PANEL V: BEYOND UVC - REFLECTIVE SURFACES AND COATINGS

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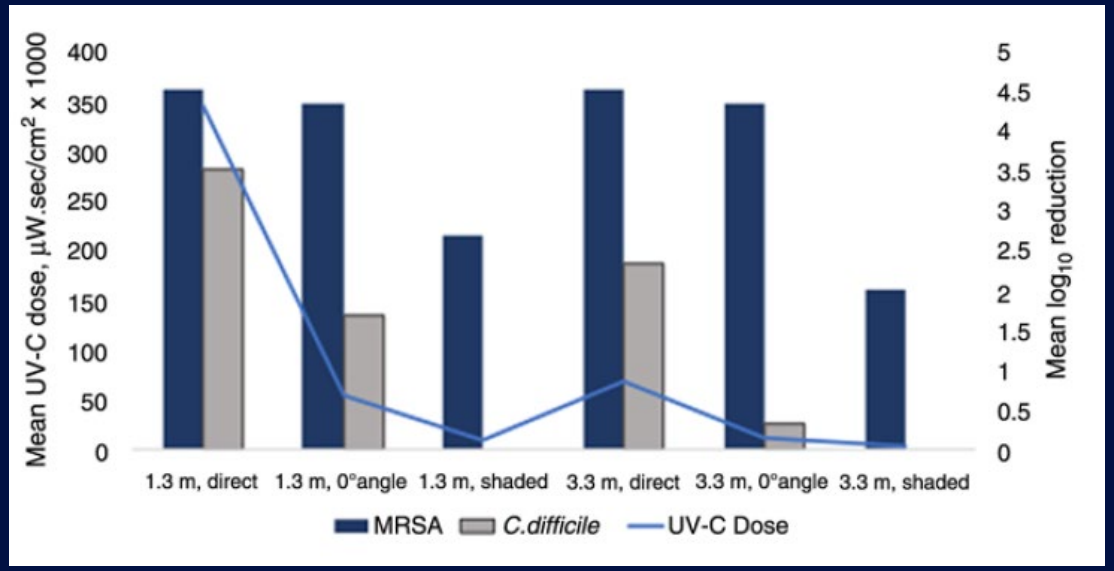
FACTORS AFFECTING UV ROOM DISINFECTION DEVICE EFFECTIVENESS

- Intensity of UV delivered (i.e., energy)
- Wavelength(s) of UV
- Distance (energy delivered falls off as a square of distance)
- Duration of exposure
- Orientation of the surface being disinfected to the UV source
  - For non-shadowed surfaces, direct line of sight to UV source
  - For shadowed surfaces, UV reflectivity of walls/surfaces



- Intrinsic susceptibility of microbes (e.g., spore formers such as *C. difficile* more difficult to inactivate than vegetative bacteria such as MRSA and VRE
- Study variables: 1) microbial strain (there may be strain variability to UV); 2) spreading the inoculum over a greater surface area enhances killing; 3) organic load (e.g., 10% fetal calf serum) significantly decreases killing; 4) test surface, in general does not affect killing (e.g., Formica, glass, steel); 5) humidity

Cadnum JL, et al. ICHE 2016;37:555-560; Boyce JM, Donskey CJ. ICHE 2019;40:1030-1035

IMPACT OF A REFLECTIVE WALL COATING ON MICROBIAL INACTIVATION IN HOSPITAL ROOMS, #1

- Goal: To assess impact of a reflective wall coating on microbial inactivation buy UV-C of MRSA and *C. difficile*
- Methods: UV-C device (Tru-D, Lumalier) at 254 nm investigated in a hospital room with and without reflective coating
  - UV intensity: 12,000 μWs/cm^2 for MRSA and 22,000 μWs/cm^2 for *C. difficile*
  - Reflective coating: Increased reflectivity from 3-7% to ~65%; cost estimated to be <$300 per hospital room
  - Surfaces (N=10): bedside table, top of bed, closet door, top of toilet seat, chair back, floor near bed, foot of bed, side of sink, back of computer, bathroom wall above toilet
- Conclusions: A reflective coating significantly reduced the time required to achieve adequate microbial inactivation

TABLE 1. Ultraviolet C (UV-C) Decontamination (Mean Log_{10} Reduction) of Formica Surfaces in a Patient Room That Were Experimentally Contaminated with Methicillin-Resistant *Staphylococcus aureus* (MRSA) and *Clostridium difficile* Spores with and without a Reflective Coating on Walls

	MRSA		*C. difficile* spores	
	With coating (inoculum, 4.75 log_{10})	Without coating (inoculum, 4.69 log_{10})	With coating (inoculum, 4.45 log_{10})	Without coating (inoculum, 4.19 log_{10})
Cycle time	5m3s (3m28s–6m39s)	25m13s (9m10s–41m16s)	9m24s (5m49s–12m59s)	43m42s (29m14s–58m9s)
Line of sight				
Direct	4.70 (4.36–5.04) [n = 42]	4.71 (4.53–4.89) [n = 36]	3.29 (1.92–4.66) [n = 39]	3.41 (2.33–4.49) [n = 33]
Indirect	4.45 (3.67–5.22) [n = 28]	4.27 (3.37–5.17) [n = 24]	2.43 (1.65–3.20) [n = 31]	2.01 (1.28–2.75) [n = 27]
All	4.60 (4.00–5.20) [n = 70]	4.53 (3.81–5.25) [n = 60]	2.91 (1.49–4.33) [n = 70]	2.78 (1.12–4.44) [n = 60]

Rutala W, Gergen M, Tande B, Weber DJ ICHE 2013;34:527-529.

IMPACT OF A REFLECTIVE WALL COATING ON MICROBIAL INACTIVATION IN HOSPITAL ROOMS, #2

- Goal: To assess whether coating surfaces other than walls with a UV reflective coating improves microbial killing
- Methods: We studied a UV-C device (Tru-D, Lumalier) in 2 patient rooms to inactivate MRSA and *C. difficile* on Formica
- Results: 1) Without reflective coating >4-$\log_{10}$ reduction of MRSA in ~23min and >2.75-$\log_{10}$ reduction of *C. difficile* in ~43min; 2) Improved inactivation when pathogens placed in direct vs indirect line of sight ($p<0.05$); 3) When wall coated, similar inactivation achieved with significantly shorter exposure times (MRSA, ~23 to ~5min, *C. difficile*, ~43 to ~8min); 4) Coating additional room surfaces (i.e., ceiling, floors) only minimally improved microbial inactivation and killing time (~1min)

TABLE 1. Effectiveness ($\log_{10}$ Reduction) of Coating Different Room Surfaces with an Ultraviolet C Light–Nanoreflective Coating

	Control (no coating)			Coated walls			Coated walls and floors			Coated walls and ceilings			Coated walls, floors, and ceilings		
Pathogen, outcome	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect
MRSA															
CFU reduction	4.12	4.46	3.70	4.21	4.50	3.83	3.95	4.27	3.64	4.02	4.40	3.64	3.80	4.12	3.47
	(3.98–4.25)	(4.34–4.58)	(3.50–3.89)	(4.09–4.32)	(4.40–4.61)	(3.63–4.03)	(3.80–4.11)	(4.06–4.48)	(3.49–3.78)	(3.86–4.18)	(4.25–4.54)	(3.46–3.82)	(3.65–3.95)	(3.92–4.33)	(3.33–3.61)
Time, minutes	23.12 (19.40–26.84)			4.53 (3.99–5.08)			4.51 (3.89–5.14)			4.08 (3.80–4.37)			3.55 (3.42–3.67)		
C. difficile															
CFU reduction	2.75	3.48	2.09	2.67	3.08	2.12	2.68	3.08	2.09	2.32	2.76	1.89	1.94	2.37	1.51
	(2.59–2.91)	(3.33–3.62)	(1.97–2.21)	(2.53–2.82)	(2.90–3.26)	(1.98–2.26)	(2.48–2.88)	(2.85–3.30)	(1.93–2.25)	(2.14–2.51)	(2.56–2.95)	(1.68–2.09)	(1.78–2.09)	(2.18–2.56)	(1.47–1.55)
Time, minutes	42.82 (39.04–46.60)			8.22 (7.07–9.34)			8.12 (6.72–9.51)			7.51 (6.73–8.29)			9.17 (8.59–9.76)		

NOTE. Data in parentheses are 95% confidence intervals. Reductions are expressed as $\log_{10}$. CFU, colony forming unit; MRSA, methicillin-resistant *Staphylococcus aureus*.

Rutala W, Weber DJ, Gergen M, Tande B ICHE 2014;35: 323-5

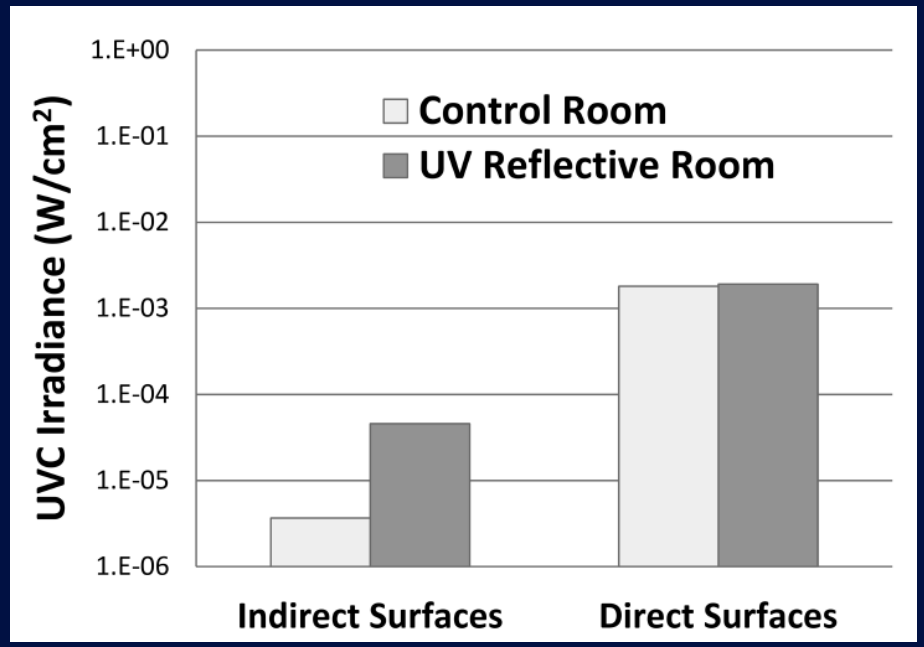
IMPACT OF A REFLECTIVE WALL COATING ON MICROBIAL INACTIVATION IN HOSPITAL ROOMS, #3

- Goal: To assess room decontamination with and without reflective paint using a UV device (V-360+, UltraViolet Devices) with short exposure times
- Methods: 1) Measurements performed in two hospital rooms; 2) microbes tested were MRSA and *C. difficile*; 3) Cycle times were 5min for MRSA and 10min for C. difficile; 4) test surface was Formica
- Results: 1) Most significant improvement in microbial inactivation were seen with indirect UV exposure (1.46-$\log_{10}$ improvement with MRSA and 0.81-$\log_{10}$ improvement with *C. difficile*)

TABLE 1. Ultraviolet-C Decontamination of Formica Surfaces in Patient Rooms That Were Experimentally Contaminated with Methicillin-Resistant *Staphylococcus aureus* (MRSA) and *Clostridium difficile* Spores with and without a Reflective Coating on Walls

	MRSA		*C. difficile*	
Variable	Without coating	With coating	Without coating	With coating
Cycle time, minutes	5	5	10	10
Direct surfaces	4.10 (3.88–4.32); 30	4.68 (4.61–4.76); 30	3.35 (3.14–3.55); 30	3.34 (3.10–3.59); 30
Indirect surfaces	2.74 (2.53–2.94); 20	4.21 (4.00–4.42); 20	1.80 (1.36–2.24); 20	2.61 (2.24–2.97); 20
Overall	3.56 (3.31–3.80); 50	4.50 (4.38–4.61); 50	2.78 (2.48–3.07); 50	3.05 (2.82–3.28); 50

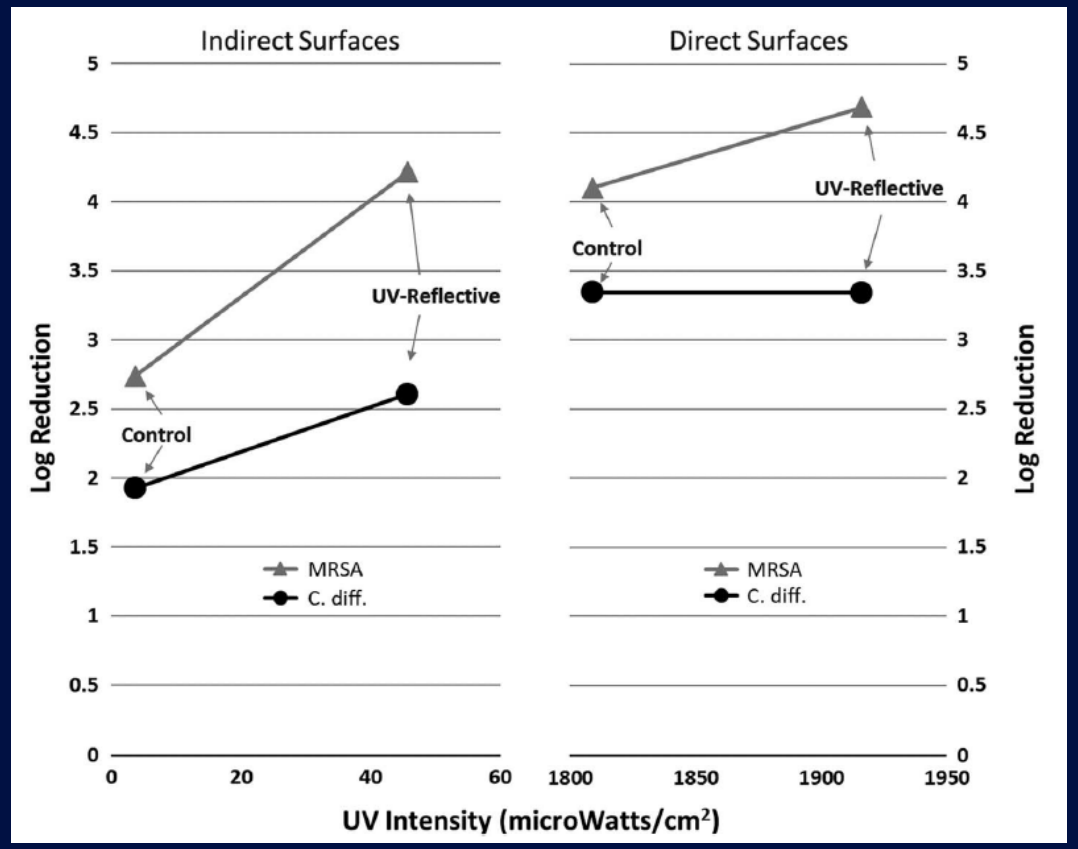
NOTE. Data are mean $\log_{10}$ reduction in colony-forming units (95% confidence interval) and no. of samples, unless otherwise indicated. Patient room is 130 square feet (12.077 m^2) in area. Confidence intervals were calculated based on a Poisson distribution.



Rutala W, Gergen M, Tande B, Weber DJ. ICHE 2014;35:1070-2

IMPACT OF A REFLECTIVE WALL COATING ON MICROBIAL INACTIVATION IN HOSPITAL ROOMS, #4

- Goal: To increase understanding of behavior of UV in a hospital room
- Methods: We studied a UV-C device (UltraViolet Devices, Valencia, CA) in 2 patient rooms
  - MRSA: 5 min cycle time; *C. difficile* spores: 10 min cycle time
  - UV irradiance measured by ILT1700 Research Radiometer
  - Coating = UV reflecting paint (Lumacept, Grand Forks, NC)
- Results
  - Direct surfaces = ~1800 μW/cm^2; Indirect surfaces = 3 μW/cm^2
  - Reflective coating increased UV intensity by >1-log$_{10}$ (i.e., 3 to 45 μW/cm^2) resulting an improved log$_{10}$ reduction of 4.2 for MRSA and 2.6 for *C. difficile*



Accumulated UV energy = intensity x exposure times (s)

Tande B, Pringle T, Rutala W, Gergen M, Weber DJ. ICHE 2018;39:1122-1124

IMPACT OF A REFLECTIVE WALL COATING ON MICROBIAL INACTIVATION IN HOSPITAL ROOMS, #4

- Goal: To increase understanding of behavior of UV in a hospital room
- Methods: We studied a UV-C device (UltraViolet Devices, Valencia, CA) in 2 rooms (with and without UV reflective coating)
  - A 3-dimensional computer model of both rooms was created based on measured UV irradiance
  - 10 surfaces studied
- Conclusions:
  - Indirect exposure leads to substantial lower energy intensity
  - UV reflective coating significantly increases UV intensity
  - A computer model can accurately be used to predict via simulation UV intensity delivered to various room locations

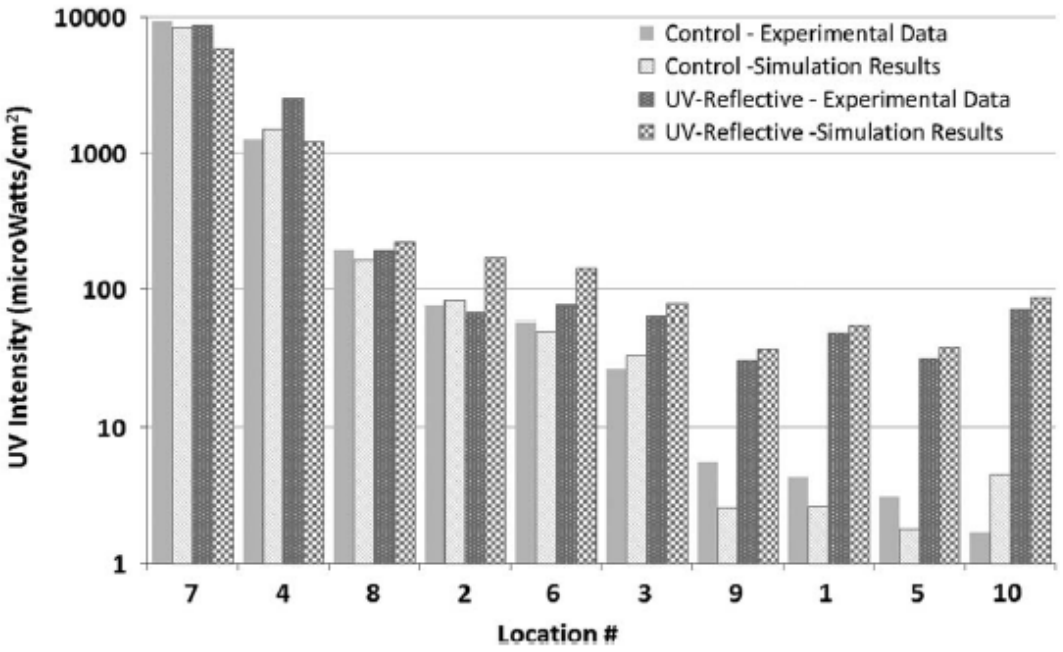


Fig. 2. Comparison of measured ultraviolet (UV) intensity values (log scale) to simulation results for both the control and the UV-reflective room. Numbers indicate the following locations: (1) the far side of the bedside table facing the wall; (2) the top of the bed; (3) the top of the toilet seat; (4) the closet door; (5) the bathroom wall above the toilet; (6) the floor on the right side of the bed; (7) the foot of the bed facing the door; (8) the back of the chair; (9) the side of the sink facing the bedside table; (10) the back of the computer facing the wall. Locations 1, 5, 9, and 10 are indirect surfaces, while the others are direct.

ASSESSMENT OF UV REFLECTIVE PAINT ON MICROBIAL DECONTAMINATION OF ROOM SURFACES

- Goal: To assess impact of a UV reflective wall coating on microbial inactivation in a hospital room
- Methods: 1) UV-C device studied = TORCH, ClorDiSys Solutions); 2) Surface coupons (plastic from a bedrail, stainless steel, and chrome plated light switch cover) contaminated with MRSA or VRE placed at 6 different sites within the hospital room
- Results: 1) Aggregate MRSA concentrations on plastic bedrail surface coupons reduced 3.0-$\log_{10}$ with standard paint vs 4.3-$\log_{10}$ with UV reflective paint ($p<0.001$); 2) Average VRE concentrations reduced by <4.1-$\log_{10}$ on all surface types with standard paint vs $\geq$4.9-$\log_{10}$ with UV-reflective paint ($p<0.05$).
- Conclusions: Coating hospital walls with UV-reflective paint enhanced UV disinfection of MRSA/VRE on multiple surfaces compared to standard paint, especially on surfaces indirectly exposed to UV-C
- Limitations: 1) Only one site evaluated with indirect UV exposure; 2) only vegetative microbes tested; 3) 93% of VRE and 92% of MRSA achieved a >6-$\log_{10}$ reduction, limiting the quantification of $\log_{10}$ reductions

Jelden KC, et al. J Occupational and Environmental Hygiene 2017;14:465-460

ASSESSMENT OF UV REFLECTIVE PAINT ON MICROBIAL DECONTAMINATION OF ROOM SURFACES

Table 2. Comparison of mean Log_{10} reduction (Geometric Standard Deviation [GSD], percent reduction [%]) for methicillin-resistant *Staphylococcus aureus* (MRSA) or vancomycin-resistant *Enterococcus faecalis* (VRE) between each surface type.

	MRSA			VRE		
	log_{10} (GSD, %)			log_{10} (GSD, %)		
Surface[b]	Standard Paint	UV-Reflective Paint	p-value	Standard Paint	UV-Reflective Paint	p-value
Plastic from a bedrail	3.0 (1.8, 99.9%)	4.3 (1.3, 99.99%)	0.0005[a]	4.1 (1.5, 99.99%)	5.6 (1.2, 99.999%)	<0.0001[a]
Stainless steel	5.0 (1.6, 99.999%)	5.5 (1.1, 99.999%)	0.39	3.6 (1.6, 99.9%)	5.0 (1.0, 99.999%)	<0.0001[a]
Chrome	5.5 (1.4, 99.999%)	5.4 (1.2, 99.999%)	0.10	3.5 (1.7, 99.9%)	4.9 (1.1, 99.99%)	0.0005[a]
Mean UVC Dose[c] (mJ/cm^2, range)	213 (201–225)	220 (214–226)		201(171–216)	215	

[a] Indicates a statistically significant ($\alpha = 0.05$) difference between Standard Paint and UV-reflective paint.
[b] Surface type data is aggregated from six sites.
[c] Indicates the Mean UVC Dose and range measured by the UVC sensor in the directly exposed hospital room corner during trials.

Table 3. Comparison of Mean Log_{10} Reductions (Geometric Standard Deviation [GSD], Percent Reduction [%]) for Methicillin-resistant *Staphylococcus aureus* (MRSA) and Vancomycin-resistant *Enterococcus faecalis* (VRE) Between Standard Paint and UV-Reflective Painted Hospital Rooms.

	MRSA			VRE		
	log_{10} (GSD, %)			log_{10} (GSD, %)		
Exposure[a]	Standard Paint	UV-Reflective Paint	p-value	Standard Paint	UV-Reflective Paint	p-value
Direct	5.2 (1.4, 99.999%)	5.1 (1.2, 99.999%)	0.017[a]	4.4 (1.4, 99.99%)	5.3 (1.1, 99.999%)	<0.0001[a]
Indirect	1.3 (1.7, 95%)	4.7 (1.3, 99.99%)	<0.0001[a]	1.2 (1.5, 95%)	4.6 (1.1, 99.99%)	<0.0001[a]
UV Dose[c] (mJ/cm^2, range)	213 (201–225)	220 (214–226)		201(171–216)	215	

[a] Indicates a statistically significant ($\alpha = 0.05$) difference between standard paint and UV-reflective paint.
[b] Exposure data is aggregated from five sites for direct exposure.
[c] Indicates the mean UVC Dose and range measured by the UVC sensor in the directly exposed hospital room corner during trials.

AMBULENCE DISINFECTION USING UV: EFFECTS OF FIXTURE LOCATION AND SURFACE REFLECTIVITY

- Goal: Assess UV to decontaminate an ambulance
- Background: Following chemical disinfection, many surfaces in ambulances harbor MRSA
- Methods: UV device place in front, middle or back of an ambulance patient compartment; UV irradiance measured at 49 locations; aluminum sheets and UV reflective paint added to assess effects of increased surface reflectivity on disinfection times; *B. subtiles* spores used as surrogate for pathogens
- Results: Depending on device location and use of reflective surfaces, disinfection time varied from 59min to 16.5hr

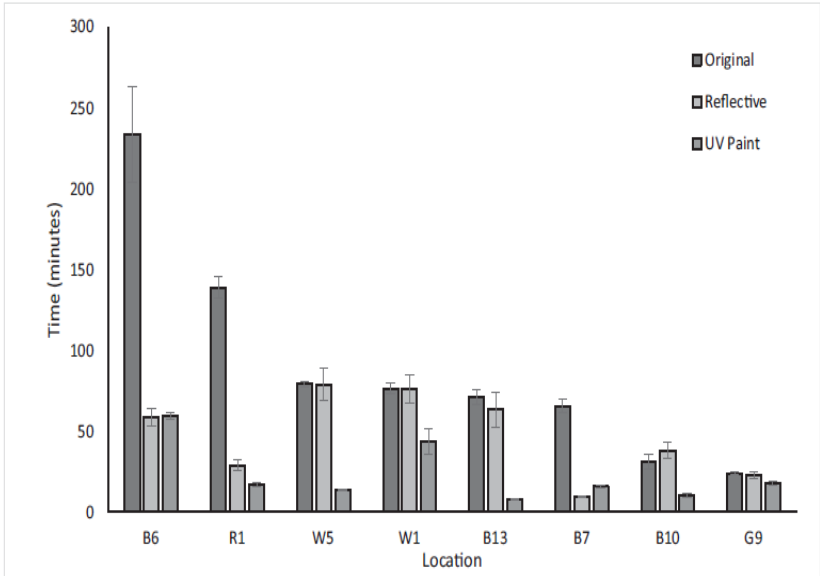


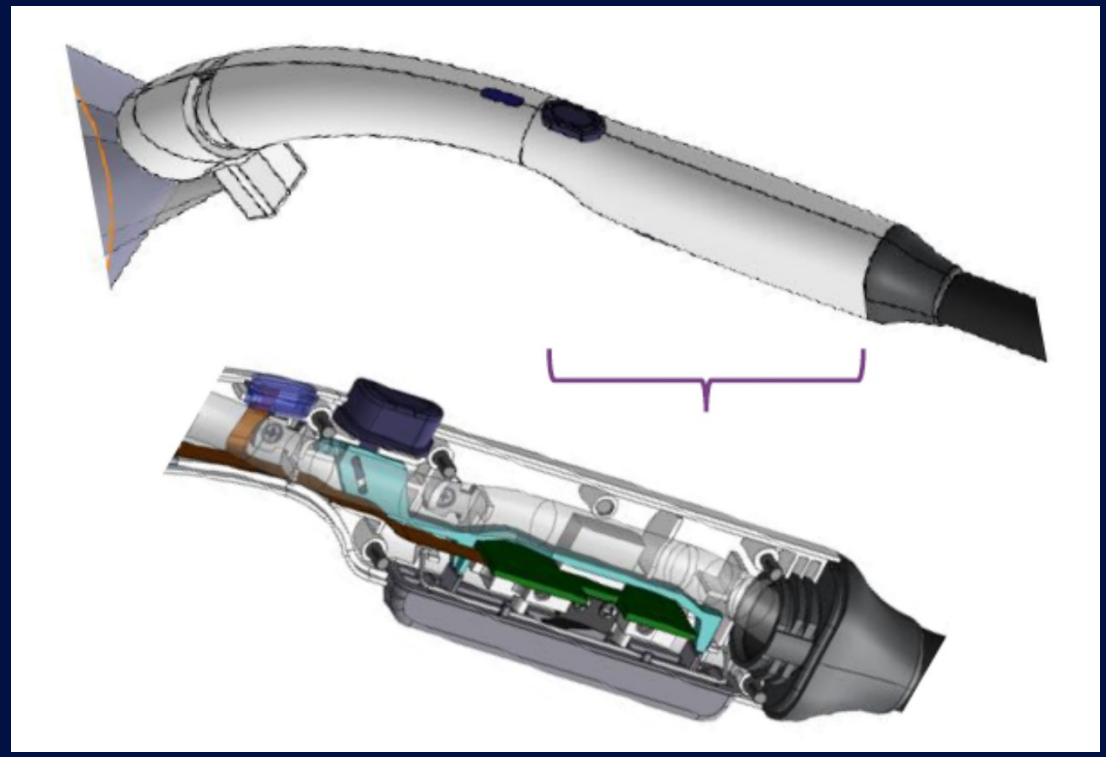
Figure 4. Effect of ambulance interior surface treatments on the surface disinfection time. These results were calculated assuming that the UVGI fixture was placed in the front, middle and back positions for one-third of the exposure time each. As described in the materials and methods section, original refers to the ambulance interior surfaces as they were originally made by the manufacturer. Reflective refers to the addition of reflective aluminum plating to various interior surfaces as shown in the online supplemental material. UV paint refers to coating the white melamine interior surfaces of the ambulance with white UV-C reflective paint. The locations shown were chosen based on the five longest disinfection times for each interior surface. Each bar shows the average of three experiments. Error bars show the standard deviation.

Lindsley WG, et al. J Occupational Med & Environmental Hygiene 2018;15:1-12

UV FOR OTHER DISINFECTION NEEDS IN HOSPITALS:
CLOSE PROXIMITY TO SURFACE PLUS MIRRORS IMPROVES EFFECTIVENESS

Antigermix s1 (Germitec)

Handheld UV Device (Lumagenics)



CONCLUSIONS

- UV-C reflective wall coatings significantly improves UV intensity delivered directly and indirectly to room surfaces – improvement more significant for indirect exposures
- UV-C reflective wall coatings significantly improves microbial inactivation with reduced exposure time to achieve similar $\log_{10}$ inactivation levels
- Coating ceilings and/or floors does NOT improved microbial killing in hospital rooms when walls are coated
- Reflective paint demonstrated to improve UV intensity with multiple UV room devices
- Future needs
  - Assess impact and costs of coating in actual hospital units (e.g., an intensive care unit)
  - Cost effective analysis demonstrating benefit of use of reflective wall coatings (parameters: cost of UV-C reflective coating vs standard paint, timing for reapplication vs standard paint, number of rooms needed to be covered)