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Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Brief Report

Efficacy of an ultraviolet-A lighting system for continuous decontamination of health care–associated pathogens on surfaces

Scott H. Livingston MD^a, Jennifer L. Cadnum BS^b, Kevin J. Benner BS^c, Curtis J. Donskey MD^{a,d,*}^a Case Western Reserve University School of Medicine, Cleveland, OH^b Research Service, Louis Stokes Cleveland Veterans Affairs Medical Center, Cleveland, OH^c Current, powered by GE, Cleveland, OH^d Geriatric Research, Education, and Clinical Center, Louis Stokes Cleveland Veterans Affairs Medical Center, Cleveland, OH

Key Words:

Ultraviolet-A light

Environment

Methicillin-resistant *Staphylococcus aureus*

Stethoscope

We found that ultraviolet-A (UV-A) light exposure resulted in a modest reduction in recovery of methicillin-resistant *Staphylococcus aureus* (MRSA), *Candida auris*, bacteriophage MS2, and bacteriophage Phi X174, but not *Clostridioides difficile* spores, on steel disk carriers. Four hours of UV-A exposure from a ceiling light fixture resulted in a significant reduction in pathogenic microorganisms recovered from in-use medical equipment. These findings suggest that UV-A could be useful as a means to provide continuous low-level decontamination of surfaces in health care facilities.

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Contaminated environmental surfaces are an important source of transmission of health care–associated pathogens.¹ Unfortunately, performance of manual cleaning and disinfection is often suboptimal. Automated room decontamination devices such as ultraviolet-C (UV-C) light devices can be effective as an adjunct to routine cleaning.¹ However, UV-C room decontamination devices cannot be used when people are present and re-contamination occurs quickly after device operation.² Thus, there is a need for effective approaches that provide continuous and safe decontamination of surfaces while people are present.

Ultraviolet-A (UV-A) light at 365-nm wavelength has been shown to have antimicrobial activity against pathogens such as *Escherichia coli* and *Candida albicans*.^{3–6} In contrast to UV-C, UV-A is present in sunlight and in modest doses may be safe for use when people are present.³ A commercial UV-A light fixture that is intended for use in health care settings is currently in development. In the current study,

we examined the efficacy of UV-A light in reducing microorganisms on carriers and on portable medical equipment.

METHODS

Description of test devices

The test devices were provided by Current, powered by GE (Cleveland, OH). For initial laboratory testing, we used a benchtop device (62 × 20 × 29 cm) with a diffused array of light-emitting diodes (LEDs) producing UV-A light at 365-nm wavelength with carriers placed 14 cm from the diffusing optic. The intensity of light output by the LED was adjustable up to a maximal irradiance of 30 W/m² at the location of the carriers. For the assessment of efficacy in reducing contamination on portable equipment, a light fixture, emitting both LED-generated UV-A light at 365 nm and visible light, was placed at a typical ceiling height of 3 m from the floor. This light fixture was a prototype of the product being commercially developed as a continuous decontamination system.

The ceiling light fixture was set to provide irradiance of ~3 W/m² at 2 m from the UV-A source. At this setting, the irradiance at 1 and 3 m from the UV-A source was ~8 and ~2 W/m², respectively. Based on standards provided by the International Electrotechnical Commission (IEC) and the International Commission on Illumination (IEC standard 62471:2006), lamps or lighting systems that do not meet hazard thresholds of 10 W/m² irradiance for near UV (315–400 nm) and 0.001 W/m² weighted irradiance for actinic UV (weighted

* Address correspondence to Curtis J. Donskey, MD, Geriatric Research, Education, and Clinical Center 1110W, Louis Stokes Cleveland Veterans Affairs Medical Center, 10701 E Blvd, Cleveland, OH 44106.

E-mail address: Curtis.Donskey@va.gov (C.J. Donskey).

Funding/support: This work was supported by a Department of Veterans Affairs Merit Review grant (1 I01 BX002944-01A1) to C.J.D.

Conflicts of interest: C.J.D. has received research grants from Clorox, Merck, Pfizer, PDI, GOJO, and Boehringer Laboratories. There are no additional conflicts of interest to report.

Author contributions: K.J.B. provided the results of safety assessments and edited the sections of the manuscript related to description of the devices and safety.

function >200–400 nm, peaking at 270 nm) are not considered a photobiological hazard to humans.⁷ The UV-A continuous decontamination system is configured such that the maximum continuously-allowable near UV irradiance of 10 W/m² is reached at a distance of approximately 85 cm from the light source, or 215 cm from the floor. At this distance, the weighted actinic UV irradiance is 0.094 W/m², which is less than the actinic hazard limit. The actual irradiance that an individual would be exposed to in practice is less than these values, as the body of even a very tall individual would not protrude 215 cm above the floor, and the irradiance at the eye (where it is important for consideration of ocular hazards) would only reach these levels if the individual was looking directly at the light source with their eyes positioned at this height. According to the manufacturer, exposure to the UV-A output delivered by the light source for up to 8 hours per day provides less near and actinic UV irradiance than the IEC defined limits. Therefore, the light source can be considered to pose no photobiological hazard when operated for up to 8 hours per day in occupied rooms. In areas that are not occupied or intermittently occupied, the light source could be run continuously.

Efficacy in reducing microorganisms on steel disk carriers

Using the benchtop device, we tested the efficacy of UV-A light in reducing recovery of microorganisms using a modification of the American Society for Testing and Materials standard quantitative carrier disk test method (ASTM E-2197-02).⁸ The test organisms included 1 strain each of methicillin-resistant *Staphylococcus aureus* (MRSA) (a clinical isolate with pulsed-field gel electrophoresis type USA400), *Clostridioides difficile* spores (American Type Culture Collection number 43598), *Candida auris* (Centers for Disease Control and Prevention strain 0381), the enveloped virus bacteriophage Phi X174 (ATCC 13706-B1), and the nonenveloped virus bacteriophage MS-2 (ATCC 15597-B1). The bacteriophages were propagated in *E coli* as previously described.⁹ A total of 10 μ L aliquots of the organisms in 5% fetal calf serum were inoculated onto 20-mm steel disk carriers, spread to cover the surface area, and air dried. The carriers were exposed to 3 W/m² of UV-A for 4, 8, or 24 hours, resulting in a total dose of 4.32×10^3 , 8.64×10^3 , or 2.59×10^4 J/m², respectively; for

the *C difficile* spores, only the 24-hour exposure was included. The disks were processed as previously described and log₁₀ colony-forming unit (CFU) or plaque-forming unit (PFU) reductions were calculated by comparing recovery from UV-A-exposed carriers versus untreated controls for each experimental time point that differed only in lack of exposure to the UV-A light source. For each organism, triplicate samples were tested.

Efficacy in reducing pathogens on portable medical equipment

We examined the efficacy of the ceiling light fixture in reducing contamination of 32 items of in-use portable medical equipment from medical wards. Equipment included Doppler ultrasound machines, glucometers, wheelchairs, electrocardiogram machines, workstations-on-wheels, and bladder scanners. Three or more of each type of equipment were tested. No manual cleaning or disinfection was performed prior to UV-A exposure. Items of equipment were placed under the ceiling light fixture at 2 meters from the UV-A light source with an exposure time of 4 hours; the 4-hour exposure time was chosen to minimize disruption of work on the study wards as the devices were being used for clinical care. Moistened rayon swabs were used to sample one-half of the surface area of the equipment in direct line of light exposure before UV-A exposure and the other half after UV-A exposure. The swabs were vortexed in 1 mL of phosphate-buffered saline and dilutions were plated on selective and nonselective media for recovery of MRSA, vancomycin-resistant enterococci, gram-negative bacilli, and total bacterial counts.¹⁰ The microbiologist processing the cultures was blinded to whether samples were collected with or without UV-A exposure. The Fisher exact test was used to compare proportions of contamination among groups. The Wilcoxon signed-rank test was used to compare the mean numbers of colonies recovered for treated versus untreated equipment.

RESULTS

At an irradiance of 3 W/m² there was a progressive reduction in recovery of the vegetative microorganisms over 24 hours in comparison to untreated controls (Fig 1). After 8 hours of exposure to UV-A,

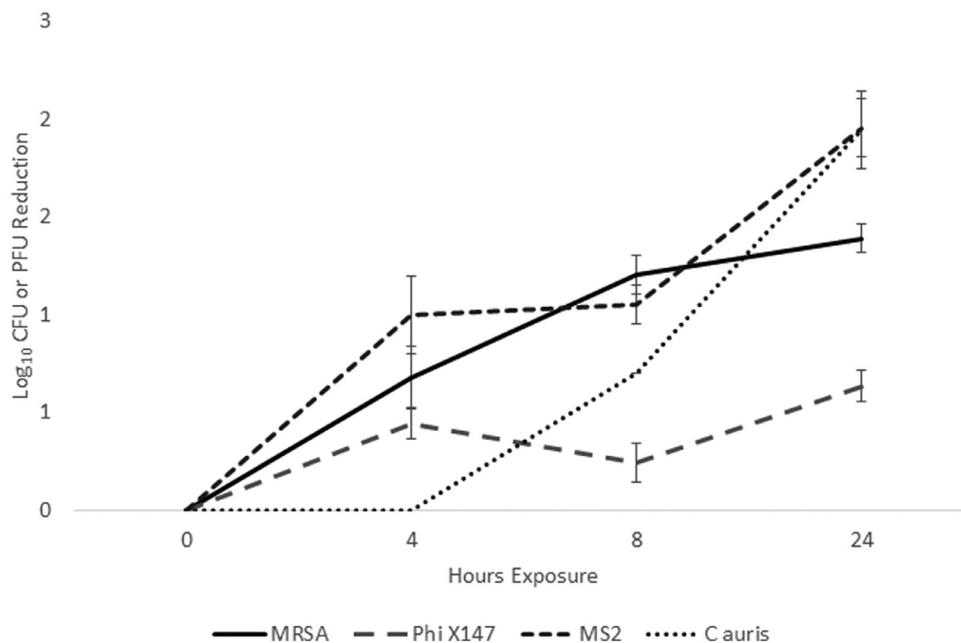


Fig 1. Efficacy of ultraviolet-A light at 3 W/m² in reducing pathogens inoculated on steel disk carriers. Error bars indicate SEM. *C auris*, *Candida auris*; CFU, colony-forming unit; MRSA, methicillin-resistant *Staphylococcus aureus*; PFU, plaque-forming unit.

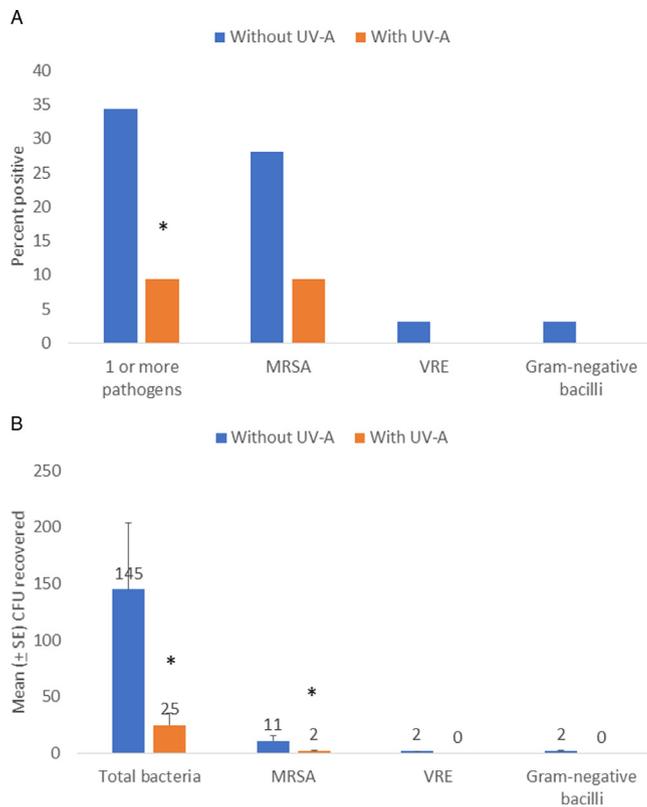


Fig 2. Percent recovery of pathogenic microorganisms from in-use medical equipment before versus after exposure to ultraviolet-A light from the ceiling light fixture for 4 hours. The asterisk indicates $P < .05$. Error bars indicate SEM. MRSA, methicillin-resistant *Staphylococcus aureus*; UV-A, ultraviolet-A; VRE, vancomycin-resistant enterococci.

MRSA and MS-2 were reduced by $>1 \log_{10}$ CFU or PFU, whereas *Candida auris* was reduced by $0.7 \log_{10}$ CFU. Phi X174 was reduced by only $0.6 \log_{10}$ PFU over 24 hours. *C difficile* spores were not reduced or minimally reduced after 24 hours of exposure to UV-A at 3 W/m^2 ($0-0.2 \log_{10}$ CFU reduction).

Pathogenic microorganisms, particularly MRSA, were frequently recovered from in-use medical equipment (Fig 2). UV-A exposure from the ceiling light fixture for 4 hours resulted in a significant reduction in the frequency of recovery of 1 or more pathogens from the equipment (11 of 30, 37% vs 3 of 30, 10%; $P = .03$). There were no significant reductions in the frequency of recovery of the individual pathogens ($P \geq .09$). The mean CFU of total aerobic bacteria recovered from the equipment on nonselective plates and of MRSA were significantly reduced after UV-A exposure ($P < .01$). The mean CFU of vancomycin-resistant enterococci and gram-negative bacilli were reduced after UV-A exposure, but the differences were not statistically significant.

DISCUSSION

We found that UV-A light exposure resulted in modest reductions of MRSA, *C auris*, bacteriophage MS2, and bacteriophage Phi X174 on steel disk carriers after several hours of exposure. In addition, 4 hours of UV-A exposure from a ceiling light fixture resulted in a significant reduction in the frequency of recovery of pathogenic microorganisms and in counts of total aerobic bacteria and MRSA on in-use medical equipment. These findings suggest that UV-A could potentially be useful in health care settings to provide continuous low-level decontamination of surfaces.

If UV-A light is used in health care settings when people are present, safety will be an important consideration. High levels of exposure to

UV-A have been linked to development of skin cancer, cataracts, and premature aging of skin (ie, wrinkle formation). As noted previously, the anticipated levels of exposure to UV-A during an 8-hour period in an occupied room would be in a range that would not be considered a photobiological hazard to humans. According to the manufacturer, a person exposed to the maximum irradiance of the UV-A light system at 85 cm from the light source for 8 hours would receive total near and actinic UV-A doses equivalent to direct mid-day sunlight exposures of 2 hours and 17 minutes and 2 minutes and 40 seconds, respectively. If UV-A light were restricted to areas or times when people are not present or only intermittently present (eg, equipment rooms, unoccupied patient rooms, or operating rooms), the UV-A light could be operated continuously without a time limit.

Our study has some limitations. We tested a limited number of organisms and only tested 1 strain of each organism. Additional testing is needed with other pathogens. We do not have an explanation for the fact that the enveloped bacteriophage Phi X147 was reduced to a lesser degree than the nonenveloped bacteriophage MS2. Further studies are needed with other enveloped and nonenveloped viruses. We did not compare the efficacy of UV-A with other continuous decontamination approaches such as high-intensity visible light. Finally, we did not examine the potential for use of adjunctive approaches to enhance UV-A. There is evidence that UV-A killing may be enhanced by benign compounds such as organic acids and the photocatalytic compound titanium dioxide.^{5,6}

CONCLUSIONS

We found that UV-A light exposure resulted in modest reductions of vegetative microorganisms, but not *C difficile* spores on steel disk carriers, and reduced recovery of pathogenic bacteria from in-use medical equipment. Further studies are needed to examine the efficacy of UV-A in health care settings.

Acknowledgments

The authors would like to thank Current, powered by GE for providing the devices used for testing.

References

- Donskey CJ. Does improving surface cleaning and disinfection reduce health care-associated infections? *Am J Infect Control* 2013;41(Suppl 5):12-9.
- Donskey CJ. Decontamination devices in health care facilities: practical issues and emerging applications. *Am J Infect Control* 2019;47(Supplement):23-8.
- Santos AL, Oliveira V, Baptista I, Henriques I, Gomes NCM, Almeida A, et al. Wavelength dependence of biological damage induced by UV radiation on bacteria. *Arch Microbiol* 2013;195:63-74.
- Ubomba-Jaswa E, Navntoft C, Polo-López MI, Fernandez-Ibáñez P, McGuigan KG. Solar disinfection of drinking water (SODIS): an investigation of the effect of UV-A dose on inactivation efficiency. *Photochem Photobiol Sci* 2009;8:587-95.
- de Oliveira EF, Cossu A, Tikekar RV, Nitin N. Enhanced antimicrobial activity based on a synergistic combination of sublethal levels of stresses induced by UV-A light and organic acids. *Appl Environ Microbiol* 2017;83, e00383-17.
- Kuhn KP, Chaberny IF, Massholder K, Stickler M, Benz VW, Sonntag H, et al. Disinfection of surfaces by photocatalytic oxidation with titanium dioxide and UVA light. *Chemosphere* 2002;53:71-7.
- International Electrotechnical Commission. (IEC) 62471:2006 standard: photobiological safety of lamps and lamp systems. Available from: <https://webstore.iec.ch/publication/7076>. Accessed July 1, 2019.
- ASTM International. ASTM E2197-11: standard quantitative disk carrier test method for determining bactericidal, virucidal, fungicidal, mycobactericidal, and sporicidal activities of chemical germicides. Conshohocken (PA): ASTM International; 2011.
- Tomas ME, Kundrapu S, Thota P, Sunkesula VC, Cadnum JL, Mana TS, et al. Contamination of health care personnel during removal of personal protective equipment. *JAMA Intern Med* 2015;175:1904-10.
- Kanwar A, Thakur M, Wazzan M, Satyavada S, Cadnum JL, Jenson AL, et al. Clothing and shoes of personnel as potential vectors for transfer of health care-associated pathogens to the community. *Am J Infect Control* 2019;47:577-9.