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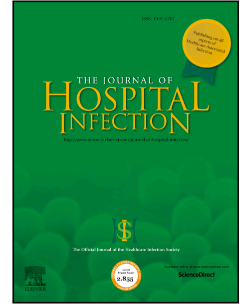

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S. Ali, S. Yui, M. Muzslay, A.P.R. Wilson

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Comparison of Two Whole-Room UV-Irradiation Systems for Enhanced Disinfection of Patient Rooms Contaminated with MRSA, carbapenemase-producing *Klebsiella pneumoniae* and *Clostridium difficile* spores

S. Ali[a]

S. Yui[a]

M. Muzslay[a]

A P R Wilson[b*]

[a] Environmental Microbiology Research Laboratory, University College London Hospitals, London, UK

[b] Department of Microbiology, University College London Hospitals, London, UK

*Corresponding author

Address: Department of Clinical Microbiology & Virology, University College London Hospitals, 60 Whitfield Street, London W1T 4EU, UK. Tel. +44 2034479516; fax: +44 02034479211

Running title: Ultraviolet decontamination of the patient environment

Keywords: *Clostridium difficile,* Environmental contamination, Ultraviolet light

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Summary

Background:

Ultraviolet light decontamination systems are being used increasingly to supplement terminal disinfection of patient rooms. However efficacy may not be consistent in the presence of soil particularly against *Clostridium difficile* spores.

Aim:

To demonstrate in-use efficacy of two whole-room UV decontamination systems against three hospital pathogens with and without soil.

Methods:

For each system, six patient rooms were decontaminated with UV-irradiation (enhanced-disinfection) following manual terminal cleaning. Total aerobic colony counts of surface contamination were determined by spot-sampling 15 environmental sites before and after terminal disinfection and after UV-irradiation. Efficacy against biological indicator coupons (stainless-steel discs) was performed for each system using test bacteria (10^6 cfu EMRSA-15 variant A, carbapenemase-producing *K. pneumoniae*) or spores (10^5 cfu *C. difficile* 027), incorporating low soiling (0.03% bovine serum albumin [BSA]), heavy soiling (10% BSA) or synthetic faeces (*C. difficile* only) placed at five locations in the room.

Findings:

UV disinfection eliminated contamination after terminal cleaning in 8/14 (57%) and 11/14 (79%) sites. Both systems demonstrated 4 to 5 $\log_{10}$ reductions in MRSA and *Klebsiella pneumoniae* at low soiling. Lower and more variable $\log_{10}$ reductions were achieved when heavy soiling present. Between 0.1 and 4.8 $\log_{10}$ reductions in *Clostridium difficile* spores were achieved with low but not heavy soil challenge.

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Conclusion:

Terminal disinfection should be performed on all surfaces prior to UV decontamination. In-house validation studies should be considered to ensure optimal positioning in each room layout and sufficient cycle duration to eliminate target pathogens.

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Introduction

Ultraviolet light decontamination systems are increasing in popularity as a means to remove *Clostridium difficile* spores and other pathogens from the hospital environment following terminal cleaning. Manual cleaning of surfaces is essential in reducing transmission but is labour intensive and open to user error despite use of biocidal/sporicidal agents. Areas missed during terminal cleaning continue to represent a risk of transmission. Using a UV fluorescent gel to demonstrate surfaces that have not been cleaned, compliance in a multicentre trial suggested cleaning compliance was only 49% (range 35%-81%).[1] Use of hypochlorite for terminal disinfection has been associated with reduction in incidence of *Clostridium difficile* infection in areas where the background incidence is high, although control of confounding factors are often inadequate.[2]

There is accumulating evidence that *C. difficile* in the environment is responsible for hospital-acquired cases of *C. difficile* infection in vulnerable patients.[3] Although less effective than hydrogen peroxide vapour/aerosol systems, UV light decontamination systems are faster and less disruptive. Unlike hydrogen peroxide vapour disinfection, UV-C systems do not require changes to the heating, ventilation or air conditioning systems within the room. The major disadvantage with all automated systems is that they cannot be used while the patient is in the bed area and their use is generally limited to supplement terminal disinfection of single rooms. Furthermore the positioning of the emitters is critical to the level of coverage of the environment i.e. area without shadows. UV-C systems do not replace terminal cleaning but a high level of disinfection can be achieved more easily than by manual cleaning.[2]

In this study the efficacy of two UV-irradiation disinfection devices with different patterns of arrangement and number of emitters were compared in the clinical environment against

surface contamination and validated against in-house biological indicator organisms (*C. difficile spores, Klebsiella pneumoniae*, MRSA) in the presence of a high/low organic soil challenge.

Methods

For each test system, six patient single-isolation-rooms of similar size and layout were selected at a London teaching hospital. Each room was decontaminated prior to any efficacy testing following the hospital protocol (manual cleaning with ~1000ppm concentration peracetic acid solution; Diff-X, MTP Innovations, UK). As part of routine hospital practice, there was monitoring of the quality of terminal cleaning by domestic supervisors in a sample of rooms using ATP bioluminescence.[4] However, the cleaners were not aware of the sampling sites and no additional training was provided during the study. Sampling was performed immediately after terminal cleaning and was followed without delay by the setting up and use of the UV devices.

Ten microlitre aliquots of test bacteria (~10^6 cfu EMRSA-15 variant A, non-metallo-carbapenemase-producing *K. pneumoniae* ST-258 (typed at AMRHAI Colindale UK) or spores (10^5 cfu *C. difficile* 027 spores), prepared in low soiling (0.03% BSA), heavy soiling (10% BSA) or synthetic faeces (*C. difficile* 027 spores only) were inoculated onto 1cm^2 biological-indicator coupons (stainless-steel discs) and placed at various locations (1-Floor, 2-Under bed, 3-Footrail, 4-Headboard, 5-bedside table) in the room. During UV disinfection the rooms were sealed and air changes maintained in a steady state (8 air changes/h). Enhanced cleaning/disinfection (UV-irradiation) of the room was performed using one of two devices:

A: Surfacide® Helios ™: a triple-emitter system (UVC, λ=254nm) arranged around the bed in triangular formation (medium setting). The emitters have a built-in laser mapping system

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to scan the dimensions of the room and calculate the duration of the prescribed disinfection cycle.

B: Hygiene Solutions Ultra-V™: a single-emitter device (UVC, λ=265nm) relocated intermittently as determined by sensors in room. Sensor-units were positioned around the room to measure the dose of UV-energy received allowing the operator to deliver a minimum-required dose of irradiation.

Biological indicator coupons were assayed to quantify bacterial/spore numbers and compared against numbers obtained from a control array (non-exposed BI coupons). For each UV-decontamination system, all six test-rooms were evaluated pre and post-UV disinfection by spot-sampling. Three of the rooms were evaluated for efficacy using in-house biological-indicator coupons. Total aerobic colony counts of surface contamination were measured in six rooms by spot-sampling up to 15 environmental sites before and after terminal disinfection and after UV-irradiation. Surface swabs were taken using tryptone-soya agar contact plates (25cm^2; Oxoid, UK) incorporating a neutralising solution (to quench residual disinfectant activity).

Microbiological assessment for efficacy using in-house Biological Indicators

Bacteria were grown aerobically in 10ml nutrient broth (Oxoid, UK) at 37°C for 18 hours. Cultures were centrifuged at 1500 x g for 10 minutes and resuspended in 10ml sterile bovine serum albumin (BSA; Sigma Aldrich, UK) at low (0.03% w/v) or heavy soil (10% w/v) concentrations. *C. difficile* spore suspensions were prepared to a titre of 10^6 CFU/ml in 10ml as described previously.[5] Stock spore suspensions were centrifuged and resuspended in 1ml BSA (0.03%) to represent low soiling or 1ml synthetic faeces (5% [w/v] tryptone, 5%

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[w/v] BSA, 0.4% mucin [w/v] in phosphate buffered saline [PBS]) to represent heavy soiling.

Ten µl of bacterial (~10^6 cfu) or spore suspension (~10^5 cfu) prepared in an organic soil were inoculated onto stainless steel coupons (n=3) and placed on a microplate lid. Microplates containing the biological indicator coupons were replicated equally six times (including control plate) and placed in various locations in the test side-room at pre-selected sites. Coupons were used within 30 minutes of inoculation. Test microplates were exposed to a full cycle of the test UV-decontamination system in accordance with manufacturers' instructions on time and positioning of emitters. Control (unexposed) sets of microplates were placed in the rooms during cycles and each control microplate sealed with Parafilm™ tape and wrapped with 3 layers of aluminium foil (to shield from UV-irradiation).

After testing, coupons were aseptically transferred to tubes containing either 10ml (unexposed control coupons) or 1ml (exposed test coupons) PBS. Approximately 5 sterilised glass beads were added to each tube and samples were vortexed for 30 seconds. Resulting suspensions were diluted in PBS and plated onto Columbia blood agar (Oxoid, UK) or Braziers *C. difficile* agar (Oxoid, UK). Plates were incubated aerobically at 37°C for 24 hours for bacteria and anaerobically at 37°C for 48 hours for *C. difficile* spores.

Two-tailed tests were used for all analyses and differences were considered statistically significant when $P<0.05$. Log_{10} reduction = $Log_{10}(A) - Log_{10}(B)$, where A and B are the numbers (cfu) before and after UV disinfection respectively.

The study was considered to be service evaluation and ineligible for Research Ethics submission by UCL/UCLH Joint Research Office.

Results

All rooms selected were of similar size and included a dedicated en-suite bathroom. Terminal cleaning of the room and bathroom ranged between 95min ±35min (system A) and 81min ±34min (system B) (Table I). Additional time incurred by supplementing terminal disinfection with enhanced (UV) disinfection was similar between the two systems when completing a full cycle in the room and a further cycle in the bathroom.

Environmental contamination

All (14/14) environmental sites were contaminated before terminal disinfection in both arms of the study (Table II). Contamination was highest on the floor areas of the room and patient en-suite bathroom and high-frequency touch areas (foot rail, bed-control panel, nurse-call button, bedside table, chair arm). Terminal disinfection was often ineffective in reducing contamination including near-patient surfaces. UV disinfection eliminated contamination in 8/14 (57%) and 11/14 (79%) sites using systems A and B respectively. Sampling of *C. difficile* in the patient environment showed median 1 cfu pre terminal clean, pre UV clean and median 0 post UV clean on the toilet floor for both systems.

Efficacy against biological indicator coupons

Both systems demonstrated between 4 and 5 $\log_{10}$ reductions in MRSA and *K. pneumoniae* at low soiling (Table III). Lower and more variable $\log_{10}$ reductions were found at heavy soiling. 0.5 to 2.5 $\log_{10}$ reductions in *Clostridium difficile* with low soiling were achieved on floor surfaces, and for one system the bedside table, but not when heavy soil (synthetic faeces) was present.

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Discussion

Efficacy of ultraviolet-C light (wavelength: 100-280 nm) disinfection systems depends on intensity of the radiation, cycle duration, position of the emitter, presence of physical barriers and air movement. As radiation is subject to inverse square reduction with distance from the source and some surfaces such as glass do not reflect light efficiently, repeated cycles at different positions are often recommended to achieve a dose sufficient to reduce contaminating organisms to low levels. Various solutions are offered, for example, one system monitors the reflected light (254nM) and stops the cycle when the target level (reflected dose of 36000µWs/cm^2) is reached. Spores are reduced by 2-4 log_{10} on surfaces in direct line of sight but less elsewhere.[6]

Disinfection using UV irradiation is significantly less effective than hydrogen peroxide vapour, which achieves a 6 log_{10} reduction against *C. difficile* spores.[7] The presence of a heavy soil challenge on the surface to be disinfected can attenuate bactericidal activity. Hence it is important the environment has been adequately decontaminated of dirt and debris during terminal cleaning. Nevertheless, there is evidence that use of UV-C disinfection of the patient environment is effective in reducing healthcare-acquired infection. Use of portable pulsed xenon devices in single rooms after discharge of the patient were proposed to have been responsible for a reduction of hospital-acquired *C. difficile* infection from $9.46/10^5$ patient days to $4.45/10^5$ patient-days ($p<0.01$) in a retrospective study.[8] The study also associated the implementation of UV-C disinfection with a fall in the numbers of colectomies. Another retrospective study suggested a 20% reduction in all hospital-acquired infection during a 22 month period.[9] However, there may have been confounding factors in either study. In an interrupted time series, the use of ultraviolet irradiation to decontaminate single-isolation

rooms after discharge of the patient was associated with a fall in incidence of *C. difficile* infections compared with a rise where it was not used.[10] A non-randomized study showed an additional 5% fall in *C. difficile* infections when UV disinfection was added to a package of measures.[11] Finally a recent cluster-randomised study compared the use of combinations of quaternary ammonium disinfection, bleach and UV-C on acquisition and infection rates of MRSA, vancomycin-resistant enterococci, *C. difficile* and *Acinetobacter*.[3] The overall incidence of these pathogens in patients next occupying the rooms was reduced when UV-C was added to standard cleaning. However, the incidence of *C. difficile* was not reduced by adding UV to bleach.

The efficacy of UV disinfection is dependent on the presence of shadowing and the number of cycles used for the size of the room. Unlike biocidal efficacy testing, no test criteria stipulating reduction thresholds exist for the validation of UV-irradiation systems proposed for whole-room disinfection of the patient environment. Reduction thresholds should reflect the likely level of bacterial contamination on surfaces after terminal cleaning. Previous assessments of the clinical environment identified *C. difficile* bioburden on surfaces in the order of ~1 $\log_{10}$ cfu/cm^2 in both high and low-frequency touch sites.[5]

In the current study, enhanced disinfection using UV light was effective against MRSA and *K. pneumoniae* and reduced contamination from surfaces in the patient room missed during terminal cleaning. The most important factor affecting efficacy was the positioning of the emitters according to the size and arrangement of the room, accounting for the differences between systems (Table III). Despite variations in reduction with high inocula on coupons, both systems achieved reductions in bacterial numbers in the environment with low soil sufficient to prevent further transmission. *C. difficile* spores were more difficult to eradicate.

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In a comparison of two other UV systems, they were equally effective against *C difficile*, VRE and MRSA but *C difficile* spores required 40 minute exposure for 3-$\log_{10}$ kill compared with 10 minutes for other pathogens.[12] UV cycle durations should therefore be increased in rooms exposed to or at risk of *C. difficile* contamination.

Conclusions

In the absence of efficacy testing criteria for the validation of UV-irradiation devices, thresholds for reductions of contaminating bacteria and spores should be appropriate for levels representative of the setting. Careful positioning of the devices was effective in preventing shadowed areas. However when introducing a new system, in-house validation studies should be considered to ensure optimal positioning in each type of room layout and a sufficient cycle duration used to eliminate pathogens. Thresholds for reductions of contaminating bacteria should reflect the anticipated numbers in the environment after terminal cleaning.

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The manufacturers of the systems funded the microbiological testing but did not participate in the analysis of the results or writing of any part of the manuscript.

Conflict of interest

APRW is on a Global Advisory Panel for 3M.

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References

1. Carling PC, Parry MF, Von Beheren SM, Healthcare Environmental Hygiene Study Group 2008. Identifying opportunities to enhance environmental cleaning in 23 acute care hospitals. *Infect Control Hosp Epidemiol* 29:1–7. 10.1086/524329

2. Barbut F. How to eradicate *Clostridium difficile* from the environment. *J Hosp Infect* 2015; 89: 287 - 295

3. Anderson DJ, Chen LF, Weber DJ, *et al*. Enhanced terminal room disinfection and acquisition and infection caused by multidrug-resistant organisms and *Clostridium difficile* (the Benefits of Enhanced Terminal Room Disinfection study): a cluster-randomised, multicentre, crossover study. *Lancet*. 2017;**389**:805-814.

4. Moore G, Smyth D, Singleton J, Wilson P. The Use of ATP Bioluminescence to Assess the Efficacy of a Modified Cleaning Program Implemented within an Intensive Care Setting. *Am J Infect Control* 2010 **38**: 617-622.

5. Ali, S., Muzslay, M., Wilson, P. A novel quantitative sampling technique for the detection and monitoring of *C. difficile* contamination in the clinical environment. *J Clin Microbiol*. 2015;53:2570–2574

6. Mahida N, Vaughan N, Boswell T. First UK evaluation of an automated ultraviolet-C room decontamination device (Tru-D™). *J Hosp Infect*. 2013;**84**:332-5.

7. Havill NF, Moore BA, Boyce JM. Comparison of the microbiological efficacy of hydrogen peroxide vapor and ultraviolet light processes for room decontamination. *Infect Control Hosp Epidemiol.* 2012; **33**: 507–512

8. Levin J, Riley LS, Parrish C, et al. The effect of portable pulsed xenon ultraviolet light after terminal cleaning on hospital-associated *Clostridium difficile* infection in a community hospital. *Am J Infect Control* 2013; **41**: 746–748

9. Haas JP, Menz J, Dusza S, et al. Implementation and impact of ultraviolet environmental disinfection in an acute care setting. *Am J Infect Control.* 2014; **42**: 586–590

10. Pegues DA, Han J, Gilmar C, et al Impact of Ultraviolet Germicidal Irradiation for No-Touch Terminal Room Disinfection on *Clostridium difficile* Infection Incidence Among Hematology-Oncology Patients. *Infect Control Hosp Epidemiol.* 2017; **38**: 39-44

11. Miller R, Simmons S, Dale C, Stachowiak J, Stibich M. Utilization and impact of a pulsed-xenon ultraviolet room disinfection system and multidisciplinary care team on *Clostridium difficile* in a long-term acute care facility. *Am J Infect Control* 2015; 43: 1350–53.

12. Nerandzic MM, Fisher CW, Donskey CJ. Sorting through the Wealth of Options: Comparative Evaluation of Two Ultraviolet Disinfection. Systems. *PLoS ONE* 2014; **9**: e107444.

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Table I. Turnaround and duration of individual decontamination processes during terminal cleaning and UV-disinfection using the Surfacide® Helios and Ultra-V™ system (systems A and B respectively).

Phase of decontamination episode	**Time required system A** Mean (±SD) minutes	**Time required system B** Mean (±SD) minutes
Duration for domestic team to attend	59 (±33)	48 (±32)
Terminal clean cycle	95 (±35)	81 (±34)
Time to set up UV-device[1]	20 (±6)	28 (±6)
UV-disinfection cycle	42 (±11)	36 (±6)
Time to vacate (post UV-cycle)[2]	7 (±5)	5 (±3)
Total: Decontamination without UV	**154 (±33)**	**120 (±12)**
Total: Decontamination including UV-disinfection	**215 (±33)**	**199 (±17)**

[1] – Includes transport of equipment to the site and set-up/ arrangement of the UV system
[2] – Time required removing all UV equipment and returning room to original state for patient accommodation.

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Table II. Efficacy of System A (Surfacide® Helios) and System B (Ultra-V™) UV disinfection system against surface contamination in the patient environment (n=6) (aerobic colony count per 100 cm²) (IQR = interquartile range)

		Environmental Surface Contamination (Aerobic colony counts) / 100cm^2						
		Cleaning Phase	Pre-terminal clean		Pre-UV		Post-UV	
# Sample point	System	Description	Median	IQR	Median	IQR	Median	IQR
1	A	Floor corner	1048	920-3056	7040	5280-7776	28	24-52
	B		936	324-1768	2944	2400-3200	64	28-108
2	A	Foot rail	120	108-276	4	0-4	0	0-0.8
	B		208	140-272	32	16-60	2	0-4
3	A	Bed control panel	72	40-100	0	0-40	8	0-12
	B		236	88-300	40	4-88	0	0-4
4a	A	Nurse call button (front)	184	100-516	40	0-92	0	0-0.8
	B		328	196-724	4	0-28	0	0-8
4b	A	Nurse call button (back)	112	40-476	24	8-204	0	0-0
	B		216	144-920	4	1-40	0	0-8
5	A	Bedside table	84	52-104	20	12-24	0	0-0
	B		88	44-280	8	0-8	0	0-8
6	A	Chair arm	88	44-184	12	4-20	4	0-0
	B		220	124-272	20	8-36	0	0-0
7	A	Bin lid	132	108-152	28	20-32	0	0-4
	B		236	144-264	20	12-24	0	0-4
8	A	Inside door handle	44	8-80	4	0-8	4	0-4
	B		68	36-120	8	4-12	0	0-4
9	A	Outside door handle *	22	20-28	8	0-20	88	24-160
	B		76	48-180	20	4-68	88	68-136
10	A	Toilet floor	1360	920-2652	2016	1648-6000	196	160-200
	B		1680	708-3120	3072	2208-4472	68	48-92
11	A	Toilet assist bar	4	0.8-24	0	0-8	0	0-0

	B		16	4-32	0	0-24	0	0-0
12	A	Toilet flush	84	20-204	0	0-8	0	0-0
	B		84	40-120	8	4-12	0	0-0
13	A	Toilet seat	148	36-360	4	4-8	4	0-12
	B		180	64-280	24	8-40	0	0-0
14	A	Shower handle	148	44-268	4	0.8-16	4	0.8-8
	B		248	76-424	4	0-8	0	0-0

*Not included in UV irradiation

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Table III. Efficacy of UV disinfection against bacterial number on biological indicator coupon in median $\log_{10}$ reduction colony forming units.

Reductions (Log_{10} CFUs) in biological indicator test organisms						
Sites	MRSA		*Klebsiella pneumoniae*		*Clostridium difficile*	
	Low soil 0.03% BSA	Heavy soil 10% BSA	Low soil 0.03% BSA	Heavy soil 10% BSA	Low soil 0.03% BSA	Heavy soil Synthetic faeces
System A						
Floor corner	4.9	4.5	6.3	5.7	2.5	0.5
Floor under bed	5.5	4.5	5.2	5.7	2.1	0.6
Foot rail	4.9	5.0	6.3	5.0	1.9	0.4
Headboard	5.3	4.4	6.3	4.7	1.2	0.3
Bedside Table	5.1	5.1	6.3	6.3	4.8	1.0
System B						
Floor corner	3.9	2.3	4.2	1.4	0.3	<0.1
Floor under bed	4.5	2.2	5.6	2.5	1.1	<0.1
Foot rail	4.5	3.7	4.5	3.5	0.7	<0.1
Headboard	3.9	3.6	3.9	1.0	0.7	<0.1
Bedside Table	4.1	2.4	3.9	3.1	0.1	<0.1