls, ceilings,

floors, or other items in the room and calculates the operation time required to deliver the programmed lethal dose for microorganisms.⁸ The ability of the device to deliver lethal doses of UV-C to epidemiologically important microorganisms on nonreflective surfaces was evaluated, and we found that the quantities of these organisms were significantly reduced, reproducibly by 3–4 log₁₀, under high contamination levels that exceed the levels normally found in healthcare facilities. In fact, studies have shown that, although the frequency of contamination by these pathogens (eg, *C. difficile*) is high (10% to more than 50%), the microbial load is generally low (less than 10 to 100 CFUs per plate or sample).¹³

In our experiments, we did not pre-clean the surfaces in patient rooms before treatment with UV-C. However, because the presence of dirt and debris can decrease the effectiveness of UV-C disinfection, rooms should be cleaned before UV-C treatment. Use of a pre-cleaning step, such as wiping all surfaces and objects with an Environmental Protection Agency-registered disinfectant, followed by UV-C exposure should effectively decontaminate the surfaces and objects in the room. During the second phase of the study, we studied situations in which the bioburden levels are those naturally found on surfaces. In these situations, UV-C is capable of completely inactivating the entire population of vegetative bacteria (eg, MRSA or VRE) within approximately 15 minutes.

All disinfection and sterilization technologies have both advantages and disadvantages, and healthcare workers must consider these issues and decide which product or process provides the greatest value to them in their infection prevention efforts. The advantages of this system include the following: biocidal activity is reliable against a wide range of pathogens; surfaces and equipment can be decontaminated; decontamination for vegetative bacteria is rapid (approximately 15 minutes); the heating, ventilation, and air conditioning system does not need to be disabled and the room does not need to be sealed; the process is residual free and does not give rise to health and safety concerns; there are no consumable products, so the only costs are capital equipment and staff time; and UV energy is distributed well in the room with use of an automated monitoring system. The disadvantages include the following: we do not know whether use decreases the incidence of healthcare-associated infections; decontamination is performed only at terminal disinfection (ie, not daily cleaning); all patients and staff must vacate the room or area; capital equipment costs are substantial; it does not remove dust and stains, which are important to patients and visitors; and it has sensitive use parameters (eg, UV dose delivered).

In summary, UV technology offers an option for room decontamination in healthcare facilities. MRSA, VRE, MDR *A. baumannii*, and *C. difficile* spores comprise a growing reservoir of epidemiologically important pathogens that have an environmental mode of transmission. Because contamination of environmental surfaces is common even after surface dis-

infection and because contamination of healthcare worker hands can transfer these pathogens to patients, resulting in substantial numbers of infections, this technology (and other effective room decontamination technology) should be considered for use in selected patient rooms and care areas to augment current surface disinfection practices. Because of the high frequency of failure of manual cleaning and disinfection to contact all surfaces, room decontamination units, such as those using UV-C and hydrogen peroxide vapor, should be considered for use when the environmental mode of transmission is important.

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Potential conflicts of interest. W.A.R. reports that he is a consultant to Advanced Sterilization Products and Clorox Corporation and has received honoraria from Advanced Sterilization Products. D.J.W. reports that he is a consultant to Clorox Corporation and has received honoraria from Advanced Sterilization Products. M.F.G. reports no conflicts of interest relevant to this article.

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