2012

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Recommended Citation
Buttner, Mark P.; Yee, Thomas; Cruz, Patricia; and Stevens, Vanessa (2012) "Effectiveness of a Portable, Large-Area Ultraviolet Germicidal Device," Nevada Journal of Public Health: Vol. 9: Iss. 1, Article 1.
Available at: http://digitalscholarship.unlv.edu/njph/vol9/iss1/1

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Cover Page Footnote
The authors wish to thank Ms. Sarah Gasiewicz for technical review of the manuscript.

This article is available in Nevada Journal of Public Health: http://digitalscholarship.unlv.edu/njph/vol9/iss1/1
Effectiveness of a Portable, Large-Area Ultraviolet Germicidal Device

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Abstract

Effective disinfection of the hospital environment is a key component in the prevention of healthcare-associated infections. The objective of this project was to evaluate the effectiveness of an ultraviolet germicidal device in reducing the concentrations of culturable bacteria on indoor surfaces. The ultraviolet germicidal device was installed and operated in four experimental trials conducted in a microbiology research chamber. Agar plates inoculated with known concentrations of two test microorganisms were placed on benches inside the chamber at two distances, 1.5 meters and 3.0 meters from the machine, for exposure times of 5 minutes, 10 minutes, and 20 minutes. With test agar plates directly exposed to ultraviolet radiation, percent reductions were all >99.9% compared with the laboratory control plates. However, with indirect UV exposure, the edge of the plastic petri dishes provided some protection from the UV source, as indicated by the presence of colonies along the edge of the agar plates. Additional research will be conducted to further characterize the device for optimal use in surface decontamination and to determine its effectiveness in reducing airborne culturable bacterial concentrations.

Key words healthcare-associated infections, ultraviolet germicidal device, Staphylococcus aureus, Escherichia coli, surface decontamination

Introduction

The estimates of direct medical costs of healthcare-associated infections (HAI) to U.S. hospitals range from $28 to $45 billion annually (Scott, 2009). Contaminated environmental surfaces may play an important role in the transmission of emerging pathogens, such as methicillin-resistant Staphylococcus aureus, vancomycin-resistant Enterococcus, and Clostridium difficile, to hospital patients (Nerandzic, Cadnum, Pultz, & Donskey, 2005; Rutala, Gergen, & Weber, 2010). Therefore, effective disinfection of the hospital environment is a key component of HAI prevention. One method of disinfection is ultraviolet (UV) radiation. UV-C radiation (wavelength 100-280 nm) is the most harmful to living organisms because of its damaging effect to the nucleic acids, DNA and RNA (WHO, 2002). UV-C irradiation inactivates nucleic acids by abnormally chemically bonding adjacent thymine and cytosine bases, forming thymine dimers. Previous studies have shown varying degrees of susceptibility of all groups of microorganisms to UV irradiation, including bacterial endospores and protozoan cysts (Blatchley & Peel, 2001). UV radiation has been used for the control of airborne transmission of pathogens in hospital operating rooms for more than 50 years. However, its use has been mainly for disinfection of air through duct and upper-room air irradiation (Blatchley & Peel, 2001).

More recently, UV irradiation has been applied to the disinfection of surfaces, and portable devices incorporating germicidal UV lamps have been designed and tested (Katara, Hemvani, Chitnis, Chitnis, & Chitnis, 2008; Nerandzic et al., 2005; Owens et al., 2005; Rutala et al., 2010). A new device has been developed by Hypermed, Inc. that combines air and surface disinfection capabilities, the Portable, Large-Area Ultraviolet Germicidal (UVG) Device. The objective of this project was to evaluate the effectiveness of the UVG Device in reducing the concentrations of culturable bacteria on indoor surfaces. Four experimental trials were performed in the microbiology research chamber located at the University of Nevada, Las Vegas.

Experimental Design

The UV unit was evaluated to determine its efficacy in reducing culturable concentrations of surface-associated bacteria. The UVG Device was installed and operated in a total of four experimental trials in
the research chamber to determine the effect of the device on culturable surface-associated bacteria. In the first three trials, agar plates inoculated with known concentrations of two test microorganisms were placed on benches inside the chamber at two distances, 1.5 m and 3.0 m, from the machine. The plates were uncovered, and the UVG Device was activated in open mode (no air flow) for exposure times of 5 minutes, 10 minutes, and 20 minutes. Covered, shielded chamber control plates were placed in the chamber next to test plates, and laboratory control plates were also inoculated, but not placed in the chamber. Ozone concentrations were measured in the chamber during each of the three experiments. The agar plates were incubated, and colony forming units (CFU) were enumerated. CFU data were analyzed, and the reductions in CFU were calculated for each of the test bacteria at the two distances and the three exposure times. Results obtained showed that the edge of the plastic petri dishes provided some protection from the UV source, as indicated by CFU present along the edge of the agar plates, and that this effect was greater at a distance of 3.0 m from the UV source than 1.5 m from the source. Therefore, one additional trial was performed consisting of exposure for 10 minutes, but with the benches holding inoculated plates tilted so that the entire plates were subjected to UV radiation.

Materials and Methods

Ultraviolet Germicidal Device
The Portable, Dual-Mode, Large-Area Ultraviolet Germicidal (UVG) Device (Hypermed, Inc., Las Vegas, NV) is equipped with 8 UV light bulbs (Philips 25 Watt UV Germicidal Bulb) (Figure 1). In the open mode, the UVG Device bulbs extend horizontally to disinfect surfaces within 3.0 m of the device. In closed mode, a fan operating at 57 cubic meters per minute draws air past UV bulbs in the central core, disinfecting the air.

Test Organisms and Culture Preparation
The test microorganisms were *Staphylococcus aureus* (ATCC #6538), a gram-positive bacterium, and *Escherichia coli* (ATCC #25922), a gram-negative bacterium (American Type Culture Collection, Manassas, VA).

For each experiment, stock cultures of *S. aureus* and *E. coli* were used to inoculate one 125 ml flask containing 25 ml of tryptic soy broth (TSB, Difco Laboratories, Sparks, MD) for each microorganism. The cultures were incubated overnight (37°C, 60 rpm) in an environmental shaker (G24 Environmental Incubator Shaker, New Brunswick Scientific Co. Inc.). The following morning, a working culture was prepared for each microorganism by adding 1 ml of the overnight culture to a 250 ml flask containing 100 ml of TSB and incubated in the environmental shaker (37°C, 200 rpm). The cultures were checked periodically for the desired optical density (OD) at a 600 nm wavelength using a spectrophotometer.
Test plates were uncovered. For each test covered and were wrapped in aluminum foil, while UVG Device. Chamber control plates remained chamber, at distances of 1.5 m and 3.0 m from the agar plates were placed on benches in the test For trials 1 UVG Device Tests

Data Analysis

Results

For trials 1-3, the concentration of both E. coli and S. aureus test cultures after harvesting, washing and spread plating was 1.6 × 10^7 CFU/ml, as determined by triplicate laboratory control plates. The CFU enumerated on the chamber control plates that were
covered in aluminum foil before exposure to UV light were nearly identical to the laboratory control plates, with concentrations ranging from $1.5 \times 10^9$ to $1.8 \times 10^9$ CFU/ml. No ozone was detected in the chamber in any of the three tests (lower detection limit, 0.1 ppm). The temperature and relative humidity at the beginning of testing were 23.9°C and 35%, respectively, and at the end of testing the temperature and relative humidity were 25.0°C and 40%, respectively.

The CFU enumerated on the test plates were averaged, converted to CFU/ml of the inocula, and the mean values obtained from trials 1-3 were used to determine the percent reduction compared with the laboratory control plates (Table 1). The data showed that longer UV exposure time resulted in greater percent reductions in CFU, and shorter distances from the UV source also resulted in greater percent reductions. In addition, greater reductions were observed with S. aureus than with E. coli.

The edge of the plastic petri dishes provided some protection from the UV source, as indicated by CFU present along the edges. Results from trial 4 suggest that percent reductions are greatest when the entire surface is subjected to UV radiation and no interference is present. The percent reductions observed in trial 4 indicate at least a 3 order of magnitude decrease in culturable bacteria after UV light exposure for 10 minutes with the UVG Device. It is possible that greater reductions may occur; however, only two concentrations of the test microorganism were tested in this phase of the study, with a corresponding limit of detection of 3 orders of magnitude reduction in culturable bacteria.

The 10-minute exposure results observed in this study were comparable to those observed in other studies that evaluated UV surface decontamination devices (Nerandzic et al., 2005; Owens et al., 2005; Rutala et al., 2010). However, bacterial spores have been shown to be more resistant to UV irradiation than vegetative cells. One device achieved a 2-3 log reduction in culturable Clostridium difficile spores and methicillin-resistant Staphylococcus aureus after 45 minutes of exposure (Nerandzic et al., 2005). A shorter exposure of 20 minutes was effective against vegetative bacteria, but disinfection of spores was reduced. Similarly, another device was tested that reduced culturable vegetative bacteria by over 3 logs in 15 minutes, but 50 minutes was necessary for a 3-log reduction of C. difficile spores (Rutala et al., 2010). The effectiveness of the UVG Device was not evaluated with bacterial spores in this study.
Table 1. Percent reduction in colony forming units (CFU) obtained after exposing agar plates inoculated with the two test microorganisms to UV light for different times and distances.

<table>
<thead>
<tr>
<th>UV Exposure Time (minutes)</th>
<th>Distance from UV Source (feet)</th>
<th>Percent Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>E. coli</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>94.9</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>56.3</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>96.8</td>
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<tr>
<td></td>
<td>10</td>
<td>78.1</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td>98.8</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>90.0</td>
</tr>
</tbody>
</table>

Figure 2. Photograph of agar plates after UV exposure for 10 minutes. Top row: E. coli (left) and S. aureus (right) colonies growing on plates that were covered and wrapped in aluminum foil. Middle row: No growth on plates that were exposed to UV at a distance of 1.5 m from the source. Bottom row: No growth on plates that were exposed to UV at a distance of 3.0 m from the source.

A limitation of this research was that the radiation dose at the plate surfaces was not determined in this study. Eight 250-watt bulbs were used in the UVG Device. Previous disinfection device tests have indicated effective surface doses ranging from 3,000-36,000 µW/cm², depending on the output of the device and the microorganism being tested (Nerandzic et al., 2005; Owens et al., 2005; Rutala et al., 2010). A germicidal UV bulb with 40-watt power was shown to have efficient inactivation of bacteria to a distance of up to 2.44 m on either side of the bulb with an exposure time of 30 minutes (Katara et al., 2008).

In summary, the UVG Device tested in this study achieved a reduction of vegetative bacterial cells >99.9% up to a distance of 3.0 m with an exposure time of 10 minutes. The edge of the plastic petri dishes provided some protection from the UV source; therefore, direct irradiation of surfaces was required. Future studies will characterize the UV-C radiation dose per area of surface for the UVG Device in the test chamber, and additional microorganisms, including bacterial spores, will be tested to determine the effective operation of the unit for surface disinfection. In addition, research will be conducted in which microorganisms will be aerosolized in control and test events in the chamber, and the UVG Device will be operated in closed mode (with air flow through the machine) to determine the effectiveness of the device in reducing airborne culturable bacterial concentrations. This study demonstrated the effectiveness of the UVG Device in reducing concentrations of culturable bacteria on indoor surfaces, a key component in the prevention of health-care associated infections in hospital environments. Therefore, potential applications of this technology are deployment of the UVG Device for at least five minutes in the following hospital settings: (1) in operating rooms between surgeries, repeated as necessary to overcome any blind-spots; (2) in intensive care units during patient changeover and when patients are out of the room undergoing tests; (3) in regular patient rooms during patient changeover; and (4) in emergency rooms during patient changeover.

Acknowledgment
The authors wish to thank Ms. Sarah Gasiewicz for technical review of the manuscript.
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