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Comparison of two whole-room ultraviolet irradiation systems for enhanced disinfection of contaminated hospital patient rooms☆

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SUMMARY

Background: Ultraviolet (UV) 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, especially 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 *Klebsiella 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 4–5 $\log_{10}$ reductions in meticillin-resistant *Staphylococcus aureus* and *K. pneumoniae* at low soiling. Lower and more variable $\log_{10}$ reductions were achieved when heavy soiling was present. Between 0.1 and 4.8 $\log_{10}$ reductions in *C. difficile* spores were achieved with low but not heavy soil challenge.
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 (UV) light decontamination systems are increasing in popularity for removing *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 that 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 is 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 may be achieved more easily than by manual cleaning [2].

In this study the efficacies 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*, meticillin-resistant *Staphylococcus aureus* (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 ~1000 ppm concentration peracetic acid solution; Diff-X, MTP Innovations, Huddersfield, 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% bovine serum albumin (BSA)], heavy soiling (10% BSA) or synthetic faeces (*C. difficile* 027 spores only) were inoculated on to 1 cm^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 (eight air changes per hour). Enhanced cleaning/disinfection (UV irradiation) of the room was performed using one of two devices:

- Surfacide® Helios™ (Bates Group, Rayne, UK): a triple-emitter system (UV-C, $\lambda = 254$ nm) arranged around the bed in triangular formation (medium setting). The emitters have a built-in laser mapping system to scan the dimensions of the room and calculate the duration of the prescribed disinfection cycle.
- Ultra-V™ (Hygiene Solutions, King's Lynn, UK): a single-emitter device (UV-C, $\lambda = 265$ nm) 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 biological indicator coupons). For each UV decontamination system, all six test-rooms were evaluated before and after 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 (25 cm^2; Oxoid, Basingstoke, UK) incorporating a neutralizing solution (to quench residual disinfectant activity).

Microbiological assessment for efficacy using in-house biological indicators

Bacteria were grown aerobically in 10 mL nutrient broth (Oxoid, UK) at 37°C for 18 h. Cultures were centrifuged at 1500 *g* for 10 min and resuspended in 10 mL 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 10 mL as described previously [5]. Stock spore suspensions were centrifuged and resuspended in 1 mL BSA (0.03%) to represent low soiling or 1 mL synthetic faeces [5% (w/v) tryptone, 5% (w/v) BSA, 0.4% mucin (w/v) in phosphate-buffered saline (PBS)] to represent heavy soiling.

Ten microlitres of bacterial (~10^6 cfu) or spore suspension (~10^5 cfu) prepared in an organic soil were inoculated on to 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 min 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