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Concise Communication

Understanding the effect of ultraviolet light intensity on disinfection performance through the use of ultraviolet measurements and simulation

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Abstract

We measured the disinfection of MRSA and *Clostridium difficile* spores using an ultraviolet C (UV-C) device, and we correlated those results to measurements and computer simulations of UV-C surface intensity. The results demonstrate both large differences in UV light intensity across various surfaces and how this leads to significant differences in disinfection.

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Recently published results from a cluster-randomized, crossover trial at 9 hospitals in the United States demonstrate that the use of ultraviolet C (UV-C) in terminal cleaning of a patient room significantly reduces the transmission of common hospital pathogens from one patient to the next patient in the same room.[1] Previous studies have shown that a UV-C reflective coating on the walls of a hospital room can either decrease the time required to disinfect the room, or, for a device with a fixed cycle time, significantly improve the $\log_{10}$ reduction of both MRSA and *C. difficile*.[2,3]

The purpose of this study was to increase our understanding of the behavior of UV light in a hospital room. We are particularly interested in characterizing the UV intensity on various surfaces that may become contaminated. Because a hospital room contains many touchable surfaces in various locations and orientations relative to the UV device, it is critical that we understand how much UV light is illuminating these surfaces and how that affects the degree of disinfection. To accomplish this, we used radiometry to measure UV intensity, and we correlated these values to $\log_{10}$ reduction of MRSA and *Clostridium difficile*. Furthermore, we evaluated a novel computer simulation tool to predict UV intensity, an approach that could be used to optimize disinfection protocols.

Methods

We utilized a UV-C device (V-360 +, UltraViolet Devices, Valencia, CA) in 2 patient rooms of the Clinical Translational Research Center at the University of North Carolina Medical Center. Microbiological measurements were performed using *C. difficile* spores and a clinical isolate of MRSA using methods described previously.[2,3] The device cycle times were set at 5 minutes for MRSA and 10 minutes for *C. difficile* spores, based on the manufacturer's recommendations. This study was conducted in both a control room containing traditional UV-absorbing paint and an identical study room containing UV-reflecting paint (Lumacept, Grand Forks, ND). A total of 10 surfaces, identified previously,[2] were studied and included both directly and indirectly illuminated locations in both rooms.

Ultraviolet irradiance (energy per area per time, typically expressed as microWatts per square centimeter, $\mu W/cm^2$) was measured using an ILT1700 Research Radiometer (International Light Technologies, Peabody, MA) and a calibrated, NIST-traceable UV-C detector with a filter and diffuser (SED240/NS254/W, International Light Technologies). Ultraviolet intensity simulations were performed with customized software that uses physics-based illumination algorithms to predict the distribution of UV-C light in a room. Three-dimensional computer models of both rooms were created, and the reflective properties of the surfaces in the room were specified based on previous measurements. The only difference between the control room and study room was the reflectivity value for the walls. A light source was then defined, and the software calculated a predicted intensity for all surfaces of interest.

Results

Figure 1 illustrates the effect of UV intensity on the $\log_{10}$ reduction of both MRSA and *C. difficile*. Surfaces were categorized as either direct or indirect based on whether the surface was in line of sight of the device, determined using a laser pointer. For the control room, the indirect surfaces received, on average, a UV

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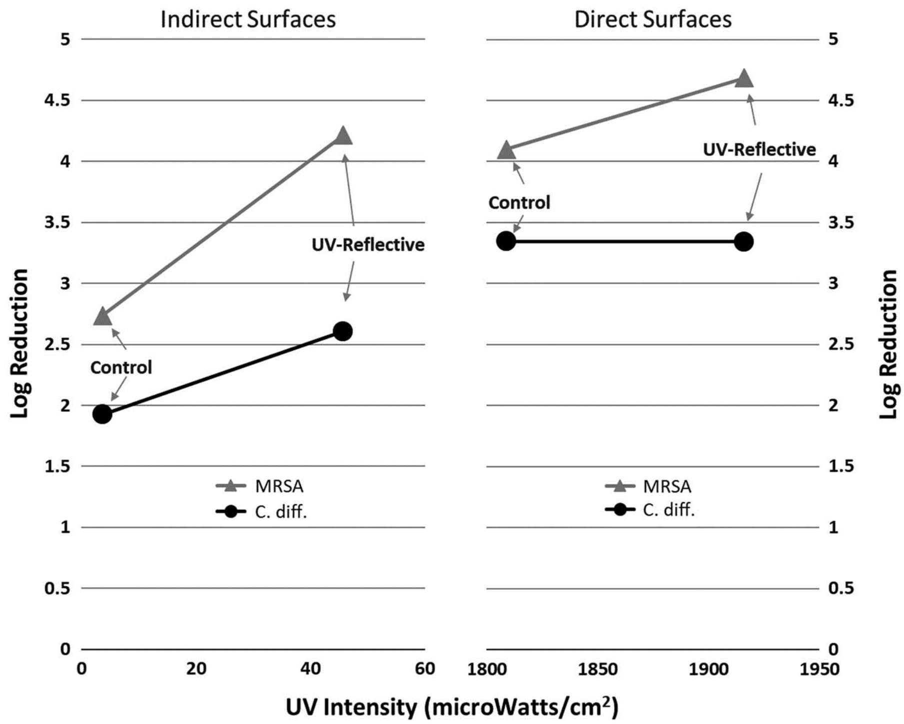

Fig. 1. Log reduction in *Clostridium difficile* and methicillin-resistant *Staphylococcus aureus* (MRSA) as a function of the average ultraviolet (UV) irradiance (μW/cm^2). Note the large differences in intensity between directly and indirectly illuminated surfaces.

intensity of roughly 3 μW/cm^2, while direct surfaces received an average intensity of ~ 1800 μW/cm^2. The differences in intensity were strongly correlated with disinfection performance. The average $\log_{10}$ reduction increased from 2.7 (indirect) to 4.1 (direct) for MRSA and from 1.8 (indirect) to 3.4 (direct) for *C. difficile* in the control room.

As expected, the reflective coating had a relatively lower impact on direct surfaces than on indirect surfaces, primarily because direct light is significantly more intense than indirect (scattered) light. For indirect surfaces, the reflective coating increased the UV intensity by more than an order of magnitude, to 45 μW/cm^2, resulting in an improved $\log_{10}$ reduction of 4.2 for MRSA and 2.6 for *C. difficile* spores. This difference is statistically significant at a confidence level of 95%, as reported previously.[3] These results are generally consistent with previous measurements and simulations, which demonstrates that the effect of reflective wall coatings were more substantial for indirectly illuminated surfaces.[3,4] Notably, UV intensity, as shown in Figure 1 in units of μW/cm^2, is not the same as the accumulated UV energy (in units of μW*s/cm^2), which would be calculated by taking the intensity multiplied times the exposure time in seconds. For example, a UV intensity of 3 μW/cm^2 for a 10-minute cycle time would deliver an accumulated UV dose of 1800 μW*s/cm^2.

Figure 2 shows a comparison of measured UV intensity data to that predicted by computer simulations for all 10 surfaces used in this study, ordered from highest to lowest intensity. In general, good agreement can be seen across several orders of magnitude. The computer simulations accurately represent the significant differences in intensity between direct and indirect surfaces as well as the effect of the UV reflective wall paint.

Discussion

The UV intensity values clearly demonstrated how the UV dose received by surfaces in a single room can differ by orders of magnitude, with some surfaces receiving very little UV light. The use of UV reflective paint led to greater uniformity in the intensity because significantly more light reaches indirect surfaces. Microbiological results confirmed, as expected, that higher UV intensity led to better surface disinfection.

As healthcare facilities continue to consider the role of portable UV disinfection devices as part of their terminal cleaning protocol, it is important that infection control staff have a basic understanding of the behavior of UV light in a hospital room. The location of the device, the length of time the device is on, and the reflectivity of the surfaces in the room all have important implications on the level of disinfection. While it is impractical to repeat this study in every hospital room, a simulation-based approach, like

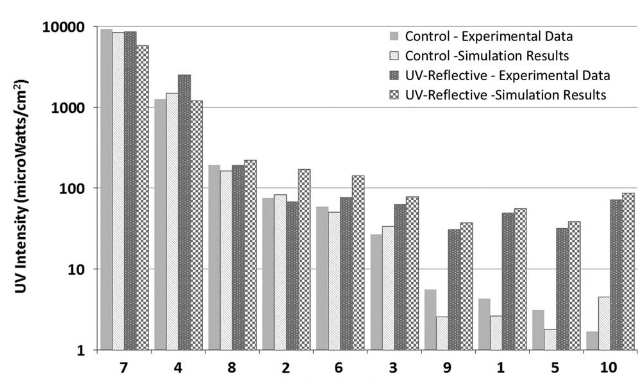

Fig. 2. Comparison of measured ultraviolet (UV) intensity values (log scale) to simulation results for both the control and the UV-reflective room. Numbers indicate the following locations: (1) the far side of the bedside table facing the wall; (2) the top of the bed; (3) the top of the toilet seat; (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.

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the one described here, could potentially be used to understand and optimize the use of these devices in specific rooms.

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Potential conflicts of interest. B.M.T. and T.A.P. report that they are the coinventors of the patented reflective coating and co-owners of Lumacept, which makes the reflective coating. W.A.R. reports that he is a consultant to Advanced Sterilization Products and Professional Disposables International, Inc. (PDI). D.J.W. reports that he is a consultant to PDI. No other authors report conflicts of interest relevant to this article.

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