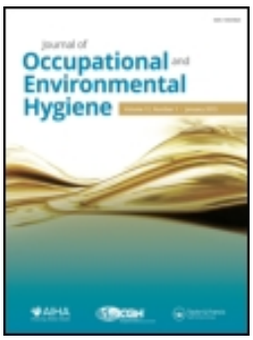

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Comparison of hospital room surface disinfection using a novel ultraviolet germicidal irradiation (UVGI) generator

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ABSTRACT

The estimated 721,800 hospital acquired infections per year in the United States have necessitated development of novel environmental decontamination technologies such as ultraviolet germicidal irradiation (UVGI). This study evaluated the efficacy of a novel, portable UVGI generator (the TORCH, ChlorDiSys Solutions, Inc., Lebanon, NJ) to disinfect surface coupons composed of plastic from a bedrail, stainless steel, chrome-plated light switch cover, and a porcelain tile that were inoculated with methicillin-resistant *Staphylococcus aureus* (MRSA) or vancomycin-resistant *Enterococcus faecalis* (VRE). Each surface type was placed at 6 different sites within a hospital room and treated by 10-min ultraviolet-C (UVC) exposures using the TORCH with doses ranging from 0–688 mJ/cm^2 between sites. Organism reductions were compared with untreated surface coupons as controls. Overall, UVGI significantly reduced MRSA by an average of 4.6 $\log_{10}$ (GSD: 1.7 $\log_{10}$, 77% inactivation, $p < 0.0001$) and VRE by an average of 3.9 $\log_{10}$ (GSD: 1.7 $\log_{10}$, 65% inactivation, $p < 0.0001$). MRSA on bedrail was reduced significantly ($p < 0.0001$) less than on other surfaces, while VRE was reduced significantly less on chrome ($p = 0.0004$) and stainless steel ($p = 0.0012$) than porcelain tile. Organisms out of direct line of sight of the UVC generator were reduced significantly less ($p < 0.0001$) than those directly in line of sight. UVGI was found an effective method to inactivate nosocomial pathogens on surfaces evaluated within the hospital environment in direct line of sight of UVGI treatment with variation between organism and surface types.

KEYWORDS
Decontamination; hospital room; surfaces; ultraviolet disinfection; UVGI

Introduction

Hospital-acquired infections (HAIs) afflict 1 in 25 hospitalized patients daily in the United States for an estimated 721,800 yearly HAIs.[1] Device-associated infections (e.g., ventilator-associated pneumonia) and surgical-site infections total 47% of all nosocomial infections, while the remaining 53% are unrelated to these sources.[1] HAI-associated pathogens contaminate the environment of patients and the hands of healthcare workers, contributing to the transmission of infections caused by microorganisms such as *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus* (MRSA), and vancomycin-resistant *Enterococcus* (VRE).[2] Hands have been found equally likely to be contaminated with nosocomial organisms after contacting patients with HAIs or contacting surfaces within hospital rooms of patients with HAIs.[3,4] Inconsistent quality of manual disinfection between hospital rooms further promotes environmental infection transmission.[5]

Ultraviolet germicidal irradiation (UVGI) treatment by a portable ultraviolet-C (UVC) generator has emerged as a successful disinfection method in the hospital setting with established limitations for areas shadowed from UVC treatment.[6–10] The TORCH UVC generators were applied as a tertiary disinfection process in the decontamination of ambulances and the Nebraska Biocontainment Patient Care Unit following care for patients with Ebola virus disease, a virus which is less environmentally hardy than VRE or MRSA.[11,12]

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uoeh.

Few studies have systematically examined the parameters of UVGI disinfection on diverse surfaces and none applied to room-wide decontamination of varied surfaces found in the clinical setting. This study evaluated a novel, portable UVGI generator (the TORCH, ChlorDiSys Solutions, Inc., Lebanon, NJ) in disinfecting surfaces located within a hospital room that were inoculated with a standardized concentration of HAI-related bacterial strains.

Methods

Setting

UVGI treatment trials were completed within a 20 m^2 hospital room in the Nebraska Biocontainment Patient Care Unit at the University of Nebraska Medical Center with features similar to biosafety level (BSL) 3 containment including controlled access and >15 air exchanges per hour.[13] The hospital room contained medical equipment, a patient bed and mannequin, and computers on wheels simulating the patient care environment. UVGI treatment should not be performed while personnel are present within the hospital room.

Organisms

Bacterial strains of methicillin-resistant *Staphylococcus aureus* (MRSA) ATCC 43300 and vancomycin-resistant *Enterococcus faecalis* (VRE) ATCC 51299 were selected for this study. MRSA and VRE stock organisms were cultured in tryptic soy broth and brain-heart infusion broth respectively to >7 $\log_{10}$ colony forming units (CFU) per mL at 37°C for 24–48 hr.[14,15] The broth culture was centrifuged and washed in phosphate buffer saline (PBS) twice. The resulting soft pellet was diluted in PBS to ~ 6 $\log_{10}$ CFU/mL. The stock organism concentrations were measured each trial by plated CFU counts and stored at 4°C for no more than 10 days.[16,17]

Preparation of surface coupons

Surfaces coupons (~35 cm^2) of stainless steel, chrome, porcelain tile, and bedrail (cut from actual hospital bedrails) were inoculated with 100 µL organism solution in four even drops across surfaces and dried for 3 hr.[16]

UVGI treatment

Five trials of UVGI treatment on bacteria-inoculated surface coupons in the hospital room were completed. Six sites were chosen for surface coupon placement (Figure 1). Prior to the trials, a UVC sensor (ChlorDiSys Solutions, Inc., Lebanon, NJ) was placed at each site and treated by UVGI for 10 min to record the average UVC dosage at each site (Table 1). The UV sensor is cosine corrected with a spectral response of 249–261 nm (greatest response at 254 nm) and range of 0.01–2000 µW/cm^2. During trials, the UVC sensor was placed in the corner of the room (Figure 1).

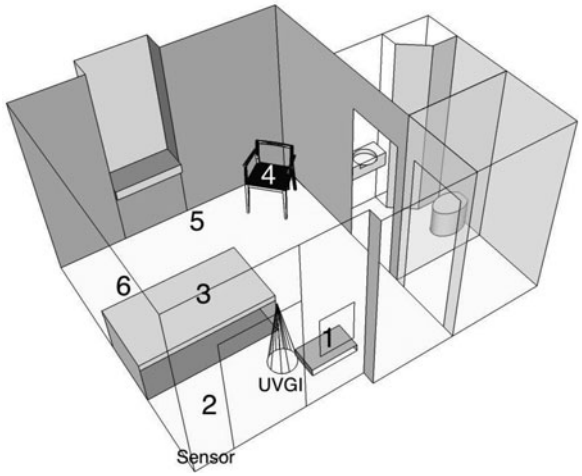

Figure 1. Ultraviolet germicidal irradiation (UVGI) generator, surface coupon placement sites (1–6), and UVC sensor placement in Nebraska Biocontainment Unit hospital room during UVGI treatment. Control surface coupons were positioned within the Nebraska Biocontainment Unit during treatment but were not moved out of the transport container or exposed to the UV light.

As Figure 2 displays, each of the four types of surface coupons was evaluated in triplicate at each site. Each type of surface coupon was inoculated with either VRE or MRSA, contained within an open petri dish, attached to a panel, and placed at sites 1–6 in the hospital room (Figure 3). Surface coupons on panels were angled vertically (~60°) so the UV treatment dose was representative of that recorded by the UVC sensor (angled vertically at 90°) rather than horizontal placement (0°). Control surface coupons were prepared identically and positioned within the Nebraska Biocontainment Unit during treatment, but control surface coupons were not moved out of the transport container or exposed to the UV light.

For treatment, the UVGI generator (the TORCH, ChlorDiSys Solutions, Inc., Lebanon, NJ; Figure 3) was placed in the center of the hospital room the UVC sensor in the room corner (Figure 1). The TORCH™ bulbs were warmed for 10 min immediately prior to each trial. Hospital room windows were covered, lights were turned off, the door closed, and a remote was used to activate the TORCH™ from outside the hospital room. Surface coupons were treated using a single UVGI generator for a 10-min exposure while the UVC sensor measured UVC dosage from the corner of the room. A 10-min exposure is the UV disinfection treatment time utilized by the Nebraska Medicine hospital. The TORCH

Table 1. Hospital room surface coupon placement and UVC dose.

Site[a]	Description	Distance in Meters		Mean UVC Dose[b] (mJ/cm^2)
		UVGI Generator	Floor	
1	Wall mounted counter	1.0	0.9	688
2	Floor near UVC generator	1.5	0.0	413
3	Top of bed mattress	3.5	0.5	323
4	Top of corner chair	3.5	0.5	78
5	Floor near window	3.5	0.0	9
6	Floor behind bed	2.8	0.0	0
Sensor	Corner of room	1.5	0.2	206[c]

[a]Surface coupons representing each surface type were placed at sites 1–6. Sites 1–6 were tested with MRSA and VRE. The UVC Sensor was placed in the corner of the room during trials. [b]Prior to trials, the UVC Sensor was placed at each site for three 10-min exposures to record mean UVC Doses. [c]Indicates Mean UVC Dose recorded during trials.

is a novel UVGI generator capable of connecting multiple units together for simultaneous use; a single unit was used in this study. The center of the TORCH is open to allow UVC light to expand 360° in the treatment room, and UVC emitting bulbs are tilted at 4°.[18] The TORCH's 8 quartz, low-pressure T5 UVC bulbs are 5 ft in length and emit 264 W UVC total. The UVC lamps were seasoned ~100 hr prior to the study.

Processing

Immediately following UVGI treatment, surface coupons (including controls) were transported to a BSL-2 laboratory to quantify bacterial reduction. Both the irradiated coupons and control coupons were processed at the same time. Organisms were collected from surface coupons by standard swabbing techniques.[19,20] Organisms were diluted in 900 µL PBS, plated, and cultured at 37°C for 24 hr. Plate CFUs were counted using Doc-It LS Image Analysis Software (UVP, Upland, CA).

Data analysis

The $\log_{10}$ reductions due to vegetative bacteria desiccation were controlled for by subtracting the $\log_{10}$ reductions in the untreated control surfaces from the treated surfaces. Geometric mean log reductions, geometric standard deviations (GSD), and percent log inactivation were

Figure 2. Surface coupons contained within petri dishes in triplicate placed onto vertical panel at site 3 on top of the patient bed within hospital room prior to UVGI treatment. Surface coupons from left to right: porcelain tile, chrome light switch cover, stainless steel, bedrail.

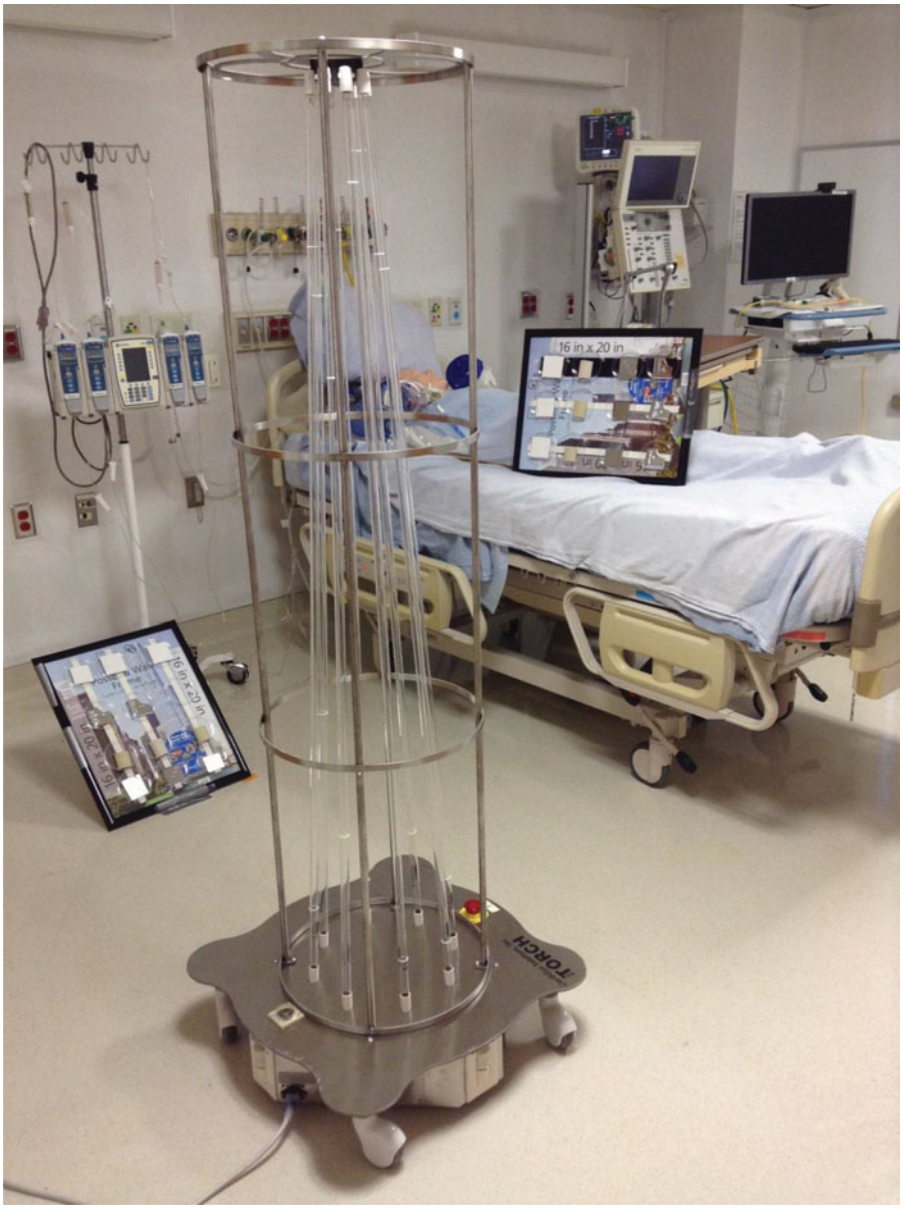

Figure 3. Ultraviolet germicidal irradiation (UVGI) portable generator and surface coupon/panel setup within hospital room for UVGI treatment. Surface coupons of each type are attached to panels at site 2 (floor next to UVGI generator) and 3 (top of patient bed) and placed vertically (~60°). A mannequin was present on the patient bed during UVC exposures; however, personnel should be evacuated from the hospital room before UVGI use.

calculated using Microsoft Excel (Microsoft Corporation, Redmond, WA). A three-factor ANOVA model was used to determine differences in mean log reduction between groups (control to treatment, site, and surface) using SAS Statistical Software version 9.4 (SAS Institute Inc., Cary, NC). Follow-up testing, using a Tukey adjustment, revealed pair-wise differences between groups.

Results

After adjustment for multiple comparisons between surface types and sites, overall UVGI significantly reduced MRSA by an average of 4.6 $\log_{10}$ (GSD 1.7 $\log_{10}$, 77% inactivation; $p < 0.0001$) and VRE by an average of 3.9 $\log_{10}$ (GSD 1.7 $\log_{10}$, 65% inactivation; $p < 0.0001$) (Table 2). MRSA was reduced at sites 1–5 (wall mounted counter, floor near UVC generator, top of patient bed, top of corner chair, and on floor near window) by $\geq$4.7 $\log_{10}$ (75% inactivation) and by an average of 1.3 $\log_{10}$ at site 6 (behind hospital bed) (GSD 1.7 $\log_{10}$, 23% inactivation), with significantly less reduction at site 6 compared to sites 1–5 ($p < 0.0001$). VRE was reduced by $\geq$3.8 $\log_{10}$ (62% inactivation) at sites 1–5 and by an average of 1.2 $\log_{10}$ at site 6 (GSD 1.5 $\log_{10}$, 22% inactivation), with significantly less reduction at site 6 compared to sites 1–5 ($p < 0.0001$). Overall at sites 1–6, MRSA on porcelain tile, stainless

Table 2. Comparison of mean Log_{10} reduction (geometric standard deviation (GSD)), percent inactivation (%)) for methicillin-resistant *Staphylococcus aureus* (MRSA), and vancomycin-resistant *Enterococcus faecalis* (VRE) between room sites.

		MRSA		VRE	
Site	Mean UVC Dose (mJ/cm^2)	log_{10} (GSD, %)	p-value	log_{10} (GSD, %)	p-value
1	688	5.4 (1.3, 86%)	N.S.	4.9 (1.2, 80%)	N.S.
2	413	5.9 (1.2, 94%)	N.S.	4.8 (1.3, 78%)	N.S.
3	323	5.6 (1.3, 90%)	N.S.	4.8 (1.3, 79%)	N.S.
4	78	4.7 (1.6, 76%)	N.S.	3.8 (1.5, 62%)	N.S.
5	9	4.7 (1.4, 75%)	N.S.	3.8 (1.5, 62%)	N.S.
6	0	1.3 (1.7, 23%)	<0.0001[a,b]	1.2 (1.5, 22%)	<0.0001[a,b]
Total	206 (171–225)[c]	4.6 (1.7, 77%)	<0.0001[a,d]	3.9 (1.7, 65%)	<0.0001[a,d]

[a]Indicates statistical significance ($\alpha = 0.05$). [b]$P < 0.0001$ when comparing log_{10} reduction means of sites 1–5 to site 6. [c]Mean UVC dose (range) during trials as recorded by the UVC sensor placed in the corner of the room. [d]$P < 0.0001$ when comparing log_{10} reduction means in UV-treated surface coupons to control surface coupons.

steel, and chrome was reduced by an average of ≥ 5.0 log_{10} (78% inactivation) and by an average of 3.0 log_{10} (GSD 1.8 log_{10}, 54% inactivation) on bedrail (Table 3). Bedrail was reduced by 2.0–2.5 log_{10} less than all other surfaces ($p < 0.0001$) for MRSA. VRE was reduced on all surfaces by an average of 3.5–4.4 log_{10} (59–71% inactivation). VRE on chrome and stainless steel were reduced significantly less than on porcelain, with an average of 0.9 log_{10} less reduction on both chrome ($p = 0.0004$) and stainless steel ($p = 0.0012$).

Discussion

Bacterial inactivation by UV light has previously varied between bacterial organisms and surfaces. Bae and Lee[21] found inactivation variances between surface and organism types when testing UV treatment of *Escherichia coli* O157:H7, *Salmonella* Typhimurium, *Pseudomonas aeruginosa, Listeria monocytogenes*, and *Staphylococcus aureus* on stainless steel and polypropylene surfaces. *P. aeruginosa* and *E. coli* O157:H7 were not significantly reduced ($p>0.05$) on stainless steel when treated with UV light for 3 hr, with similar findings for *E. coli* O157:H7, *P. aeruginosa*, and *L. monocytogenes* on polypropylene.[21] UVC treatment was ineffective for bacterial reduction on clothing (laboratory coats) (<1 log_{10} reduction) in comparison to aluminum and stainless steel surfaces (>4 log_{10} reduction).[22] Woodling and Moraru[23] found overall insignificant differences in *Listeria innocua* disinfection between smooth and rough stainless steel surfaces using pulsed light treatment (involves broad range of wavelengths from UV to nearly infrared). Yet, at lower doses, the smoothest surface showed less inactivation due to bacterial clustering on the relatively more hydrophobic surface.[23] Although rough surfaces allowed for bacterial hiding in crevices as confirmed by scanning electron microscopy, rough surfaces demonstrated more uniform surface distribution and inactivation of bacteria in comparison to smooth surfaces.[23] The authors also speculate that more reflective surfaces may decrease the dose of light absorbed by bacteria contributing to reduced inactivation.[23] Ringus and Moraru[24] demonstrated that *Listeria innocua* inactivation was decreased on relatively more reflective and rough surfaces (all coated with polypropylene) using pulsed light.[24]

Complexities in bacterial inactivation based on surface topography (i.e., roughness or smoothness) and reflectivity may have been exhibited in this study. The plastic bedrail surface was relatively rough in comparison to the stainless steel, chrome, and porcelain surfaces by visual observation. Chrome and stainless steel surfaces appeared to be relatively reflective in comparison to the bedrail and porcelain steel surfaces. The efficacy of UVGI on plastic bedrail with MRSA was ≥ 2 log_{10} less in comparison to chrome, stainless steel, and porcelain tile surfaces, an effect possibly due to bacterial "hiding" on

Table 3. Comparison of mean Log_{10} reduction (geometric standard deviation (GSD), percent inactivation (%)) for methicillin-resistant *Staphylococcus aureus* (MRSA), and vancomycin-resistant *Enterococcus faecalis* (VRE) between each surface.

	MRSA		VRE	
Surface	log_{10} (GSD, %)	p-value	log_{10} (GSD, %)	p-value
Porcelain	5.5 (1.5, 85%)	N.S.	4.4 (1.8, 71%)	N.S.
Bedrail	3.0 (1.8, 54%)	<0.0001[a,b]	4.1 (1.5, 65%)	N.S.
Stainless steel	5.0 (1.6, 78%)	N.S.	3.6 (1.6, 62%)	0.0012[a,c]
Chrome	5.5 (1.4, 86%)	N.S.	3.5 (1.7, 59%)	0.0004[a,b]

[a]Indicates statistical significance ($\alpha = 0.05$). [b]Significant ($p < 0.0001$) when comparing log_{10} reduction means of bedrail to all other surfaces. [c]Significant ($p < 0.05$) when comparing log_{10} reduction means of stainless steel and chrome to porcelain.

this comparatively rougher surface. This finding was not replicated with VRE. VRE reductions on chrome and stainless steel surfaces were lowered significantly ($p = 0.0004$ asnd $p = 0.0012$, respectively) when compared to porcelain tile, possibly from the increased reflectivity of chrome and stainless steel in comparison to porcelain tile. This study did not formally incorporate roughness or reflectivity measurements of surfaces other than visual observation, but these factors may have contributed to disinfection variances between surface types.

Several previous studies have evaluated portable UVC generators in hospital room decontamination (Table 4), many of which reported disinfection limitations in areas not in direct line of sight of treatment.[7,8,25] In a study from Anderson et al.,[26] a directly exposed UVC dose of 12 mJ/cm^2 produced by a single UVGI generator, Tru-D Smart UVC (Lumalier), recorded an average of 1.68 $\log_{10}$ VRE reductions (712 CFUs reduced to 15 CFUs) at 5 contaminated hospital rooms surfaces following care of patients with VRE.[26] The study from Anderson et al. [26] differs from this study in that organisms were not inoculated onto surfaces but were contaminated at lower concentrations during patient care. In addition, the bulbs of the Tru-D UVC generator were oriented vertically (90°) with center support, rather than with an open center and bulbs tilted at 4° from vertical as in the TORCH.[26] Using the Tru-D UVC device with a dose of 12 mJ/cm^2 dose at 5 locations in a surgical theater on inoculated Petri dishes, Mahida et al.[9] reported an average $\geq$4.0 $\log_{10}$ MRSA reductions for both direct and indirect line of sight exposures and 3.5 $\log_{10}$ direct and 2.4 $\log_{10}$ indirect VRE reductions. In Mahida et al.'s[9] study, Petri dishes inoculated VRE were reduced by an average $\geq$4.0 $\log_{10}$ by direct and 2.3 $\log_{10}$ by indirect UVC exposures at 12 mJ/cm^2. Rutala et al.[10] described reduction of MRSA and VRE inocula on Formica sheets by an average of 4.31 $\log_{10}$ by direct and 3.85 $\log_{10}$ by indirect and 3.90 $\log_{10}$ by direct and 3.25 $\log_{10}$ by indirect line of sight, respectively, after 12 mJ/cm^2 treatment with the Tru-D UVC generator in a hospital room. Finally, Jinadatha et al.[27] reported evaluation of a pulsed xenon ultraviolet light (PPX-UV) (Xenex Healthcare Services) at 5 sites within a hospital room contaminated following patient care and manual cleaning, which reduced MRSA by ~3 $\log_{10}$ overall. This PPX-UV device emits ~450 UVC flashes/cycle and was positioned at 3 locations for 5 min treatments each (15 min total).[27]

The study completed for this article was consistent with earlier reports with an average of 4.6 $\log_{10}$ reductions for MRSA and 3.9 $\log_{10}$ for VRE. Reductions on surfaces out of direct line of sight of UVC exposure (i.e., site 6 shielded behind the hospital bed recording 0 mJ/cm^2) were significantly lessened ($p < 0.0001$) when compared to those surfaces in direct line of sight to UV exposure. In other studies, the surfaces treated by UVC and swabbed for reductions may or may not have been positioned vertically, dissimilar to this study in which panels were angled at ~60°, possibly enhancing inactivation with a more direct exposure. This study environment within the biocontainment unit under high rates of air exchange also potentially promoted bacterial desiccation.

This study was limited by several factors. First, MRSA and VRE were chosen as study microorganisms given their common HAI incidence, but neither MRSA nor VRE are spore-forming bacteria, such as the HAI-leading *Clostridium difficile*, which requires higher doses of UVC exposure for inactivation.[1,25] Second, several surface coupons were 100% inactivated by UVGI in this study restricting quantification of the limits of UVGI $\log_{10}$ reduction. Third, control surface coupons inoculated with bacteria were positioned within a closed container during UVGI treatment, so the high rate of air exchanges within the biocontainment hospital room during the 10-min UVGI treatment may have contributed to bacterial inactivation through desiccation on treatment surfaces. Fourth, the organism carrier solution used in this study was PBS, which does not contain the organic bioburden found in bodily fluids that may decrease the efficacy of UVGI.[28] Finally, the UVC doses recorded at each site were limited by the photosensitivity and position of the UVC sensor. At site 6, the UVC sensor recorded a mean of 0 mJ/cm^2. UVC disinfection was decreased at site 6 compared to sites 1–5, yet organisms were reduced by 1–2 $\log_{10}$ in comparison to controls. Indirect UVC exposures might have reflected from room surfaces onto site 6 to cause organism inactivation, undetectable by the UVC sensor. In addition, small variances in UVC dose would likely be found between each surface coupon on the panel within each site.

Future studies should continue investigation of the effects of various surfaces, organisms, and clinical environments on UVGI efficacy. First, previous studies have evaluated the Tru-D UVC device, which differs in design with a closed center and vertically aligned bulbs in comparison to the open centered, 4° tilted TORCH lamps. Additionally, the PPX-UV device emits pulses of UVC light in ~15-min treatment. The UVGI efficacy between these devices might be systematically evaluated. Second, scanning electron microscopy might be used to examine the bacterial inactivation differences on these and other various hospital environment textures. Finally, new paint technology (applied to the walls of the hospital room) capable of reflecting UVC light has been shown to decrease the time required for UVGI decontamination while simultaneously improving disinfection efficacy in areas out of direct line of sight of UVC treatment.[29] The applications and parameters of UVC-reflective paint

Table 4. Comparison of portable UVC generators in hospital room decontamination.

Study	Device	Dose[a] (mJ/cm^2)	Exposure Time (min)	Organism	Direct, Indirect or Overall Exposure	Reduction (log_{10})	Surface and Setting
Nerandzic et al.[25]	Tru-D	22	~45	MRSA	Both	>2–3	Inoculated bench top surfaces in laboratory
				VRE		>3–4	
				Clostridium difficile		>2–3	
					Direct	2.6	Inoculated plastic carriers placed at 4 locations in hospital room
					Indirect	1.0	
Rutala et al.[10]	Tru-D	12	15	MRSA	Direct	4.31	Inoculated Formica sheets placed at 10 locations in hospital room
					Indirect	3.85	
				VRE	Direct	3.90	
					Indirect	3.25	
				Multidrug-resistant *Acinetobacter baumannii*	Direct	4.21	
					Indirect	3.79	
		36	50	*Clostridium difficile*	Direct	4.04	
					Indirect	2.43	
Boyce et al.[8]	Tru-D	22	67.8 (34.2–100.1)	*Clostridium difficile*	Direct	2.14–2.34	Inoculated stainless steel placed at 5 locations in hospital room
					Indirect	1.66–2.86	
Havill et al.[7]	Tru-D	22	73 (39–100)	*Clostridium difficile*	Overall	2.2	Inoculated disks at 5 locations in hospital room
Anderson et al.[26]	Tru-D	12	25 (20–35)	VRE	Direct	1.68	≥5 hospital room surfaces contaminated following patient care
					Indirect	NA	
				Acinetobacter spp.	Direct	1.71	
					Indirect	NA	
		22		*Clostridium difficile*	Direct	0.80	
					Indirect	1.18	
Mahida et al.[9]	Tru-D	12	30–40	MRSA	Both	≥4	Inoculated Petri dishes at 5 locations in surgical theater
				VRE	Direct	3.5	
					Indirect	2.4	
					Direct	≥4.0	Inoculated Petri dishes at 3–5 locations in hospital room
					Indirect	2.3	
				Aspergillus	Direct	≥4.0	
					Indirect	2.0	
				Multidrug-resistant *Acinetobacter*	Direct	≥4.0	
					Indirect	1.7	
		22	60–90	VRE	Direct	≥4.0	
					Indirect	3.5	
				Aspergillus	Direct	≥4.0	
					Indirect	1.0	
				Multidrug-resistant *Acinetobacter*	Direct	≥4.0	
					Indirect	3.0	
Jinadatha et al.[27]	PPX-UV[b]	~450 flashes/cycle	15	MRSA	Overall	~3	5 hospital room surfaces contaminated following patient care and manual wiping; PPX-UV re-positioned to 3 locations (5 min exposure each)
Jelden et al. (this study)	TORCH	9-688	10	MRSA	Direct	≥4.7	Inoculated chrome, stainless steel, porcelain, plastic bedrail at 6 locations in a hospital room
		0			Indirect	1.3	
		9-688		VRE	Direct	≥3.8	
		0			Indirect	1.2	

[a]The Tru-D (Lumalier) automatically powers off when the least reflective area of the room (i.e., shadowed area) reflects the minimum set Dose back to the sensor on the device. [b]Pulsed xenon ultraviolet light (PPX-UV) (Xenex Healthcare Services) emits flashes of UVC light.

technology for use in the clinical environment in conjunction with UVGI should be explored.

Conclusions

The TORCH (ChlorDiSys Solutions, Inc., Lebanon, NJ) UVGI generator achieved an average of 4.6 and 3.9 log_{10} reductions for MRSA and VRE respectively on inoculated surfaces composed of of porcelain, chrome, stainless steel, and plastic (bedrail) each placed at six sites within the hospital room after a 10-min UVC treatment ranging from 0–688 mJ/cm^2. Pathogen reduction varied between evaluated organisms, surfaces, and sites. Future study should continue examination of the effect of organism, surface

type, and device type in environmental decontamination by UVGI in various clinical settings.

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